RADIO INTERFERENCE IN AREAS OF HIGH FIELD INTENSITY

By P. A. Young
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It is well known that Standard Broadcast Receivers located within regions of high field intensity are especially liable to interference. In the FCC Standards of Good Engineering Practice, 1940 revision, it is stated: "The 'blanket area' of a broadcast station is defined as that area adjacent to the transmitter in which the usual broadcast receiver would be subject to some type of interference to the reception of other stations due to the strong signal from the station."

Certain published articles[1] have dealt with one phase of such interference, but antedating them are several unpublished reports[2] of one organization relating experience gained by investigation of a great number of interference cases. Out of a total of more than 1,000 complaints handled, 80% originated inside a one volt per meter contour and 95% occurred within a one-half volt per meter contour. The interference encountered was generally separable into two major types, (1) blanketing and (2) cross modulation.

BLANKETING

Blanketing occurs when a high level carrier overloads a radio receiver. This is evidenced by broad tuning about the fundamental frequency, and is often accompanied by distortion and blocking. Correction entails reducing the blanketing frequency input level to the receiver by such means as a wave trap.

CROSS MODULATION

Cross modulation introduces an undesired modulation on the carrier frequency of a desired signal. This interference is created by intermodulation of two or more fundamental frequencies transmitted through a nonlinear element; intermodulation produces spurious frequencies corresponding to the sums and differences of both fundamentals and their integral multiple frequencies; also, the original modulation of both fundamentals is combined to form a multiple modulation imposed upon each fundamental and spurious frequency radiated from a cross modulation source. Cross modulation has two general origins, (a) the input tube of a receiver, and (b) an external circuit element.

Receiver Cross Modulation is caused by nonlinear tube response to high input. Correction procedure is, like blanketing, to reduce the input level of the interfering frequency.

External Cross Modulation occurs in a nonlinear element of a circuit external to either radio transmitter or receiver. This circuit must possess means to collect radio energy of two or more fundamental frequencies, intermodulate them, cross modulate their initial intelligence, and then radiate the resultant multiple modulated fundamentals and spurious frequencies. Some of the collectors most frequently found were metal roofs, downspouts, gas and water pipes, furnace pipes and electric wires.

Experiments have determined that sustained cross modulation is only generated by a low impedance circuit. The majority of nonlinear elements found were low pressure contacts between oxidized metal surfaces. Those most common were between BX and plumbing, gas and water pipes, furnace and water pipes, vent pipes and metal roofs, and the overlapped joints in downspouts.

Experience indicates that cross modulation is usually confined within the 50 mv/m contours of the affected fundamentals. Certain exceptions noted had one fundamental of only 10 mv/m but in all such cases the numerical product of both fundamental field strengths in mv/m exceeded 5,000.

Before any field work is attempted, partial lists of possible spurious frequencies should be prepared. Select two fundamental frequencies with high field intensity in the region experiencing interference. Label these frequencies f_1 and f_2 and substitute them in the following table[3]:

TABLE I

$f_1 + f_2$	$f_1 + 2f_2$	$2f_1 + f_2$
$f_1 - f_2$	$f_1 - 2f_2$	$2f_1 - f_2$

The sign of the results have no significance and can be disregarded.

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[1] *See appended bibliography.*

[2] *Unpublished reports of The Crosley Radio Corporation:*

a. Blanketing and Crosstalk Studies to January 1, 1937, G. E. Branch, G. F. Leydorf

b. Continuation of Blanketing and Crosstalk Studies to May 1, 1937, G. E. Branch, J. C. Brill, G. F. Leydorf, P. A. Young.

c. Methods of Investigating and Correcting Crosstalk as of August 28, 1937, G. E. Branch, J. C. Brill, G. F. Leydorf, P. A. Young.

d. Report on Radio Interference Investigations conducted during the past year, June 3, 1938, J. C. Brill, P. A. Young.

[3] *See footnote 2a, mathematical analysis by G. F. Leydorf. Also, Terman, Radio Engineers Handbook, 1943, p. 647.*

EXAMPLE:

Suppose that $f_1 = 550$ kc/s; $f_2 = 1360$ kc/s

Substitute these values into Table I to obtain Table II shown below.

The terms of Table I that include an integral multiple do not signify the presence of second harmonic. It is emphasized that cross modulation can be generated without the existence of a second harmonic of any kind. It is also pointed out that cross modulation may be produced without a true rectifying action, only a nonlinear voltage-current characteristic being required.

The spurious frequencies listed in Table II are merely a small number of the total combinations that are possible. Cross modulation may occur without any of these particular frequencies being present. However, if present they do positively denote cross modulation.

Spurious frequencies have been utilized in correction work because they vary directly with the interference level. Elimination of the source completely removes all these artificial frequencies, whereas only the cross modulation background disappears if listening to a broadcast station. Furthermore, these spurious frequencies are still fairly strong when the undesired modulation on the desired frequency is reduced below an audible level. Therefore Table II should be expanded to include all radio stations affording high field strength to the area under consideration.

The test equipment required is a readily portable battery receiver of high sensitivity, well shielded, and tunable over a reasonable range of spurious frequencies, together with an electro-statically shielded loop antenna. Flexible shielded leads and a handle several feet long will permit the loop to be readily probed about among pipes and wires. In use the portable set is tuned to one of the spurious frequencies, a pipe or other conductor approached with the loop until a strong signal is located, and then this conductor followed until contact with some other metallic object is found. The contact is varied by moving one conductor and noting any change in spurious signal. This procedure is continued with each contact point being corrected until the spurious frequency either disappears or is so reduced that no undesired signal is audible upon the fundamental of the desired station. Correction may follow either of two procedures:

1. A short-circuit permanently and directly across the nonlinear element. Example: self-tapping screws through both downspout sections at an overlap joint.
2. An open-circuit permanently insulating the contact surfaces of the nonlinear element. Example: wood strips secured by friction tape between the contact portions of gas and water pipes.

Either correction method is quite satisfactory, the case of application determining the choice for each located source.

Building design has been found the principal obstacle to satisfactory correction of external cross modulation. Most buildings have numerous inaccessible metal-to-metal contacts, such as plumbing and conduit inside walls, that are potential interference sources. In large structures the required bonding or insulating of all casual metallic contacts would entail extensive building alterations.

Based on experience, some estimates of satisfactory correction expectancy for cross modulation originating within various size buildings are presented:

Structure	Estimated Satisfactory Correction - %
Single family home	95
Two family home	80
Four apartment building	50
Ten apartment building	1

Much external cross modulation trouble could be avoided by the adoption of adequate bonding and insulation practice in building construction. The proper construction procedures could be readily worked out by joint committees composed of qualified representatives of the radio industry and the building industry. It is highly desirable that this be done at an early date, particularly in regard to housing construction.

BIBLIOGRAPHY

D. E. Foster, A New Form of Interference - External Cross Modulation, R.C.A. Review, April 1937

A. James Ebel, A Note on the Sources of Spurious Radiations in the Field of Two Strong Signals, Proceedings I.R.E., February, 1942.

TABLE II

550 + 1360 = 1910

550 - 1360 = 810

550 + 2720 = 3270

550 - 2720 = 2170

1100 + 1360 = 2460

1100 - 1360 = 260

PRACTICAL ANALYSIS OF UHF, TRANSMISSION LINES, RESONANT SECTIONS, RESONANT CAVITIES & WAVE GUIDES

By J. R. Meagher & H. J. Markley

Field Engineers

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PREFACE

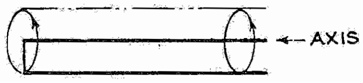
This paper was prepared as an aid to the many members of our country's Armed Forces engaged in the installation, operation and maintenance of Ultra High Frequency Radio-Electronic Equipment. It is hoped that this paper will also benefit others who are concerned with the design and production of this type of equipment.

Every effort has been made to explain the theories involved in the simplest manner without the use of mathematics. The contents have been limited to subjects of current importance.

TRANSMISSION LINES

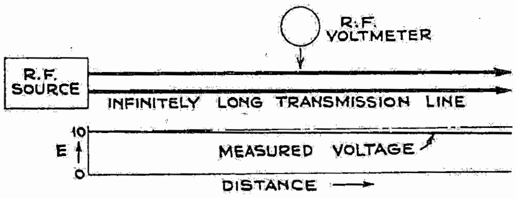
A transmission line is a means of transferring r-f energy from a source to a load in an efficient manner.

For simplicity, most of the illustrations in this booklet show parallel-wire transmission lines, but the information also applies to coaxial lines. The similarity between a section of parallel-wire line and a coaxial section may be seen by rotating a parallel-wire section about one wire so the outer arm forms a cylinder as shown.

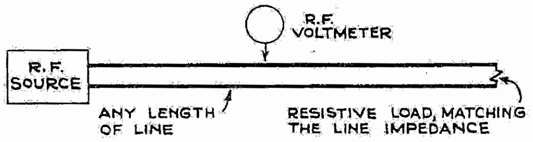


The r-f voltmeter, referred to in the text, usually consists of an r-f rectifier and meter which indicates the rectified peak amplitude of the r-f voltage at any point along the line.

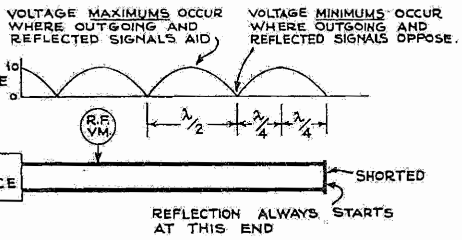
Standing Waves on Lines



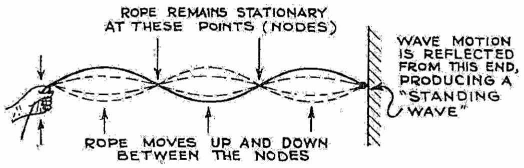
In this illustration, an r-f source is feeding r-f energy into a transmission line. If the line is infinitely long, the signal never reaches the end, and therefore cannot be reflected, so there are no "standing waves." The r-f voltage measured along the line gradually decreases due to losses in the line.



If the line is *terminated* in a resistive load that matches the line impedance (also termed "surge" or "characteristic" impedance), the outgoing signal is completely absorbed by the load. As a result, there are no reflections and no standing waves, and the voltage is essentially the same at all points along the line.



If the load is not resistive and matched to the line impedance, it reflects signal back into the line. *The combination of the outgoing and reflected signal produces a standing wave on the line.*



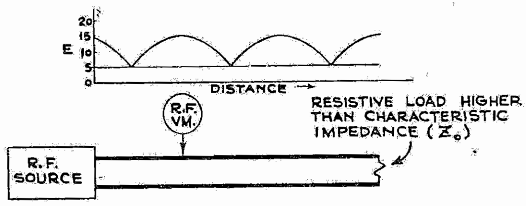
This analogy shows standing waves produced by wave motion and reflection on a rope. A similar analogy can be made to standing waves of sound along a pipe.

Standing Wave Radio

$$\text{The standing-wave ratio} = \frac{\text{Minimum Voltage}}{\text{Maximum Voltage}}$$

This ratio indicates the ratio of mismatch of the load impedance.

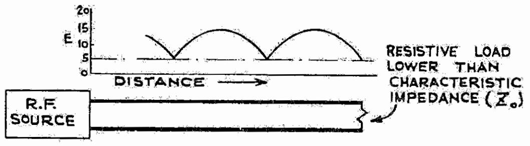
In the example shown below, the voltage at minimum's is 5, and the voltage at maximum's is 15.



The ratio is $\frac{5}{15}$ or 1 to 3.

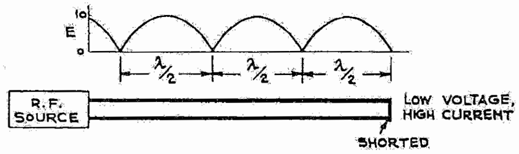
Hence, the load impedance is either 3 times larger than the line impedance, or one-third of the line impedance. (In the foregoing example, the voltage at the load is maximum, so the load impedance is higher than the line impedance.)

If the load has an appreciable reactive component the standing-wave ratio is only a rough indication of the impedance mismatch. This can be seen from the curves in the appendix.

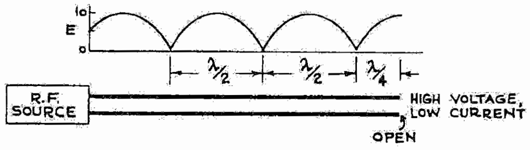


In the example shown above, the voltage at the load is minimum, so the load impedance is lower than the line impedance.

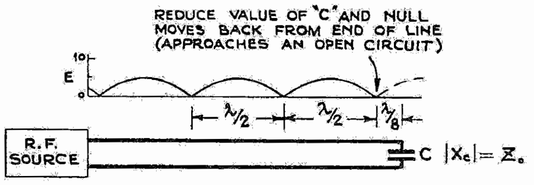
Position of Voltage Minimums and Maximums

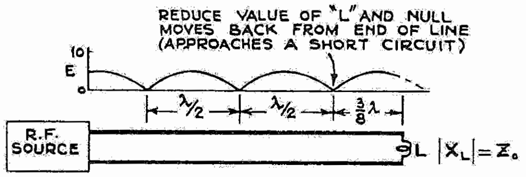


If the end of the line is shorted, the voltage at the short is low and the current is high. The first voltage minimum occurs a half-wave back from the end of the line.



If the end of the line is open, the voltage at the end is high, and the current is low. The first voltage minimum occurs a quarter-wave back from the end of the line.





For loads containing reactance, the standing-wave will be shifted, depending on the nature of the load.

Often it is desirable to speak of electrical degrees rather than fractions of a wave-length:

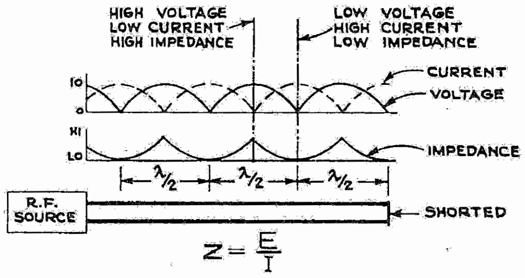
$\frac{1}{8}\lambda = 45°$	$\frac{1}{2}\lambda = 180°$	$\frac{7}{8}\lambda = 315°$
$\frac{1}{4}\lambda = 90°$	$\frac{5}{8}\lambda = 225°$	$\lambda = 360°$
$\frac{3}{8}\lambda = 135°$	$\frac{3}{4}\lambda = 270°$	

Impedance at Different Points Along the Line

The impedance at any point along the line is determined by the ratio of voltage to current at that point: If the voltage is high, the current at the same point is low, and therefore the impedance at that point is high.

If the line has low losses, and no energy is absorbed by the termination, the low-impedance points are equivalent to short-circuits, and the high-impedance points are equivalent to open circuits. If there is energy loss in the line or termination, the impedance tends to become more uniform along the line. *When the load matches the line, the impedance becomes uniform along the line, and is equal to the "characteristic" impedance.*

It should be noted that an open circuit, a short-circuit or a pure reactance at the end of the line will not absorb power. Standing-waves will therefore exist with such loads.



Summary--Effect of Line Termination

(1) If a line *of any length* is correctly terminated with a resistive load that matches the line impedance, there are no reflections, and no standing-waves.

(2) If a line is not correctly terminated, the signal is reflected back from the load and this results in standing-waves.

(3) The value and nature of the load determines the *ratio* of voltage at maximum and minimum points along the line, and also the *position* of these maximum and minimum points.

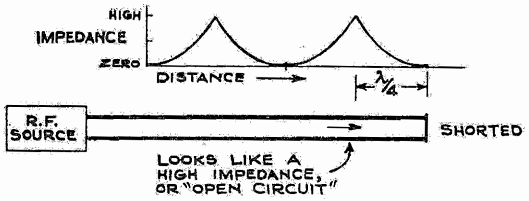
In most applications where a line is used to connect a signal source to a load (for instance, to connect a transmitter to an antenna) it is generally desirable to make the load match the line. *If the load is not matched, the length of the line becomes critical,* and incorrect length may affect the power output and frequency of the source. *When the load is matched to the line, the length of the line is not critical.* ("Matching" means that the load must be resistive and equal to the line impedance.)

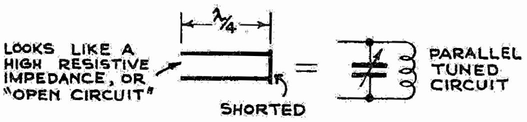
Resonant Sections

Quarter-wave and half-wave sections and their action as tuned circuits will now be considered. This action will be explained on the basis of change in impedance produced by standing waves along an opened or shorted line.

When sections of line are used as tuned circuits, their action depends on the existence of reflections and standing-waves to produce the effect of high-impedance and low-impedance tuned circuits. Therefore, sections of lines, when used as tuned circuits or transformers are either effectively shorted or opened at the end to produce the maximum standing-wave ratio and the highest or lowest possible input impedance, as desired in the application.

Quarter-Wave Shorted Section

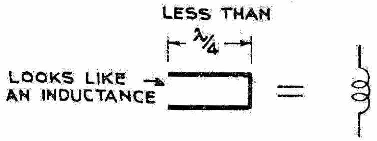




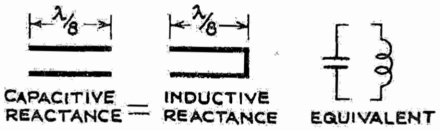
The quarter-wave shorted section at the end of the line looks like a high-impedance to the input signal, and being tuned, it is resistive. The equivalent conventional circuit is a parallel-tuned circuit, for it also has high resistive impedance at the resonant frequency.

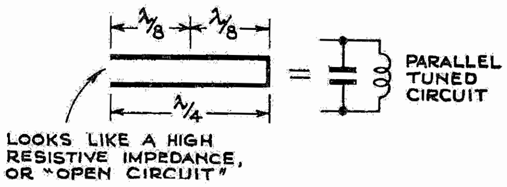
The action of a quarter-wave section may also be explained as follows:

A section of line open at each end and less than a quarter-wave long acts like a *capacity.*



A section of line shorted at one end and less than a quarter-wave long acts like an *inductance.*



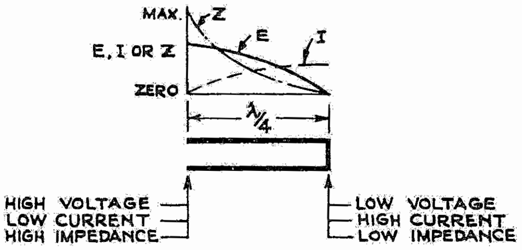


The capacitive reactance of a section of line one-eighth wave-long, open at the ends, is equal to the inductive reactance of a section of line one-eighth wave long, shorted at one end: The values of these reactances are equal to the "characteristic" impedance. (The "characteristic" or "surge" impedance depends on the size and spacing of the conductors.)

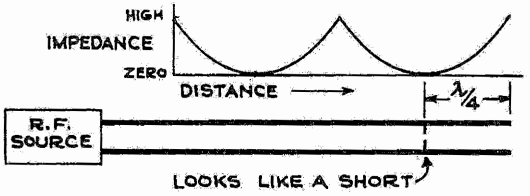
If the two sections are combined, the result is a resonant circuit that has high-resistive impedance, like a parallel-tuned circuit.

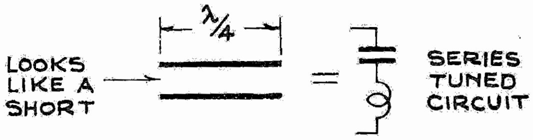
(This example is given because it is simple to visualize. Naturally, any two sections that add in length to equal one-quarter-wave electrically will have equal reactance and will produce the same result.)

The voltage, current, and impedance relations for a quarter-wave section are shown below:



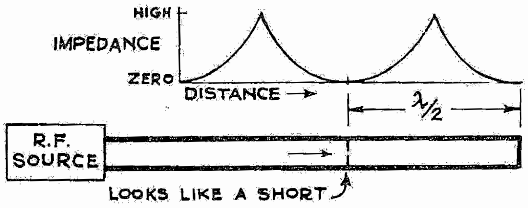
Quarter-Wave Open Section

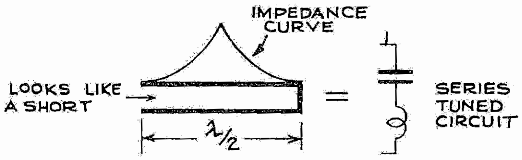




The quarter-wave section at the end of the line has very low input impedance, and, being tuned, it is resistive. It is equivalent to a conventional series-tuned circuit.

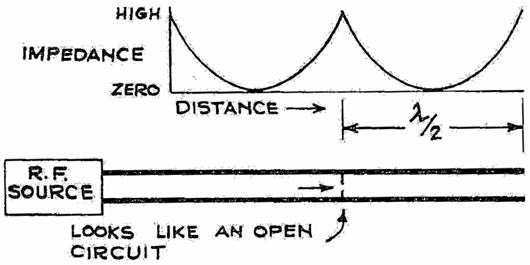
Half-Wave Shorted Section

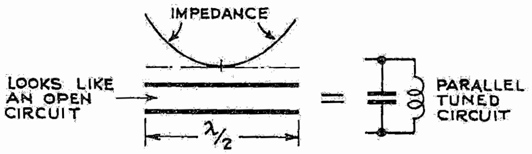




The half-wave shorted section at the end of the line also has low resistive input impedance. It corresponds to a series-tuned circuit.

Half-Wave Open Section





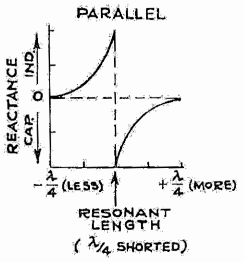
The half-wave open section at the end of the line has high input impedance. This section corresponds to a parallel-tuned circuit.

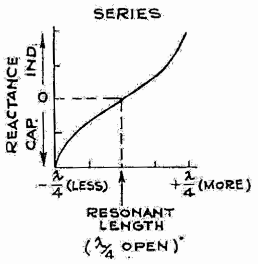
Tuning Characteristics of Resonant Sections

We have seen the four principal resonant sections:

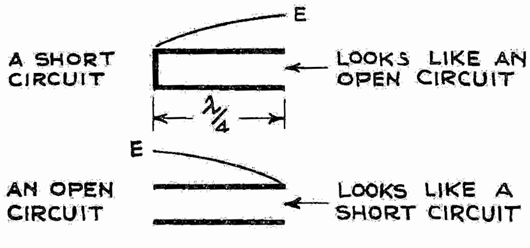
1. Quarter-wave, shorted } Equivalent to a parallel-tuned circuit
2. Half-wave, open }
3. Quarter-wave, open } Equivalent to a series-tuned circuit
4. Half-wave, shorted }

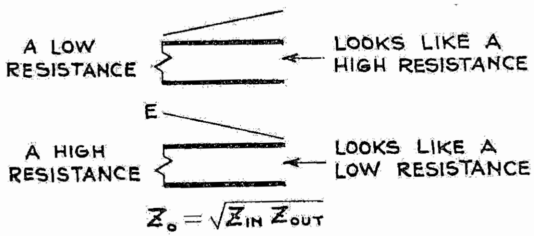
If a section of line is tuned above or below the resonant input frequency (by making the line shorter or longer) the effect is the same as in a conventional tuned circuit. The section will no longer look resistive. Either capacitive or inductive reactance will predominate. This is shown further in the tables on page 6 and in the graphs at right.





Quarter-Wave Line "Inverts" the Load



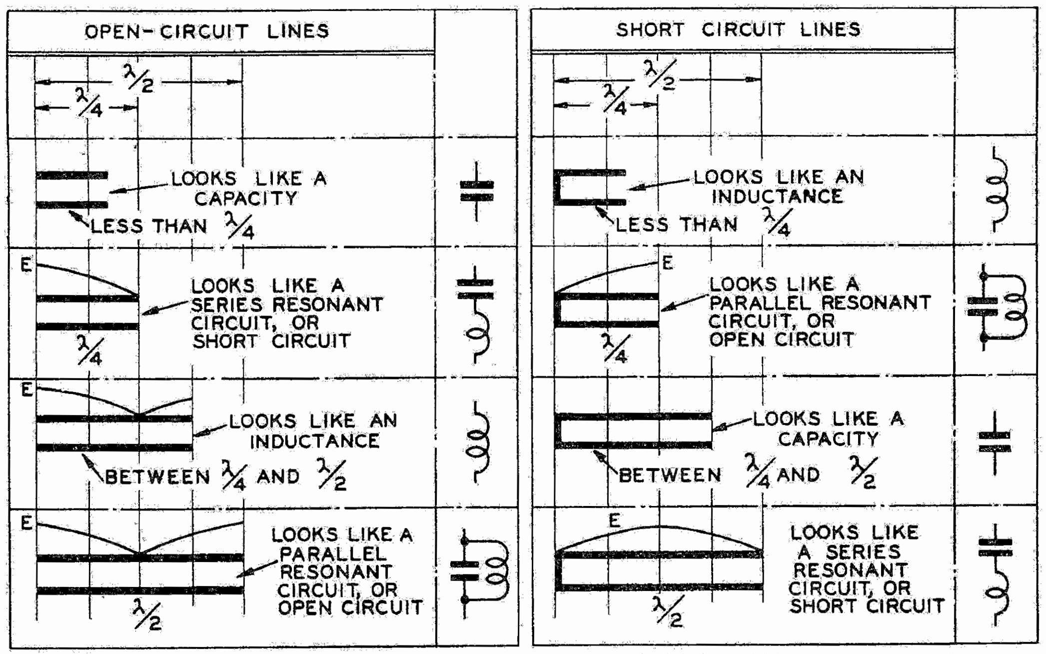


A quarter-wave line "inverts" the load as seen by source.

The input impedance in the above cases can be determined as follows:

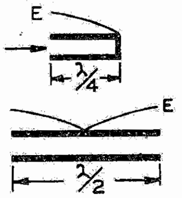
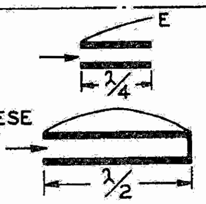
$$\text{Input impedance} = \frac{(\text{Line impedance})^2}{\text{Load impedance}}$$

Characteristics of Line Sections



CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED.

Tuning Characteristics of Resonant Sections and Conventional Circuits

WHEN INPUT FREQUENCY IS CONSTANT, AND THE CIRCUIT IS ADJUSTED		CONVENTIONAL CURCUIT	RESONANT SECTION	WHEN THE CIRCUIT IS CONSTANT, AND THE INPUT FREQUENCY IS ADJUSTED.	
ABOVE RESONANCE (SECTION MADE SHORTER) LOOKS LIKE	BELOW RESONANCE (SECTION MADE LONGER) LOOKS LIKE			ABOVE RESONANCE LOOKS LIKE	BELOW RESONANCE LOOKS LIKE
INDUCTANCE ($X_C > X_L$)	CAPACITY ($X_L > X_C$)	 AT RESONANCE THESE CIRCUITS LOOK LIKE A HIGH RESISTIVE IMPEDANCE, OR "OPEN CIRCUIT"		CAPACITY ($X_L > X_C$)	INDUCTANCE ($X_C > X_L$)
CAPACITY ($X_C > X_L$)	INDUCTANCE ($X_L > X_C$)	 AT RESONANCE THESE CIRCUITS LOOK LIKE A LOW RESISTIVE IMPEDANCE, OR "SHORT CIRCUIT"		INDUCTANCE ($X_L > X_C$)	CAPACITY ($X_C > X_L$)

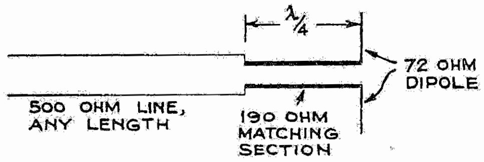
TUNED LINE CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED

QUARTER-WAVE MATCHING SECTION

The "inverting" property of a quarter-wave section can be put to practical use when it is necessary to match a line of one impedance to a load of a different impedance. To do this, the section must have an impedance calculated as follows:

$$Z_{\text{MATCHING SECTION}} = \sqrt{Z_{\text{LINE}} \times Z_{\text{LOAD}}}$$

For example: A 500-ohm line can be matched to a 72-ohm dipole through a quarter-wave section of 190 ohms.



The *line* looks into a load of

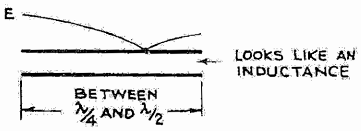
$$\frac{(\text{Z of matching section})^2}{\text{Z of load}} \text{ or 500 ohms.}$$

The *antenna* looks into a source of

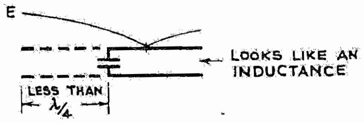
$$\frac{(\text{Z of matching section})^2}{\text{Z of line}} \text{ or 72 ohms.}$$

"INVERSION" OF CAPACITY AND INDUCTANCE

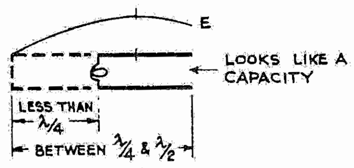
Inversion of capacity and inductance can be explained as follows:



An open section of line between one-quarter and one-half wave long looks like an inductance to the source.

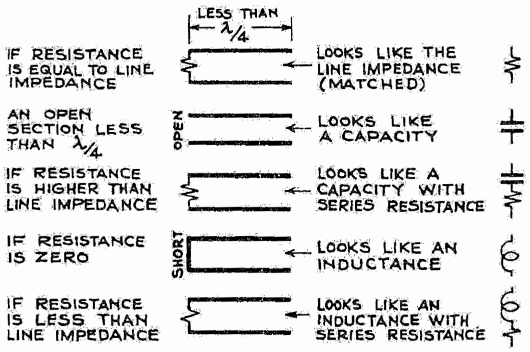


If a part (less than one-quarter wave) is replaced by a capacity (an open section less than one-quarter wave looks like a capacity), the section still looks like an inductance to the source.

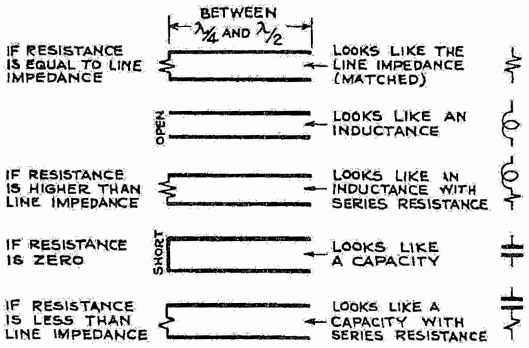


A shorted section between one-quarter and one-half wave looks like a capacity. If part (less than one-quarter wave) of the shorted end is replaced by an inductance, the section will still look like a capacity to the source.

SECTIONS LESS THAN QUARTER-WAVE

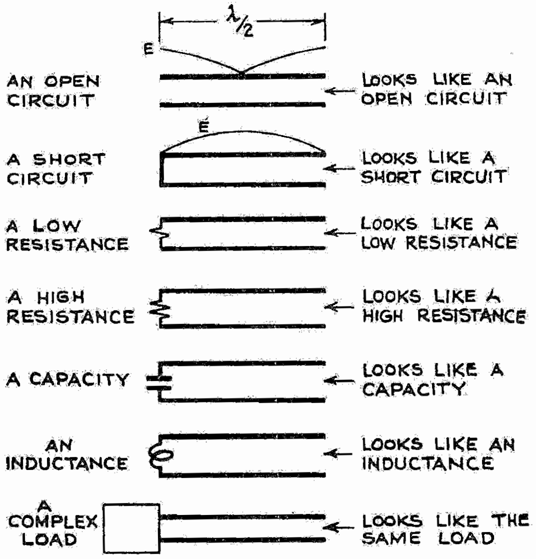


SECTIONS BETWEEN ONE-QUARTER AND ONE-HALF WAVE



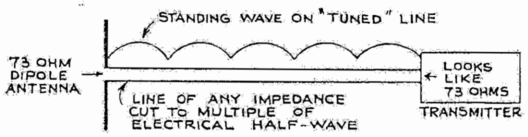
HALF-WAVE LINE "REPEATS" THE LOAD

A half-wave line acts as a "double inverter" and hence will "repeat" whatever appears on the far end:



A line that is any multiple of one-half wave has the same characteristics.

The action of a half-wave section, or a line cut to a multiple of a half-wave, is used extensively in practical applications. For example, if a dipole antenna with an impedance of 73 ohms is to be coupled to the output of a transmitter, through an open-wire line (spaced pair) with a characteristic impedance of several hundred ohms, the line can be cut to a multiple of an electrical half wave.



The transmitter will look into a load of 73 ohms, regardless of the impedance of the line.

"Tuning Out" the Reactance of a Load

One of the important applications of tuned-line sections is to "tune out" the effects of residual capacitive or inductive reactance in a load, so the load will look like a pure resistance.

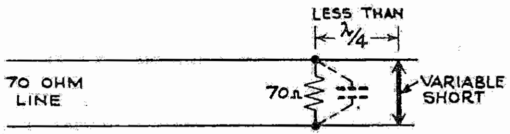
For example, assume that a 70-ohm resistor is used to terminate a 70-ohm line. If this line, with its resistor termination is connected to a slotted line and checked for match over a wide range of frequencies, it will be found that at some frequency the termination looks resistive. This is the resonant frequency of the resistor. Above and below this frequency the resistor has capacitive or inductive reactance and no longer matches the line. In other words, the resistor is not a "pure resistance" at most frequencies.

At the required operating frequency, the resistor may look like a resistance with shunt capacity as shown in "A." If an inductive section of line is connected to the termination as shown in "B," it may be adjusted to resonate with the capacity, to look like a parallel-tuned circuit.

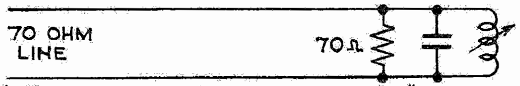
The line, therefore, instead of seeing a resistance with shunt capacity, now sees a resistance with a shunt parallel-tuned circuit, as shown in "C."

The parallel-tuned circuit looks like a high resistive impedance as shown in "D," and, therefore, has little effect on the total resistance. If the combined resistance is correct, the line will be "matched."

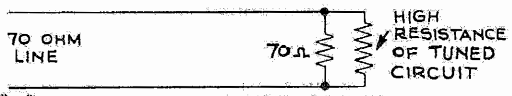
"A"- RESISTOR WITH RESIDUAL CAPACITIVE REACTANCE.



"B"- INDUCTIVE SECTION ADDED AND RESONATED WITH CAPACITY TO THE INPUT FREQUENCY.



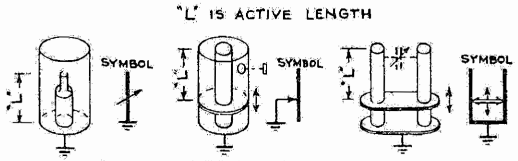
"C"- EQUIVALENT CIRCUIT OF "B"



"D"- LINE NOW LOOKS INTO 70 OHM SHUNTED BY HIGH RESISTANCE.

Tuned-Line Sections—Types of Construction

The characteristics of tuned lines are used to good advantage in UHF equipments. Quarter-wave and half-wave sections are used as parallel- and series-tuned circuits, as step-up and step-down transformers, as impedance and phase inverters, and even as insulators. Such sections of line take the place of conventional tuned circuits which become too small and inefficient at ultra-high frequencies. The tuned-line sections are made in both co-axial form, and in open-line type, from metal tubes and rods; generally silver-plated to reduce r-f losses. Some representative types of construction are sketched at left. Methods of adjustment to resonate the sections are indicated.



TELESCOPING INNER CONDUCTOR — CO-AX SECTION

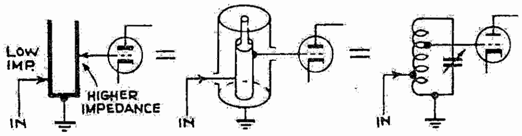
SLIDING DISK — CO-AX SECTION

SLIDING BAR — OPEN LINE SECTION

Some sections are cut short, and resonated with an adjustable capacitor (indicated by dotted lines) instead of being resonated with a sliding disc or bar.

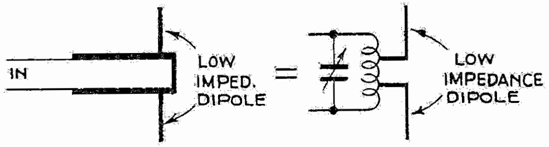
Quarter-Wave Sections as Transformers

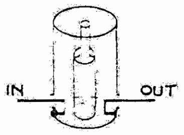
A quarter-wave section (co-ax or "open-line" type) shorted at the end, may be used as a step-up transformer, similar to a parallel-tuned auto-transformer. When a resonant section is "loaded" with reactance, for example, connected to the grid of a tube, the section must be readjusted to obtain electrical resonance).

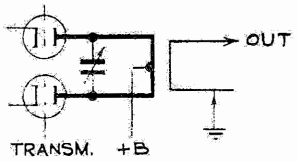


A quarter-wave shorted section may be used as a step-down transformer.

Inductive coupling to tuned sections is sometimes done as shown in the following two different examples:







Co-Ax Arms on Tuned Sections

In push-pull UHF circuits, lengths of co-ax are frequently used to form the arms of one-quarter or one-half wave shorted sections. This is done for several reasons, including:

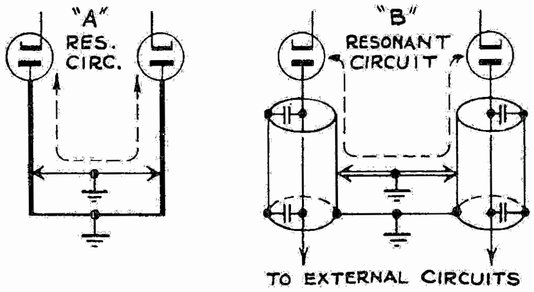
(1) The inner conductors may be used to carry d-c and a-c supply voltages, or low-frequency signals, to the tube elements.

(2) The outer conductors can be grounded.

(3) A sliding bar on the outer conductors can be used to adjust the electrical lengths of the section mentioned in (1) above.

In such applications, capacitors are used at the end of the co-ax to place the inner and outer conductors at the same r-f voltage.

An example of co-ax arms forming tuned sections is shown in the illustration.



"A" is the quarter-wave shorted section required for input tuning. But it is necessary to take the diode currents to external circuits, and (for constructional reasons) the arms of the section must be grounded. "B" shows how "A" is rearranged to do this. *The co-ax lines do not act as tuned sections by themselves, but form the arms of the quarter-wave shorted section shown in "A."*

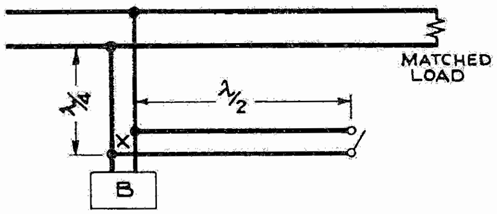
Miscellaneous Application of Tuned Sections

Tuned sections are put to many uses in addition to that of replacing conventional tuned circuits.

Some miscellaneous uses are described to indicate several of the many applications.

(1) Use of Sections in Switching Circuits

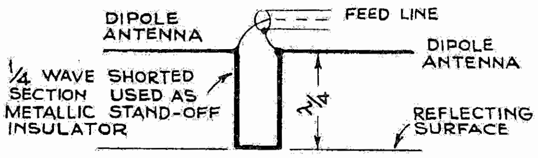
In some equipments it is necessary at times to prevent signals from "A" getting to "B." This is accomplished by shorting the end of the one-half wave section. By virtue of the action of one-half wave sections, this short appears as a short across "B" input line at "X." The one-quarter-wave line, being thus shorted at "X," looks like a high impedance to the signal from "A."



When it is desired to leave signals through to "B," the switch is opened at the end of the one-half-wave line. At "X," the one-half-wave resonant line now looks like an open circuit. With no short at "X," the one-quarter-wave section is simply an ordinary part of the line, and signals can pass to "B."

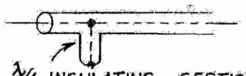
(2) Quarter-Wave Shorted Section Used as an Insulator

(a) A quarter-wave shorted section looks like a high resistive impedance. This fact is utilized in some antenna systems by employing one-quarter-wave shorted sections as metallic stand-off insulators to support and space a dipole antenna one-quarter wave from a reflecting surface, as shown below:

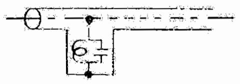


The quarter-wave section looks like a high impedance to the antenna feed line. (The feed line can be run inside one arm of the quarter-wave section.)

(b) Another example of a quarter-wave "insula-tor" is shown below, together with an analogy of a conventional parallel-tuned circuit.



λ/4 INSULATING SECTION ACTS LIKE A HIGH Z SHUNT ACROSS THE LOW IMPEDANCE LINE.

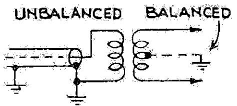


EQUIVALENT CIRCUIT

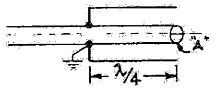
(3) Line Balance Converter (Bazooka)

In some applications, it is necessary to change from a co-axial transmission line (unbalanced, since outer conductor is grounded) to a balanced transmission line or load (both conductors approximately the same impedance above ground).

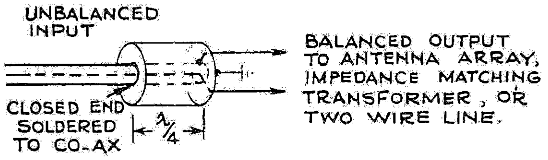
A "bazooka" is used for this purpose. The action is shown in the sketches, and may be explained as follows:



PRINCIPLE OF CONVERTER



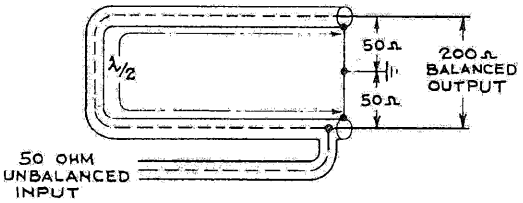
BAZOOKA FORMS SHORTED QUARTER WAVE SECTION PLACING "A" AT HIGH Z TO GROUND.

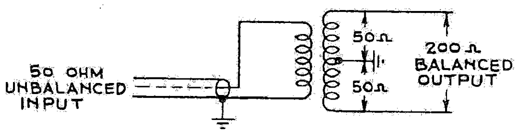


1. The quarter-wave shorted section effectively removes the r-f ground from the end of the outer conductor of the co-axial line.
2. Both the inner and outer conductors of the co-axial line are now at a relatively high impedance above ground, and effectively balanced to ground.
3. The bazooka may be used in reverse manner to feed from a balanced circuit to an unbalanced circuit.

(4) Half-Wave Phase and Impedance Converter

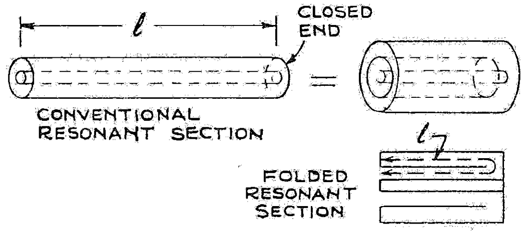
The following arrangement is used in some applications. The action may be reversed, to feed from high-impedance balanced input to low-impedance unbalanced output.





(5) "Folded" Resonant Section

At relatively low frequencies, the physical length of a resonant section may be too long for convenient use, and a "folded" section may be used. The effective length of the folded section is indicated by the dotted line. More than one "fold" may be used for further reduction of the physical length.



Characteristic Line Impedance

The impedance of a line (also termed "surge" or "characteristic" impedance) depends on the dimensions and spacing of the conductors, and the dielectric constant of the insulating material.

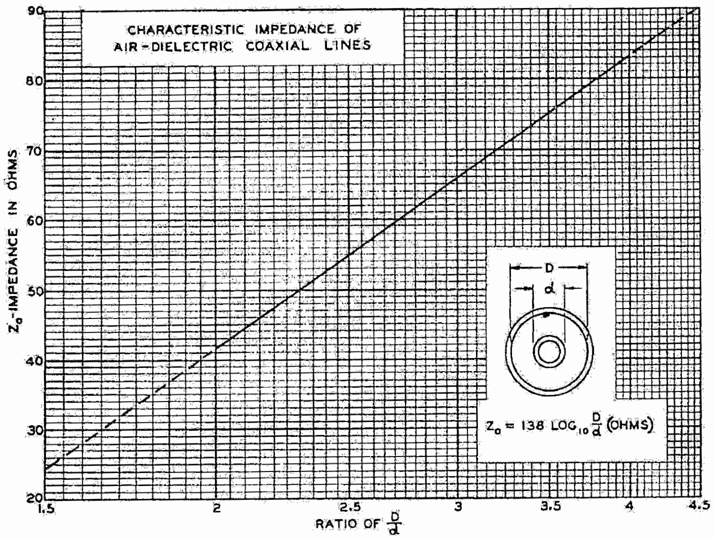
Neglecting Losses—

$$Z_{\text{OHMS}} = \sqrt{\frac{L_{\text{HENRYS}}}{C_{\text{FARADS}}}}$$

In solid dielectric lines (as compared with air dielectric) the impedance is reduced by the factor $\sqrt{1/k}$, where "K" equals the dielectric constant of the insulating material (and has the effect of increasing "C" per unit length in the general formula).

Aircraft Antenna Cable, using solid dielectric is frequently 70 or 50 ohms. Seventy (70)-ohm cable is convenient for use with quarter-wave dipoles and other antennas that have a radiation resistance of 70 ohms. Fifty (50)-ohm cable is used extensively in conjunction with suitable matching on low-impedance array-type antennas.

The two charts on the following page show how the impedance of co-axial and parallel-wire lines varies with the dimensions and spacing of the conductors.



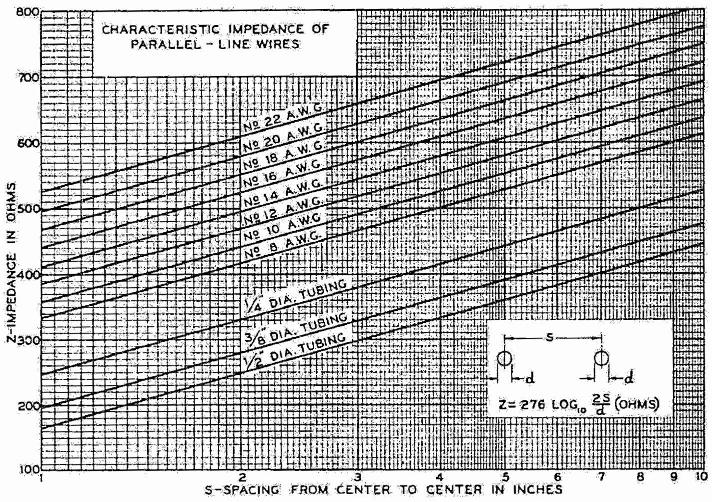
Impedance chart for air-dielectric co-axial lines.

Example: For a 50-ohm line, "D" is 2.3 times larger than "d". For a 70-ohm line, "D" is 3.2 times larger than "d".

NOTE: Refer to Section 6 of NAB Handbook for enlargements of these two charts.

Impedance chart for parallel-wire lines.

Example: To obtain a line impedance of 500 ohms, using No. 14 wire, the spacing (S) must be approximately 2 inches.



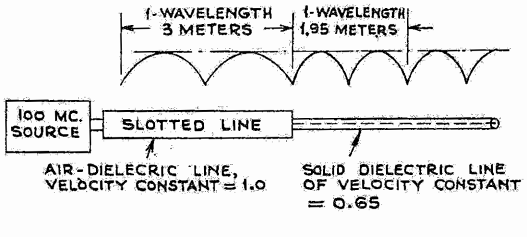
Velocity Constant of Lines

Radio waves travel at a speed of 300 million meters per second in air. The speed is reduced in lines that have spacing insulators or solid dielectric. In a slotted measuring line, with no spacing insulators, the speed is essentially the same as in air.

The speed in solid-dielectric lines of high quality, such as UHF aircraft antenna cable, is about 60-70 per cent of speed in air. Reels of such cable are tagged with the measured velocity constant of a sample cut from the reel.

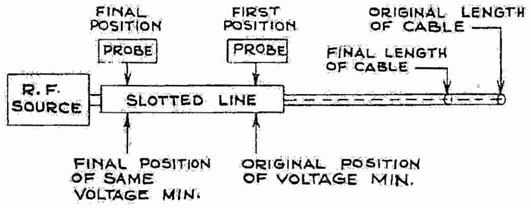
The fact that the velocity is less in the cable than in air means that a wavelength in the cable will be shorter than in air; since the wavelength equals velocity divided by frequency. For example, a wavelength in air at 100 mc. is 3 meters, but in a solid-dielectric cable with a velocity constant of 65 per cent, a wavelength at 100 mc. is only 3 x .65, or 1.95 meters.

The lower velocity in solid-dielectric lines is illustrated below. A 100 mc. signal is fed through a slotted line (air dielectric) and into a solid dielectric line that has a velocity constant of 0.65 (65 per cent of that in air).



A slotted line can be used to check the velocity constant of a co-ax cable.

The equipment is set up as shown:



The end of the cable is left open. Standing waves are therefore set up along the cable and slotted line. The probe is set accurately at the first point of minimum voltage at the cable-side of slotted line. A piece of cable is cut off at the end of the line. This shifts the voltage minimum point to the left, and the probe is reset accurately to the new position of the voltage minimum.

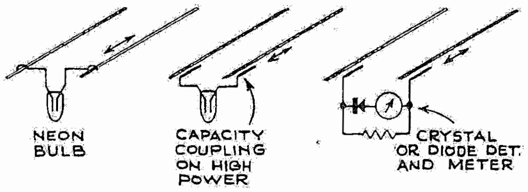
The ratio of the length of the piece of cable cut off to the distance that the probe is moved is the velocity constant of the cable. (In practice, small increments of cable are cut off until nearly the entire length of the slotted line has been traversed by the probe. Each step is plotted, and the slope of the line indicates the velocity constant).

As an example, if the length of cable cut-off is 1 foot, and the probe has been moved 2 feet, the velocity constant is .5, or 50 per cent.

Standing-Wave Indicators for Open-Wire Lines

A small neon bulb may be used to show existence of standing waves on open-wire lines. If the line is correctly terminated (no standing waves) the bulb will have constant brilliance as it is moved along the line.

Better indication can be obtained by using a crystal or diode rectifier and a meter, capacitively coupled to the line as shown.



Slotted Measuring Line

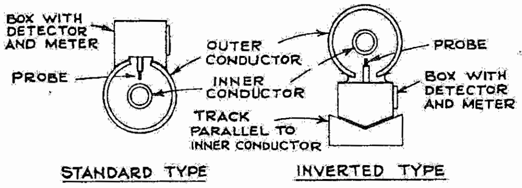
A "slotted line" is a section of co-axial line with a slot along the outer tube to permit loosely coupling an r-f voltmeter probe to the inner conductor.

The slotted line is used to determine:

(1) Ratio of voltages at maximum and minimum voltage points of standing waves along the line.

(2) Position of these points with respect to a "Reference" point.

From this data it is possible to determine the resistive and reactive nature of a load at a specified frequency.



Some Principal Applications Are

(1) To adjust antennas for correct match to a line at a specified frequency.

(2) To determine the resistive and reactive components of a load at a specified frequency, or over a range of frequencies; i. e., impedance and phase angle.

(3) To adjust input systems of receivers, dummy loads, etc., for correct match to a line.

Considerable care is taken in the design and construction of slotted lines to secure:

(1) Uniform impedance throughout the length.

(2) Uniform spacing of the probe in its travel along the inner conductor.

(3) Good grounding of the probe box to the outer conductor.

(4) Rigidity of the co-ax assembly, and minimum slop in travel of the voltmeter probe.

The impedance of the slotted line should equal the impedance of the associated co-ax line. Some slotted lines are equipped with two or more mechanically interchangeable inner conductors of different diameters so the impedance can be changed to match the impedance of commonly used co-ax lines (70 and 50 ohms, and some 63 and 40 ohms).

The r-f voltmeter used in conjunction with the slotted line is usually a diode or crystal detector with a current meter and tuned input, capacitively coupled to the inner conductor.

Diode and crystal detectors are insensitive and require a high-output UHF oscillator to excite the line. It is sometimes possible to use the UHF receiver (from an equipment) as an indicator, fitting the input of the receiver with a suitable probe. In this case, owing to the high sensitivity of the receiver, a low-powered UHF generator may be used for the source.

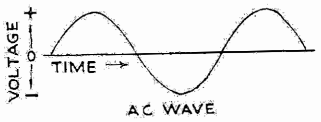
When adjusting antennas, the object in most cases is to "match" the antenna to the line. This is usually done by changing the antenna length and/or the antenna matching stub for *minimum* standing-wave ratio.

For some antennas, and in other applications of the slotted line, it is necessary to determine the resistive and reactive components and phase angle.

This requires checking both the standing-wave ratio and the distance from a minimum (or maximum) voltage point with respect to a "reference" point. This subject is covered in the appendix.

Additional Data on Standing Waves

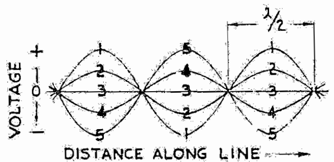
An a-c wave may be drawn as a change in *voltage* during a period of *time,* as shown below.



A.C. WAVE

A standing wave is not as easy to show, because it involves changes in *voltage* with *time,* and with *distance* along the line.

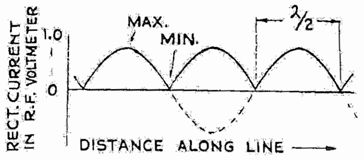
The voltages between node points of a standing wave changes from positive to negative values and back during the time equivalent to one cycle of the r-f source. This r-f change in voltage is roughly indicated by curves 1 to 5 and back in the following sketch.



STANDING WAVE

At some instant, the voltage along the line may be shown by one of these curves. It will be noted that the term "standing" wave can be misinterpreted. In a standing wave the *position* of max. and min. points does stand still, but the voltage changes at the r-f rate.

When an r-f voltmeter is moved along the line, it indicates the relative amplitude of the r-f voltage variation at each point along the line. The rectified r-f current in the meter circuit may be zero at nodes, and increases to a max. when the r-f voltmeter is moved to each voltage max. point. Thus the *measured* standing wave appears as shown below. (This is a sine wave with the negative half-cycles "flopped up.")

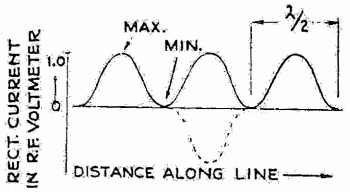


By turning one of the half-cycles down, as shown in dotted lines, it will be seen that the curve is a sine wave.

The standing wave that exists on the line is a sine wave, providing the r-f source is sine wave; that is, a fundamental frequency with no harmonics. For slotted-line measurements, the generator must furnish sine wave output. If harmonics are present, some of the min. points, with the line open or shorted will not be zero.

If the standing wave on the line is sine wave, the *measured* standing wave will be sine wave, providing the r-f voltmeter is *linear.*

If the rectifier in the r-f voltmeter is not linear, the measured standing wave will not be sine wave, but will appear as shown.



By turning one of the half-cycles down, as shown in dotted lines, it will be seen that the standing wave, as measured with a non-linear detector, is far from being a sine wave.

It will be noted that with a non-linear detector, the voltage min. points are not as "sharp" as indicated in the preceding illustration, which shows a standing wave measured with a linear detector.

The graph on page 24 shows how a non-linear detector introduces distortion in measuring a sine wave standing wave.

This non-linearity causes error in measuring standing wave ratios. In some applications of the slotted line, as for example when adjusting an antenna to "match" the line, this error may be ignored.

In other applications where it is necessary to determine the standing wave ratio accurately, correction can be determined in this way:

1. Plot the standing wave as measured with *the particular detector* at the *desired frequency,* with the line open or shorted, and with the generator output adjusted for exactly full-scale deflection at the max. voltage points.
2. Construct a sine wave (half-cycle) on top of the measured standing wave, with zero and max. points coinciding as shown in the graph on page 24. The sine wave indicates the current that would flow if the detector were linear.

Assume that a particular load produces a standing wave with a measured ratio of

$$\frac{\text{VOLTAGE MIN.}}{\text{VOLTAGE MAX.}} = \frac{0.21}{0.6} = 0.35$$

Reference to the curve shows that the value of 0.21 on the *measured* curve corresponds to 0.39 on the sine wave curve.

Also the value of 0.6 on the measured curve corresponds to 0.71 on the sine wave curve. The corrected standing wave ratio is therefore

$$\frac{0.39}{0.71} = 0.55 \text{ (instead of 0.35).}$$

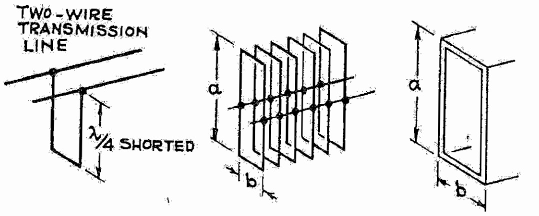
Wave Guides

A wave guide is a simple hollow metal tube having no central conductor. The losses are relatively low, since they will be produced mainly by the "inner skin" of the tube (which is of large perimeter and hence gives low loss). The *inner surface* should be clean and smooth. The *outer surface* can be grounded at any point since the r-f penetrates only a thin skin of the inner surface. *Sharp bends* are usually avoided, and all bends and twists are arranged to prevent a change in "mode" of propagation, or reflections. Instead of a hollow metal guide, a *solid dielectric* may be used as a wave guide. The action in this case is comparable to light waves traveling inside a *lucite rod.* In general, the loss in a solid dielectric wave guide is greater than in a hollow wave guide.

A wave guide cannot be conveniently treated like an ordinary transmission line. Wave guides must be approached from the viewpoint of an electromagnetic wave in a dielectric, using the same basis of treatment as that of radiation.

Wave guides may be rectangular, round, or oval. At the present time, rectangular wave guides are most simple and common; this discussion will refer to rectangular wave guides for the most part, but much of this information can be extended to guides of other shapes.

The following development of a simple type wave guide is intended to serve as a means of bridging the gap between transmission lines and wave guides, although they operate on different principles.

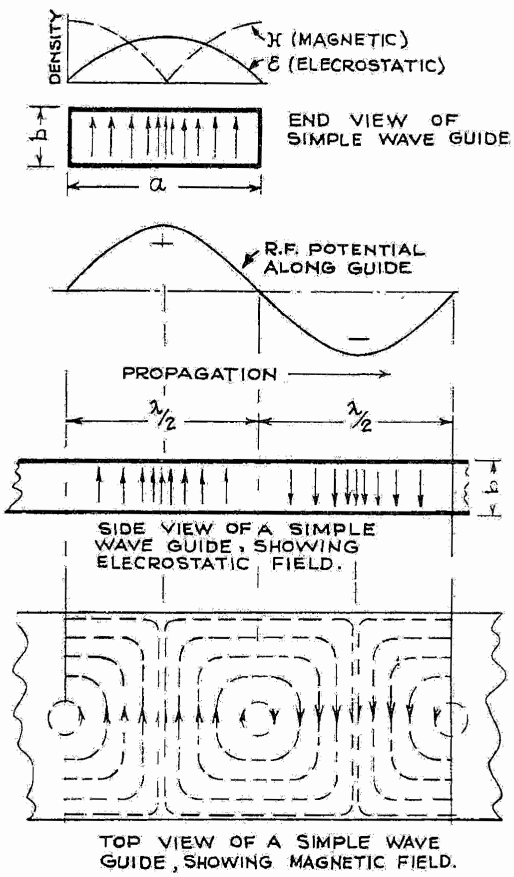


Above at left is shown a section of two wire transmission line. A quarter-wave resonant stub has been added across the line. The ends of the stub where connected to the transmission line, will represent a high impedance—many times higher than the impedance of any practical two wire transmission line. As a result the stub will have a negligible effect.

Suppose an infinite number of quarter-wave shorted stubs are added, resulting in a continuous pipe of rectangular cross section, or one type of wave guide. See illustration above.

"a"—Has a minimum dimension of half a wavelength (in order to propagate a signal) but it may be greater. The "cut-off" frequency depends on dimension "a".

"b"—Is not critical except for voltage breakdown or the possibility of operation in a wrong "mode".



WAVE-GUIDE FIELDS

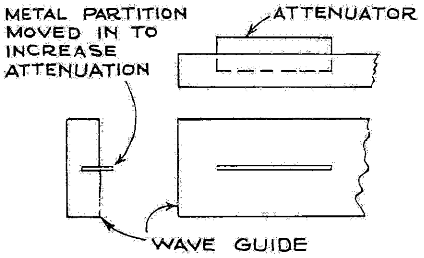
For a simple rectangular wave-guide, the electrostatic lines of force and density of distribution of the E & H fields are shown in the illustration. The electro-magnetic lines of force may be thought of as "whirlpools" in a plane, perpendicular to the electro-static lines of force, traveling down the tube in the direction of propagation. A rectangular wave guide will transmit satisfactorily if the component of the electric field tangent to the side surface is zero at every point on the surface.

A two-wire and a co-axial transmission line are shown with the magnetic and electrostatic fields indicated. A transmission line may be thought of as a guide for magnetic and electrostatic fields.

7. For some purposes, usually test, a wave guide may be matched to air by increasing the internal cross section of the guide slightly at the "air" end; normally an r-f choke, as shown above, is also used.

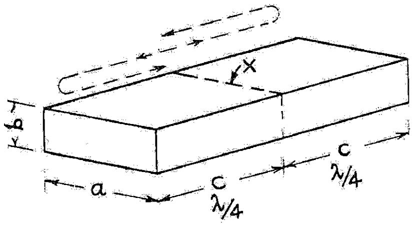
   The end of the wave guide may also be flared outward (increasing the cross section) and used for radiation.

8. A wave-guide attenuator may consist of a movable metal partition as shown below; the attenuation increasing as the partition is moved in.



9. Standing-wave ratios are checked in a manner similar to that used for a co-axial line. A section of wave guide with a narrow slot parallel to the axis of the wave guide (located in the maximum of the electro-static field) is used. A probe with a "crystal detector" or an instrument fuse (1/200A heated to almost the blowing point by d-c) is used to detect the presence of standing waves, as with a slotted co-axial measuring line. Due to the much higher frequency, measurements are considerably more delicate.

10. A section of wave guide may be used as a tuned circuit or as a transformer. In the accompanying illustration, if r-f energy is introduced at "X," reflection will occur at the closed ends. If dimension "C" is correct, the r-f voltage will be reinforced at "X." In this example "C" is a quarter of a (guide) wavelength, however other lengths may be used as long as the reflected voltage arrives back at "X" in phase with the r-f source.

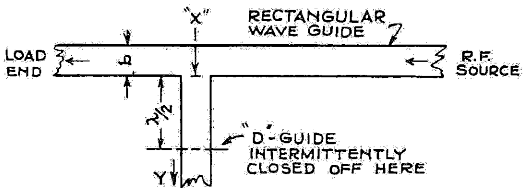


The resonant effect is due to reflections (from the closed ends) setting up standing waves in the guide. The action is similar to that of a "cavity resonator."

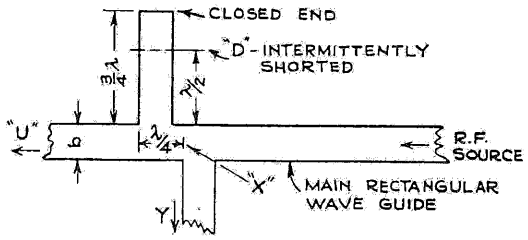
The r-f energy may be introduced inductively, capacitively, or by radiation. Output may be obtained in a similar manner.

11. Sections of open and closed wave guides may be used in switching circuits, etc. In the following examples where a quarter or three-quarters wavelength is indicated, any odd multiple of a quarter wavelength may be used. Where a half wavelength is indicated, any multiple of a half wavelength may be used. (Electrical wavelength in the guide is referred to, not physical length).

In the illustration below an intermittent short at "D" (mechanical or by means of a special tube) is used. A short at "D" will result in effectively a "solid wall" looking in at point "X" when "D" is shorted.



In the following illustration an intermittent short at "D" (mechanical or by means of a special tube) is used.



When "D" is shorted, effectively a "solid wall" will result at the junction of the closed stub to the main wave guide. Paths "Y" and "U" may receive energy.

When "D" is not shorted, effectively a "solid wall" will result looking in at point "X" which is two half waves (a full wave) from the closed end. There will be no transmission in the direction "U" but there will be transmission in direction "Y."

12. A typical wave guide in practical use now, which happened to be a standard size of rectangular tubing:

    Width—about 1.5% greater than a half wavelength (about as small as can be used).

    Thickness—about 44% of the width.

    Wavelength—about 40% longer than in air (standing-wave measurement).

    Loss—about 1/10 db per meter correctly matched).

    Standing Wave Ratio—of as high as 3 to 1 may be tolerated.

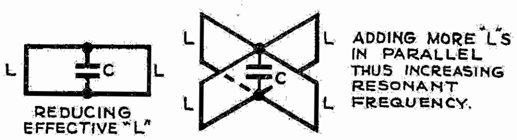
Cavity Resonators

Cavity resonators are tuned resonant circuits for extremely high frequencies where it becomes impossible or impractical to use tuned lines or lumped circuits.

No unique definition of L, C and R can be found in a cavity resonator. A cavity resonator is similar to a wave guide in that electro-magnetic lines of force oscillate back and forth within the cavity in some particular mode, depending upon the shape and method of excitation of the cavity.

UHF cavity resonators may be compared to conventional acoustic resonators. An example is the boomy sound in a room with smooth hard surfaces (good acoustic reflectors). Sound from a source will be reflected from wall to wall with only slight absorption of energy at each reflection. If the frequency of the sound is such as to produce standing waves between two surfaces, or combination of surfaces, the sound is reinforced. The resonant frequency depends on the room dimensions. The "Q" depends on the reflectivity of the walls and other losses.

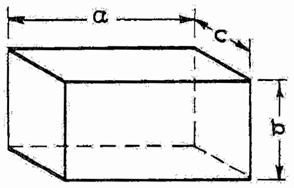
Developing a Simple Resonant Cavity



If it is desired to increase the resonant frequency, we can parallel the inductances "L," thus making the equivalent "L" quite small. There are limits as to how small "C" may be made practically, so the only thing left to do is to decrease the effective "L" of the circuit in order to tune to a higher frequency. See diagram at right.

As shown at the right above, more and more inductive stubs may be added, thus decreasing the effective "L" and increasing the resonant frequency. If this is carried on to the extreme, a closed chamber or resonant cavity results. (Strictly speaking, it is not proper to talk of the inductance of a cavity resonator.)

Modes of Operation of Cavity Resonators



Consider a rectangular section. The description of the "Mode" would be given in terms of electromagnetic fields and various frequencies. Various frequencies of oscillation (different modes) are possible, because wave energy may be propagated and reflected from various surfaces. There is also the possibility of an oscillation that is a harmonic of the basic wave. Two important points in cavity resonators are (1) how oscillations are forced and (2) how energy is removed. They will effect the mode of operation.

The r-f energy may be introduced to or removed from the resonant cavity, inductively, capacitively, or by radiation.

The energy is in the electrostatic field at one instant and in the magnetic field an instant later, oscillating from one field to the other at the frequency of the applied energy.

In referring to cavity resonators the idea that a conductor is always an "equipotential surface" is untrue; voltages and currents reverse themselves in a space measured in centimeters. An *electrostatic field* can terminate only on electrical charge, hence there must be appropriate distribution of charge on the surface. A *magnetic field* can cease suddenly only on a surface carrying current, hence there must be current flowing in the inside surface of the resonator (only penetrates a very thin skin of the metal surface and cannot be detected on the outside of the resonator).

A general statement, for simple resonators, can be made that it is necessary to have a dimension of an electrical half wave or multiples of a half wave since the electrostatic field is a maximum at the center and minimum at the sides of a simple resonator, otherwise the electrostatic field would be shorted out. (Refer to the data covering a section of wave guide used as a tuned circuit.)

Position of Standing Waves for Various Loads

With the load *short circuited,* any convenient point of *minimum voltage* on the slotted line may be used as the *"reference point."*

To determine KX° by the position of voltage maximum, place the scale so 0° is at a reference point, as shown at top of following chart.

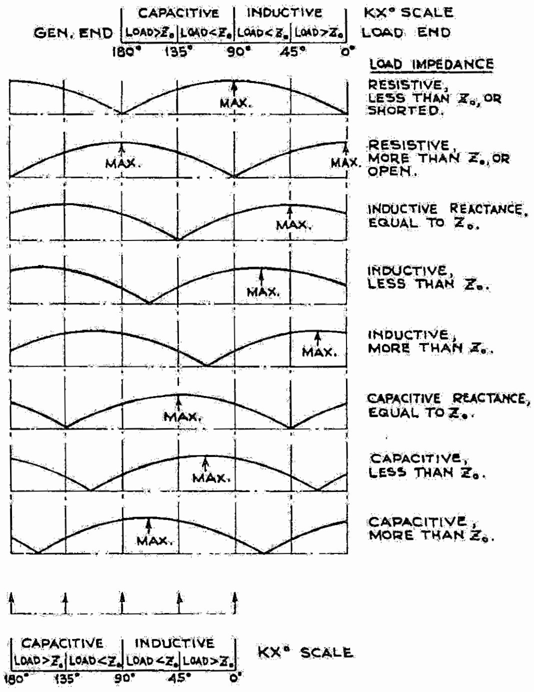
To determine KX° by the position of voltage minimum, place the scale so 90° is at a reference point, as shown at bottom.

The answer is the same in either case.

Owing to the "sharper" indication, it is generally preferable to use a minimum voltage point to determine KX°. However, when using a relatively low frequency, a half-wavelength may be longer than the slotted line and the minimum voltage points may fall beyond the ends of the slotted line. In such cases, it is possible to use a maximum voltage point in determining KX°.

The procedure is to short circuit the load and locate the minimum voltage point nearest the load end of the slotted line. Use this as the "reference point." (If the minimum voltage reference point is not close to the load end of the slotted line, change the length of the transmission line so that the minimum voltage reference point is near the load end of the slotted line. Place the prepared scale (shown in previous sketch) so that the *zero-degree mark is at the reference point.*

Remove the short-circuit and locate the first maximum voltage point from the reference mark (on generator side of reference mark). The reading on the degree scale at this maximum voltage point is KX°.



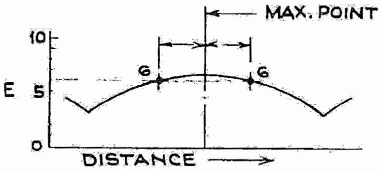
Load Connected Directly at End of Slotted Line

In some applications, the load is connected directly to the end of the slotted line, without using a transmission line. In this case the question of using the minimum or maximum voltage point in determining KX° again depends on the required operating frequency and the length of the slotted line.

With relatively high frequencies, use the first procedure (in which a voltage minimum is used in determining KX°).

With relatively low frequencies, use the point where the load is connected to the slotted line as the "reference point." Place the scale so the zero degree mark is at this reference point. The first maximum voltage point, from the reference point, is KX°.

Note on Obtaining Maximum Voltage Point



As an aid in obtaining accurate location of maximum voltage points, it is suggested that two voltage points of equal magnitude be selected, one on each side of the maximum point, then choose the distance half way between these two points as the maximum point. This same system may be used to determine the location of *minimum* voltage points.

Charts for Use with Slotted Line

Z_C = CHARACTERISTIC IMPEDANCE (SURGE IMP.) OF CONCENTRIC TRANSMISSION LINE OR PARALLEL WIRE LINE.

Z_a = MAGNITUDE OF LOAD IMPEDANCE (TERM IMP.) AT END OF TRANSMISSION LINE

θ_a = ANGLE OF LOAD IMPEDANCE

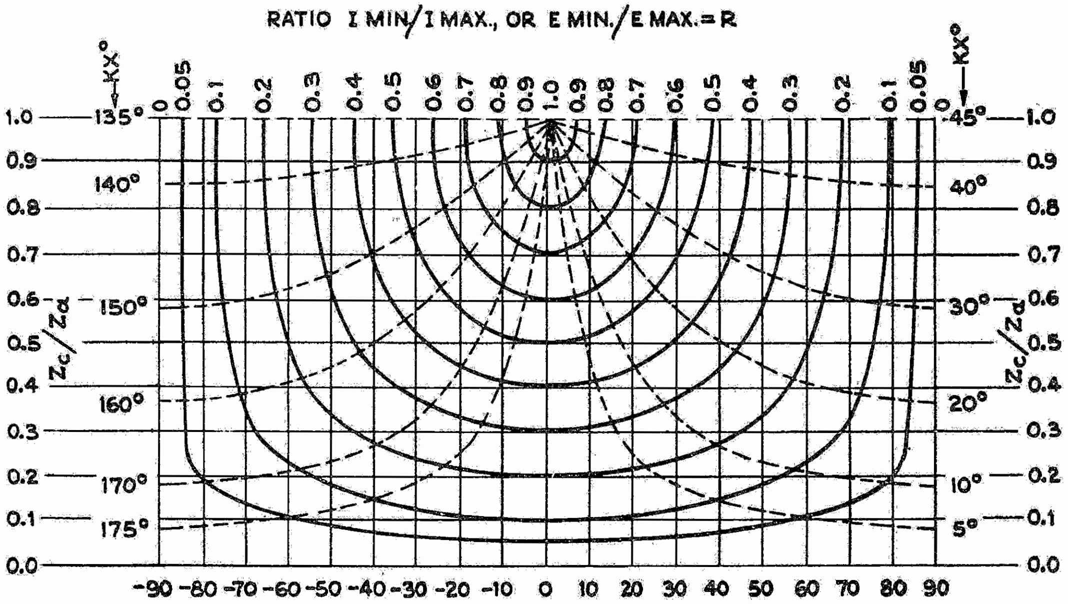


CHART #1.

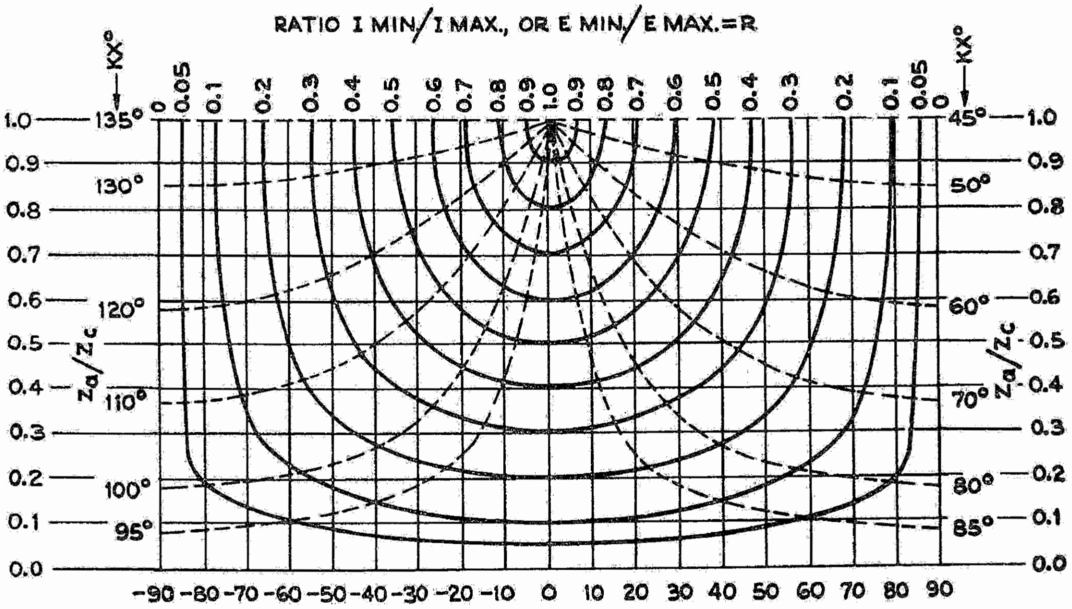


CHART #2

Charts for Use with Slotted Line

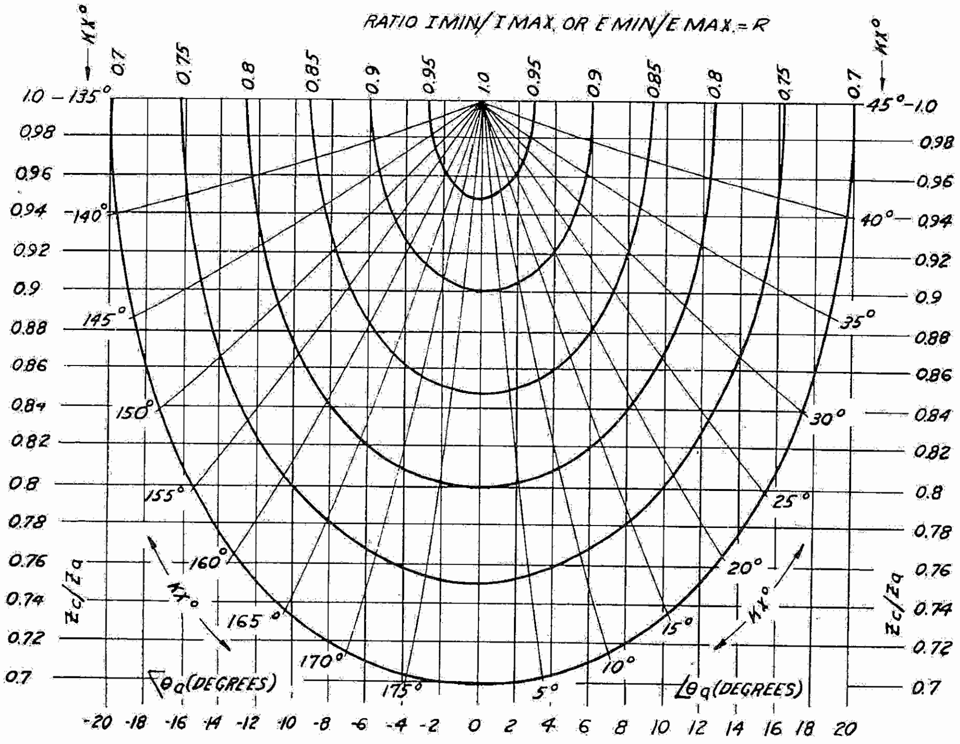


CHART Nº 3 - ENLARGEMENT OF PART OF CHART Nº 1

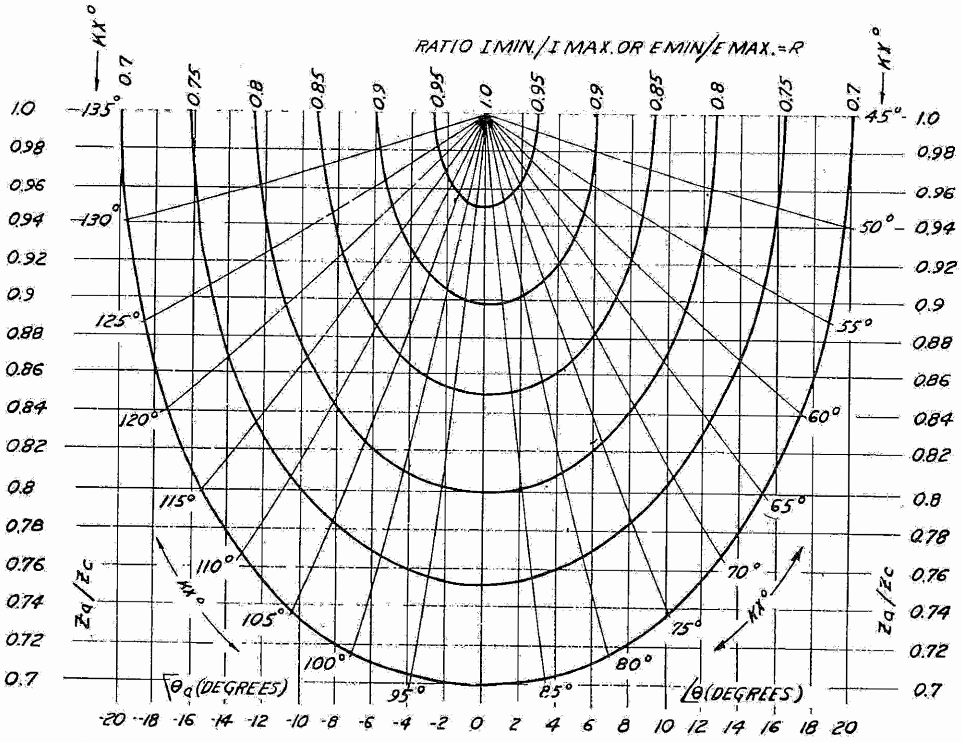
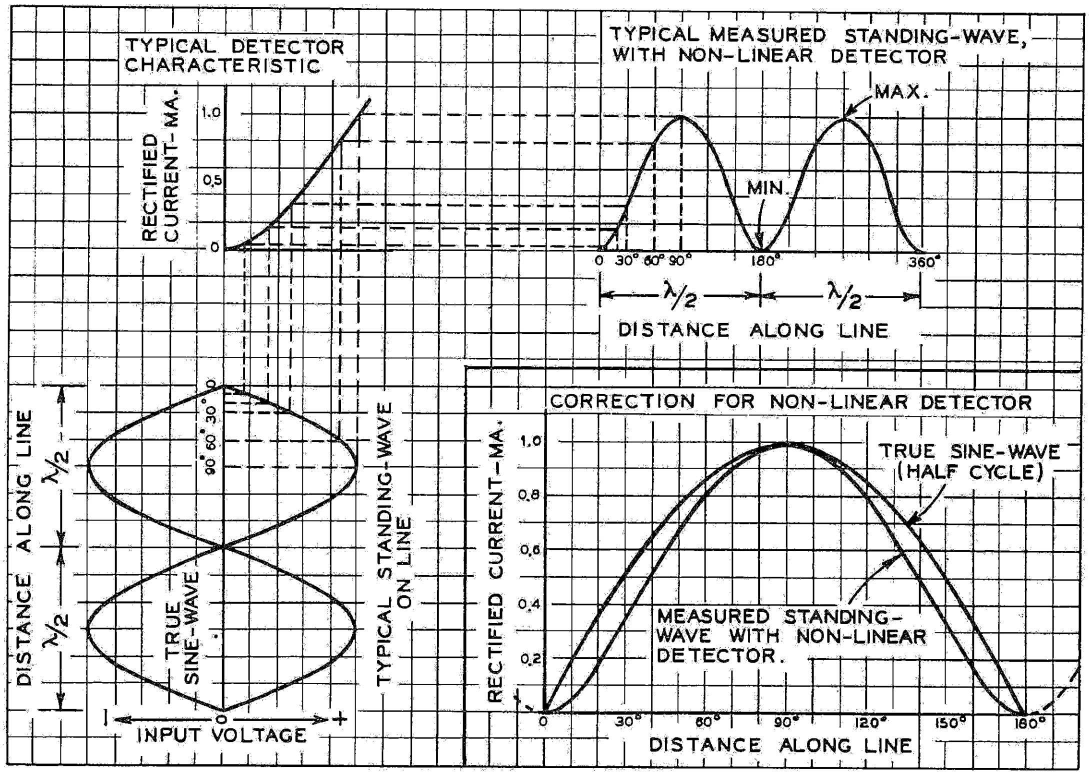
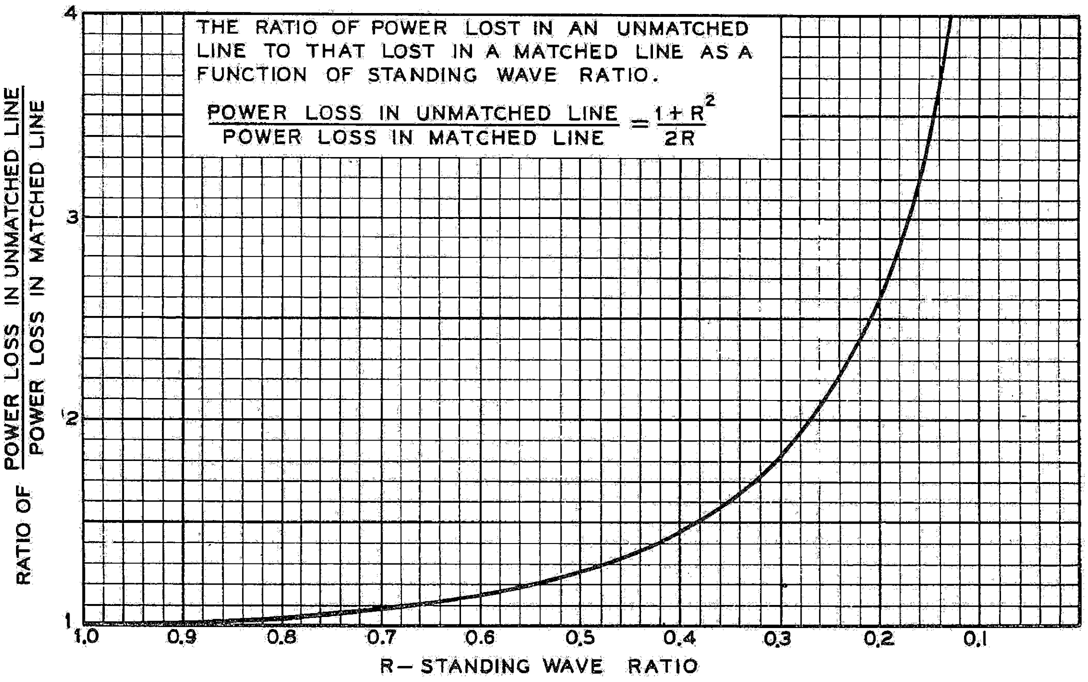


CHART Nº 4 - ENLARGEMENT OF PART OF CHART Nº 2

Effect of Non-Linear Detector



Ratio of Power Loss in Unmatched Line



Abridgement of Design Data for Beaded Coaxial Lines

By C. R. Cox

Andrew Company, Chicago, Illinois

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Beaded Coaxial Lines are sometimes called air-dielectric lines, because most of the space between the two conductors is occupied by air or some other gas.

Beaded lines, utilizing conductors made of rigid or semiflexible copper tubing, have long been used in broadcast, police, and other transmitting installations, and now are being installed in hundreds of new f-m and television stations.

Compared to solid-dielectric cables, beaded lines offer the advantages of higher transmission efficiency, particularly at uhf and vhf, and higher power-carrying capacity. They also, have superior resistance to heat. However, lack of flexibility and the inconvenience of having to maintain an internal gas pressure combine to make the beaded line undesirable in portable equipment.

CHARACTERISTIC IMPEDANCE OF BEADED LINES

In a beaded line, the regularly spaced inner-conductor supports introduce reflections whose effects depend on insulator spacing and frequency, and on the size, shape, and electrical characteristics of the insulators. When the bead spacing is small compared to a wavelength, it is a simple matter to calculate an average capacitance per unit length and an average characteristic impedance and thus reduce the analysis to that of a uniform transmission line. As the bead spacing approaches a quarter wave, however, the recurrent discontinuities due to insulators cannot be averaged uniformly in respect to length, and a more involved analysis is necessary.

Characteristic impedance is normally defined as the impedance looking into an infinite length of line. In a beaded line, the characteristic impedance is defined only at the midpoints between insulators. At all other points, the characteristic impedance includes a reactive component. The impedance may be calculated from Eq. 1 below, provided the proper interpretation is given to k, the average dielectric constant.

$$Z_0 = 138\, k^{-1/2} \log_{10} (b/a) \qquad (1)$$

When the bead spacing is less than 2 percent of a wavelength, the factor k may be determined from

$$k = [W\,(K-1) + 12]/12 \qquad (2)$$

OPTIMUM IMPEDANCE VALUES

Any choice of a standard characteristic impedance must be a compromise between mechanical convenience, attenuation, power-handling capacity (flashover), and temperature rise. The relation between these factors and the diameter ratio is shown in Fig. 1. The curves suggest the following

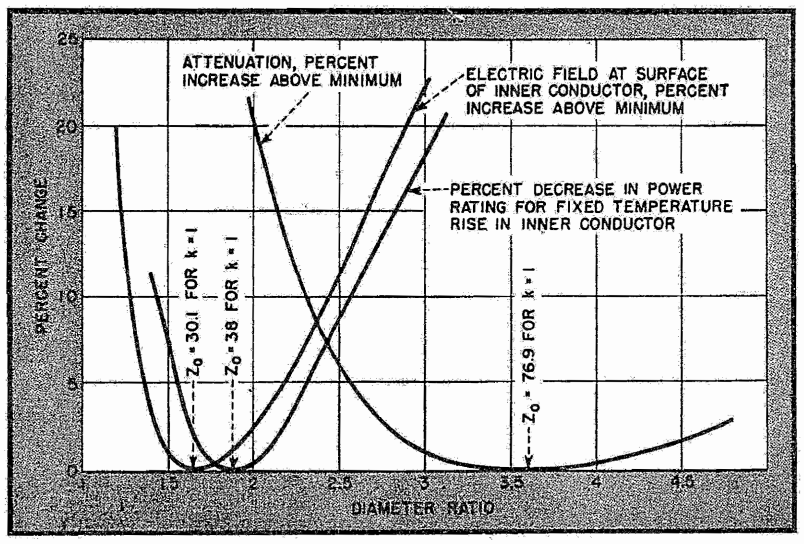


FIG. 1—Effect of diameter ratio b/a (which determines characteristic impedance as set forth in Eq. 1) on attenuation and on power-handling capacity as limited by flashover and by temperature rise. (Temperature-rise curve calculated from data compiled by H. P. Thomas of the General Electric Co.)

optimum impedances: for maximum power-handling capacity as limited by flashover, 30 ohms; for maximum power-handling capacity as limited by temperature rise of inner conductor, 38 ohms; for maximum transmission efficiency, 77 ohms.

In practice it has become common to use 70-ohm cables in standard broadcasting and 51.5-ohm cables in f-m and television broadcasting. These two impedances are also standard for solid-dielectric lines, and hence it is possible to connect rigid and solid-dielectric lines together without matching sections.

Tolerances on characteristic impedance in standard a-m broadcasting, where the lines are sometimes short and standing waves are frequently ignored, are not as important as in television where requirements are severe, and a 10 percent standing wave is thought to be the maximum allowable for proper system performance. Since variations in antenna impedance over the television channel may account for most of the 10 percent, it is thought desirable to hold the characteristic impedance of the line to within plus or minus 2 percent.

The effect on characteristic impedance of variations in conductor dimensions and dielectric constant of the insulating material may be determined by differentiating Eq. 1 and 2 above, treating the differentials as increments.

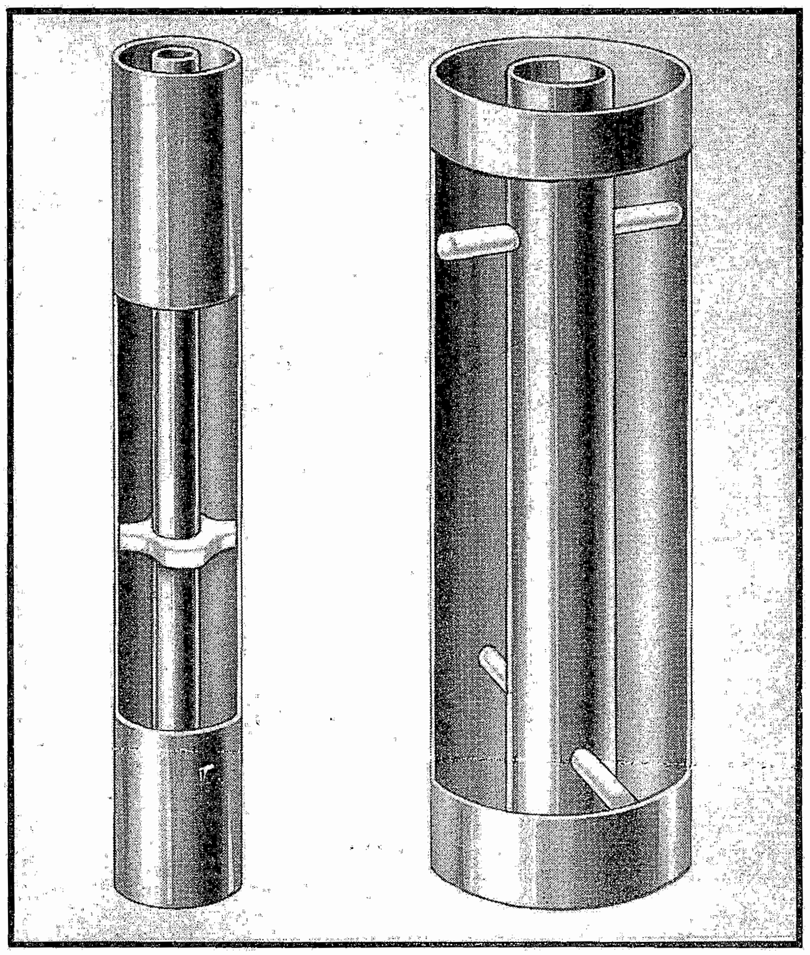
$$\Delta Z = \frac{60\,\Delta b}{\sqrt{k}\,b} \qquad (3)$$

$$\Delta Z = -\frac{60\,\Delta a}{\sqrt{k}\,a} \qquad (4)$$

$$\Delta Z = -\frac{W Z_0 \Delta K}{24\,k} \qquad (5)$$

INSULATOR SPACING

Two contradictory requirements influence the determination of insulator spacing. Close spacings are desirable for constant impedance and to make the line as uniform as possible. Large spacings are desirable to minimize insulator loss. The practical solution to this dilemma has been to keep insulation loss down by making the insulators as small as possible consistent with mechanical strength. The spac-



Cutaway views of coaxial cable with centering bead (left) and large-diameter line employing cross-pin construction

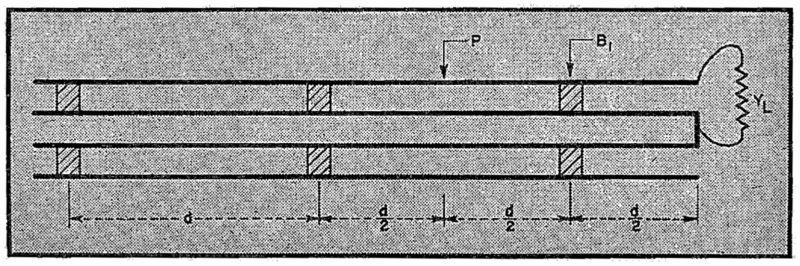


FIG. 2—Beaded coaxial transmission line terminated by an admittance

ing is then selected so that the impedance at the highest operating frequency differs from the low-frequency value by not more than 2 or 3 percent. This principle has led to spacings of 12 inches in lines used for f-m and television, at frequencies from 44 to 216 mc. At standard broadcast frequencies insulator spacing is not as important, and may be determined from mechanical considerations alone.

A mathematical expression for the impedance of a beaded line, in which insulators are spaced 2 percent or more of a wavelength apart, is easy to formulate but difficult to solve rigorously. To begin, it is convenient to write the familar impedance transformation equation in terms of admittance

$$Y = Y_c\left[\frac{Y_L \cos \beta l + jY_c \sin \beta l}{Y_c \cos \beta l + jY_L \sin \beta l}\right] \qquad (6)$$

In the above, Y_c is the characteristic admittance of the line without any bead effect. The problem is illustrated in Fig 2, in which Y_L is an arbitrary load admittance. The characteristic admittance of the line with beads is, by definition, that value of Y_L which appears unmodified at point P after transformation by two sections of line of length $d/2$ with the capacitance due to a bead connected across their junction (at point B_1).

GRAPHICAL SOLUTION

The admittance at B_1 is the admittance of the bead ($Y_B = j\omega C$) plus the admittance due to Y_L after transformation by $d/2$, as in Eq. 7 (Table I). The admittance at point P is then given by Eq. 8, and the characteristic admittance Y_0 of the line with beads is obtained by inserting the value of Y_1 from Eq. 7 into Eq. 8 as is done in Eq. 9. Since Y_0 must be a pure conductance, the desired solution is that value of $Y_L = Y_0$ which causes the reactive term on the right-hand side of Eq. 9 to vanish. The characteristic impedance is then

$$Z_0 = 1/Y_0 \qquad (10)$$

By using the Smith transmission line chart[1] a graphical solution of Eq. 9 is possible. Figure 3 shows a center section of the chart, on which have been drawn several lines corresponding to steps in the solution. The following example is illustrated:

Outer conductor 3.125 OD x 3.027 ID
Inner conductor 1.200 OD x 1.130 ID
Width of ceramic bead 0.375 inches

The characteristic impedance and admittance, omitting bead effect, are calculated from Eq. 1,

Table I—Design Equations for Beaded Coaxial Line

$$Y_1 = Y_B + Y_C\left[\frac{Y_L \cos\frac{\pi d}{\lambda} + j\,Y_C \sin\frac{\pi d}{\lambda}}{Y_C \cos\frac{\pi d}{\lambda} + j\,Y_L \sin\frac{\pi d}{\lambda}}\right] \qquad (7)$$

$$Y_P = Y_C\left[\frac{Y_1 \cos\frac{\pi d}{\lambda} + j\,Y_C \sin\frac{\pi d}{\lambda}}{Y_C \cos \qquad Y_1 \sin\frac{\pi d}{\lambda}}\right] \qquad (8)$$

$$Y_P = \quad c\left\{\frac{\left[Y_B + Y_C\left(\frac{Y_L \cos\frac{\pi d}{\lambda} + j\,Y_C \sin\frac{\pi d}{\lambda}}{Y_C \cos\frac{\pi d}{\lambda} + j\,Y_L \sin\frac{\pi d}{\lambda}}\right)\right]\cos\frac{\pi d}{\lambda} + j\,Y_C \sin\frac{\pi d}{\lambda}}{Y_C \cos\frac{\pi d}{\lambda} + j\left[Y_B + Y_C\left(\frac{Y_L \cos\frac{\pi d}{\lambda} + j\,Y_C \sin\frac{\pi d}{\lambda}}{Y_C \cos\frac{\pi d}{\lambda} + j\,Y_L \sin\frac{\pi d}{\lambda}}\right)\right]\sin\frac{\pi d}{\lambda}}\right\} \qquad (9)$$

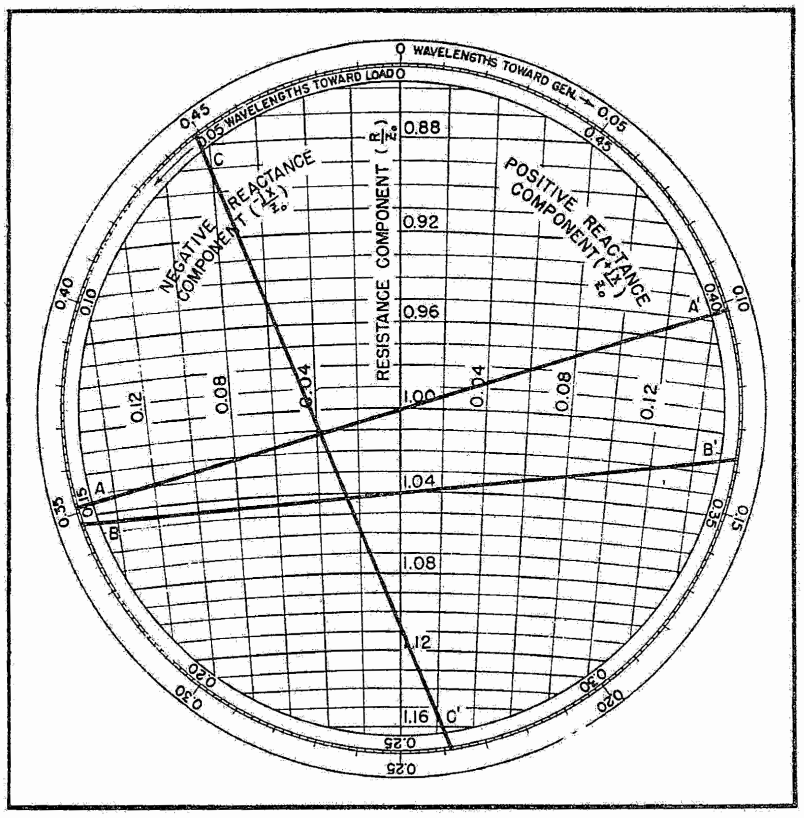


FIG. 3—Use of inner portion of Smith transmission line chart to obtain a graphical solution of Eq. 9, for determining the characteristic impedance and admittance of a beaded coaxial line at 200 mc for the example set forth in the text

using $k=1$, $b = 3.027$, and $a = 1.2$, as $Z_c = 55.5$ ohms and $Y_c = 0.018$ mho. The added capacitance due to the addition of a bead of dielectric constant $K = 6.0$ is calculated from electrostatics to be 2.86 micromicrofarads. Bead susceptance Y_B corresponding to this capacitance is then calculated and normalized by dividing by $Y_C = 0.018$, giving the following susceptance and half-bead spacing $(d/2\lambda)$ values for three frequencies

Freq	50 mc	100 mc	200 mc
Y_B	$j0.000898$	$j0.001796$	$j0.003592$
Y_B/Y_C	$j0.0499$	$j0.0998$	$j0.1996$
$d/2\lambda$	0.0254	0.0508	0.1016

Since any acceptable value of Y_L/Y_C must be a pure conductance, all possible values of this quantity lie on the vertical axis of the chart. Looking into the line at the first bead, however, the admittance values on the vertical axis appear to be rotated through an angle $d/2\lambda = 0.1016$ (at 200 mc), so that all possible solutions now lie on the line AA'. To all points on AA' we must now add the normalized susceptance Y_B/Y_C of the first bead, just as in Eq. 7. Line BB' represents the sum of these two admittances, and corresponds to Y_1 in Eq. 7. To transform the admittance Y_1 into the admittance Y_P at P, the ends of BB' are rotated through an angle $d/2\lambda = 0.1016$ forming a new line CC'. The intersection of CC' with the vertical axis at the point $Y_P/Y_C = 1.106$ corresponds to the value of Y_L which causes the reactive term in the right-hand side of Eq. 9 to vanish. Multiplying this solution by $Y_C = 0.018$ and inverting, we get an impedance of 50.2 ohms. Similar procedures give impedances of 51.4 ohms for 100 mc and 51.5 ohms for 50 mc.

It is also possible to determine characteristic impedance by assuming open and short-circuit conditions at the end of the line and calculating back to the midpoint between beads, using Eq. 6 a total of four times. This method is less tedious than solving Eq. 9, but is not as rapid as the graphical solution.

INSULATOR MATERIALS

Steatite is commonly used for insulator beads because of its excellent electrical and mechanical properties. Various grades are available, the less expensive grades being entirely suitable for use at standard broadcast frequencies where insulation loss is an insignificant part of the total loss. Comparative efficiencies of 3-1/8-inch diameter, 500-foot lines with bead spacing of 12 inches an $Z_0 = 51.5$ ohms are given below for two insulator materials (Alsimag 196 is the cheaper, and use of the more expensive Teflon is justifiable only at uhf)

Material	*Loss factor*	*Eff at 1 mc*	*Eff at 200 mc*
Alsimag 196	0.012	98.8%	67.8%
Teflon (Poly F-1114)	0.0004	98.8%	82.5%

Because creepage distances are small, steatite line insulators must be impregnated to prevent surface moisture films due to condensation. Waxes were used for this purpose until the recent appearance of water-repellent low-volatility silicone fluids. Insulators treated with these solutions maintain a high surface resistivity even in a moist atmosphere, and the impregnant is not volatilized when heated (as in soldering). Surface glazing is occasionally used on large cable beads, but only because of the ease of cleaning which a glazed surface affords. Glazing is expensive, and offers no measurable improvement in surface resistivity.

A few thermoplastic materials have been successfully used for insulators in radar cables. Although some of these plastics, notably Polystyrene, Polyethylene, and Teflon, display superior electrical properties, there are still mechanical difficulties to overcome.

INSULATOR SHAPES

A few commonly used insulator shapes are illustrated in Fig. 4. For low-loss uhf operation (30-300 mc) it is desirable to minimize the discontinuities introduced by inner conductor supports so that insulators may be kept far apart. Discontinuities are minimized in the first four bead shapes by reducing the volume of dielectric material as much as possible. The scheme shown in Fig. 4A is good electrically because excess dielectric material has been removed from the region around the inner conductor where the electric field, and hence the capacitance per unit volume, is greatest. Temperature rise due to insulator loss is also greatest in this region; consequently, mechanical fracture due to large temperature gradients is less likely with the configuration of Fig. 4A.

The cross-pin construction in Fig. 4D is useful principally in large-diameter lines. In Fig. 4E the sides of the bead have been made concave to increase the flashover rating of the cable. This design is used at broadcast frequencies, and is just the opposite of what is needed for low-loss constant-impedance operation at ultrahigh frequencies.

THEORETICAL ATTENUATION

Attenuation is defined as the loss in decibels per hundred feet at a specified frequency and at a temperature of 25 degrees centigrade. Both conductor loss and insulation loss contribute to attenuation, and these terms may be computed separately and added together to obtain total attenuation. In terms of resistance R in ohms per foot and conductance G in mhos per foot, the attenuation is

$$\text{db per 100 ft} = 434 \frac{R}{Z_0} + G Z_0) \qquad (11)$$

For radio frequencies Russell's expression[2] for resistance R may be used, so that the conductor loss only becomes

$$\text{db per 100 ft} = \frac{0.432 f^{1/2} (a + b)}{a\, b\, Z_0} \qquad (12)$$

Equation 12 assumes that both inner and outer conductors are made of chemically pure copper, which although commercially available is quite expensive. Ordinary conductor copper has a conductivity of 95 percent. When this is used, Eq. 12 becomes

$$\text{db per 100 ft} = \frac{0.443 f^{1/2} (a + b)}{a\, b\, Z_0} \qquad (13)$$

The principal problem in determining insulator loss is that of evaluating the shunt conductance G. This quantity is the reciprocal of the parallel resistance R_P due to the imperfect dielectric in one foot of line. If we let R_S be the corresponding equivalent series resistance due to dielectric losses in one foot of line, and X be the reactance due to that portion of a single foot of line which is occupied by insulation, then

$$R_P = \frac{X^2}{R_S} = \frac{X^2}{X P_F} = \frac{X}{P_F} \qquad (14)$$

$$G = \frac{1}{R_P} = \frac{P_F}{X} =$$

$$\frac{P_F\, 2 \pi f \times 10^6\, K\, C\, W}{12} \qquad (15)$$

The insulation loss is obtained by inserting Eq. 15 into the second term of Eq. 11, letting

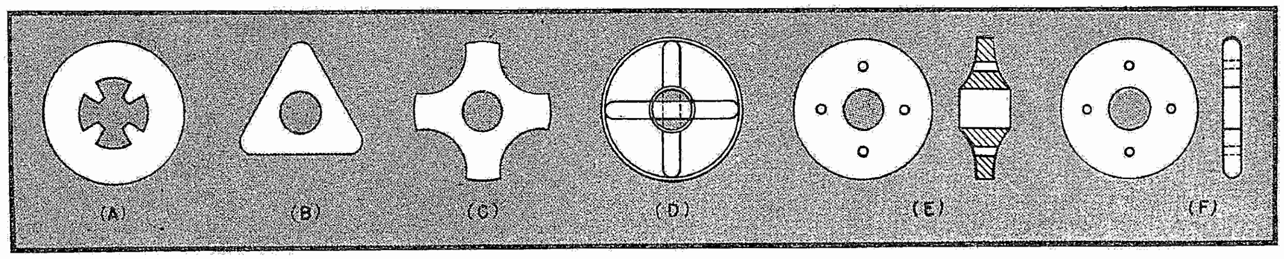


FIG. 4—Typical insulator shapes used in beaded coaxial transmission lines

L_F (loss factor) equal the product of dielectric constant K and power factor P_F, and using Eq. 1 for the characteristic impedance

$$\text{db per 100 ft} = 0.231\, k^{-1/2} L_F W f \qquad (16)$$

By applying Eq. 2, Eq. 16 may be written in another form

$$\text{db per 100 ft} = \frac{2.77\, P_F f K (k-1)}{k^{1/2}(K-1)} \qquad (17)$$

For solid dielectric, $K = k$ and the insulation loss becomes $2.77\ P_F f K^{\frac{1}{2}}$.

ANALYSIS OF EQUATIONS

Several approximations have been made in deriving Eq. 16 and 17. In practical cases, however, it happens that for frequencies less than 200 mc the conditions under which the approximations become poor ones are those for which the insulation loss is a relatively small part of the total, so that no substantial error in the total attenuation is produced.

The importance of having good insulation in lines used at ultrahigh frequencies can be seen by comparing Eq. 16 and 13. Since insulation loss increases directly with frequency, while conductor loss increases only with the square root of frequency, the former term may easily account for a substantial part of the total attenuation at 200 or 300 mc. At 200 mc, for instance, in 500 feet of 3-1/8-inch coaxial line, the difference between a steatite bead costing 10 cents and one costing 31 cents is the difference between an efficiency of 77 percent and one of 68 percent. Also, while conductor loss is roughly inversely proportional to diameter, insulator loss is independent of diameter, provided the relative volume and distribution of insulating material remains the same for all diameters. This fact has imposed a limiting factor on the development of vhf solid dielectric cables, because no matter how large a diameter is used no improvement in insulation loss can be obtained.

MEASURED ATTENUATION

In a complete transmission line system, containing connectors and other cable fittings, the measured attenuation is usually slightly greater than that predicted by Eq. 13 and 16. To allow for this discrepancy, standard attenuation ratings have been made 10 percent greater than the theoretical values. Standard attenuation curves for the nominal 70-ohm cables used in the broadcast band are given in Fig. 5, and curves applying to the 51.5-ohm cables used for f-m and television equipment are given in Fig. 6. The latter curves are based on the use of copper having 95-percent conductivity and insulators with a dielectric constant of 6.0 and a maximum loss factor of 0.004 at 100 mc. A derating factor of 1.1 was applied to give the required 10-percent increase of attenuation above theoretical values. Efficiency may be obtained from attenuation by using the equation

$$\text{Eff} = \frac{100}{\text{antilog}\left(\dfrac{L \times \text{db per 100 ft}}{1{,}000}\right)} \qquad (18)$$

Transmission line loss is increased by standing waves, due to improper termination, and by elevated temperature. An enclosed line, operating at f-m or television frequencies with restricted air circulation and carrying the maximum rated power, may suffer a temperature rise of almost 40 C. Under these conditions, the insulation loss is increased approximately 50 percent and the conductor loss is increased approximately 13 percent. At standard broadcast frequencies (500-1500 kc) coaxial lines develop only negligible amounts of heat, so the attenuation ratings are approximately the same for maximum power as for low power.

Coaxial transmission lines are occasionally connected in parallel, to form an unbalanced line of half the original impedance, or in series, to form a balanced line of twice the original impedance. No improvement in attenuation is obtained from these special arrangements, and it is easily shown that the overall efficiency in either case is the same as it would be if only one line of the same diameter were used.

POWER-HANDLING CAPACITY

Maximum power ratings for coaxial lines used at frequencies above 50 mc have been calculated on a theoretical basis, using a temperature rise of 40 C in the outer conductor as a

Table II. Maximum Power Ratings of Coaxial Lines in Watts

Diam in inches	A-M	F-M			Television		
	0.5-50 mc	50 mc	100 mc	200 mc	50 mc	100 mc	200 mc
3/8	500	....	....	....	....	....	....
7/8	3,000	2,600	1,700	1,100	4,100	2,700	1,800
1 5/8	12,000	9,100	5,700	4,000	14,500	9,100	6,300
3 1/8	50,000	36,000	24,000	15,000	58,000	38,000	24,000
6 1/8	150,000	134,000	95,000	67,000	214,000	151,000	107,000

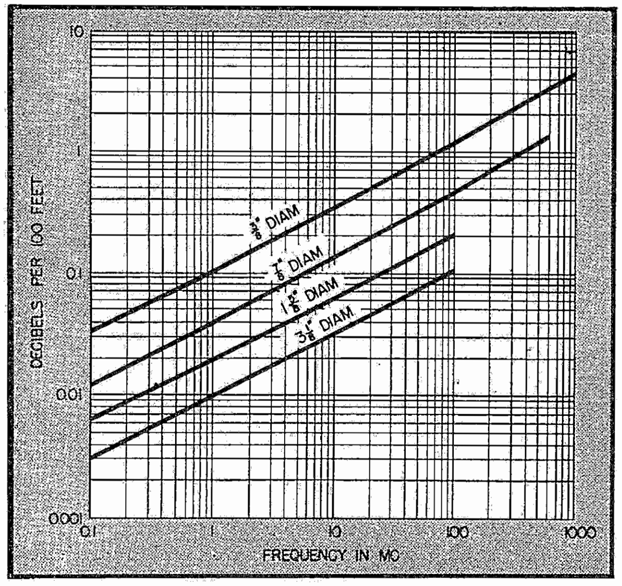


FIG. 5—Standard attenuation curves for nominal 70-ohm beaded coaxial cables used in broadcast-band work

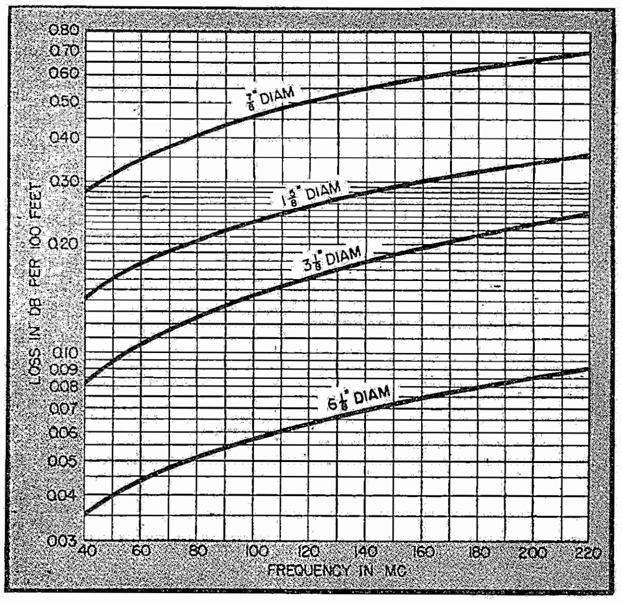


FIG. 6—Standard attenuation curves for 51.5-ohm beaded coaxial cables used with f-m and television equipment

limiting factor. At lower frequencies, voltage breakdown becomes a limitation, and ratings must be based on experience because breakdown usually occurs at lower voltages than theoretical considerations would indicate.

The following procedure is used to determine a power rating based on temperature rise:

(1) The efficiency of a length *L* (feet) is determined from attenuation figures in which copper loss has been increased 13 percent and insulation loss 50 percent.

(2) A power in watts which will produce a 40 C temperature rise in the outer conductor is calculated by multiplying the total surface area of the given length of conductor by the heat emissivity factor *p* and dividing the result by 1 - efficiency.

(3) A maximum power rating for unity standing wave is obtained by dividing the result of step 2 by a factor of 2.

(4) A maximum power rating for any standing wave ratio other than unity is obtained by dividing the result of step 3 by the proposed ratio. For ordinary a-m broadcasting, the ratio may be 2.0, for television it may be 1.1, and for f-m broadcasting it may be 1.75.

Suggested maximum power ratings for various services and frequencies are given in Table II. These are maximum ratings, based on temperature rise or flashover. Except when lines are very short, they should not be operated at maximum power because of attenuation.

In step 2, it is assumed that after equilibrium is attained all of the heat generated inside the line is delivered to the outer conductor, where it is radiated into space (the process involves both radiation and convection). The factor *p* is the heat emissivity of the surface of a copper tube, in watts per square inch for a 40 C temperature rise. This factor, which depends somewhat on diameter, has been studied by power transmission engineers who frequently use copper tubes for busses. An average value is 0.25 watt per square inch.

In step 3, a safety factor of 2 has been applied because tubes enclosed in buildings or ducts or placed against walls suffer a loss of heat emissivity.

The inner conductor operates at a much higher temperature than the outer conductor, and a rise of 75 C may occur for a 40 C rise in the outer conductor. The difference between inner and outer conductor temperatures causes differential expansion, which must be accommodated in suitable expansion joints. The insulators also generate heat (4.5 watts per insulator in a 3-1/8-inch line carrying 25,000 watts at 200 mc) and are further heated by thermal energy received from the inner conductor. Temperature gradients exist in the insulators, and can cause fracture if power ratings are exceeded.

Large-diameter lines are produced in hard-temper rigid lengths of 20 feet, which must be interconnected on the job by suitable couplings. Soft-temper coaxial cables of 3/8-inch and 7/8-inch diameter are produced in continuous 100-foot coils which may be factory-spliced to any

Symbols Used

Z_0 = characteristic impedance measured at midpoint between adjacent insulators
b = inside diameter of outer conductor in inches
a = outside diameter of inner conductor in inches
k = average dielectric constant
K = dielectric constant of insulating material ($K = 6.0$ for steatite)
W = effective width of insulating material in inches per foot of line
$\beta = 2\pi/\lambda$
$Y_0 = 1/Z_0$ = characteristic admittance measured at midpoint between adjacent insulators
$Y_C = 1/138 \log_{10}(b/a)$ = characteristic admittance of line without beads
R = conductor resistance (inner plus outer) in ohms per foot
G = shunt conductance due to imperfect insulators, in mhos per foot
f = frequency in mc
$R_p = 1/G$ = shunt resistance in one foot of line due to imperfect dielectric
$R_S = X^2/R_p$ = equivalent series resistance corresponding to R_p
$C = 7.35 \times 10^{-12}/\log_{10}(b/a)$ = capacitance per foot without beads
P_f = power factor of dielectric material
$X = 1/2\pi f KC \times 0.0833W \times 10^6$ = reactance due to that portion of 1 foot of line which is occupied by insulation
$L_f = KP_f$ = loss factor of insulation
σ = heat emissivity in watts per square inch
L = length of line in feet

desired length and shipped under gas pressure with end terminals attached.

The method of attaching insulators to the inner conductor varies with diameter, but in general an attempt is made to perform the attachment without seriously degrading the flashover characteristic. Any small deformation of the inner conductor encourages concentration of charge, and sharp corners or edges on crimped or swaged inner conductors must be carefully avoided. In 1-5/8-inch diameter and larger cables, in which the inner conductors are tubular, a good fastening may be made by inserting a spinning tool inside the inner conductor and spinning a ridge on both sides of the bead.

Coaxial lines must be pressurized with a dry gas to prevent condensation of moisture on insulator surfaces. Air and nitrogen are both used for this purpose. There is nothing critical about the amount of pressure, and anything from 1 to 30 pounds is satisfactory.

REFERENCES

[1] Smith, P. H., Transmission Line Calculator, Electronics, p 130, Jan. 1944.

[2] Russell, Alexander, Effective Resistance and Inductance of Concentric Mains, *Philosophical Magazine*, 6th series, 17, p. 524. Apr. 1909.

THE MEASUREMENT OF AUDIO DISTORTION

By H. H. Scott, Hermon Hosmer Scott, Inc.

Any modification of an audio-frequency signal between the point where it reaches the microphone and the point where it is reproduced by a loudspeaker may be considered as "distortion". In general usage the term has, however, come to have a more restricted meaning--namely, the introduction of extra components into the signal which were not originally present. This article is concerned with this type of distortion, variously known as "non-linear," "amplitude" or "harmonic" distortion, which, however, may include the generation of components which are not necessarily harmonically related to the signal.

The simplest measurement of non-linear distortion is obtained by applying a single sine-wave signal to a transmission system and measuring the various components in the output of the system with a wave analyzer. At low levels in a good system over 99% of the output voltage will be at the applied fundamental frequency, but there will also exist a percent or less of distortion components corresponding, in this case, to exact multiples of the fundamental frequency. Of these components, known as harmonics, the second and third (corresponding to twice and three times the fundamental frequency, respectively) are generally the strongest, but higher-order harmonics may also be present at appreciable amplitudes. There will also exist in the output of the system other spurious components, consisting of the fundamental and harmonics of the power-supply frequency, various noise components resulting from tube hiss and other circuit disturbances, pickup from other circuits, and other extraneous components. Many of these can also be measured on an analyzer or other distortion-measuring device. As the signal level is increased until various parts of the system overload, harmonic distortion may rise to 5%, 10% or even higher values, which in most cases are distinctly noticeable, and which are annoying in real high-quality reproduction.

Conventional practice has been to measure non-linear distortion in terms of the harmonic components added to a single-frequency testtone by the system, and various limits have been set, depending upon the requirements of the problem. For instance, distortion as high as 10% is considered tolerable in a single-tube output amplifier stage by many designers of home-type sound-reproducing equipment, such as phonographs and radios. At the other extreme, we have the new FCC requirements for frequency-modulation systems, which specify a total distortion between the microphone terminals and the modulated signal as radiated by the antenna as low as 2.5% for an entire system, including many amplifiers, transmission lines or other studio-transmitter links, various control and amplifier equipment, and the transmitter itself.

In general, for systems of comparable design features which exhibit similar characteristics in regard to the generation of harmonics, a low level of harmonic distortion measured in this manner is an indication of excellence. For systems exhibiting different characteristics, however, and which overload in various manners, it has long been realized that the amount of distortion which is audible to the ear is not necessarily related exactly to the single-frequency harmonic measurements. This is particularly true in the case of home-type receivers or other sound-reproducing equipment which must be built to meet price competition. The reason for this lies in the fact that the distortion characteristics of a non-linear system are far more complicated than can be determined by a simple single-tone measurement.

For instance, if two tones (f_1 and f_2) are applied simultaneously to a non-linear system, the distortion products include not only the harmonics of those two tones but also frequencies equal to the sum and difference of the two tones ($f_1 + f_2$, $f_1 - f_2$) and higher-order intermodulation products (such as $f_1 + 2f_2$, $f_1 - 2f_2$, $2f_1 + f_2$, $2f_1 - f_2$, etc.) which theoretically may include beats between the fundamental and all of the possible harmonics of one tone and the fundamental and all possible harmonics of the other. It will be observed that it is only by accident that any of these so-called intermodulation components ever coincide with a harmonic of one of the original frequencies. Hence, this intermodulation distortion represents discordant components added to the signal. Since any musical instrument produces tones which contain harmonics as well as the fundamental frequency, it is obvious that a moderate increase in the harmonics themselves need not be annoying. However, the addition of discordant components is distinctly audible, and it is the presence of such intermodulation products which most people call distortion. In any practical system the intermodulation products may become serious under conditions where the actual addition of harmonics themselves is of little consequency. The picture is further complicated by the fact that non-linearity in the amplitude characteristics of a system, which accounts for the distortion, is often a function of frequency, particularly at the lower and higher ends of the frequency range. This is particularly true in systems involving transformers, speakers and other electro-mechanical transducers, tone control, and filter, push-pull or feedback circuits.

The amount of distortion, therefore, is a function not only of amplitude but also of frequency.

In a system producing serious distortion it is almost impossible to simulate by any reasonable measurements the actual results which will be obtained when a signal such as music from a large orchestra is impressed upon a system. With each of the thousands of components producing intermodulation with the others, the resulting jumbled noise as heard by the ear is, however, a good indication of what is happening. The problem of distortion measurements is, therefore, to provide the simplest type of measurement which can be correlated with distortion as heard by the ear.

For years the total rms value of the harmonics added to a single tone has been used as a measure of such distortion. Where the total distortion may be kept low and the system is designed in accordance with the best standards of engineering practice without the necessity to cut corners to save cost, this type of measurement is generally satisfactory. In the case of the FM transmitter, for instance, if the total distortion is below 2.5% it is not likely that any distortion which may occur will be sufficiently serious to be noticeable. Nevertheless, it is still not impossible. As the quality of the system decreases, it becomes more important to make additional measurements to determine whether or not serious intermodulation takes place. Until further information as a result of experience becomes available, however, it may be assumed that for equipment of the type used in high-quality broadcasting a measure of the single-tone harmonic distortion will generally suffice.

A common fallacy in making harmonic measurements has been to assume that harmonics above the range of hearing were of no importance since they could not be heard. It will be noted, however, that the new FCC requirements for FM specify harmonic measurements as high as 30,000 cycles, although admittedly, no one can hear such harmonics themselves. The reason for this is that the presence of such harmonics, whether they are heard or not, indicates that distortion is taking place, and the generation of such harmonics indicates the presence to an indeterminate degree, which may be serious, of intermodulation products which may fall within the range of hearing--in fact, within the range where the ear is most sensitive. Thus, these high-frequency harmonic measurements are specified rather than more elaborate intermodulation measurements in an attempt to assure that the intermodulation shall not be serious. For a system of fundamentally high quality and designed in accordance with best engineering practice, this is not an unreasonable assumption.

In terms of what the customer hears on his receiver, distortion measurements are probably the most important measurements to be made on a radio-transmitting system. The maintenance of low-distortion limits insures, in general, clear, natural reproduction of the signals, limited only by the capabilities of the receiving system.

FCC Requirements

The Federal Communications Commission in its Standards of Good Engineering Practice concerning FM Broadcast Stations, requires that the overall harmonic distortion at any modulating frequency between 50 and 15,000 cycles be within the following limits:

Modulating Frequency	Distortion
50 to 100 cycles	*3.5%*
100 to 7500 cycles	*2.5%*
7500 to 15,000 cycles	*3.0%*

Standard test frequencies are 50, 100, 1000, 5000, 10,000 and 15,000 cycles.

Such measurements should be made employing the standard 75-microsecond de-emphasis in the measuring equipment and the 75-microsecond pre-emphasis in the transmitting equipment and should include all harmonics up to 30 kc. Measurements should be made at 25%, 50% and 100% modulation. This latter requirement has introduced certain difficulties, since commercially available analyzers will not tune much above 18 kilocycles, and distortion meters are limited in their sensitivity by the noise in the measured signal. The FCC allows a maximum of -60 db below 100% modulation for the FM noise level of the entire system in the range from 50 to 15,000 cycles. 100% modulation is equivalent to ±75 kc swing.

Since these tolerances include the entire transmitting system from the microphone to the antenna, it is obvious that any unit of the system must be better. The FCC recommends that none of the three main divisions of the system (transmitter, studio-to-transmitter link, and audio facilities) contribute over one-half of the total distortion.

For television transmitters and performance requirements of the frequency-modulated sound channel are the same as for FM broadcasting excepting that 100% modulation is equivalent to ±25 kc swing, and the allowable noise level is -55 db.

For amplitude-modulated broadcast systems the FCC has not established any definite distortion requirements. Proposed RMA standards for the transmitter alone allow a distortion of 3% for modulation percentages up to 85% and

5% for modulation percentages between 85% and 95%, for a range of fundamentals between 50 and 7500 cycles and including all harmonics up to 24 kilocycles. The allowable noise level is 60 db below 100% modulation. Proposed RMA standards for distortion in the audio facilities have a limit of 2% from 100 to 7500 cycles and 3% from 50 to 100 cycles. All of these distortion measurements are rms values--that is, the amplitudes of the various harmonics are combined by taking the square root of the sum of the squares of the individual components.

Signal Sources for Distortion Measurements

The lowest distortion obtained in any type of commercially available oscillator is found in the R-C feedback type, usually push-button operated, in which the distortion is generally better than 0.1% throughout most of the operating range. In this type of oscillator an R-C feedback network, usually of the parallel-T type, provides a high degree of degeneration for all harmonic voltages. The extremely good waveform at low frequencies is made possible by the absence of inductance coils or other non-linear elements. In commercial push-button oscillators of this type the standard frequencies include all of the FCC test frequencies. For highly accurate measurements of distortion such an oscillator is a distinct advantage since the inherent distortion in the test signal will always be small compared to the amount to be measured in the transmitted signal. An oscillator with low distortion such as the above is to be preferred for the FCC proof of performance tests.

For ordinary maintenance checks on transmitters other types of oscillators may be used, and if they are to be used also for running response curves, etc. certain of the continuously variable types may be considered more convenient. Continuously variable oscillators are generally either of the beat-frequency type or of the R-C type. High-grade units of the beat-frequency type may have distortion as low as 0.2% throughout most of the frequency range, but the distortion tends to rise to relatively high values at low frequencies. The most important advantage of the beat-frequency oscillator as a standard test instrument is that the complete audio-frequency range is available on a single dial, which may have a logarithmic or other desired scale shape.

A third type of oscillator not yet in commercial production and known as the double-beat or multiple-beat allows the simultaneous application of two test frequencies, thus facilitating measurements of intermodulation distortion. There are considerable theoretical reasons to believe that when such oscillators are available two-tone distortion tests will become quite generally used, particularly in cases where high amounts of distortion are encountered, since it is usually agreed that the intermodulation products are considerably more annoying than the spurious harmonics. Of course, intermodulation measurements can always be made using two individual oscillators.

Distortion-Measuring Instruments

The most common form of distortion-measuring instrument is the distortion meter. Various types have been manufactured over a period of years, earlier types being of the fixed-frequency variety. More recent types have been continuously adjustable. One of these has operated by bucking the transmitted signal against the applied signal, which requires careful adjustment of both phase and amplitude and measuring the resulting difference, which is an indication of distortion. The most recent types involve null circuits of the Wien bridge, parallel-T or similar types, which attenuate the fundamental sufficiently so that the remaining signal represents almost entirely the harmonics and noise. Switching the null network out of the circuit allows direct measurement of the noise, which obviously should be considerably lower than the level of the harmonics if accurate measurements are to be made. This fact limits the usefulness of the distortion meter in some applications. The distortion meter readings, of course, represent the total of all harmonics combined, there being no indication of the relative amplitude of each individual harmonic.

In using a distortion meter, a preliminary check should be made of the noise level in the system under test to be sure that it is not comparable to the magnitude of the distortion to be measured. This is particularly important in circuits having de-emphasis, since the standard 75-microsecond de-emphasis curve is down approximately 8.2 db at 5000 cycles, 11.4 db at 7500 cycles, 13.6 db at 10,000 cycles and 17 db at 15,000 cycles. For proof of performance tests on FM transmitters the FCC has accordingly agreed to require the 50% and 25% modulation distortion measurements only for frequencies of 5000 cycles and below as a temporary measure. The problem is further complicated in the case of television transmitters, where the allowable noise level is 5 db higher.

One of the earliest, and still one of the best methods for measuring distortion is the wave analyzer. Such devices in present commercial forms are generally of the heterodyne type, having a fixed-frequency filter. In such an analyzer tuning is accomplished by heterodyning the component being measured up to the filter frequency. The use of a fixed filter allows a very high degree of selectivity. Consequently such measurements are relatively unaffected by noise and other factors, even under conditions where distortion meter measurements may be useless. Present commercial types of wave analyzers, however, do not tune to frequencies above approximately 18 kilocycles, which limits their use for some of the high-frequency distortion measurements now required by the FCC. The great advantage of the analyzer, however, is its versatility. Since it measures such component separately, it may be used equally well for single-tone harmonic measurements or for multi-tone intermodulation measurements.

Another distortion-measuring device is the so-called intermodulation meter, which is intended only for intermodulation measurements. Such a device is quite similar to a modulation meter as used for measuring percentage modulation of a broadcast station excepting that the intermodulation meter is an audio-frequency instrument. It measures the depth of modulation produced on one tone, generally at a high audio frequency, by another tone, generally of a low audio frequency. This type of intermodulation meter is often limited to operation at only a few selected frequencies.

Coupling Test Equipment To Transmitter

Fig. 1 shows the conventional means for coupling the test oscillator to the transmitter, and in general this simple arrangement will be found quite satisfactory. The resistance R_S should equal the impedance from which the equipment under test is designed to work. The attenuator, which is of the T type, should be of the impedance from which the equipment under test is designed to work, or a matching pad should be interposed. The connections shown are for unbalanced circuits. If the circuits are balanced an H-type attenuator must be used, and one-half of the resistance R_S should be inserted in each input lead. A VU meter is shown for convenience, but any good audio-frequency or vacuum-tube voltmeter may be substituted. For a 600-ohm circuit R_S will equal 600 ohms, and the input level to the equipment will be the reading of the VU meter minus 6 db minus the setting of the attenuator. The attenuator may be eliminated in cases where the input level is sufficiently high so that it can be read on the VU meter directly.

For measurements on audio-frequency sections of the transmitter the distortion meter or analyzer may be connected directly to the output of the audio-frequency equipment, as shown in Fig. 2. The resistance R_L, in parallel with the input impedance of the distortion meter or analyzer, should equal the rated load impedance for the equipment.

For measurements of distortion on an amplitude-modulated carrier the arrangement shown in Fig. 3 may be used. The AM demodulator is generally included as a part of the amplitude-modulation monitoring equipment, but the arrangement shown is typical. Suitable values for the circuit are as follows:

C_1 = 50 micromicrofarads

C_2 = 35 micromicrofarads

L_1 = L_2 = 25 millihenries

R_1 = R_2 = 100,000 ohms

D_1 = 6AL5 or 6H6

The audio-frequency input impedance of the distortion meter or analyzer should be large compared to $\frac{1}{2}R_2$ to avoid distortion at high modulation percentages.

For testing frequency-modulated transmitters the same system is used except that a frequency-modulation discriminator must be used in place of the AM demodulator. The requirements for this demodulator are sufficiently strict and the adjustments sufficiently critical so that no simple diagram would be of any use. Generally a suitable discriminator will be included as part of the frequency-modulation monitoring equipment utilized with the transmitter.

Before making distortion measurements it is well first to connect the distortion meter or analyzer directly to the output of the oscillator to determine that the distortion in the applied signal is sufficiently low for the tests. This check should be made with the oscillator terminated in the same value impedance as it will be operating into during the tests but without the equipment to be tested actually connected. When checking the noise level of the system prior to making measurements with a distortion meter, if it is found that hum or other noise components are abnormally high it may be necessary to use an isolating transformer at the output of the oscillator. This is particularly true when working with low-level input circuits. Needless to say, all low-level leads should be well shielded.

Differences Between Distortion Measurements On AM and FM Transmitters

On AM transmitters the distortion measurements are fairly simple because of the relatively high tolerances and the flat frequency response. However, it is characteristic of AM transmitters that the distortion rises rapidly as 100% modulation is approached. With certain types of AM transmitters, particularly those employing Class B systems, it may also be found that the distortion increases at very low modulation levels. The FM transmitter, on the other hand, must be capable of swinging to an extent equivalent to 133% modulation, considering a 75-kilocycle swing as 100%. Hence the distortion of an FM transmitter should not rise noticeably in the neighborhood of 100% modulation. The television transmitter must be able to swing 40 kilocycles, which is the equivalent of 160% modulation. The lower allowable distortion of the FM transmitter, plus the fact that a de-emphasis circuit which further reduces the amplitude of the high-frequency harmonics is used for the measurements, somewhat complicates the measurement of FM transmitters, particularly at higher modulation frequencies, and care should be taken to check noise levels to be sure that they are not interfering seriously with the measurements.

For transmitters with sufficiently low distortion to meet the FCC and RMA requirements it is probable that simple single-tone harmonic measurements with a distortion meter or a wave analyzer will provide a satisfactory check on operating performance. In cases where, in spite of low harmonic measurements, however, the quality as judged by the ear appears to be rough or distorted, the source of such difficulty can generally be most easily traced by resorting to two-frequency intermodulation measurements, which may be made with a wave analyzer and either two oscillators or a double-beat oscillator. Such measurements may be particularly valuable in case of high-frequency distortion in FM transmitters, since the relative sensitivity of harmonic measurements is so greatly reduced by the de-emphasis circuit.

Relative Value of Different Types of Distortion Measurements

The choice between various types of distortion measurements is a subject which cannot be easily settled at the present time because of the relatively limited experience with all except the single-frequency type. To meet the FCC Proof of Performance tests single-frequency tests are required, and such tests are probably satisfactory for ordinary routine checks on high-grade equipment. In cases, however, where audible distortion exists to a degree considerably higher than the harmonic measurements would indicate, intermodulation measurements are generally desirable. In some instances a simple two-tone check with an intermodulation meter may be sufficient, but in general more complete tests utilizing a wave analyzer and either a double-beat oscillator or two high-quality oscillators are desirable.

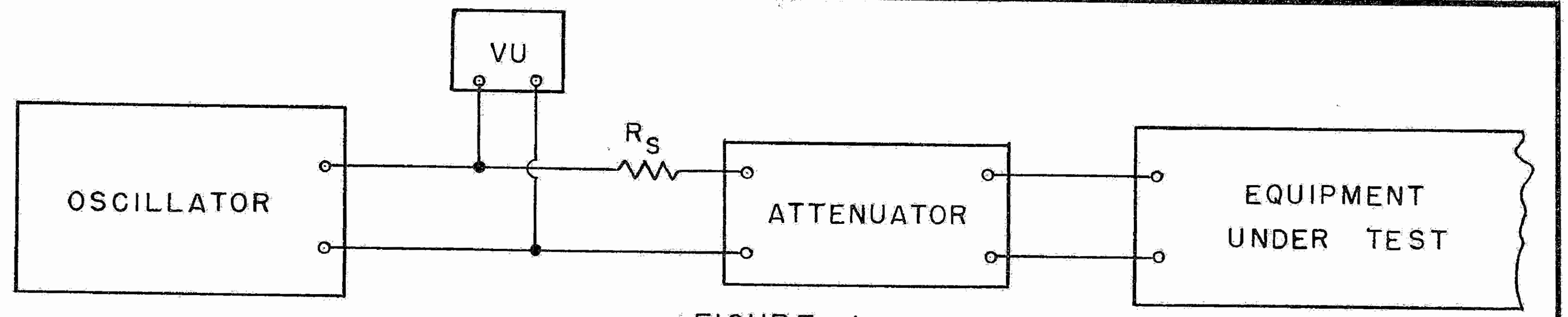


FIGURE 1

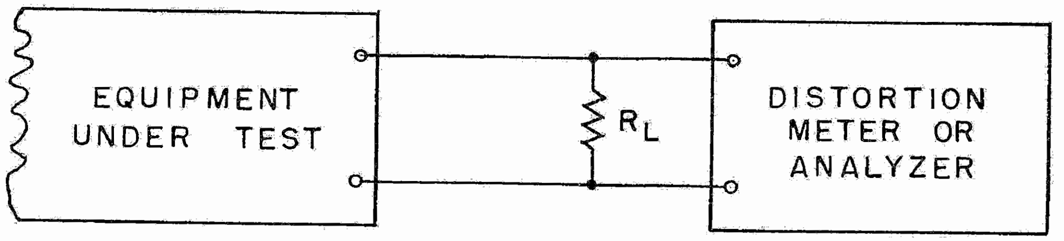


FIGURE 2

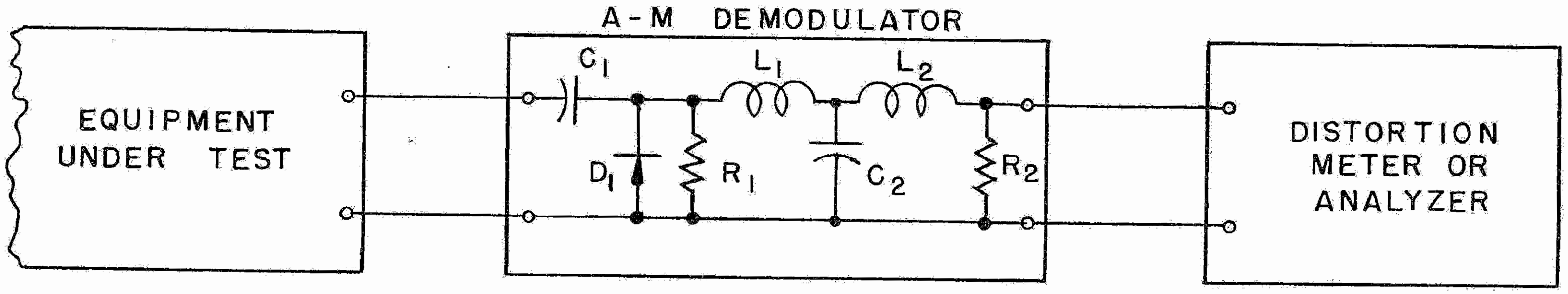


FIGURE 3

LOCATION AND SIZE CONSIDERATIONS
of
TELEVISION TRANSMITTING AND PROGRAMMING PLANTS

Before examining requirements for the location and size of the individual components of a television plant, it appears appropriate to emphasize one general point which is made almost without exception by television station owners, managers, engineers, and production people at stations of all sizes and types. Their advice is this:

Maintain the maximum degree of flexibility in all building plans. Prepare for almost constant change during the first few years of operation, and be sure that expansion will be possible without upsetting operations too seriously and bringing on undue expense. The nature of the business is such that even the most meticulously made plans will require modification from time-to-time (probably much more often than one would prefer) to keep in step with the progress of this dynamic new industry.

The discussion which follows is divided into two main sections, namely: location of the transmitting and programming plants; and "rule of thumb" estimates which may be applied with regard to the amount of operational space required at the transmitting and programming plants. The first section pertaining to location of sites is based almost in its entirety upon two papers prepared by the RCA Victor Division of the Radio Corporation of America. The contents of this section have been reviewed by RCA and it is included herein with their permission.

The section pertaining to "Size and Design" is taken largely from Chapter Four of the NAB Staff Study entitled "Report on the Visual Broadcasting Art". This section was compiled after considerable research into the problems encountered by those television stations in actual operation and is intended as a guide to those who will be called upon to prepare estimates, design data, and general information in connection with the planning of television operations. Although the discussion is not of the slide-rule variety it is set forth here primarily because the engineering department of a station is, almost without exception, called upon initially by management to prepare the first phases of such data. It is obviously impossible at this early state of the television art to give definite formulae for what may be termed standard practice in the design of almost any of the complexities covered in these discussions. It is, however, hoped that by setting down here what others have learned through experience, the all important stage of planning a television plant may be more thoroughly and less arduously accomplished.

SELECTING SITES

Even before an application for a construction permit can be filed, the prospective television station licensee is faced with the necessity of deciding upon locations for both his programming and transmitting plants. Although these decisions can under some circumstances be changed later, they are crucial ones, naturally, affecting vitally future day-to-day operations of a successful applicant.

Establishing both transmitting and programming facilities in the same location frequently offers several immediate advantages, which the broadcaster will undoubtedly want to capitalize upon if possible. It is advisable to study the two sites separately at first, however.

The antenna's location governs to a major degree the coverage which a station can expect. And, as in all types of broadcasting, the programming plant cannot be placed in too remote and inaccessible a spot. In many cases, obviously, the disadvantages of a single location can easily outweigh all other considerations.

While the location of the studio site is a matter dictated to a considerable degree by commercial reasons, the location of the transmitting equipment and antenna is almost entirely an engineering problem.

The importance of situating the transmitter most advantageously is of such magnitude that selection of this site must be given precedence.

TRANSMITTER

The factors which govern the location of television transmitters are several, and their relative importance will vary widely with local conditions. Some of these factors have to do with competition, prestige, population distribution and other local conditions about which it is obviously impossible to generalize. The technical requirements, on the other hand, are fairly universal and can be set down in well-defined terms.

BASIC REQUIREMENTS

The objectives in choosing a transmitter site are as follows.

(A) The location should be centrally located with respect to the area to be served (unless a directional antenna is to be used).

(B) The location must be as high as possible--always higher than surrounding buildings or elevations where there are no obstacles to reflect the transmitted signal.

(C) Power, water, and other facilities must be accessible, and it must be possible to accomplish all of this within the bounds of economic reason.

Some pertinent excerpts from the FCC's Standards of Good Engineering Practice for Television Broadcast Stations should serve to amplify and emphasize these points:

> The transmitter location should be as near the center of the proposed service area as possible consistent with the applicant's ability to find a site with sufficient elevation to provide service throughout the area.
>
> Location of the antenna at a point of high elevation is necessary to reduce to a minimum the shadow effect on propagation due to hills and buildings which may reduce materially the intensity of the station's signals in a particular direction.
>
> In general, the transmitting antenna of a station should be located at the most central point at the highest elevation available. In providing the best degree of service to an area, it is usually preferable to use a high antenna rather than a lower antenna with increased transmitter power.
>
> The location should be so chosen that line-of-sight can be obtained from the antenna over the principal city or cities to be served; in no event should there be a major obstruction in this path.

These considerations, coupled with the fact that television (like FM and unlike AM) requires no extensive ground system, has led many telecasters to place their antennas atop the tallest available building. The business district and population center do not always coincide, of course, but such structures are apt to be centrally located. If there are no other tall buildings nearby to deflect signals, the problem of attaining height can be solved in this manner. Thus, if we assume that the antenna and terrain are such that approximately uniform transmission occurs in all directions, then the site must obviously be near the center of the area. This is illustrated in Figure 1.

The difficulty of finding a central location will vary with the nature of the local terrain. It is desirable to serve the retail shopping or "trade" area surrounding the city in which the station is located and it will often be found that this area lies more or less symmetrically around the city. Thus, if a suitable site in the city is available, such a location will automatically answer the economic service requirements.

IMPORTANCE OF HEIGHT

Height of an antenna above prevailing ground level will determine the "Horizon" for the station as well as the ability to avoid shadows from obstructions. While VHF signals travel somewhat beyond the mathematical horizon, the attenuation beyond it is relatively sharp. For most practical purposes, over flat terrain, a factor of four-thirds of the distance to the horizon may be used as a criterion when considering the radius of service for VHF television. On UHF channels it is felt that unity, rather than the four-thirds factor, will provide a more accurate indication. In general, the higher the antenna the greater the coverage will be.

An economic limit will be imposed by the height of existing elevations or the cost of erecting a tower to support the antenna. Among the ready-made means of gaining height are the use of buildings and hills. However, a hill some distance from the settled area will not be satisfactory because, while it provides good height, it will be so far away that the signals will be relatively weak by the time they reach the area to be served.

This serves to emphasize the fact that while height is important, it is not the sole consideration. A television antenna 1500 feet high would have a line-of-height horizon of some 47 miles on level country. Unless the effective power (transmitter power times antenna gain) is sufficiently great to produce a usable signal at 47 miles, the range will actually be less than the distance to the horizon. Hence, the effective power should be great enough to realize the advantages of a high antenna location.

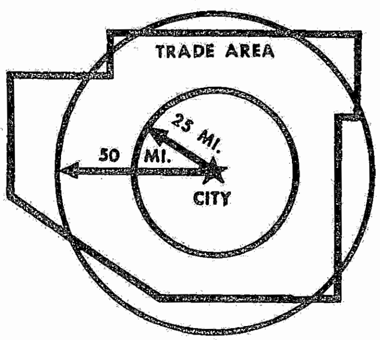


Fig. 1.--Where the trade area of a city is more or less symmetrical, a site near the city will give the most uniform coverage.

PRACTICAL CONSIDERATIONS

Height, despite its great desirability, should not be allowed to become a fixation. Every site selected as meeting the foregoing two requirements, that is, of central location and of height, should be subjected to a careful consideration as to its practical merits. It is obviously not wise to plan a mountain-top installation to obtain height if the installation cost will be prohibitive. On the other hand, certain types of tall building construction may preclude the use of antennas with high gain and it may be necessary to use larger transmitters.

There are certain practical requirements which a site must meet. These should be checked when preliminary consideration is being given to the site.

For example, an important consideration for "mountain-top" locations is the availability of power. In most cases power lines will have to be built to the location. The cost of this must be considered, particularly if the location is very remote. Telephone lines also will have to be built or a radio link established. Finally, there is the building itself to consider. This building must house the transmitter, provide living space for operators, storage space for spares and, preferably, provision for originating recorded programs in an emergency.

Another consideration--which may apply whether the antenna is mounted on a building, a tower, or a mountain top--is the question as to whether the civil aeronautics authority will give the necessary approval. In some locations --near airports or on airways--the CAA will not approve structures which exceed certain heights.

VARIOUS TYPES OF TELEVISION SITES

There are several kinds of locations which may meet the requirements of a television site as listed above. These are of five general categories which may be described as follows: (A) locations involving the use of a tall building; (B) locations on mountain tops or high natural elevations; (C) locations at the site of AM transmitter plants with the television antenna mounted on the AM tower; (D) locations involving the use of low buildings on which a steel tower is erected to give the required height to the television antenna; and (E) dual location of a television antenna and an FM transmitter, with the television antenna and the FM antenna mounted on the same tower. In some cases, use of a common site and tower by several television stations will be highly desirable for all concerned. Special multiplexing equipment or combination TV antenna systems are now available for this purpose.

Some of the advantages and disadvantages of these types of locations, as well as particular considerations to be applied in considering each, are as follows:

(A) Locations Using Tall Buildings

The most popular type of location is on a tall building in the center of the "principal city." The transmitter is usually located on one of the top floors and the antenna erected on the top of the building, with studio located either in the same or a different building as shown in Figs. 2 and 3.

For such use, the buildings chosen are usually 300 feet to 600 feet tall (with a few, of course, even taller). If the surrounding countryside is reasonably level, an antenna located on such a building will provide very effective coverage. Moreover, the field pattern of such an installation is highly advantageous in that it automatically results in the highest

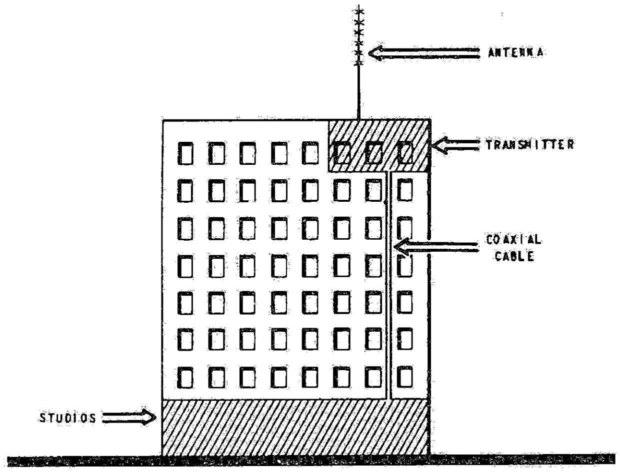


Fig. 2.--Studio and transmitter in same building.

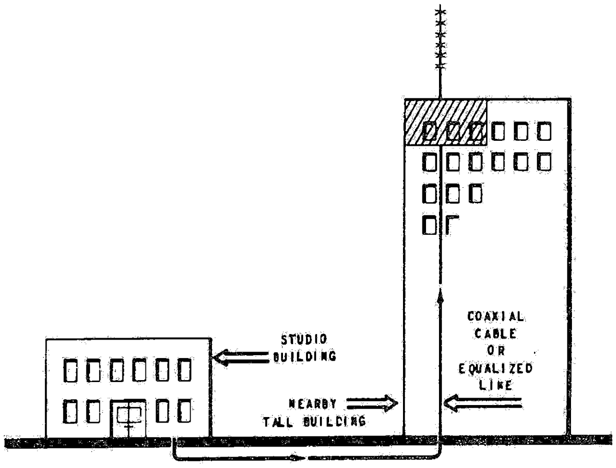


Fig. 3.--Transmitter on a nearby tall building.

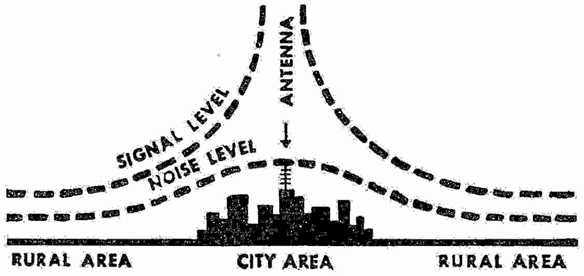


Fig. 4.--A "city-located" station has its highest signal where most needed; i.e., where noise level is highest.

signal strength in the center of the built-up area, where interference (such as ignition noises) is also strongest. The signal decreases going away from the downtown area, as does the interference noise, with the result that signal-to-noise ratio is of the same order throughout the service area (Figure 4).

Installation on a tall building has the further advantage that no land need be purchased, no transmitter building need be erected, there are no power lines to erect to a remote spot and no so-called studio-transmitter-link is required (since for the short distances between studio and transmitter satisfactory telephone lines are usually available). Thus, the first cost of a location of this latter type is low. The eventual cost depends on the rental. If this is high, the long-time cost may exceed that of a site and building owned outright by the station.

In the way of disadvantages, there is the fact that buildings are limited as to height and in many instances will be surrounded by nearby hills. In this case, shadows may exist behind the hills. Even nearby buildings of greater or equal height have been known to cause shadow patterns, even in the monitors of the transmitting station.

Another common drawback is that it is often not possible to erect a multilayer antenna, so that desirable antenna gain must be sacrificed.

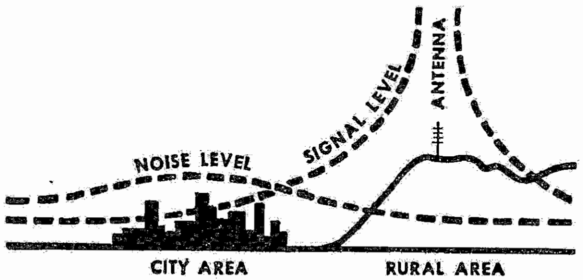


Fig. 5.--A "mountain-top" station has its highest signal where least needed; i.e., where noise level is lowest.

Finally, there are the usual difficulties entailed in making a fairly complicated and elaborate installation in a building owned by another party.

(B) Locations on Mountain Tops

Quite the other extreme, as far as the cost and labor of installation go, are the locations on mountain tops or high hills. Such locations have just one advantage, namely, height. As noted above, the effect of height on coverage is striking. By locating the transmitter on a mountain or other natural elevation, it is possible to obtain coverage not practical by any other means. This factor alone justifies such locations where large rural coverage is required.

The disadvantages of mountain tops are several. They entail the purchase of land and the construction of buildings, power lines and other services under the most difficult conditions. The locations are remote, inconvenient, and often almost inaccessible. The signal distribution is bad in that the signal is greatest where it is little used and much less (ordinarily) where it is most needed (Figure 5).

It should be noted that the competitive situation (where there are other stations located in the principal cities) suffers in this respect. As Figure 6 shows, the station in town has a strong signal where most of the audience lives; the mountain-top station, if very far away, is much weaker.

The above conditions, of course, apply only to installations on remote mountain tops. In some cases, moderately high hills exist on the edge of town, or even in the town. These are natural sites for television stations if procurable. In the cases of very hilly cities, they will be almost a necessity.

In many cases, however, the city in question will--because of irregularities of terrain or the proximity or distance of other cities--lie to one side of or in one end of the trade area with which it is associated, as shown in Figure 7. Again, because of availibility or non-availability of suitable elevations, it may be necessary to locate the transmitter to one side of the area, regardless of symmetry. The question then arises as to how to satisfy the requirement that coverage be provided to the proper areas.

Antennas which give radiation patterns of special configuration, such as shown in Figure 8, can be designed, and some are actually in use for television broadcast purposes. It is relatively simple to combine in one design both high gain and special directivity. With such antennas it is possible to provide more complete coverage in an irregularly shaped service area. Co-channel protection of nearby TV station is also possible

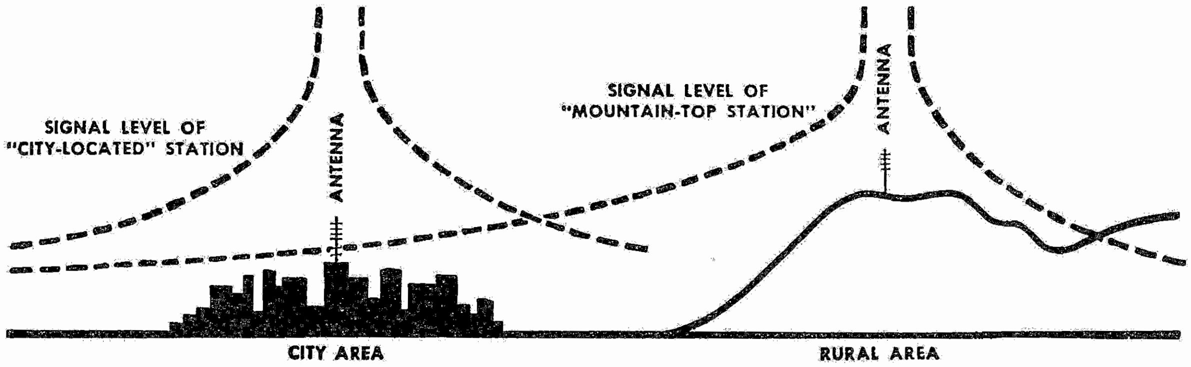


Fig. 6.--The signal of a "mountain-top" station may suffer by comparison with that of a competitive "city-located" station.

with directional arrays. That directive antennas will in the future be used to a very considerable extent seems fairly certain.

(C) Use of AM or FM Tower

When the television station is to be under the same ownership as an existing AM broadcasting station, there is a third possibility which is sometimes worth considering, viz., location of the television transmitter in the same building with the AM transmitter. The television antenna may then be mounted on top of one of the AM towers.

The chief advantage of this type of installation is the saving effected, not only in first cost, but in operating cost as well. First costs are low because there is no land to purchase, no building or tower to erect, little or no extra cost for running in power lines, etc. Operating costs are lower because of the centralization of operating and maintenance facilities.

Cooperative effort can (and has been known to) reduce the individual station's costs and difficulties in those instances where more than one licensee plan to place their transmitters in the same area. Incidentally, FCC regulations require sharing of sites where competition would be unduly restricted if one licensee gained exclusive rights to the only desirable location.

There are several disadvantages to this type of installation. For one thing, the location is usually not the very best and some sacrifice of coverage is entailed. For another, mounting the television antenna on the AM tower is a tough mechanical job. Unless the tower has been especially designed for the purpose, it will usually not support an elaborate array. (One way to get around this is to remove part of the existing tower, allowing the television section to replace it approximately as to weight and wind resistance.) Again, a problem occurs in bringing the television transmission line around the tower insulators (if of insulated type), although this can be handled by installation of suitable blocking circuits. Also, there is the fact that the tower is usually several hundred feet from the building, which, together with the height of the tower, makes for a rather long transmission line with losses which may run to 20 percent or 30 percent of the transmitter output. Finally, the AM band lies completely within the range of video frequencies; therefore, special shielding or other

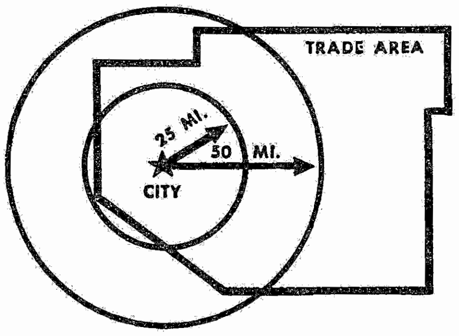


Fig. 7--Where the area is not symmetrical about the city, it will usually not be possible to cover the whole area with a non-directive antenna.

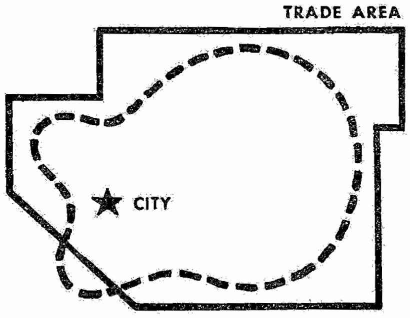


Fig. 8--Directional antennas are recommended for use in irregularly shaped service areas. or where it is necessary to protect the coverage of another television station.

installation precautions will undoubtedly be necessary in order to prevent interference with the video signal.

In the event existing AM and FM stations find that their present sites and towers can be used for television, the chances will no doubt be far better for FM installations since the propagation characteristics of FM and TV have much in common. But, as stated before, placing a television antenna atop a standard broadcast station tower may prove practicable if the latter happens to be properly located.

Superimposing television transmission on an existing FM operation can, in some cases, be accomplished either by placing a separate TV antenna on top of the one being used for FM or by "triplexing" the TV sight and sound plus the FM aural service on a single antenna. The latter possibility, however, is restricted to certain appropriate combinations of FM and TV channels. And, if all other factors should be favorable, this triple-duty antenna can be mounted on an AM tower.

While aural FM and TV combinations are commonplace, dual or triple transmission from an AM mast figures in the television picture less frequently. Changes in the over-all height of an AM radiator can create difficulties for that service, particularly in a complicated directional array. The problem of electronic isolation is much greater when AM is involved than with the simpler combination of FM and TV.

Of interest in this connection, however, is the fact that Commission rules do permit the approval of site proposals for TV involving directional antenna systems. At least one operating station has received permission to use its out-of-town AM tower in combination with a directional television pattern. The Commission emphasizes, however, that "it is generally preferable to choose a site where a non-directional antenna may be employed".

Any combination of transmissions from the same antenna assembly requires special Commission approval. As a basis for considering a proposal of this type, the FCC demands "complete verified engineering data showing that satisfactory operation of each station will be obtained without adversely affecting the operation of the other station," as well as evidence to show that other rules concerning antenna height, field intensity, etc., are being complied with properly.

(D) Use of Special Structures

If there are no mountain tops nor other high elevations within reasonable distance--and no sufficiently high buildings available--only two alternatives are left. One, of course, is to make the best of lower points, using increased power to make up the difference and hoping that the shadows will not be too bad. The other, and better alternative, is to erect a special structure to support the television antenna. Usually this will be a steel tower of the self-supporting type, although guyed towers are in use. In extreme cases, this tower may rest on the ground itself; more usually it will be erected on a building of medium height.

What are the advantages of this type of installation? The most obvious, of course, is that it offers a much greater latitude in the choice of the building to be used. Not only does this choice allow the selection of a good space for the transmitter, but also it may permit the studios to be located in the same building as the transmitter, or vice versa, if the studio site has already been decided on.

Imposing masts jutting five hundred feet and more into the air are not uncommon among today's television stations, particularly in flat areas where terrain advantages are few and difficult to capitalize upon. In hillier country, shorter towers frequently enable a station to approach the 500 feet-above-average-terrain norm prescribed by the FCC for stations of the metropolitan class.

The disadvantage of higher towers is the added cost of the steel which must be erected. In most cases, the roof, if a building is used, will require extra reinforcing (usually a frame of I-beams) which, together with the difficult working requirements, tends to make erection costs a sizable item. Obviously, the first and most important thing to check when considering an installation of this type is whether the roof will support the tower and what the cost of the extra construction is likely to be.

While possible disadvantages of this type installation are obvious, experience has shown that in addition to the definite plus value of being able to choose among several different locations, this choice can make easier the matching of strongest signal area with densest population. The station's bargaining position with real estate agencies is improved, also.

CALCULATION OF COVERAGE

For purposes of filing an application for construction permit with the Federal Communications Commission, it is presently necessary to calculate the five millivolt per meter and one-half millivolt per meter signal contours. This will, of course, provide an indication of the expected coverage. Such data should be prepared by a qualified engineer.

It is beyond the scope of this discussion to describe in detail the methods used for determining the coverage of a television station. However, a review of the factors involved in location studies may be useful in illustrating some of the problems.

The factors which influence the coverage of a television station are not entirely identical with those which determine the range of a standard broadcast station. The coverage of a television station will be affected by:

(A) Power of transmitter
(B) Gain of antenna
(C) Height of antenna above prevailing ground level
(D) Obstructions between transmitting and receiving antennas
(E) Noise level at receiving location

The power of the transmitter and the gain of the antenna are completely interchangeable as far as coverage is concerned. A one-kilowatt transmitter used with an antenna whose power gain is four will produce the same results as a two-kilowatt transmitter and an antenna with power gain of two. It would thus appear that one might use a very low-power transmitter and a high-gain antenna with resulting economy. However, there are limits to each. First, television antennas must be broad band and an increase in antenna gain is often accompanied by a decrease in bandwidth. Also, as antennas are increased in gain, they become taller, heavier, more costly, and require more substantial and expensive supports. Antenna power gain of the order of four is practical in most cases and, with a five-kilowatt transmitter, will produce the equivalent of twenty kilowatts radiated power.

Obstructions between transmitting and receiving antennas will cause shadow areas where signals will be weak or even unusable. Such obstructions may be groups of tall buildings or hills. Naturally, antenna height will aid in overcoming the effect of such obstructions. Shadow areas behind interfering objects do not extend indefinitely, but tend to "fill in" because of refraction effects. In general, obstructions near the transmitting station will create shadow areas of greater extent than if they are farther from the station.

It will be important to examine the shadow areas and to determine whether or not they fall over important residential sections. If so, an alternative transmitter site may be preferable. With fairly level territory, shadows can be predicted within reasonable limits, but in hilly terrain, the problem is both complicated and helped by the fact that signals may be reflected from some hills. Some reflections may tend to reduce shadows, but may also result in both a direct and reflected signal being received in some spots, causing "ghosts". The problem of location in rough terrain is one which demands individual study.

Noise level at the receiving location is not within the control of the transmitting station, but the location of the transmitting antenna can be planned to produce maximum signal strength at points where noise level is highest. High receiving noise level will generally be experienced in densely populated areas, along main highways and near railways or manufacturing areas. It is usually most important to provide high signal strength to densely populated sections. This means that if the station is closest to such areas, the signal strength will be greatest where it is most needed (re Fig. 5). Rural and suburban areas can ordinarily be served successfully with signal intensities considerably lower than in metropolitan localities.

In cases where suggested antenna locations are questionable, the Commission recommends, and may sometimes require, that special propagation tests be conducted and field intensity measurements taken. Recently developed items of equipment utilizing a pulse technic offer promise of greatly simplifying this advance testing of sites.

Stations contemplating the selection of a site in a thickly populated part of town may want to give some thought to what effect their transmission might have on other activity in the area. If it appears that the proposed station's "blanket area" may interfere with reception of other stations in the vicinity, the Commission may require that the applicant "assume full responsibility for the adjustment of reasonable complaints arising from excessively strong signals of the applicant's station."

No serious problems of this nature have developed with present transmitter powers, but the possibility will be present when higher power transmitters come into use.

Television service conveys more intelligence than audio transmission and, in general, requires a higher signal strength for satisfactory operation. Hence the importance of a reasonably high effective power of the station.

From the foregoing, it will be apparent that antenna height and proximity to built-up areas are desirable from a coverage standpoint. In many cities this points to the use of a tall building in the business area as a transmitter site because height can thus be obtained economically, also, business districts are usually centrally located. As an alternative, a hill near the center of the city may be equally desirable.

Speaking in general, the problems inherent in locating a television transmitter are capable of solution, but they must be approached with intelligence based on technical experience.

PROGRAMMING PLANT

Practical aspects of day-to-day operation can influence the choice of a programming plant location to a much greater degree than the selection of a transmitter site. In many respects the factors which determine the desirability of a particular spot as a location for a television programming center are identical to those which would affect a similar decision in aural broadcasting.

The location for the programming plant should be chosen with care -- for the suitability of this location may have considerable bearing on the successful operation of the station. On it may depend the availability of programs, the operating convenience, and other considerations of interest to the station owner and station staff.

While there are certain factors which must always be considered in choosing a location it is not possible to lay down general rules which will be applicable in every instance. Local conditions are usually the determining factor and these may vary greatly. For instance, in some cases the competitive situation or the necessity of maintaining prestige may outweigh ordinary economic considerations. Again, it may be desirable to combine the television operations (or some part of them) with another business which is under the same ownership. Obviously, every prospective station owner will have to evaluate such factors himself in order to arrive at the most satisfactory overall solution.

CONSIDERATIONS IN CHOOSING A LOCATION

There are certain considerations which apply to every possible site and it will be of value to set these down as a sort of preliminary check list. These considerations are:

(A) Adequate space for operations.
(B) Cost of land and buildings (or rent and building modifications).
(C) Provision for future expansion.
(D) Convenience of reaching location.
(E) Freedom from interference.
(F) Facilities: Power, water, etc.
(G) Nearness to outside program sources.
(H) Location with relation to transmitter site.

(A) Adequate Space for Operations

Space requirements may well be the most influential of all factors. A full section must be devoted to the many facets of that subject. However, before going into this subject we will first discuss the other factors.

(B) Cost of Land, Buildings or Rent

It is essential to know the initial capital expenditures as well as the likely operating costs of the plant, exclusive of broadcasting equipment.

The real estate market, and other local factors, will have important bearing on the decision. Real estate rentals and purchases are especially important in television because of the relatively large amounts of space needed.

If the studios are housed in a specially constructed building, the initial costs will include land, structure, furnishings, etc. The operating cost can be arrived at by amortizing the investment (initial cost) over the period permitted for tax purposes and adding thereto the estimated taxes, repairs, building service, heat and air conditioning, etc. If the studios are to be located in an existing structure, the cost of modifying the space to its original condition will constitute capital expenditures. In this case, rent for space, taxes, and plant operations will comprise the principal operating expenses. It is suggested that in making cost comparisons the equipment and broadcasting operating costs be figured separately, since these are somewhat independent of plant location and are dependent upon the type of service to be rendered. However, if the sites being compared affect such costs, of course they should be considered.

In a good many cases, the station owner must choose between locating his studios in an existing building in the business area of a city or erecting a suitable structure on the outskirts of the city. An examination of the initial and operating cost of each choice should be made, taking into consideration the other factors which are listed above. It should be kept in mind that suitable studio space in existing buildings will not be easy to locate because of limited ceiling height, close spacing of columns, etc. Such structures as public halls, warehouses, garages are likely prospects for investigation.

In the selection of land outside the business area, building restrictions, limitations on trucking in streets and tax rates must be examined. Local zoning restrictions must be met. With props and scenery going to and fro, there will be more commercial traffic around a television studio.

(C) Provision for Expansion

Most television station operators will wish to provide, initially, only such facilities as are required immediately or in the near future. This will keep the initial expenditures at a reasonable level and prevent an over heavy amortization during the formative period. Moreover, operating expenses, including rent, will be kept to a minimum if the plant size is not too large.

An inadequate layout, however, will be a severe handicap to operations. Hence, the wisest course will be to arrange for space to be added when needed or to deliberately install more space than will be required initially, leaving the extra rooms in an unfinished condition. If a specially built structure is to be used, the architect can design the ultimate building and indicate the portions which are to be erected initially.

Curtain walls can be used at points where additions are to be made. It may be economical to install heating, cooling and other common facilities of such a size that no replacement need be made when building additions are made. If the building is a low-cost structure, provision for expansion may be limited to providing an oversize plot of land with the initial structure located so that additions can be made.

Studios in office buildings or other centrally located structures are more likely to be limited when additional space is sought. If space is rented, an option may be taken on adjacent quarters and plans made initially for the ultimate use of the space.

The problem of providing for expansion is considered in greater detail in the section on Size and Design.

(D) Convenience in Reaching Locations

Television is likely to employ actors who may appear in theaters or other entertainment centers. If the studio location is difficult to reach, actors may be unable to take part in their performances and also telecast. Clients may object to visiting a remotely located studio. Time will be saved for remote crewmen going to and from location. Adequate public transportation for staff members is essential.

Obviously, the central city location is likely to be the most convenient and the far distant studio the most objectionable from the viewpoint of accessibility.

In a number of cities there will be found areas which are not far from the business center and which are not built up with either high grade business structures or residential construction. Providing that adequate transit facilities exist, such localities may be potential studio sites. It is likely that land costs will be low and no great objection can be raised to traveling time.

Lowest land costs and best opportunities for expansion will exist outside city limits. Such sites may be advantageous, particularly in cases of cities whose residential reaction lies in one direction away from the downtown area or in the instance of "Twin Cities" where a site between the two may not be inconvenient to reach.

In any event, the wise planner will be sure that his studios can be reached easily in a reasonably short time.

(E) Freedom from Interference

Just as in the case of sound broadcasting studios, it is unwise to select a location for television studios which will result in troubles costly to eliminate. Such sources of trouble include vibration, noise and electrical disturbances.

Studios located in factory buildings or in newspaper plants where large presses are mounted are likely to experience trouble from vibration.

Vibration is apt to cause microphonic effects in both picture and sound circuits. It can be corrected by special arrangements for "floating" the studio on suitable absorbing materials, but the cure is expensive and requires careful engineering treatment. The best solution is to avoid such locations.

Noise will cause trouble chiefly in the sound circuits--by pickup in the microphones. In quiet locations, simpler sound proofing may be satisfactory. Use of sound absorbent material between walls and ceiling spaces may be sufficient, and may also serve as heat insulation.

In the case of studio buildings on a separate plot, the best cure for noise is a quiet location. Some common sources of noise are heavy street traffic, railroad whistles and airplanes. Studio buildings located near airports or along airways will be subject to roar from passing planes. Since air travel is on the increase, it is well to select a location which is unlikely to be near a future air route.

In either city or suburban locations, if more than one studio is planned, arrangements must be made to keep sound originating in one studio from being transmitted into the other. This problem is common to standard broadcast studios and may be handled by conventional means, and is treated at some length in the "Studio" Section of this Handbook.

Electrical disturbances are not usually a serious consideration in sound broadcasting but present problems peculiar to television. Changing electric fields caused by breaking or switching high power electric circuits may affect video systems. Sources of such disturbances are elevator contactors, heavy electrical machinery, electric locomotives or traction systems, smoke or dust precipitators, X-ray machines and radio transmitters including high frequency and standard band broadcast stations. Inasmuch as AM broadcast carrier frequencies are well within the range of the video channel, elimination of R-F pickup in cameras is apt to be a problem. Such cases may occur if the television studio is close to a high power transmitting antenna. Note that no interference results from location of a television studio near a broadcasting studio, unless the broadcast transmitter is there, too.

If electrical disturbances are prevalent, but other factors are favorable, shielding can be resorted to. Either the studio or the source of the disturbance may be shielded, depending on which is the most practical method. Adequate shielding and bonding is somewhat costly and hence it is better to avoid the problem if possible rather than to attempt a solution.

(F) Facilities

Water, power, and other public utilities must be accessible. A television studio's power requirements will be far greater than those in aural broadcasting, and a well-regulated source of power, preferably coming from the same system supplying power to residential areas, will be required thus, if any "hum" is present in the picture signals, it will be synchronous with the "hum" in the receiver and will not be disturbing. While this is not apt to be a major factor, it is worthy of consideration.

Steady power supplies, free from voltage fluctuation, will greatly simplify operating problems. In urban locations such power sources are usually available, but a special transformer and distribution circuit may be required to carry the lighting load. The switching of lights should not affect the power source for equipment.

Both single phase and three phase supplies are desirable. Video equipment is designed primarily for single phase operation, but some associated equipment such as film projectors may require three phase supplies. It may be advantageous to operate banks of lights across different phases to reduce "hum".

(G) Nearness to Program Sources

The propagation characteristics of television signals do not enter this phase--with one exception. If the studio location is to be used as either a transmitting or receiving point for microwave relay connections, consideration must again be given to height, centrality of location, and freedom from obstructions.

Microwave relay links are highly-directional, have a limited range and are extremely sensitive to physical obstructions in their line-of-sight transmission path. It is usually necessary to be able, theoretically at least, to see the receiving antenna from the point of origination.

If the main programming center is built on low ground or in the midst of tall buildings, its value as a receiving point for the mobile unit's microwave relay will be very limited. Since the remote truck will be operating at constantly changing points, many of which may be difficult to work at best, a receiving antenna that is high and free of obstructions in all directions will save many man-hours which would otherwise be spent trying to line up an acceptable connection. And since about fifteen miles is the maximum range for most relay transmitters, a central location is desirable. As an alternative in the instance of outlying studios, a steel tower may be used to give adequate height to the receiving antenna for the relay system, or the relay receiver may be located in the main transmitter building and its antenna installed on the main antenna tower or support.

Signals from the field apparatus may also be transmitted by short distance telephone circuits or coaxial cables to the studio or to the main television transmitter directly. If the studio is in mid-city, it will probably be convenient to send the field signals there, for handling and retransmission to the main transmitter. Some advantages can be realized by locating the studio centrally with respect to points where outside programs would take place. Such points might be theatres, arenas, stadiums, auditoriums, athletic fields, churches, department stores, etc. Line circuits can thus be reduced to the minimun length.

(H) Location with Relation to Transmitter Site

The location of the studios, with respect to the location of the transmitter, is another factor which will have an important bearing on the initial and operating costs of a television station. While it is not necessary to have the studios and transmitter in the same building, or even nearby, it should be recognized that program lines in addition to possible network, studio-transmitter, other special video lines, and many aural circuits will be necessary. Usual practice at present is to feed the audio portion of remote originations by regular telephone company lines.

In general, there are four situations which may arise. These are:

(A) Studio and transmitter in same building.
(B) Transmitter in a nearby building.
(C) Transmitter located in suburbs.
(D) Transmitter on a mountain top, etc.

In the first three, the audio circuits will undoubtedly be telephone lines. In the fourth they may be either telephone or radio relay.

The video link in (A) will undoubtedly be coaxial cable. In (B) and (C) it may be either coaxial cable, equalized telephone line, or microwave relay--with the latter two most likely. In (D) it will almost certainly be R.F. relay.

It will be quite obvious that the cost of link circuits will vary greatly from one installation to another. Locating the studios and transmitter in the same building will ordinarily be the least expensive. When the transmitter is in a nearby building the initial cost will depend on the problem met in running the connecting coaxial cable. In either event the maintenance cost should be relatively low. Moreover, the proximity of studio and transmitter operations makes for convenience and some saving in operating cost. A transmitter location in the suburbs (with studios downtown) ordinarily means a distance which will make a coaxial line very expensive and an equalized telephone line may be the alternative. In this case the rental is an additional cost which must be considered. Transmitter locations on a remote mountain top will almost certainly require a radio link. This will necessitate a high location for the antenna of the studio relay transmitter as well as other provisions which may make the original cost fairly high. The operating and maintenance costs, however, should be relatively low.

Stations planning mountain top locations will probably find purely academic any further discussion of concentrating all station activity in one spot.

Those which have a choice, though, may find that certain economies in both construction and operating costs can be achieved by a single location--in such ways as these:

Need for studio-transmitter links is eliminated;

Duplication of some facilities, such as maintenance shops, can be avoided;

Cost of original building construction or adaptation can be reduced if all units are housed together;

Test pattern transmission periods can be handled by transmitter personnel alone without installation of duplicate picture projection instruments;

Some master control functions can, in certain types of operation, be assumed by the transmitter crew.

Stations attempting to operate near minimum expense levels may find the latter two points of keen interest. If an extra person must be on duty at the programming center to originate the test pattern signal, manpower costs will be increased. Or if duplicate equipment is installed at the transmitter, an extra ten or twelve thousand dollars must be spent.

A similar situation can prevail during portions of the active programming schedule--during periods of solid network service, for example. It is not unusual for stations with direct interconnected network service to complete all local production early in the evening, at least on certain days of the week. Some of them have their plants so arranged that all operations after that time can be integrated with transmitter control, thereby permitting manpower economy.

Film projection facilities will be required at the transmitter if activity of this character becomes very extensive, of course, and stations with only station identification instruments there will be unable to concentrate operations in this manner.

Unless studios for live shows are a part of the plant, program operations will almost certainly be carried on at the transmitter location. Some stations which do have studios, but cannot feasibly have them at the transmitter site, are dividing their program operations, putting everything except studios at the transmitter and manning the studio location only for special features.

This latter arrangement does make particularly difficult, however, the integration of film into studio productions, an increasingly popular method of handling titles, commercials, and special effects.

There are many situations, of course, in which a single location would involve over-riding disadvantages. A mountain-top transmitter site, as mentioned earlier, comes near ruling out such a possibility completely, especially if a studio is desired.

Some building-tops which provide splendid transmitter sites simply will not accommodate a programming plant adequately. In other such cases, the rent may be prohibitively high.

Even stations which erect towers in open area on level ground may find that the cost of constructing new buildings is too expensive, compared to cost of renting existing space elsewhere.

In summary, though, this generalization seems safe enough: Most stations prefer to concentrate all their activity in the fewest possible number of places, and integrate all operations as closely as possible, consistent with the situation which exists in their company and community.

SIZE AND DESIGN

At the outset of discussions relating to size and design it may prove valuable to draw in the broad outlines of a television plant for purposes of perspective, by comparison with aural broadcasting. Operational layouts of these two broadcasting services are remarkably parallel. Both concern studio, remote, network, and mechanically reproduced programs, feeding into master control for mixing, and being fed to a transmitter.

Experienced broadcasters entering the visual field will be faced with some familiar decisions: Shall master and studio control be combined or separate? How can studio area be provided for peak demand without wasting a lot of space? And, how can additional production facilities be added to the original nucleus without upsetting the basic arrangement?

While the outlines and proportions bear some resemblance, the scale of the two services will be quite dissimilar. Obviously, even the housing of equipment and personnel calls for more floor area.

Some authorities on both aural and visual broadcasting have found that television demands three or four times as much space as a comparable aural operation--when studios are involved.

Deciding what constitutes "comparable" aural and visual stations is important, of course. The answer can be found, within limits, by examining major points of comparison, such as: (1) availability of network service; (2) emphasis placed on live studio programming; (3) amount of time devoted to mechanically reproduced programs, i.e. records and transcriptions in aural and film in visual; and (4) extent to which special events, sports, and other outside program sources are utilized.

Space needs at the programming plant are really determined by the extent to which the station uses each of the four programming sources: network, film, remotes, and studios.

Transmitter

A good round-figure starting point when calculating the floor area needed for a 5 KW transmitter installation is 1000 square feet. This space should accommodate a modest storage compartment and maintenance workshop in addition to the basic transmitting equipment.

In a 500 watt installation, the transmitter proper will be about one-half to one-third the size of the 5 KW unit, but several pieces of associated equipment will be of the same size. Consequently, a little more than half of 1000 square feet will probably be required. About 600 square feet should be a good working figure for the smaller transmitter.

If necessary, both these figures can be trimmed about 20% by exercising extreme care in fitting the various pieces of equipment together. A more likely prospect, though, is some expansion of these average minima to provide more elbow room and space for future expansion.

It should be kept in mind that some stations using 5 KW's of power initially will want to step up to 50 KW's when transmitters of that size become available. And, FCC willing, a normal progression from 500 watts to 5 KW's is always possible.

You will recall from the discussion above that stations with separate transmitting and programming plants often find it advisable to have station identification equipment at the transmitter. Stations anticipating such an eventuality will want to pad these estimates a bit to provide room for two or three racks of equipment, turntables and the like.

Exact dimensions of individual pieces of equipment will vary among different manufacturers. Some fluctuations will also occur in a few of the components according to the channel used, lower frequencies in general requiring larger units. But these differences should not be great enough to cause serious trouble unless the square footages quoted above are being trimmed too closely.

These figures cover operating area only. Such additional features as sleeping and cooking facilities, lounges, baths, etc. must be based strictly upon the local situation. Problems in this area, of course, are not different from those encountered in aural broadcasting.

Since equipment racks are usually about seven feet tall, minimum ceiling height is approximately nine feet. More height facilitates cooling.

To get some idea of the total amount of land required for a transmitting plant located on the ground, we must look at the base of the tower as well as the transmitter house. Using the building as the base of the tower is not an unheard of arrangement, but more often the tower is based on the ground alongside the building.

Since no elaborate ground system is necessary with a television antenna, the transmitter house and the tower base are the only two factors--except in some cases where local zoning regulations may enter the picture.

Height is the principal factor governing size of a tower's foundation, of course, with weight and design variations exerting lesser influences. Self-supporting structures varying in height from 200 to 500 feet must have foundations covering something like 500 to 5000 square feet respectively, with gradations in between.

Guyed towers, of course, require much more space, since anchorages for guys must be available on all four sides at a distance which approaches the tower height.

Providing some protection against the future construction of tall buildings or other obstructions in the vicinity of the station's antenna is another factor which may influence the size of a transmitter site. To insure against some obstacle being built which would interfere with the station's coverage pattern, a prospective licensee might possibly find it wise to option a larger plot of ground than would otherwise be necessary.

Even stations with a building-top antenna installation may want to give some consideration to such a possibility.

In any event, a study should be made of the various measures of protection which may be afforded by zoning and other local regulations.

Programming Plant

A clear view of the station's future program structure is invaluable at this stage of development. The greater depth of focus the planner can obtain, including the reasonably distant as well as immediate future in his visualization of program operations, the greater chance there will be of building a plant which will need a minimum of major alteration.

Deciding which of television's program sources (network, film, remotes, and studios) will be employed is not enough. It is important to know the extent to which each of the four program sources will be employed. A program philosophy for the new station now becomes essential.

The fact that outlining a completely firm program pattern is patently impossible accounts for the emphasis given earlier to the importance of flexibility. On the other hand, there will undoubtedly exist some fairly clear idea of the emphasis to be given programs from each of the program sources.

The availability or absence of network programs is an obvious factor. Stations planning to use large quantities of film, including perhaps off-the-tube recordings of network features, will want to provide more operating area in the projection department than a station which expects to use film only for commercials and to fill unavoidable gaps between other types of programs. There are cases in which outside pickups are featured to such an extent that two mobile units have been found necessary. This point is most pronounced in the decision concerning studio size.

With these thoughts in mind, the discussion of space requirements in the ensuing paragraphs can be interpreted properly. As always, the thinking here is in terms of average minima. Depending upon the emphasis to be placed upon each of the program sources to be incorporated in a plant, it is logical that these requirements may be shaded slightly or increased considerably.

We will now look at the program sources and control room needed to mix any combination of the four.

Program Nucleus

The heart of a television programming plant is a synchronizing generator.

Closely associated with the sync generator usually is a monoscope,* a simple, one-picture camera used extensively for visual station identification and test pattern transmission.

These two pieces of equipment, along with amplifiers, monitors, power supplies, turntables, audio oscillators, and switching gear, both audio and video, comprise the basic control center of a television programming plant. Around this center is built the master control unit.

An announcers' booth is operated in close conjunction with this control setup to complete a "programming nucleus." Such facilities and functions will be found, in one form or another, at every television station.

Onto this torso may be appended any combination of the four basic programming sources. Naturally, the more sources a station uses, the more complex this control center will become.

When film is used, the camera control apparatus fits logically into this unit. Only in extremely large installations are separate film control rooms to be found.

The mobile unit's microwave relay receiver can be housed here advantageously, reception conditions permitting.

Network service requires certain terminal equipment. While the communications company's coaxial line amplifiers or radio receivers need not be in the control room itself, they are frequently. Regardless, space must be provided for these common-carrier installations, and these needs will logically fit as part of the master control operation.

A major problem is posed when the programming plant contains a studio: Will the foregoing equipment, which is of the genus master control, be placed in the same room with studio control?

In an elaborate plant with a wealth of facilities, the answer will be a simple no. The question is closer when there is only one studio and a concerted effort is being made to keep costs at a minimum.

Considerable duplication of equipment can be avoided if the two control operations are

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*Or a "Flying Spot" camera, now commercially produced, which permits transmission of slide transparencies without more elaborate film equipment.

housed together, and the possibilities of some personnel doubling in brass are increased.

A number of stations now on the air do utilize, or did utilize at one time, a single location for all their programming control. During periods of relatively simple activity, when there is ample off-the-air time to accommodate all rehearsals, there appears to be no doubt that such an arrangement is advantageous.

The success of such a combined operation depends largely, however, upon simplicity of program schedule. When it becomes necessary to conduct studio rehearsals while other program operations are in progress, complications begin to set in. Additional manpower and equipment may become essential. If so, economy is lost, and confusion can be avoided by separating studio and master control.

With these thoughts in mind, stations which decide to begin with one control room may want to provide space for a divided operation in the future when activity is intensified.

Where there are multiple control rooms, certain advantages accrue from having them located as closely together as possible. Use of the same test gear in both is facilitated, for example.

Switching systems can be arranged so as to permit integration of all program sources at either master or studio control--if it is desired.

Exact space and layout requirements depend to some extent upon the make of equipment to be used. This is particularly true in the control center, where a large amount of equipment must be fitted into a comparatively small area.

Decisions should be made as to exactly what pieces of equipment will be used and plans made accordingly. Assuming that the initial installation will have some degree of permanence, it will certainly be desirable to provide extra room for future expansion.

Looking for average minimum requirements, however, this general rule-of-thumb may be found to have some practical value:

Start with about 150 square feet of space for basic control.

Add about 50 square feet for an announcers' booth.

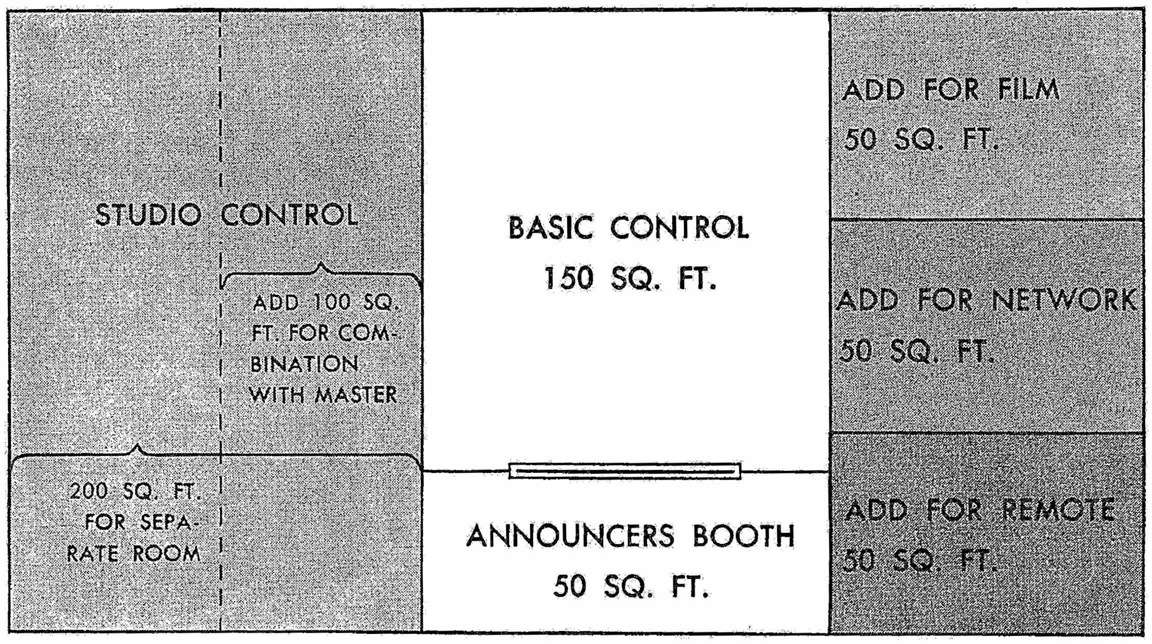
Add 50 square feet for <u>each</u> of these <u>three</u> program sources; network, remotes, and film.

Add 100 square feet for a two-camera studio control setup which is combined with master control.

Add another 100 square feet if studio control is to be separate from master control.

Although controls for a third camera will occupy only a very few additional square feet, a three-camera installation, by its very nature, is likely to be more lavish and require something like twice the amount of space shown above for studio control.

Ceiling height is not a critical factor in the <u>master</u> control section, since seven-foot-high racks will be the tallest items of equipment to be accommodated. It will be well to keep in mind, however, that a considerable amount of heat is generated by an extensive control installation;



greater ceiling height will be valuable in heat dissipation.

The desired shape of a master control room will also be determined to some degree by the type of equipment used, but almost any installation will be composed of some combination of equipment racks and one or more consoles.

Sync generator, monoscope, amplifiers, some monitors, patch panels, microwave receivers, and other miscellaneous apparatus will normally be rack-mounted.

Special switching instruments, film camera controls, audio control equipment, and master monitors will usually fit together into one or more consoles.

AT&T terminal equipment is also rack-mounted but usually in special units which are only about four feet tall. One rack of amplifiers is required for each incoming (network, remotes, etc.) and each outgoing (network feeds, transmitter, etc.) line.

Actually, there is no striking difference between the physical space and layout needs of a video master control room and those for a comparable aural operation--except that there is apt to be a lot more of everything when the visual and the aural are combined in television.

Studio Control Room. The first step in designing a studio control room is to decide what the role and position of program producers* shall be. If there will be a technical director, or switcher, and assistants to the director, needs will be greater than the more modest situations in which the producer does his own switching.

It may be well to keep in mind that a number of stations feel strongly that the producer, especially on studio shows, cannot do his own switching and maintain program quality. Consequently, even stations which are not planning to use special switchers may want to provide space and facilities for this activity in the event it should prove essential in their particular operation.

In addition, those stations whose program activities normally permit the director to do his own switching may find that on special features from time-to-time the services of a specialist in this job are indicated. The arrangement can be such that operation with or without a special switcher is optional.

Next step is to decide who, if anyone, must see into the studio from the control room. There is some disagreement among stations on this point, ranging from a few who feel it is not really important whether or not anyone can see into the studio, over to the other extreme where it is felt everyone in the control room should have the best possible view of the entire studio.

Acceptors of blind operation feel it is more important for both technicians and program people in the control room to concentrate on what they have on the monitoring screens rather than on what they could see through the studio window.

While not disagreeing exactly with the keep-your-eyes-on-the-monitor school, proponents of the other extreme feel that there are certain times--emergencies as a prime example--when the best possible vision for everyone concerned is invaluable.

In the middle is a group of stations which follow a compromise course. They believe that camera control men should be so placed that they must watch their monitors exclusively, but that directors must be able to see into the studios, at least when the occasion warrants.

It is difficult to disagree with those who point out that on extemporaneous programs, for instance, the director may miss much that is of interest unless he is able to observe activity in the studio directly and instruct his cameraman accordingly.

On the other hand, there is ample evidence that blind operation is certainly possible. Some stations do it, and most remote programs, the most unrehearsed of all originations, are usually handled blind from the mobile unit.

There appears to be a definite consensus, however, in favor of visibility, at least for directors, whenever it is feasible.

With these two dominant factors in mind, studio control rooms are usually laid out in one of four or five different ways:

Simplest arrangement of all calls for only one console, placed in front of and facing the studio window. The director sits alongside his camera control men. One disadvantage is that the director gets only an angled view of the individual camera monitors.

To overcome this handicap, a number of stations place the director in a raised position immediately behind the main console. Here he gets a more direct view of the monitors and can see into the studio over the heads of the operators.

Biggest disadvantage of this system is that the director--since people are working in front

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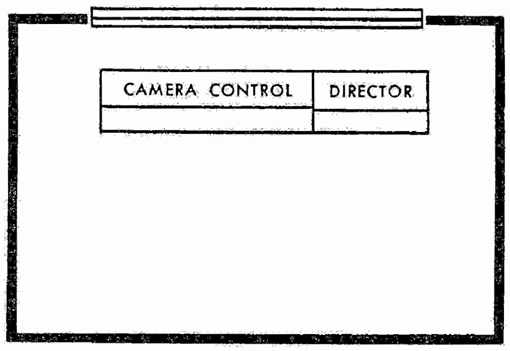
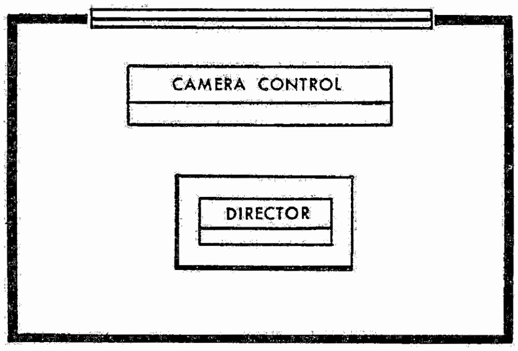
*Since it is the general trend for individual stations not to have both a producer and a director assigned to a given program and working in the control room simultaneously, the two terms will be used interchangeably.





of him--must sometimes be an acrobat in order to see the particular monitor or other view he needs at the moment. Not only is his observation of the monitors sometimes obstructed, but they are apt to be a little distant at best.

These problems are often overcome by putting two or more special monitors immediately in front of and below the director. One of these always carries the on-the-air picture, the other (or others), previews of upcoming shots.

All of these are systems in which everyone is afforded the best possible view of the studio. When it is not considered important that camera control men be able to see the studio, this basic console is moved away from the window, usually to one side. In the simplest setup of this type, the director sits at an angle which permits him to see both the studio and the monitors.

More elaborate version of this layout calls for the director to have two or more special monitors and sit directly in front of and facing the studio window.

When visual monitors are placed directly in front of studio windows, high intensity light from the studio floor may interfere with proper viewing. Various devices, including special glass to reduce glare and amount of incoming light, shields over the monitors, specially-constructed consoles, and other arrangements, are in use to meet this problem.

It is easy to find flaws in any of these arrangements. Sitting alongside his camera control men, the director gets a poor view of certain monitors. Behind them, his view is sometimes obstructed. With camera controls to one side of the window, and the director placed at an angle to see both, he may develop neck motion not unlike a tennis fan sitting on the net line. And with monitors jammed up against the studio window, he may be bothered by contrast between viewing screens and studio lights.

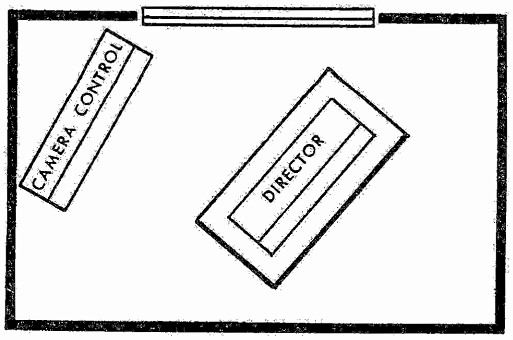
Ceiling height is a factor to be considered in studio control room design, especially if the director and his immediate associates are to work on a raised platform.

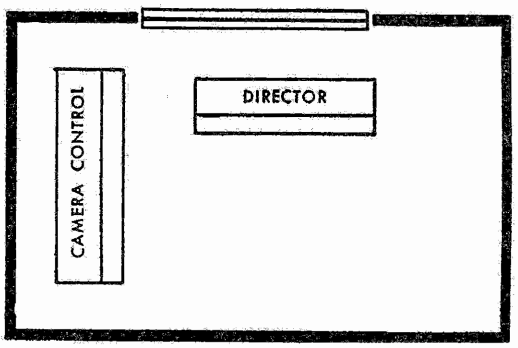
Something like three feet seems to be standard elevation for such a platform. With a ceiling height of eight or nine feet, a problem can easily arise. Ten feet is likely to be the minimum.

It is not difficult to arrange the room in such a way that any equipment racks which may be needed in studio control are on the lower floor level. Therefore, the only problem is to obtain sufficient head room for personnel standing on the platform.

Securing plenty of ceiling height is not difficult usually, since the studio proper will almost surely be abnormal in that sense, probably extending through two floors of average dimensions.

Some stations take advantage of this fact and raise even the lower control room level two or three feet above the studio floor. Some





studio designers point out, however, that the control room should not be raised all the way to the second story level, unless perhaps the studio is enormous. Extreme height creates an angle of view which reduces visibility sharply in the studio area immediately below the control room.

Maintenance Shop. Schedules and facilities for maintenance are a major topic of interest among television station engineers. They urge uniformly that careful advance thought be given the subject.

Desirable size of a maintenance shop will fluctuate according to the amount of equipment to be serviced, naturally. A workable rule of thumb for determining average minimum needs runs like this:

BASIC 100 SQ. FT.	FILM 50 SQ. FT.	REMOTE 100 SQ. FT.	STUDIO 100 SQ. FT.

Start with 100 square feet. Add fifty feet for film equipment servicing. Add 100 each for studios and remotes.

This programming plant maintenance shop should be located so that remote gear can be unloaded easily. If station layout makes it impossible to do this and keep the shop conveniently located with respect to other programming equipment, two shops may possibly be indicated. If so, start with 100 square feet in each case and add according to the formula outlined above.

If programming maintenance facilities can be combined with the transmitter shop, which is separately provided for in this plan, so much the better. Economy can be achieved.

Network

Since terminal and related apparatus for incoming network service will be housed in the main control room, or at least in space allocated for that purpose, no additional operating area need be provided for handling network programs.

Film Facilities

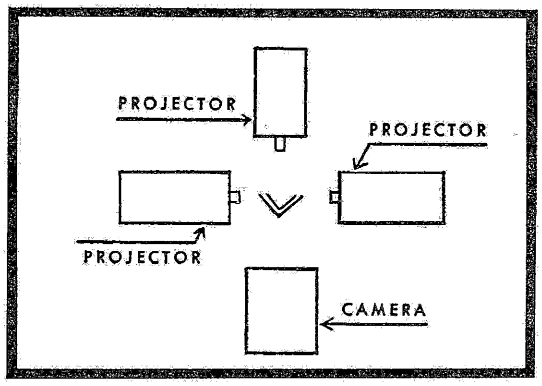
A careful examination of local ordinances on fire prevention, as they relate to the handling of motion picture film, is a good starting point in the planning of projection and preview rooms. Rigid regulations devised originally for theaters will often apply to television stations.

Provisions for use of 16 mm film will be very simple, as a general rule. Stock used for this size is nearly always non-inflammable.

Most 35 mm prints are highly combustible, however, and meticulous precautions against fire are indicated. Projection rooms, for preview as well as on-the-air operations, must be completely fireproof. Special vaults are normally provided for film storage.

Some stations planning to use only 16 mm film at the outset have found it desirable to design their projection rooms to 35 mm standards in order to avoid rebuilding later if and when they find the larger scale desirable.

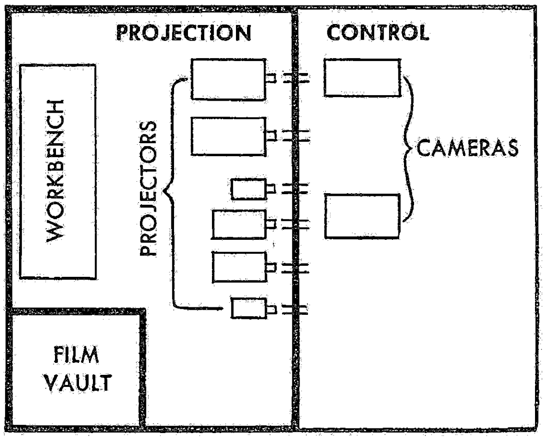
With 16 mm equipment, projectors and film cameras are usually housed in the same room. Only the camera control gear is in the control room. The same is very often true when 35 mm projectors are used. In these cases, two or more projectors are clustered around a single film camera, with a mirror arrangement permitting instant changeover from one projector to another.



On the other hand, some local laws require, and some stations prefer, a fireproof wall between their 35 mm projectors and film cameras. Under this arrangement, control and projection rooms are usually side-by-side, and the entire camera chain is housed in the control room. This involves projecting the picture through small ports in the fireproof wall separating the two rooms, in this fashion:

Space needs in the projection room begin around 200 square feet. This would be ample for a modest outfit consisting of one camera, two 16 mm projectors, and one slide projector, plus a worktable, monitor, and small storage cabinet.

About 50% more space than this is required for a 35 mm installation consisting of the same items of equipment, plus a storage vault. The projectors are larger; the vault is extra; and a 35 mm operation is inherently more elaborate.



An extra camera with a cluster of auxiliary equipment, such as spare slide projectors, balopticon, etc., can be added to either of these units within something like 100 square feet of additional space.

Consequently, these estimates are based on an average need of 200 square feet for a two-projector, one camera 16 mm installation; 300 square feet for a similar 35 mm outlay; and 100 square feet for an auxiliary camera cluster.

In those cases where the cameras are in the control room, separated by a fireproof wall, the projection room maybe somewhat smaller than this figure, but the saved space must be added to the program nucleus.

Preview Room. The program department will need a place to screen film in advance, to time, edit, cut, and splice the reels before they are ready to go to the projection room. The sales department will want a place to preview film for clients, to check slide and film commercials before they are finally approved, and do a variety of other chores in connection with sales of film features. Using the main projection facilities for these purposes is not usually feasible.

It is not at all unusual to see directors and salesmen using the walls of their offices for these purposes, at the present stage of development, but a special preview room is a useful arrangement which experienced stations turn to whenever possible. If 35 mm film is used, a special fireproofed room is essential.

One station which is building new studios, incorporating features based on several years of operation, is placing its special clients' room alongside this previewing room and providing a port in the wall between the two. In this way, slides and motion picture film can be projected through the port onto a screen in the clients' room, thereby putting projection equipment to double duty.

The desirable size of a preview room will bear some relationship to the extent of projection room facilities. One station which uses both 16 and 35 mm projectors has separate cubbyholes for previewing each size film. This gives more freedom in using the facilities.

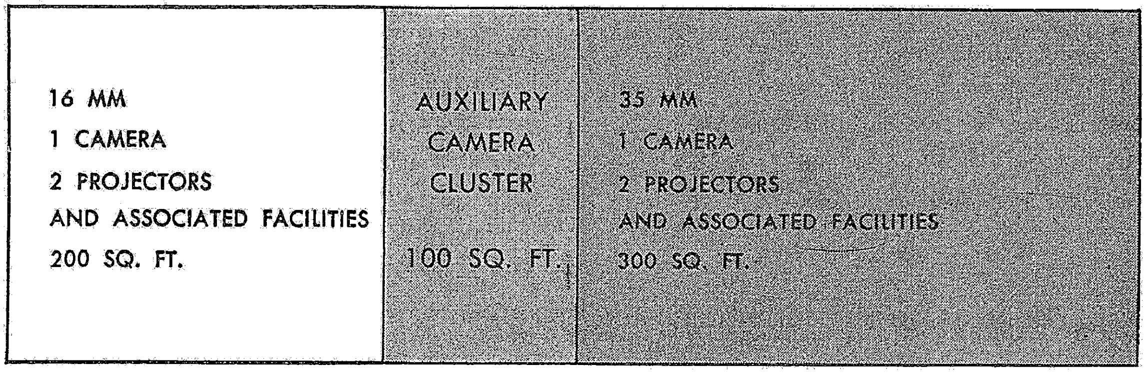
Something like 150 square feet will probably be the smallest amount of working space that you will want to provide in a preview room. A station which also uses 35 mm equipment will probably have an operation warranting about twice that much space, or more.

Film Production

Stations which plan to shoot motion picture film locally and process it themselves will need extra room in which to house this activity. Space needs outlined above apply to film projection, rather than production.

In any operation, motion picture production facilities can be useful, especially for filming commercials, titles, and special features. Where local newsreels are to be emphasized, this phase of the planning takes on particular importance.

Some stations farm out this entire activity to commercial concerns, thereby eliminating the need for film production facilities in their own plants. This is especially true of stations which do not feature newsreels, although a few stations--in cities where a local processing outfit is



geared up to high speed--have been successful in handling even this latter undertaking on a contract basis.

Generally, though, stations which specialize in newsreels handle their own film production from start to finish. They have their own cameras and all the laboratory equipment needed to process the film from the time it is exposed until it actually goes on the air.

Most stations use a standard processor, which carries out the entire processing of 16 mm film in one continuous operation. Exposed film is fed into the machine and a completed product comes out a few minutes later ready for editing and projection.

A simple, one-processor installation of this type, along with a modest area for splicing gear and film storage as well as space for mixing the developing chemicals, requires approximately 150 square feet as a minimum.

Although there are stations which find two processors necessary to meet their demands for speed, quantity, and insurance against operating difficulty, very few stations have more than one processor. At least one station which has given great emphasis to film production, especially newsreels, reports that it has operated for over a year with only one machine, on a very demanding schedule, and has had no trouble with breakdowns or other mishaps.

If a second processor is used, space must, of course, be increased accordingly. More space will also be necessary if a station expects to find multiple copies of some film essential.

A station planning to supply other organizations with copies of its newsreel footage, for example, would probably find a special printing machine necessary, in order to make several copies of each item.

For normal operations, though, the processor will turn out a master copy which can be used directly on the air. This is known as a "reversal". A standard processor can turn out positives and negatives as well as reversals.

Printing and associated activity will require something like an extra 100 square feet--in addition to the 150 square feet specified above for processing.

Expansion. In the midst of examining the broad outlines of a television operation, this may be a good point to pause for a moment and restore perspective by looking closely at one of the many small operational problems which crop up after a station gets underway.

A visual time signal can be a valuable station-break feature. An effective presentation is to show an actual clock, so that the second hand may be seen moving precisely up to the minute mark.

The immediately obvious way of doing this, of course, is with a studio camera. But even at stations where these cameras are conveniently located for such a purpose, operating studio equipment for an occasional odd feature can, at times, be an expensive proposition.

In this case, as in others, a balopticon is a useful piece of equipment. With it the film camera can be used for picturing the clock and its associated commercial or station identification, without actually putting anything on film.

Should you be interested in the principle, an intense light is reflected off the clock, through a lens, and focused on the tube of the film camera--in the same manner that motion picture projectors focus their pictures on the camera tube.

The clock is only one example of work the "balop" can do. It also affords a convenient and less expensive means of reproducing still pictures directly from glossy prints, art work from the original drawings, etc.

Principles of the balopticon aside, though, our point is that stations seem to be constantly finding new gadgets which simplify their problems and increase the station's effectiveness. The original blueprints should be drawn to accommodate this natural growth.

While it is true that a one-film-camera station may find that it can "multiplex" (with mirrors) a balop into its single channel, it is also true that over a period of time the station will probably want to add other projection room items, such as, perhaps, a kaleidoscope (which permits projection of moving patterns onto a screen that would otherwise be still), and soon two film cameras would become essential.

Many stations consider two film camera chains essential right from the start as insurance against loss of commercials resulting from trouble in a single-chain installation.

New inventions and equipment improvements must also be expected over the normal life span of a television plant. While there were no revolutionary changes in equipment during 1948, certain changes will almost surely come during the next few years. True, new models do not make existing equipment useless, but there is always the possibility that the improvements will be so great that stations will find replacements or additions advisable.

To cite an example in the area just discussed, a new camera is being developed in the laboratories which some people believe will be superior to the iconoscope for film reproduction. If so, space and operational requirements in the projection and control rooms might be altered.

No doubt this point has been belabored, but it is advice which experienced telecasters emphasize: keep your plant flexible; prepare for change and expansion, in the film and all other departments.

Remotes

Inclusion of remote origination facilities in the programming apparatus of a station involves space and layout considerations and three points:

Storage area is required for the vehicle, or vehicles as the case may be.

Maintenance shop capacity must be expanded so as to permit servicing of field equipment.

Receiving instruments--line terminals, equalizing amplifiers, cables, monitors, microwave relay gear--must be housed.

Space for the latter two functions has been earmarked in our previous discussion of the program nucleus. They will be integrated with similar needs created by other program sources.

Here then only vehicular storage space will be considered.

A composite of the mobile units sold by regular equipment manufacturers would have overall dimensions running something like these: twenty-five feet long, bumper-to-bumper; eight feet wide; and ten feet tall, at the extremes. Such a vehicle would completely cover 200 square feet. To provide 2-1/2 feet of clearance all around the vehicle, plus 50 additional square feet for miscellaneous storage, this square footage jumps quickly to 500.

Stations which build (or have specially built) their own mobile units, starting with large truck or bus chassis, frequently end up with vehicles having proportions somewhat larger than those described above. Even the so-called standard models are changed from time-to-time. It is important, therefore, to know the exact dimensions of the truck to be housed before any close decisions are made.

A few stations have found that two mobile units are essential to meet their requirements, a decision which has perfectly obvious effects upon garage needs. An additional 300 square feet, in combination with the original 500 should do nicely for a second unit.

More commonly accepted is the need for an auxiliary vehicle to work with the main mobile unit. Several stations have found a small pickup truck, station wagon, or other vehicle of this size essential for use in transporting personnel to and from distant or out-of-the-way pickup points, advance surveying of locations, and other odd jobs for which the main mobile unit is totally unsuited.

One station which scrutinized its costs very closely found that it could save money by purchasing a small pickup truck. Savings came primarily in the form of fewer manhours wasted. Prior to purchase of the "tender," the entire remote crew sometimes had to ride to location in the main unit, with the result that several people were on the scene several hours too early.

About 200 square feet should be ample storage space for most auxiliary vehicles.

While there is disagreement among experts concerning the usefulness of mobile power plants for remote pickups, station builders may wish to investigate their possible value in the particular operation being planned and, perhaps, provide space for such an outfit in the part of the plant devoted to field facilities.

Mobile generators have been tried and abandoned in some instances because the frequency of their power output could not be maintained at a stable 60 cycles per second. In at least one case, however, a station has found that it can secure reasonable steadiness and tolerate the slight variations in frequency.

Technical experts of this station report that the discrepancy between the frequency of city current and its self-generated power is no greater than the difference between its city current and power being used at network origination points in other cities.

If it is decided to use a generator, space should be provided for it in addition to the other items accounted for here:

First mobile unit--500 square feet.

Second unit--300 square feet.

Small tender--200 square feet.

Building Studios

The television station construction permittee who can look far into the future and visualize clearly what his studio programming schedule will be like is indeed a fortunate, and probably nonexistent, person.

The importance of plant flexibility, emphasized throughout this section, is most readily apparent in the studio considerations. Here the needs rise and fall sharply in proportion to the amount of time devoted to studio programs. (With a couple of motion picture projectors, for instance, it would be at least possible to handle almost any quantity of film the station may wish to broadcast, but studio requirements do not maintain such equilibrium.)

The most immediately important objective, therefore, is to tailor the studio layout as closely as possible to the station's program structure.

Is it planned to do dramatic programs? They make great demands on studio space.

Are across-the-board shows planned which need pretty much the same set every day? A homemakers' program with a kitchen setting might be an example. If so, it may be wise to provide space to keep such sets intact, avoiding the expense of striking and resetting them several times a week.

How will audience participation programs and other shows be handled where an audience must be seated? If there is only one big studio, with sets and props all over the place, accommodating numerous program guests can be difficult and expensive.

Are vaudeville-type variety programs planned? If so a raised stage is desirable with curtains, wings, and many of the provisions of a legitimate theater. Intimate night club style variety shows can be produced more easily on the main studio floor.

Keep in mind, too, that a one-minute local live spot announcement can be as demanding upon studio space as a more elaborate production.

Studio Space Requirements. The rapid expansion of television has brought with it a decided trend toward larger and larger studios, not only among network production centers but among individual stations as well.

Granting that the local programming situation is the controlling factor, let's scrutinize existing operations in search of some general guidance:

Among non-network owned stations on the air at the beginning of 1949, the range in floor area for main studios was from slightly more than 500 square feet to more than 4000 square feet. About two-thirds of all stations on the air had principal studios with square footage ranging between 1000 and 2000. Of remaining stations, about half had smaller studios and the other half had more than 2000 square feet.

Anticipating with reasonable accuracy the maximum number of staging areas, with sets actually in place, which a station will need at any one time is the first key to matching studio facilities and program structure. This may be an impossible objective, true, but at least it gives us something definite at which to shoot.

If it is planned to originate, for example, an early evening children's program followed closely by a regular news program which uses a fairly elaborate set, it will probably be found that two staging areas are essential.

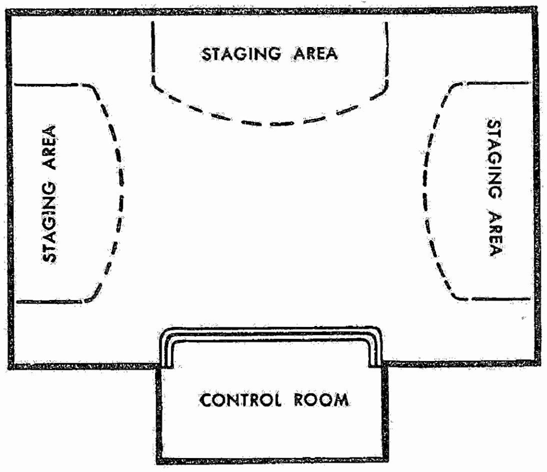
Perhaps, as in the example cited above, there may be a daily homemakers' show which requires a permanent set. Or there may be any number of other sets and scenes which it would be desirable to keep in position on a semi-permanent basis. Like one station, there may be a series of commercials requiring use of an actual filling station scene on a regular basis. The question raised here is whether it is less expensive in the long run to provide more space than to be continually striking and resetting the same scene.

Dramatic programs will often require several sets, and they must be in place for rather extensive periods to accommodate lengthy rehearsals. Audience participation programs may require the use of more than one staging area--one area for the performers, another for the audience.

The tendency among individual stations to use simple, impressionistic sets does provide one means for reducing these needs. Another simple expedient is to provide curtains which may be used to divide staging areas into smaller units. Other methods of increasing the usefulness of studio space will undoubtedly occur to the designer, but he may want to let such developments prove helpful as natural expansion takes place, rather than counting on them from the first.

Once some estimate has been made of the number of staging areas which will be required, we can turn our attention to various studio sizes and see how many such areas each affords.

Stations with about 1000 square feet of studio floor area find that they can usually squeeze three pretty good-sized sets into that area--one at each end of the studio and a third along the wall opposite the control room, in this fashion:



If space falls a little under 1000 square feet, it may be wise to consider the third area as a spare for tight squeezes only. If space is too tight, cameras, microphone booms, floor lights perhaps, and other off-set equipment will continually be trespassing on the center stage while working the end areas. For these reasons, it may prove inadvisable to keep a set in place for long periods in the third space even when a full 1000 square feet are available.

As we move up from 1000 square feet, the number of staging areas is increased. Several stations with studios of 1200-1300 square feet find that they can accommodate four separate staging areas. This increases to six or eight when something like 3000 square feet are available.

It is safe to think of a single staging area as requiring between 300 and 500 square feet of space--so long as we are continuing to think about average station needs rather than those in network production centers.

More flexibility and operating elbow room is obtained by having two or more of these staging areas housed in a single studio. In this way it is possible to overflow the restricted areas when some elaborate show requires more space. And even in run-of-the-mill operations, the cameramen and other off-set people have more freedom of position.

When we group a number of staging areas within the same walls, though, schedule conflicts begin to arise, and another question is raised:

How Many Studios? Where local programming schedules are extensive, the advantages of having more than one studio are obvious. No matter how many staging areas a single studio may contain, rehearsing one program while another is being broadcast from there is not feasible. Even rehearsing two programs simultaneously becomes difficult.

Building and equipping two or more studios of goodly proportions is, of course, one happy solution to such scheduling problems, provided, naturally, that the amount and quality of production warrants the expenditure. Other than network-owned stations which also serve as major chain production centers, however, few stations have such elaborate facilities.

A somewhat more popular procedure is to provide a second, very modestly equipped studio for simple news programs, interviews, and other "intimate" programs.

Still, stations which have more than one completely equipped studio, built especially for television, are in the minority. Expensiveness of equipment and the fact that, with careful scheduling, so much can be accomplished in one unit has led most telecasters to this at-least-for-the-time-being decision.

Among stations with only one studio, four devices to alleviate the shortage of facilities have found fairly wide acceptance:

Installing at strategic spots curtains which may be lowered to divide the main studio up into smaller units. With this arrangement, two rehearsals may be conducted simultaneously, and, if the curtains are sufficiently sound-absorbent, one program may be rehearsed while another is actually being broadcast.

Building but not equipping a second studio. This additional unequipped unit serves nicely in some operations as a rehearsal studio. Preliminary planning and practice can be done here, thus cutting down the amount of time spent in the camera-equipped studio. In some cases the rehearsal studio is equipped with lights, making it possible to actually broadcast from there by bringing in field equipment.

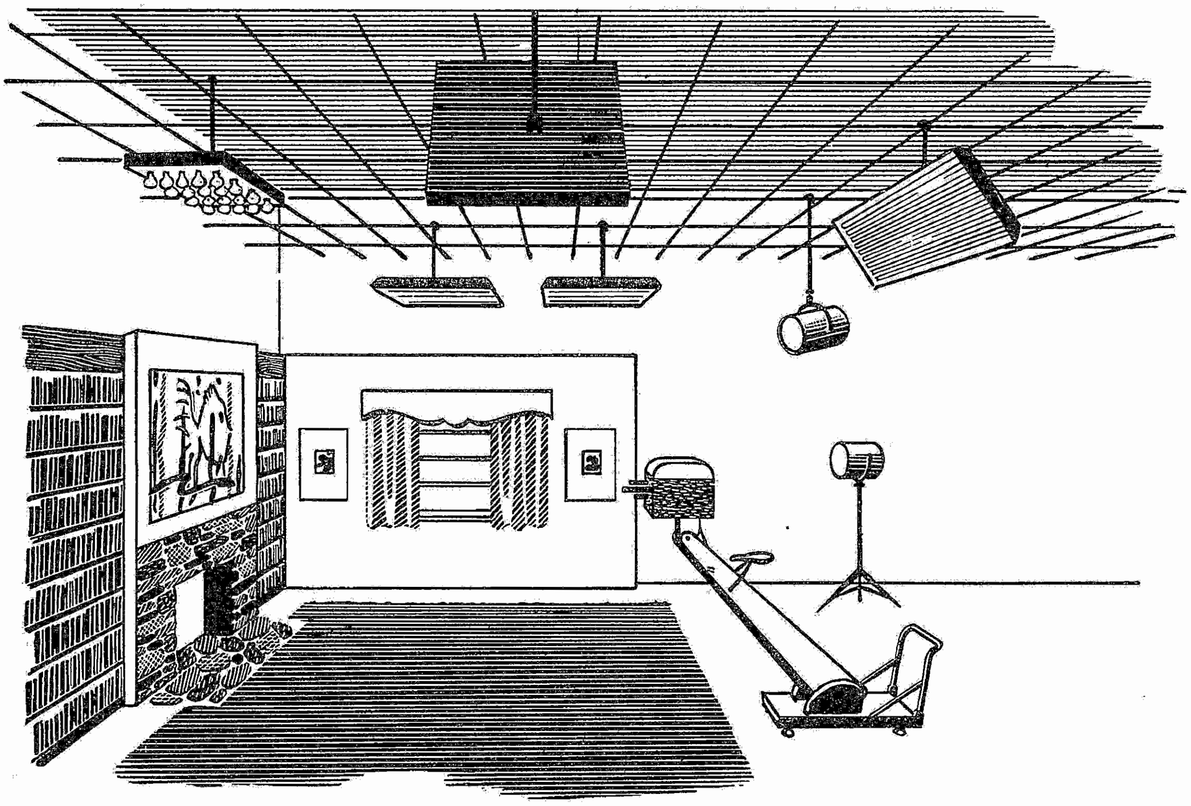
Preparing an aural studio for television use. In those operations where TV and AM or FM are closely associated physically, the installation of video circuits, additional electrical wiring to carry the load of lights, and some system of either mixing or adding audio circuits, frequently makes it possible to utilize the space for video during hours when it would otherwise be idle.

Utilizing a theater or some other existing auditorium for the origination of special shows. Mobile equipment is often used for this purpose. The addition of some special lighting will probably be necessary, however, and you may find it necessary to change camera tubes to obtain the best effect.

These last two devices sometimes offer a handy means of housing programs that require a studio audience, such as audience participation and variety shows. They may also provide a raised stage, wings, and other features of a legitimate theatre which are valuable on some features.

Ceiling Height. Putting television studios in office buildings where ceiling height is normally restricted to about nine feet is possible. Programs are being produced regularly and successfully under these conditions. However, it will be found that those responsible for such operations are the first to say emphatically that greater ceiling height is extremely desirable.

With a low ceiling, cameramen must be very careful to avoid getting overhead lights in their pictures. Thus the variety of interesting camera work which can be put into a program is sharply curtailed. If a crane-type camera dolly is available, this is particularly true. Under



a nine-foot ceiling, this valuable instrument cannot be extended to its full height, which normally permits shots down into a set.

Keeping microphone booms out of the picture is especially difficult with a low ceiling, and has the effect of limiting camera angles still further. Other disadvantages could be enumerated, but suffice it to say that we must look higher to find our "average minimum" requirement in this area.

On the opposite extreme, ceiling heights of 50 feet and more are in use. Motion picture sound stages are often that high, and some of them are in use for television. Even a few of the big studios built exclusively for television have heights approaching this figure. These are network production centers, though, and stations will rarely, under present standards and practices, find themselves dealing with ceiling heights measuring above the twenties.

Some of the governing factors are these:

Flats and other items of background scenery are usually about ten feet high.

If cameras are to have full freedom of movement, they must be able to shoot down into sets.

Lights will require two, three or more feet of vertical space above the camera and microphone operating area--exact amount of space depending upon type of lighting fixtures and arrangement used.

Cycloramas and other special scenic effects can take up additional space.

Spare overhead space will probably enable you to keep ropes, cables, and many other bits of paraphernalia off the crowded studio floor.

Taking all or part of these factors into account, something like 12 to 14 feet is usually accepted as the absolute minimum for satisfactory operation. The really desirable low point usually falls between 18 and 22 feet. Stations which have freedom of choice usually select heights in the latter vicinity but occasionally go on up to the high twenties.

All of this boils down almost always to a very natural solution: Let the studios extend through two floors. Twice the normal ceiling height of, say, 9 to 12 feet puts the studio ceiling in a very comfortable area.

Studio Design. Simplicity is the dominant motif in all television studio design. The objective is to provide the maximum amount of open working area. Organic encumbrances will be numerous at best, so any semblance of decorative froufrou is usually avoided assiduously.

Elaborate and glamourous acoustical treatment of walls, for instance, is futile. Scenery and draperies will nearly always cover the walls to a point well above head-height, nullifying or reducing the effect of sound treatment and covering any attractive design which may have been achieved. Standard practice is to use rock wool, held in place by narrow-mesh chicken wire, as the sound proofing material, and this treatment is most often seen around television stations. In some cases rock wool blankets cover the entire wall and ceiling area; in others, walls are covered only down to the normal top level of scenery. Stations in the latter group say the walls are always covered by flats, drapes and other scenery anyway. Some stations use asbestos sheeting around all or part of the lower wall area, below the scenery level.

A grille of pipes or angle iron is usually found in the overhead area of the studio, providing a means of suspending lights and other paraphernalia. Height and extent of this grille usually depends upon the type of lighting arrangement used. Curtains dropping from travelers in this grille can be used to give greater flexibility in cutting off sections of the staging areas. Some of the more elaborate studios have catwalks around the walls above the camera zone which give lighting technicians and other studio workers easier access to the overhead area.

Concrete seems to be the most popular material for studio floors, although heavy linoleum blocks are sometimes employed. Important thing is to have a substantial floor which will bear up under constant moving of heavy props, such as kitchen ranges, refrigerators, even automobiles, plus cameras, microphone booms, and the like. When cement is used, a smooth, waxed surface to avoid powdering has been found valuable.

Not only must the surface withstand this wear, but the structural stability must be such that vibration will not be transmitted to the cameras. As discussed earlier, microphonic effects can cause serious interference in the picture tube. Heavy cork under concrete has been used to minimize this possibility.

In this connection, some stations find that one-foot square markings etched into the floor are a boon to production people. When plotting motion, these stations find that the lines are great time savers for directors, cameramen, performers, et al. This is a controversial point, however, because other stations object to any pattern at all on the floor. They feel that the floor shows so often in their pictures that any visible markings become objectionable to viewers.

Large doors opening into the studio are highly desirable. The heavy props mentioned above are usually bulky. Room enough to drive automobiles on set is one common criterion. At least one station has made specific provision to drive its mobile unit into the studio, facilitating use of remote equipment inside. In some instance, huge doors on two sides of the studio are available. Freight elevators are essential, of course, when studios are above the ground level.

The most common studio shape is rectangular. Keeping the walls clear of protruding obstructions is considered desirable. A control room jutting out into the studio area can reduce appreciably the usability of floor space, although some stations prefer a slight protrusion to increase visibility.

At least at present, then, the layout and design of a television studio proper presents no vast and complicated issues. A simple box-like structure, without fancy adornment, and with straight, clean lines, appears to be ideal. Recall to mind the enormous sound stages of Hollywood and you will see the parallel. Even in fabulous, lavish Hollywood, these are simple, austere structures, designed to provide the maximum amount of enclosed space, with ample access to the outside world.

Auxiliary Space. The studio proper represents only a small part of the space needs created by studio programming. Storage area, carpenter and paint shops, dressing rooms, and space for other activities incidental to production of local live programs frequently occupy much more area than the studio itself.

One rule-of-thumb which has gained rather wide acceptance in the industry is this: floor area devoted to these auxiliary services should be at least 150% as large as the studio.

As would be expected, a number of today's stations have a higher proportion than this, and, on the other hand, some of them work with virtually no auxiliary space.

Stations in the latter category usually construct and paint many of their sets and props right in the studio, and store a substantial amount of scenery and stage property there, too. The net result is that, in terms of space used, the proportion is closer to the above rule-of-thumb than might be first expected.

The need for plenty of storage space, conveniently located, is a point which is stressed uniformly by all experienced television operators who use studios, large or small.

Initial decision to be reached when planning dressing rooms is whether or not individual cubicles will be provided for stars. Stations generally are inclined toward the practice of having only two main dressing rooms, one for men and one for women, to be used by all performers.

Whatever the final decisions may be concerning exact amounts of space to be devoted to each of these supporting activities, their value will be increased by placing them as close to the studio as possible. When costume changes are necessary during a performance, distant dressing rooms can be a problem. Proximity of storage space, especially for items in current use, is of obvious importance.

If storage and studios are on different floors, freight elevators, or at least some system of ramps for slight elevations, will be essential. All connecting doors should be designed to accommodate the largest props.

Studio Lighting

Universal acceptance of the image orthicon camera for studio as well as field work has shifted the emphasis in studio lighting. Creating a sufficient amount of light is no longer the serious problem it was when iconoscopes were the standard studio camera. Present-day practices and theories revolve around getting the right kind of light in proper quantities in the right places to produce the best artistic effect.

Since iconoscopes are generally used now only with motion pictures, slides, balopticons, and other devices which make it possible to project intense light into the camera, the "ike's" characteristics need not influence any part of a television station's illumination plan.

Lighting specialists in the new medium have found no existing system which applies exactly in their field. Movies are made in short "takes" which seldom last more than two or three minutes. Continual rearrangement of lights between takes is possible. During a continuous television performance, few if any changes can be made.

Techniques of the legitimate theater correspond more closely to demands of video, in this respect, but again there is a vital difference: Television's ever-inquisitive cameras pry around and shoot from two, three, even four directions--contrasted with the audience's constant position in the theater.

In one important way, though, television's lighting needs have been moving toward those of the theater and movies. Stage illumination is designed to react directly on the human eye. Hollywood's procedures were devised to reflect light rays through a lens and record properly on film. Television lighting must be controlled so that it will create a pleasing and reasonably accurate impression when it has been reflected through a lens and fallen on the face of an electronic tube. The newest of these image orthicon camera tubes have color response which according to the manufacturer compares favorably with both panchromatic film and the human eye.

Improvements which are being made constantly in the pickup tubes alleviate many lighting problems, but contribute to the lack of uniformity which exists in much available literature on the subject. The switchover from iconoscopes to orthicons is a prime example, but the same effect extends to more recent developments.

Amount of Light. The term foot candle, a standard unit for measuring amounts of light, is the amount of light which a single candle throws on a one-square foot spherical surface at a uniform distance on one foot.

Demonstrations have shown that certain image orthicon cameras can produce a satisfactory picture with as little as one or two foot candles of light. It might be easy to assume, therefore, that normal indoor illumination levels would be suitable for studio purposes. Such is not the case.

True, these exceptionally low light levels will be useful for special effects. And they are indispensable for on-the-spot pickups where there just isn't any more light. But for all practical purposes, the television lighting man will be using greater intensities of illumination.

First of all, there is depth of focus. In television, as in photography, the less light there is present, the wider the lens opening must be. Axiomatically, the wider the lens opening, the shallower the depth of focus.

Take an example. A glee club is being televised. Its members stand several rows deep. If light levels are extremely low, it may be impossible to bring all rows into proper focus. With more light, the lens can be "stopped down" more, thus increasing depth of focus and making it possible to get a clear picture of the entire group. Maintaining focus on moving objects is much easier with greater depth of tolerance.

The need to develop contrast and shading of light is another of the several reasons why studio lighting levels will be higher than normal room illumination. Pictures will be more interesting if there is back, side, and other highlighting, in addition to general illumination.

Scientists doing research on orthicon tubes have found that light levels lower than about sixty to eighty foot candles are impractical for normal studio usage. Below that, planned lighting on the set can be too easily upset by stray rays spilling over from another staging area, or coming through an unexpectedly opened door, or from a variety of unwanted sources.

Even the latest studio image orthicons are designed, therefore, to function at optimum light levels of approximately 100 foot candles.

Kind of Light. Acceptance of the image orthicon for studio work has brought with it a corresponding increase in the use of fluorescent light sources. The relatively small amounts of light which can be created by fluorescent means were of little value in meeting the "ikes" enormous demands, but today's modest needs have brought the glowing tubes into their own.

Fluorescent light cannot be easily focused, however, and this disadvantage, among others, leads to one general pattern which now exists:

Some combination of fluorescent and incandescent light is the most widely used type of illumination among operating stations.

A few stations still use incandescent exclusively, and there is strong sentiment in some quarters for mercury-vapor lamps.

The latter have a long history in television, and have often been a subject of controversy. Their ability to produce high intensity light made them valuable for use with iconoscopes. In some instances, their use has been discontinued with the installation of orthicon camera chains.

At the same time, however, one of the foremost Hollywood lighting firms has recently made a series of tests, conducted in conjunction with an operating station, in which it concluded that cadmium-mercury lamps are highly desirable for television.

When incandescent and fluorescent light sources are used in combination, the most common method of mixing is to use fluorescent for general illumination, or "key" lighting, and incandescent for highlights. The glowing tubes provide a softer, more diffused light, with fewer harsh shadows--ideal for overall illumination. Incandescent is sharper, more dramatic and manageable, qualities which make it preferable for highlighting.

Blending key and highlighting is an artistic matter, and no precise formula for mixing the two has universal acceptance. The designers of the newest orthicon tubes speak, however, in terms of fifty or more foot candles of key lighting, with enough additional special light to bring the level up to approximately 100 foot candles.

If the studio light is unbalanced, the black-and-white picture produced by the camera will not be a faithful reproduction of the original. Some colors will be darker, others lighter than expected, depending upon the color deficiency of the particular light source.

Used alone, incandescent lamps furnish light that is heavily weighted in favor of the red end of the color spectrum and almost totally lacking on the opposite (blue) extreme. Fluorescent light is better balanced, but blues do predominate somewhat in some types, a fact which favors its combination with red-rich incandescent.

Some other advantages of fluorescent lights are these:

Less heat is produced, reducing the air conditioning load.

Fewer infra-red rays are radiated, increasing performer comfort. (Infra-red rays release their heat only when they strike a solid object, such as a performer. Therefore, no amount of air conditioning can remove this type discomfort. Heat filters do help.)

Higher efficiency produces more light per unit of electricity. This can permit economy in operation, even though initial cost is higher.

Scientists working on the project feel at the time of this writing that fluorescent tubes of 3500 degrees kelvin white or, perhaps, 4500 degrees kelvin white will prove to be the best source of general illumination for the latest orthicon camera tubes.

Incandescent lamps in use run the gamut from small "birdseye" bulbs, with self-contained reflectors, to enormous floods and focusing spotlights.

Placement of Lights. The big issue here is whether all lights will be overhead or whether there will be additional fixtures on the studio floor.

Mounting all lights on the ceiling offers some operational advantages which are easily apparent. Studio floors have a tendency to become cluttered even under the best circumstances. Cameras can have more freedom of movement if they are not crowded by floor lights.

Some stations with extensive production experience find that they can operate very satisfactorily with nothing but ceiling lights. One system which was designed with this point in mind is known as the "inverted pyramid" system.

On the other hand, a number of stations report that they have found floor lights absolutely essential to obtain the kind of artistic effect they must have. One of the motion picture lighting companies has concluded that ceiling-mounted lights alone will not suffice in television.

This is but one example of the highly divergent opinions which pervade this phase of television. Fortunately, floor lights are a plug-in proposition. They can be used, or not, as the situation indicates, provided that power outlets are installed and the current they draw will not overload the wiring system.

Broadcasters entering television may find studio lighting the most foreign subject with which they must cope in the visual field. Those who have had experience caution against underestimating its importance. Even with hundreds of thousands of dollars worth of electronic equipment, no better image can be transmitted than the one which is focused on the face of the camera tube. Lighting determines to a very large degree whether that picture will be sharp, clear, and pleasing.

Even among experienced telecasters, however, there is no far-reaching agreement on the principles of television lighting. At the point where light is focused through the camera lens and onto the photosensitive surface of the cathode ray tube, electronics meets and joins forces with art and its variety of individual preferences.

* * * *

Conclusion

After decisions have been reached concerning the type of transmitting and programming facilities to be used, overall space needs for a television station can begin to take shape. Now that the individual components of a television plant have been examined, perhaps we can back away and get a long shot of the entire scene.

Outside the programming and transmitting plants, the principal space requirement is for offices. Here, of course, we move into an area where needs are determined by factors not peculiar to television. The amount of space to be devoted to personnel offices, and its arrangement, is something which is determined to a greater degree by the station's philosophy of operation than any other factor.

The same is true of space to be devoted to lobbies, reception rooms, lounges, and other special features which may be included in a broadcasting plant. In all these respects, the needs are no different from those with which aural broadcasters are already intimately acquainted.

Some overall guidance in this area may possibly be obtained however, from another rule-of-thumb which has been kept in mind during the building of several existing stations: Total space needs frequently run to about five or six times the amount of studio floor area used.

On this basis, a television station with a 1500 square foot studio would need a total area of approximately 9000 square feet. If we follow the rule-of-thumb stated above for determining auxiliary studio space needs, some 3750 square feet of this total would be required for the studio and its associated storage area, dressing rooms, carpenter shops, etc.

Any such formula must be used with extreme caution, of course. Stations utilizing network, film and remote program sources extensively, and using only a tiny studio for intimate programs, such as interviews, news shows, and the like, would obviously find such a proportion completely out of the question. In some cases it would not work at all--for stations without any studios, for example.

But most stations do have studios of substantial size, and it is quite true that live talent studios are the dominating influence in the building of a television plant.

This brings us back to the major theme: intelligent planning of a television station's physical outlay depends largely upon the possibility of visualizing to the clearest possible degree that station's future programming structure.

INTERCONNECTING FACILITIES FOR BROADCASTING

(Revised and Amended as of August 1949)

(The material in this Section was prepared by the American Telephone and Telegraph Company and was derived in part from the results of cooperative activities with the Columbia Broadcasting System, the Mutual Broadcasting System and the National Broadcasting Company.)

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PART 1 - GENERAL

With a few exceptions the interconnecting circuits used in audio and television broadcasting - between pickup points and studios, between studios in different cities and between studios and their associated transmitters - are furnished by the facilities of the telephone companies. The transmission of broadcast program material over these circuits and networks requires a certain amount of transmission supervisory activity in which the broadcasters and the telephone company are mutually involved.

The common problem of the telephone company and the broadcasters in this connection is the transmission of audio or television programs from the point of origination to one or more transmitting stations throughout the country. The ultimate objective is the transmission and reception of these programs without noticeable loss of fidelity compared with the original production. Obviously, there are a great many factors both physical and economic which stand in the way of full attainment of this objective. The development of new equipment, the adoption of new methods, and the increased knowledge of line transmission phenomena, however, all contribute toward the better control or elimination of the factors and permit a closer approach to the ideal.

In this Section of the Engineering Handbook will be a description of the various types of services offered by the telephone companies as well as a discussion of principles and practices which will assist the broadcaster in obtaining optimum results with these services. A statement of rates and charges for these services is beyond the scope of this Section and for information on these matters reference should be made to the local telephone company.

It is planned that additional parts will be issued in this Section to cover new aspects of broadcasting as practices become sufficiently well stabilized to warrant formal treatment.

PART 2 - COMMON TERMINOLOGY

In order to facilitate a proper understanding between the representatives of the broadcasters and the representatives of the telephone company who deal with the technical problems of interconnecting facilities the following terminology has been established.

BROADCASTING TERMS

1. Studio

In general a studio consists of an enclosed space specially arranged and permanently equipped for use of performing groups with their attending studio technicians, engineers, or program control operators who regulate or control level transmitted from this point for each specific program. Studios may be on the same premises with master control or at other fixed locations.

2. Master Control

This is the central point of a broadcasting plant at which supervision is exercised by the broadcaster over program transmission. It is also the main point with which the telephone company checks volume or video signal level.

3. Transmitter

Unless otherwise qualified this refers to the audio or television broadcasting transmitter complete with power, audio, video and radio equipment and radiating system. In a few cases where this point is connected by audio or video channels directly with a test room, the telephone company checks volume or video signal level with this point.

4. Broadcasting Plant

The combination of 1, 2, and (where on same premises) 3 above.

5. Field Pickup - Remote Origination

These terms indicate a point of program origin outside of the regular studio location, at which the same functions are performed as at a studio, but where portable pickup equipment is used. The telephone company checks volume, or video signal level, with this point when program is transmitted from it directly to a telephone toll office.

TELEPHONE COMPANY TERMS

1. Telephone Company

In this Section this term refers to a Bell System Telephone Company, either an Associated Company or the Long Lines. Where other than Bell System Telephone Companies are involved, there may be instances where practices differing from those discussed in this Section will prevail, and in such cases, it is desirable to reach a mutual understanding regarding local practices.

2. Associated Company

This term refers specifically to an Associated Bell System Company whose function is to conduct that part of the various services, including program transmission which, in general, do not extend outside the limits of its particular service area. The Associated Companies are -

New England Telephone and Telegraph Company
Southern New England Telephone Company
New York Telephone Company
Bell Telephone Company of Pennsylvania
Diamond State Telephone Company
New Jersey Bell Telephone Company
Chesapeake and Potomac Telephone Company
Chesapeake and Potomac Telephone Company of Baltimore City
Chesapeake and Potomac Telephone Company of Virginia
Chesapeake and Potomac Telephone Company of West Virginia
Southern Bell Telephone and Telegraph Company
Ohio Bell Telephone Company
Michigan Bell Telephone Company
Indiana Bell Telephone Company
Wisconsin Telephone Company
Illinois Bell Telephone Company
Northwestern Bell Telephone Company
Southwestern Bell Telephone Company
Mountain States Telephone and Telegraph Company
Pacific Telephone and Telegraph Company
Cincinnati and Suburban Bell Telephone Company
Bell Telephone Company of Canada

3. Long Lines

This term refers specifically to the Long Lines Department of the American Telephone and Telegraph Company. The function of the Long Lines Department is to conduct that part of the various services including program transmission which, in general, interconnect the territories of the different Associated Bell System Companies.

4. Test Room - Toll Office

As referred to in program transmission service activities, these terms usually refer to a long distance telephone office where the loops from the local broadcasting plants connect with the sound or television program network circuits. This is the office with which the broadcasters' operating personnel communicate in reference to routine program transmission matters. In most cases this office is in the same city with the broadcasting plant but in a few cases it may be in a nearby city on a main telephone route.

5. Loop

In this Section this term may refer to either of the following:

a. Local loops, i.e., the audio or video channels connecting a field pickup point with the broadcasting plant, or interconnecting various units of the broadcasting plant within a local service area.

   The circuits between the main studio and its associated broadcast transmitter are commonly referred to as "studio-transmitter" circuits.

b. Network loops, i.e., those connecting a broadcasting plant or a field pickup with the telephone company test room at which point connection is made with an intercity program circuit.

6. "Line" and "Drop" Terminals

These terms refer to those terminals of equipment facing toward and away from the line, respectively. For example, the "line" side of a coil on a loop is that facing the loop, and the "drop" side is that facing the other office equipment.

PART 3 - AUDIO AND VIDEO TRANSMISSION CHANNELS AVAILABLE TO BROADCASTERS

The following types of audio and video transmission channels are generally offered by Bell System Companies, subject to the availability of facilities.

Audio

Interexchange Channels, providing for the use of program transmission facilities for the transmission of program material, are furnished under the schedule classifications shown below:

Studio-to-Transmitter Channels are not provided under the above schedules. The requirements of such facilities vary widely as between cases and the channels are provided on a basis to meet the particular requirements of each case.

Local Channels are furnished under the Schedule F classification which provides for program transmission facilities within a program exchange area between stations, or between stations and the point of connection with interexchange channels.

Video

Interexchange Channels are furnished with a frequency range of approximately 3 megacycles for monthly use and for occasional use.

Local Channels are furnished with a frequency range of approximately 4 megacycles for monthly use and for occasional use.

Studio-to-Transmitter Channels are furnished with a frequency range of approximately 4 megacycles for monthly use.

Note: Specific service offerings are set forth in tariffs of the Bell System Companies.

To further this mutual understanding the practices and procedures described in this Part are presented as the results of experience which has resulted in generally satisfactory service.

PART 4A - PROGRAM LOOP TRANSMISSION AUDIO CHANNELS

The common meeting ground of the telephone companies and the broadcasters is on each telephone loop interconnecting them and it is here that the principal need for uniformity of thought and practice exists. With the benefits of a uniform type of volume level indicator (See Part 5 - The Standard Volume Indicator) and with proper mutual understanding, possibility of confusion at this point should be minimized.

EQUIPMENT ARRANGEMENTS ON NON-LOADED EQUALIZED LOOPS

Transmission over a circuit such as a non-loaded program loop, is usually equalized over a desired band of frequencies by application of measures which introduce certain amounts of loss at low frequencies and progressively decreasing amounts toward the higher frequencies to counteract the opposite characteristic of the bare circuit by itself. Two general methods are widely used to accomplish this. One is to bridge across the circuit a special attenuation equalizer which produces a greater loss at low frequencies than at high, this difference being adjustable as required for different loops. The other is to apply repeating coils of 4:1 impedance ratio at the two ends of the loop circuit. These introduce mismatch losses at the low frequencies and will equalize short lengths of cable, depending on the gauge of conductors and frequency bandwidth desired. For example, the second method may be used to provide transmission uniform to within about 1 db from 35 to 8,000 cycles for the cable lengths and gauges listed in Table 1. Beyond these lengths the special equalizer has to be added or used by itself without the assistance of 4:1 impedance ratio coils. For those circuits involving the transmission of frequencies from about 30 cycles to 15,000 cycles, the 4:1 impedance ratio coils together with a special equalizer are generally used in providing a circuit whose transmission frequency response is uniform within about 1 db of the response at 1,000 cycles.

Schedule	*Use*	*Approximate Frequency Range*
AAA	Continuous	50 to 15,000 cycles per second
BBB	Occasional	" " " " " "
AA	Continuous	50 to 8,000 " " "
BB	Occasional	" " " " " "
A	Continuous	100 to 5,000 " " "
B	Occasional	" " " " " "
C	Continuous	200 to 3,500 " " "
D	Occasional	" " " " " "
E	Occasional	300 to 2,500 " " "

TABLE 1

Lengths of Non-Loaded Cable Which
Can Be Equalized By Use Of
4:1 Coils Alone

Gauge	Length (Miles)
16	*5*
19	*2.3*
22	*1.5*

With loops combining various gauges of conductors other lengths would, of course, apply.

When equalized loops are furnished by the telephone company and no special requirements are imposed as to the arrangements to be employed, equalizers and 4:1 impedance ratio coils are likely to be used in combination. By proper adjustment of the equalizer, it is also possible to secure comparable transmission characteristics with 1:1 impedance ratio coils, except in the cases of loops of irregular makeup and of lengths approaching the limits which can be equalized in one section. Other considerations, involved in the use of volume indicators on loops, may control as to which method is preferable. Where the arrangement shown in Fig. 7 of Part 5 is used it is important to reduce deviations in volume indicator readings to a minimum and it is also desirable to keep the size of the pad between the volume indicator and the loop as small as possible. In this case, therefore, a 4:1 impedance ratio transmitting coils should be avoided.

If the deviations caused in the volume indicator readings are to be compensated, or if the volume indicator can be adequately isolated, the equalizing effect of the 4:1 impedance ratio transmitting coil may be combined with that of the equalizer if desired.

The use of a coil at the receiving end of a loop is usually desirable for minimizing danger of noise or other unbalance effects. Whether this coil should be of 1:1 or 4:1 impedance ratio will depend largely upon the results obtainable with the equalizer used. Certain equalizers are designed to operate with 4:1 impedance ratio coils between them and 600-ohm receiving terminal circuits; that is, facing 150 ohms. Others are designed to face 600 ohms directly, requiring 1:1 impedance ratio coils.

In order to minimize the possibility of experiencing noise or crosstalk disturbance on program loops, the attenuation equalizer, when used, should be installed at the receiving end of the loop.

In a case where a loop may be used for either transmitting or receiving, duplicate coil and equalizing equipment should be available at both terminals of the loop. When the direction of transmission is to be changed, the equalizer at the normal receiving terminal should be disconnected and another equalizer connected at the terminal which is to be made receiving. If different coil arrangements are used at the two terminals, similar changes should be made in this equipment. The equipment arrangements at both terminals should provide means for making these changes readily.

In Fig. 1 are shown arrangements of loop equipment to suit various conditions. Discussion of the important differences between these follows:

Fig. 1-A - For Use With 600-Ohm Transmitting Equipment

This arrangement minimizes deviations in volume indicator readings, where the volume indicator is used directly on the output of an amplifier, transmitting through a pad to a loop. It affords the flexibility of a special equalizer in providing for either short or long loops, and it provides a coil at the receiving end for minimizing noise. This coil is of 4:1 impedance ratio, which assumes an equalizer designed to face a 150-ohm impedance.

Fig. 1-B - For Use With 600-Ohm Transmitting Equipment

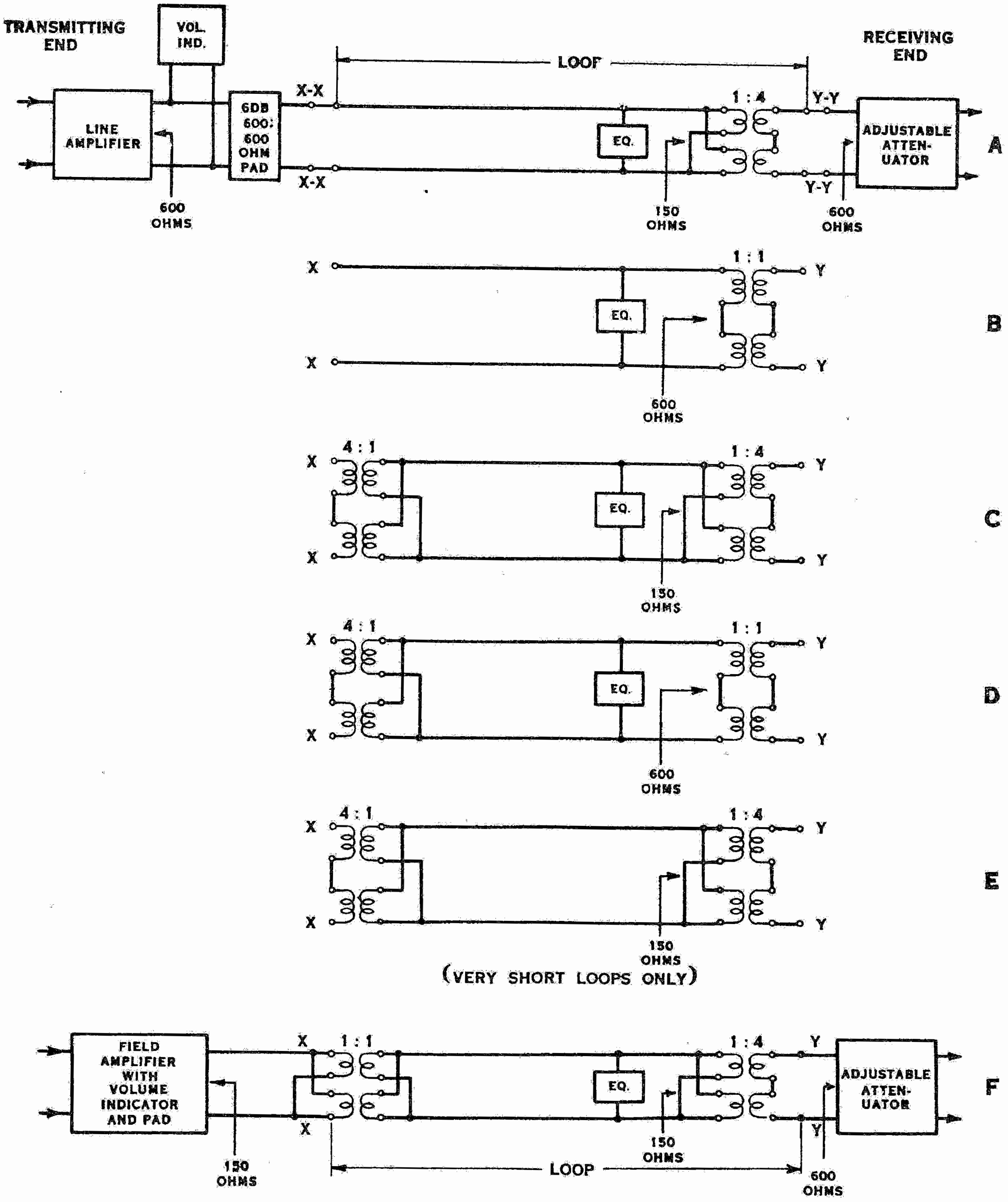
This arrangement which minimizes volume indicator deviations to the same degree as Fig. 11-A differs only in using a 1:1 impedance ratio coil at the receiving end, which assumes an equalizer designed to face 600 ohms.

Note: In either Fig. 1-A or Fig. 1-B a 1:1 impedance ratio coil may be provided at the transmitting end, if required, for protection or for correction of unbalance difficulties, without appreciable altering the results obtainable. This coil, if provided, should be included with the loop when it is being equalized.

Fig. 1-C - For Use With 600-Ohm Transmitting Equipment

The use of a 4:1 impedance ratio coil at the transmitting end in this case assumes that the higher impedance presented to the transmitting circuit by the loop is not objectionable and that the equalizing effect of this coil may, therefore, be utilized. It also assumes a condition where better results are obtained by having the equalizer face a 150-ohm impedance at the receiving end.

This arrangement is usually applied when equalized loops of considerable length are furnished by the telephone company and when no



EQUIPMENT ARRANGEMENTS
ON NON-LOADED EQUALIZED LOOPS

FIG. 1

special requirements are specified by the broadcaster. If it is desired to avoid the 4:1 impedance ratio coil at the transmitting end this should be so specified in the order placed with the telephone company. A suggested wording of orders for this arrangement is as follows:

> "Install loop equalized for use with 600-ohm transmitting equipment without four to one impedance ratio coil at transmitting point."

Fig. 1-D - For Use With 600-Ohm Transmitting Equipment

This arrangement differs from Fig. 1-C only in assuming an equalizer which affords the best results facing a 600-ohm termination.

Fig. 1-E - For Use With 600-Ohm Transmitting Equipment

Coils of 4:1 impedance ratio, used alone are quite generally used by the Telephone Company for equalizing very short loops where there are no other controlling factors, (see discussion and Table 1 on page 1). The impedance presented by the loop from the transmitting point, as in other cases utilizing a 4:1 impedance ratio transmitting coil, is increased, and this fact must be taken into consideration in the use of volume indicators on such loops.

Fig. 1-F - For Use With 150-Ohm Transmitting Equipment

The Telephone Company will normally equalize a loop for use with 600-ohm transmitting apparatus. Where it is planned to use 150-ohm transmitting apparatus and it is desired to have the loop arranged for this, therefore, the order placed with the Telephone Company should so specify. A suggested wording of orders for this arrangement is as follows:

> "Install loop equalized for use with 150-ohm transmitting equipment."

The arrangement at the transmitting point for this condition is shown including a 1:1 impedance ratio transmitting coil with the halves of both the primary and the secondary windings connected in parallel. This affords the preferable arrangement of this coil from the standpoint of its internal resistance and equalization should be adjusted with the coil connected in this manner, if it is left on the circuit.

PROVISION FOR 150-OHM RECEIVING EQUIPMENT

The arrangements shown in Fig. 1 assume use of 600-ohm receiving equipment for service. If 150-ohm receiving equipment is used, the drop windings of the receiving coils should be connected in parallel, instead of in series as shown.

> *Note:* If a 600-ohm transmission measuring set is used at the receiving end during equalization, the receiving coil connections should be as in Fig. 1 during equalization, but their drop winding should be paralleled when the 150-ohm service equipment is connected.

The proper methods of wiring Western Electric Company 111-C and 119-C coils for various conditions are shown in Table 2.

LOOP EQUALIZATION

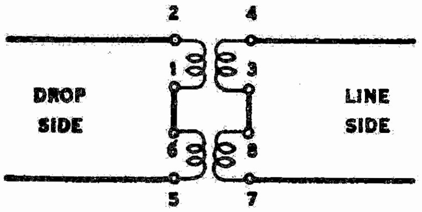
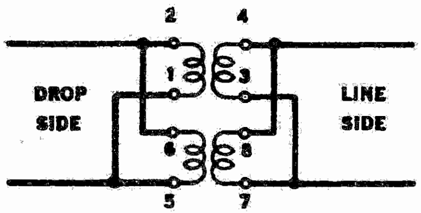
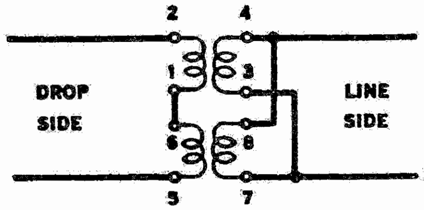
The operation of equalizing a non-loaded loop consists of modifying its electrical characteristics until its insertion loss; that is, the loss it causes when connected between the transmitting and receiving circuit impedances with which it is to be used, is essentially the same at all frequencies within the band to be transmitted. Insertion loss includes not only the attenuation loss of the conductors, coils, etc., but also such reflection and interaction losses as may be present due to junctions of dissimilar impedances at the terminals or other points. It is important, therefore, that testing methods employed in equalization work properly take into consideration the effects of impedance junctions between the testing equipment and the loop circuit.

Where equalization tests can be conducted through the actual amplifier and output pad which will be used in service, this is advantageous as far as reflection loss considerations are concerned. Use of an amplifier in this way for equalization, however, carries with it a complication in the matter of adjusting the levels of the testing frequencies. This can be appreciated from contemplation of the fact that the output circuit of an amplifier is essentially a voltage in series with an impedance. With a properly equalized circuit connected directly to a transmitting amplifier of the impedance for which equalization was provided, maintenance of the voltage (E) constant over a range of frequencies should result in reception of uniform levels at these frequencies by receiving equipment of the proper impedance at the far end of the loop.

Since the transmitting voltage (E) has to reach the loop terminals through the output impedance of the amplifier, and since the impedance of a non-loaded loop is higher at low frequencies than at high frequencies, the voltages measurable across the terminals of the loop under these conditions will not be uniform, but will be higher at the low frequencies than at high frequencies. Obviously, therefore,

TABLE 2

Terminal Connections and Impedance Data For Western Electric Company No. 111-C and No. 119-C Coils

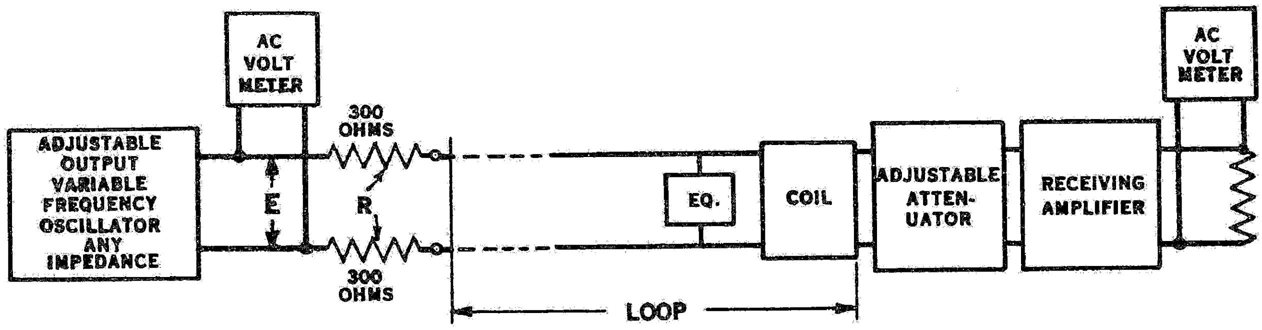
	111-C		*119-C*	
	Impedance Ratio	Nominal Impedances in Ohms	Impedance Ratio	Nominal Impedances in Ohms
	Drop Line	Drop Line	Drop Line	Drop Line
 A	1: 1	600: 600	1.15: 1	600*: 600*
 B	1: 1	150: 150	1.15: 1	150*: 150*
 C	4: 1	600: 150	4.6: 1	600*: 150*

**Note:* The No. 119-C coil was designed to make a 600-ohm termination look as nearly as practicable like 600-ohms when seen through the coil from its line side, instead of slightly higher due to the resistance of the coil, as is the case with a coil of exactly 1:1 impedance ratio. For most purposes, however, the No. 119-C coil may be used wherever the No. 111-C would serve.

adjustment of testing levels applied to the loop for equalization by maintaining a constant voltage across the output terminals of the transmitting amplifier, as indicated by a voltmeter or volume indicator at that point, would not be the equivalent of maintaining the voltage (E) constant and would result in an improperly equalized circuit; that is, one in which, under service conditions, low frequencies would be transmitted at higher levels than high frequencies. To avoid this, sufficient transmitting pad loss should be introduced between the amplifier and the loop, to make the voltage at the amplifier terminals practically independent of the loop impedance. Under this condition, substitution of a 600-ohm resistance for the loop at either the high or low extremities of the frequency range should leave the volume indicator reading virtually unchanged. This will usually require a total loss of 12 or 15 db.

Use, in the manner discussed, of the volume indicator built into many types of field amplifier would be subject to the objection mentioned if the output circuit contains only a small pad of ordinary type.

It should be borne in mind in this connection that the use of smaller amounts of pad loss during service conditions than during equalization does not involve the transmission frequency performance of the circuit but only the deviation of the volume indicator readings from the true values; i.e., what they would be with a pure 600-ohm resistance load.



Note: Coils to be used at either or both ends should be included as parts of the loop during equalization.

FIG. 2

If a convenient means were available for measuring the voltage (E) in an amplifier directly instead of through the output impedance, this would be useful for equalization purposes. A testing circuit which is the equivalent of such an arrangement, and others which produce the same results, are discussed in the following paragraphs, for use under field or plant conditions.

A generator which meets the foregoing requirements can be provided quite simply as shown in Fig. 2. The oscillator should be a variable frequency oscillator of low harmonic content and should have an adjustable output which will remain constant at any frequency. Constant output at different frequencies is not necessary, however. The meter may be a volume indicator or an a-c voltmeter which has a flat frequency characteristic over the desired band, or is one whose deviations with frequency have been determined, so that proper correction at each frequency can be made.

The oscillator is adjusted to maintain the same reading of the voltmeter for any testing frequency during equalization of a given circuit. This provides the required constant voltage (E). The two 300-ohm series resistances provide the required 600-ohm impedance which remains constant for any frequency or any load. (If equalization is required for use with 150-ohm transmitting equipment the series resistances should be 75 ohms in each side). The equalizer is adjusted until the same level (into a 600-ohm load) is obtained from the receiving amplifier at all frequencies.

> *Caution:* In this connection it must be borne in mind that an ordinary 600-ohm pad should not be substituted for the series resistances in this circuit as erroneous measurements would result. Maintenance of the voltage (E) constant produces effectively a zero impedance across the terminals of the voltmeter. A pad substituted for the series resistances would, therefore, behave effectively as if its input terminals were shorted instead of terminated by 600 ohms as would be necessary to make it present a 600-ohm impedance to the loop. A 600-ohm pad may, however, be used between the series resistances and the loop as it will then be properly terminated.

The arrangement shown in Fig. 3 makes use of a 600-ohm oscillator which may be equipped with a pad if necessary for securing uniformity of its output impedance over the testing range of frequencies. The oscillator and pad are first connected to the measuring set and the oscillator adjusted until an appropriate testing level, such as 1 milliwatt, is indicated by the measuring set, at the first testing frequency. Without making any change in the oscillator the loop is then connected in place of the measuring set, the level at the receiving end of the loop is noted and recorded. For each measurement at other testing frequencies, the oscillator is adjusted to show the same value on the measuring set at the transmitting end; that is, 1 milliwatt, before transferring the connection of the oscillator and pad to the loop circuit. The adjustment of the equalizer is altered until uniform levels are received at all frequencies.

Fig. 4 illustrates the use of a field pickup amplifier having a built-in volume indicator. Testing power in this case may be transmitted over a spare loop from an oscillator in the broadcasting plant since the portable amplifier affords a convenient means of adjusting testing levels. A portable oscillator may, however, be used at the field testing point.

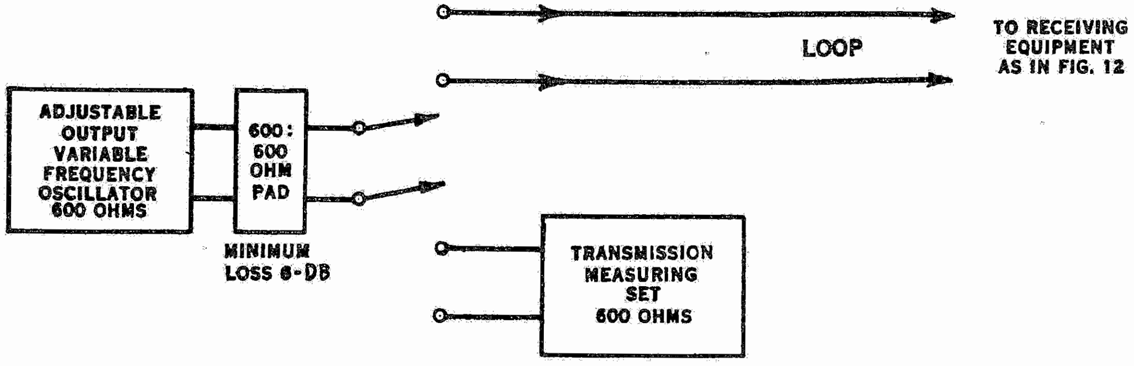


Fig. 3

A correct procedure in this case, where the test amplifier is of 600 ohms output impedance and where 600-ohm transmitting equipment is to be used in service is as follows at each testing frequency: a. Connect 600 ohms resistance (R) to the output terminals of the amplifier; b. Adjust the output to the desired testing level as shown by the volume indicator; c. Substitute the loop (with coil, if used) for resistance (R) without changing the output; d. Record level into 600 ohms at receiving point. Adjust equalization until levels under (d) are uniform.

An alternative method is to add 600 ohm pads between the amplifier and the loop to provide a total loss of 12 or 15 db. The amplifier output is then adjusted, with the loop and coil connected, to obtain uniform readings on the volume indicator at each frequency.

Equalizing For Use With Other Than 600-Ohm Transmitting Equipment

Where the test transmitting equipment used in Figs. 3 and 4 is of different impedance than the transmitting equipment to be used in service, a coil of proper impedance ratio should be so connected to the loop terminals during equalization as to compensate for this difference in impedance or incorrect equalization will result. If, for example, 600-ohm testing equipment is used, as shown in Figs. 3 and 4 and the service equipment is to be of 150 ohms output impedance, a 4:1 impedance ratio coil should be used with its low impedance side connected to the loop. The loop and coil are then substituted for the 600-ohm measuring set in Fig. 3 or for the 600-ohm resistance (R) in Fig. 4. After equalization the coil should be reconnected for 1:1 impedance ratio as shown in Fig. B, Table 2, if it is to be left on the circuit.

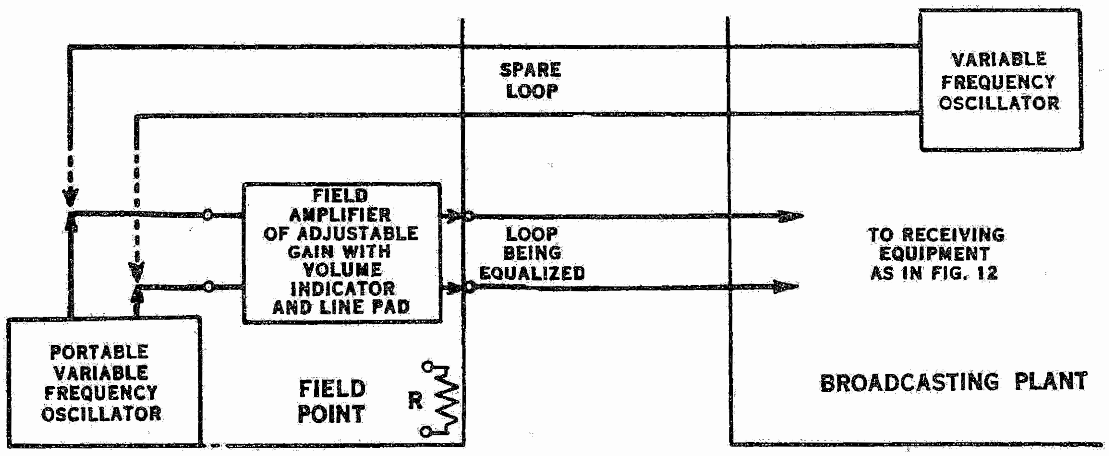


Fig. 4

and studio, or studio and network consist of either point-to-point radio or non-loaded cable conductors. In the latter case, the cable pairs are either similar to those normally used for telephone subscriber service, or, more frequently, special 16-gauge polyethylene string-insulated video pairs included in the exchange cable complement. Because of the high cable loss in the upper video frequencies, amplifiers and equalizers are required every few miles. The sound portion of the television program is carried by separate audio facilities similar to the regular program loops discussed in Part 4A.

The question of input and output levels in video loops is currently being reviewed. Under present operating practice, however, video channels are generally designed to provide 0 db loss for a 2-volt ± 25% signal.* The repeating coils used in the establishment of local video channels introduce low frequency distortion in the video signal. This distortion may be removed by means of a device known as a clamper, placed at the output of the video channel, which restores the essential low frequency components. The signal is delivered by the broadcaster without pre-emphasis from a 75-ohm unbalanced line or from a 110-ohm balanced circuit. The 110-ohm balanced input is suitable for connection directly to the nominal 110-ohm balanced cable conductors while the 75-ohm unbalanced input must be converted to a balanced 110-ohm impedance by means of a repeating coil to prevent reflections and to minimize the effect of any longitudinal noise voltages which may be present.

EQUALIZATION OF VIDEO CABLE LOOP

As noted in reference to audio frequency facilities, equalizing a loop consists of modifying the electrical characteristics until the insertion loss (the additional loss caused when it is inserted between normal transmitting and receiving circuit impedances) is essentially the same at all frequencies in the transmitted band. This insertion loss includes not only the attenuation loss of the conductors, coils, etc., but also the reflection and interaction losses which may be present due to junctions of dissimilar impedance at the terminals or other points.

With the present video transmission systems for cable facilities, the equalizer equipment is associated with the amplifiers. These may consist of amplifier input or output networks in conjunction with other basic equalizers located between sections of the amplifier, or may include fixed equalizers not associated with input or output networks and located within the amplifiers. In addition, a variable equalizer is also provided which permits independent adjustment in relatively small steps of the "slope" "bulge" characteristics. In some cases, mop-up or special equalizers may also be included. Flat gain adjustments can, of course, also be made at the amplifier points. Phase equalization within the transmitted band is automatically introduced by the attenuation equalizers. Residual phase distortion near the upper frequency limit is reduced by means of phase equalizers inserted at amplifier points.

The method of measuring the insertion loss of the video circuit is essentially the same as that discussed in Part 4A in reference to equalization of audio loops, with the exception, of course, that different line impedances are involved. To produce the equivalent of a one volt peak-to-peak testing level, a signal generator is required having an output impedance equal to the nominal line impedance and delivering a one volt peak-to peak signal when terminated in this nominal impedance. Under these circumstances the actual voltage across the line terminals will vary with frequency depending on changes in line impedance, and will be one volt peak-to-peak only when the line impedance is equal to the nominal value. If a signal generator such as illustrated in Figure 2 of Part 4A is used, the constant driving voltage should be adjusted to two volts peak-to-peak since when impedances are matched, one-half the driving voltage will be developed across the internal impedance of the generator and the other across the line terminals.

EQUALIZATION OF RADIO CIRCUITS

Equalization of loops consisting of point-to-point radio channels is not usually required in the field since the terminal apparatus is designed to exhibit a flat attenuation-frequency characteristic and is capable of delivering a 2-volt peak-to-peak signal with 0 db loss.

TESTING FREQUENCIES

Preliminary adjustment of the slope and bulge equalizers is made at 10 kc, 1-megacycle and 3.8-megacycles. The difference between 10 kc and 3.8-megacycle loss is representative of the line slope characteristics whereas, with the slope equalizer inserted, the difference between 1-megacycle and 3.8-megacycle loss is adjusted to zero by means of the variable bulge equalizer. Having thus obtained a tentative equalizer setting, an adjustment of equalization is made at additional frequencies throughout the transmitted frequency band. The testing frequencies suggested for preliminary adjustments and for over-all equalization are listed as follows:

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*Peak-to-peak measurement.

Suggested Testing Frequencies - Video Loops

Preliminary Check	*Over-all Equalization Measurements*
	60 cycles
	5 kilocycles
10 kilocycles	10 "
	25 "
	50 "
	75 "
	100 "
	150 "
	200 "
	250 "
	300 "
	400 "
	500 "
	600 "
1 megacycle	800 and at 200 kc intervals between 1.0 and 4.6 megacycles
3.8 megacycles	

EQUALIZATION TESTING LEVELS

The input level customarily used in equalizing a video loop is a signal of 1-volt peak-to-peak (zero dbv). Although somewhat higher levels can probably be tolerated, this reference has been found convenient and various signal generators and detectors have been calibrated to read in db above or below 1-volt peak-to-peak, based on a nominal circuit impedance of either 75 ohms, or 110 ohms. *The testing levels employed in line-up and equalization should not be confused with the voltages which are impressed by the broadcaster during transmission of a video signal.*

As noted previously, a device known as a clamper is sometimes used to reduce the effects of excess loss in the low frequencies. It should be noted in this connection that an attenuation-frequency run made with a sine wave signal generator will *not* show the effect of the clamper at the low frequencies for a video signal even though the clamper is operating in the circuit at the time of the tests. This results from the fact that the effect of the clamper on the very low frequencies is based upon the presence at all times of a large component of video line frequency at 15.75 kc.

PART 5 - THE STANDARD VOLUME INDICATOR

GENERAL CHARACTERISTICS

The standard volume indicator now in general use in the communication industry, including the major broadcasters and the Bell Telephone System, is one having characteristics as prescribed in American Recommended Practice for Volume Measurement of Electrical Speech and Program Waves - ASA C16.5-1942."*

The volume indicator is calibrated to read volumes in terms of vu (defined below) and is designed to be bridged across a 600-ohm circuit. The essential characteristics of the instrument are as follows:

1. It employs a full wave, copper oxide rectifier contained within the instrument case.

2. The dynamic characteristic is such that the sudden application of a single frequency volume of such value as to give a steady state reading of 100 (0 vu mark) will cause the pointer to overswing by 1 to 1-1/2 per cent (0.1 to 0.15 vu). The pointer speed is such that under the same conditions, a deflection of 99 per cent of the steady state value is reached 0.3 second after the sudden application of the single frequency voltage. (This characteristic is consistent with C.C.I.F. recommendations).

3. The scale card is a cream yellow and has markings in black and red. The scale markings indicate per cent voltage (0 to 100) and vu (-20 to +3).

4. The instrument sensitivity does not depart more than 0.2 db from its value at 1000 cps over the frequency range from 35 to 10,000 cps nor more than 0.5 db over the range from 25 to 16,000 cps.

5. The instrument is capable of withstanding without injury or effect on calibration, voltage peaks of ten times the voltage equivalent to a reading of 100, (zero vu mark) for at least 0.5 second, and a continuous overload of five times that voltage.

STANDARD REFERENCE VOLUME

Standard reference volume level (zero vu) shall be defined by specifying (a) the characteristics and method of use of the volume indicator instrument, and (b) a steady state reference of 1 milliwatt. The impedance of the circuit across which the instrument is calibrated shall be 600 ohms. The characteristics of the instrument as well as the value of the calibrating power are important features of the definition.

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* The standard volume indicator and the subject of volume measurements is treated comprehensively in a paper "A New Standard Volume Indicator and Reference Level" by H. A. Chinn, D. K. Gannett and R. M. Morris - Proceedings of IRE January 1940.

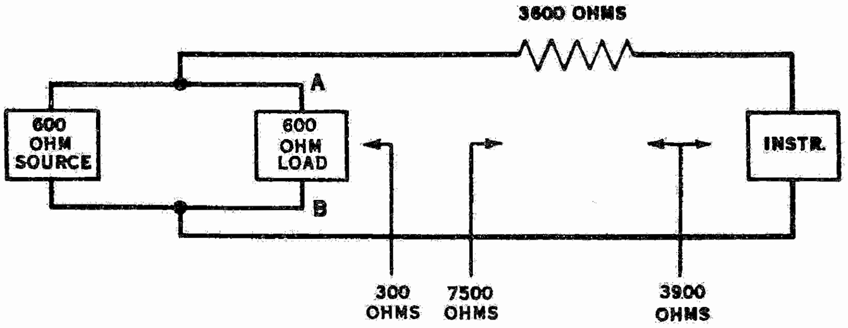


FIG. 1

In order to avoid the more cumbersome term "db above (or below) reference volume level" and confusion with several earlier standards, the readings of the standard volume indicator are designated as so many "vu" numerically equal to the number of db above (or below) the reference volume level. Volumes above and below reference are designated + and -, respectively. It should be borne in mind that volume expressed in "vu" *implies a measurement made with the standard instrument. Most previous types of volume indicators, even when recalibrated to a 1 milliwatt basis will not give indications on all types of program material corresponding to those of the new instrument.*

THE CIRCUIT OF THE STANDARD VOLUME INDICATOR

In order to calibrate and use the volume indicator intelligently it is necessary to understand clearly certain basic details of its design.

The dynamic characteristic of the standard volume indicator is fully as important and fundamental as any other feature in its design. In order to maintain the proper dynamic characteristic it is necessary that the instrument, with its internal impedance of 3900 ohms, always be used in such a manner as to face 3900 ohms. The arrangement of the volume indicator in its simplest form, therefore, is as shown in Fig. 1.

As can be seen in this figure, the instrument faces 3900 ohms (3600 ohms in series with 300 ohms). The complete volume indicator, therefore, presents a shunt impedance of 7500 ohms to the circuit across which it is bridged.

Under this condition a voltage of 1.228 volts rms, sine wave, applied across the load circuit terminals A and B should cause the pointer of the instrument to deflect to the 100 mark and will indicate that +4 vu (or 4 db above 1 milliwatt) is being dissipated in the load. This is the most sensitive arrangement of the standard volume indicator as it is available today.

In practice it will generally be necessary to read volume levels higher than +4 vu. This is made possible by inserting between the 3600 ohm resistance and the instrument a calibrated attenuator. A T-type attenuator of 3900:3900 ohms impedance is employed for this purpose in order to avoid changing the impedance relationships which would alter the dynamic characteristic of the volume indicator. The arrangement with the attenuator is shown in Fig. 2.

The variable attenuator in its "+4 vu" position or setting has zero insertion loss. Consequently, with this setting the instrument will still indicate 100 with an applied voltage of 1.228 volts rms, sine wave. Higher volume levels are read by adjustment of the attenuator to insert corresponding amounts of loss. The upper range of the volume indicator may be extended to any useful limit by suitable design of the attenuator.

CALIBRATION OF THE STANDARD VOLUME INDICATOR

None of the circuit arrangements described has taken into consideration any means for correcting the indications of a volume indicator or for bringing two or more instruments into alignment. Methods of accomplishing this are shown in the following Fig. 3, 4, and 5.

Referring to Fig. 3, a variable calibrating resistor R-2 of approximately 1000 ohms is used in conjunction with the attenuator. One-half of this value is removed from the 3600-ohm resistance R-1 shown in the previous arrangements. The result is a means of calibrating the volume indicator without materially altering the shunt impedance of the circuit or the dynamic characteristic of the instrument as it still faces approximately 3900 ohms. Many commercial types of attenuators now available for use with the new standard volume indicator have resistor R-1 built into the series arm of the attenuator for simplicity in wiring connections.

The first step in calibration is to make sure the instrument pointer stands on 0 of the 0-100 scale when no voltage is applied. If not, it should be brought to 0 by means of the me-

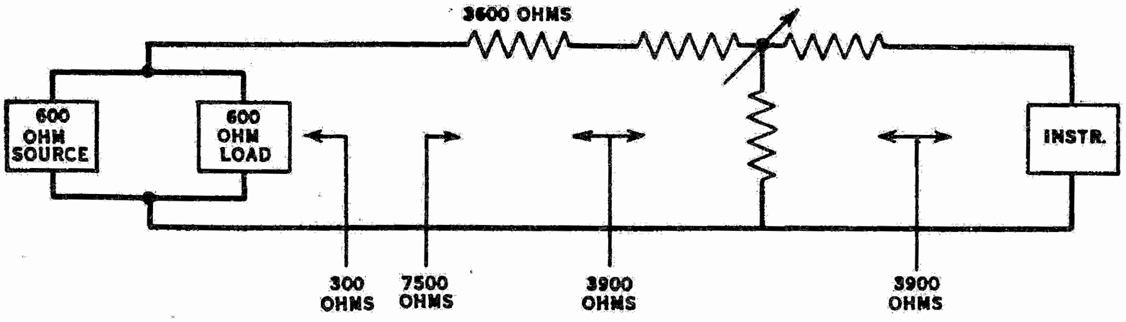


FIG. 2

chanical pointer adjustment on the front of the instrument. The next step varies slightly, depending upon the way in which the volume indicator is to be used, as set forth in the following paragraphs.

Method No. 1

This method is used in those cases where the volume indicator is permanently connected across and provides compensation for the bridging loss of the instrument. With the attenuator A in Fig. 3 set on step +4 vu (zero insertion loss) and a voltage of 1.228 volts rms, sine wave, applied to the load terminals, the calibrating resistor R-2 is varied until the pointer is deflected to the 100 mark. The volume indicator is then calibrated for use bridged across the 600-ohm load into which the measured volume is being transmitted.

Method No. 2

For routine checking of the calibration of volume indicators a "reference" instrument properly calibrated may be used in a simple comparison method as shown in Fig. 4.

An oscillator or other source of a-c voltage of adjustable output is required. To the terminals of this source the reference volume indicator and the volume indicator to be calibrated are connected in parallel. The attenuators of both volume indicators should be set on +4 vu. The applied voltage should be adjusted until the reference volume indicator pointed is at the 100 mark. If the pointer of the volume indicator being checked is not then on the 100 mark, its calibrating resistor should be adjusted until it reads the same as the reference volume indicator. It is then calibrated for the same method of use as the reference volume indicator.

Some volume indicators are equipped with a "1 mw." step - which effectively taps off a portion of the 3600-ohm series resistance. If bridged across a 600-ohm resistance in which one milliwatt of single frequency power is being dissipated with the attenuator set on this step, the instrument should show a deflection of 100. Since this arrangement alters the impedance which the instrument faces and hence its dynamic characteristics, it *must not* be used to indicate program volume. Furthermore, since the scale is also altered the markings will not be accurate except at the 100 mark.

Method No. 3

This method of calibrating, shown in Fig. 5 is applied when the volume indicator is to be

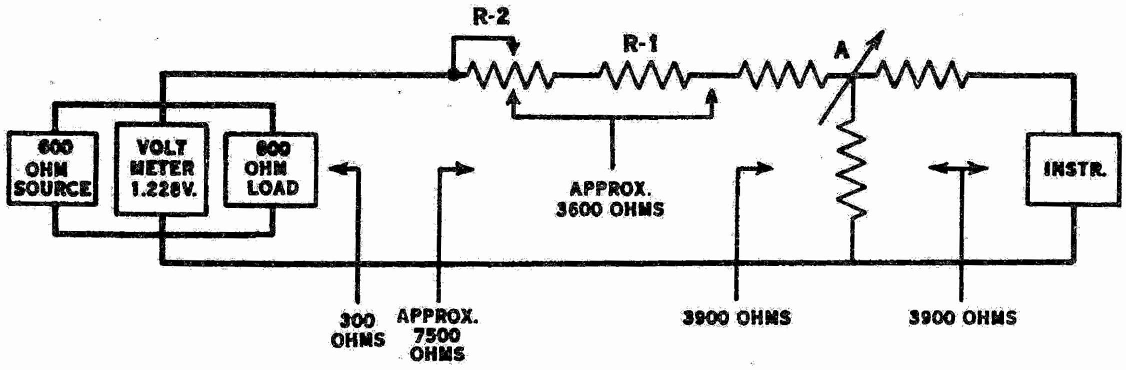


FIG. 3

used in such a manner that its bridging loss does not affect the circuit being fed, as for example, when it is to be energized by a separate amplifier terminated in 600 ohms. Both the source and the measuring circuit used in this method must be of 600 ohms impedance.

The source is adjusted until the measuring apparatus indicates 4 db above 1 milliwatt with the volume indicator not connected. The volume indicator is then connected to the circuit. Without making any change in the generator setting, adjust the resistor R-2 in the volume indicator circuit until the meter deflection is 100 divisions with sensitivity (attenuator) set for +4 vu. The measuring set should read about 0.3 db lower with the volume indicator connected.

METHODS OF CONNECTING VOLUME INDICATORS

In the methods of use of volume indicators outlined in this Section, the gain of an amplifier is considered as that determined by one of the following methods:

a. Voltage gain in db $= 20 \log_{10} \dfrac{\text{Voltage measured across the output terminated in 600 ohms (or other load impedance to be connected)}}{\text{Voltage measured across the input}}$

Voltage gain determined by this method may properly be used as the gain of any amplifier in the cases to be discussed.

b. The gains of amplifiers whose output and input impedances are both 600 ohms, and which are used between those impedances, can be measured correctly with 600-ohm transmission measuring equipment.

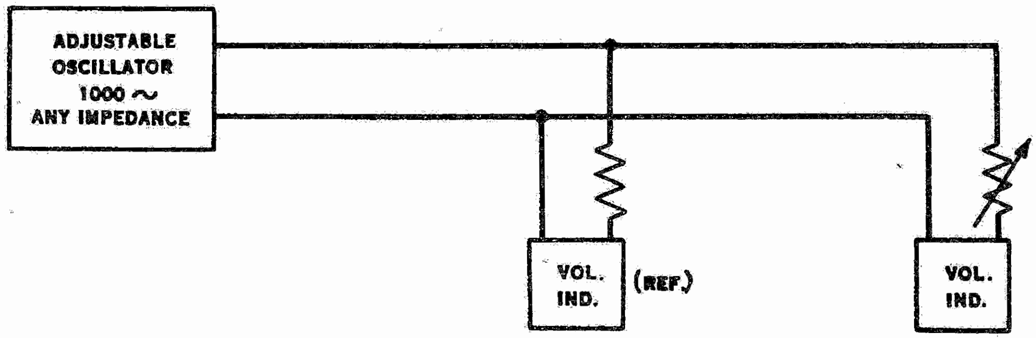


FIG. 4

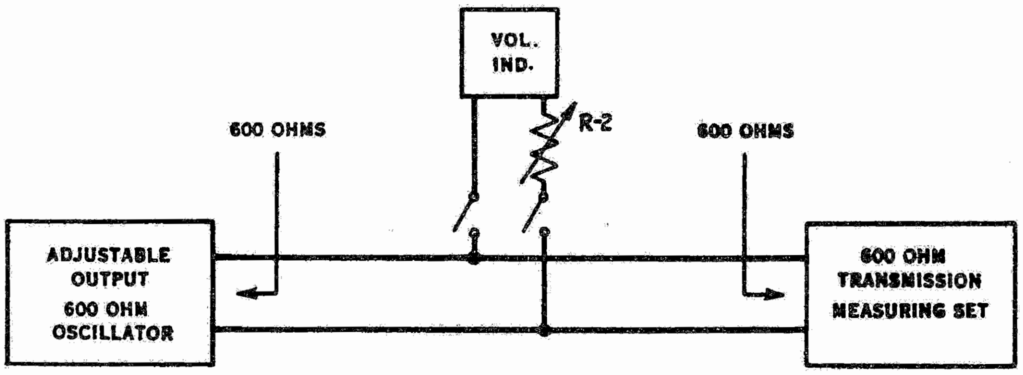


FIG. 5

Following are two variations of a method of use of the volume indicator in which it is connected permanently across the circuit or loop on which the volume is to be measured. It should, therefore, be calibrated by Method 1 or Method 2 under "CALIBRATION."

Method 1-A (Fig. 6)

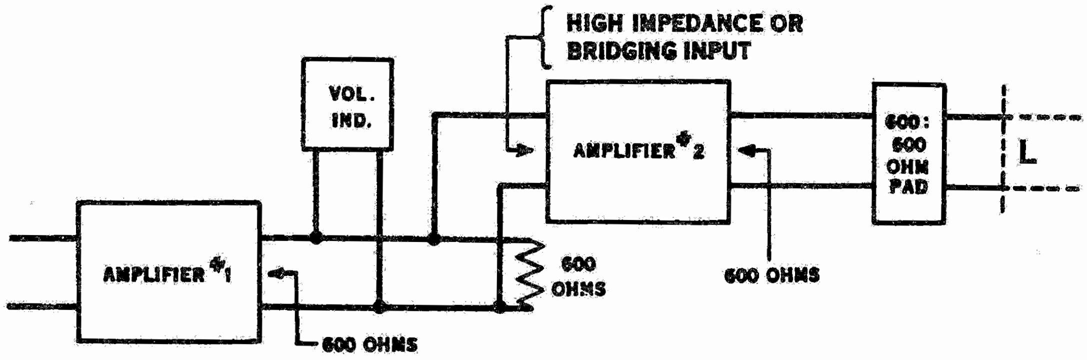


FIG. 6

The indication of the volume indicator plus the gain of Amplifier #2, minus the loss of the pad, is considered the volume at Point L.

Method 1-B (Fig. 7)

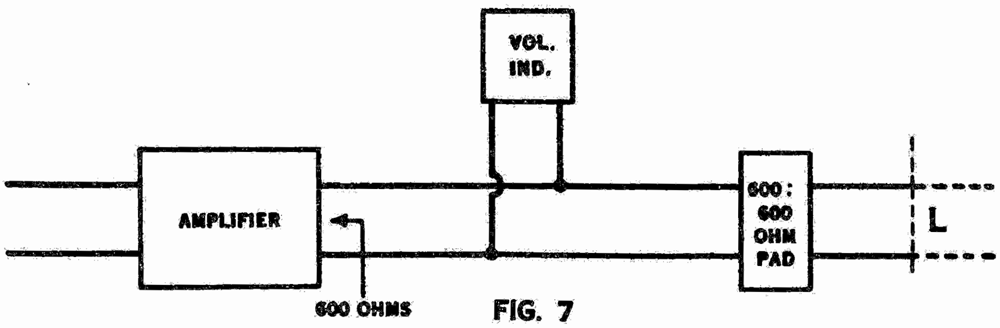


FIG. 7

The volume indicator reading, minus the loss of the pad, is considered the volume at Point L.

Note: In some cases the impedance of the loop or circuit may differ from 600 ohms by such an amount as to require a correction to the actual volume indicator reading. This correction may be determined as given under the heading "CORRECTION OF VOLUME INDICATOR READINGS".

Following are three variations of a method of use of the volume indicator in which it should be calibrated by Method 3 under "CALIBRATION".

Method 2-A

This method, shown in Fig. 8, is used by the telephone company at many network branching points where it is necessary to feed a number of circuits simultaneously. The resistance bridge has constant loss and impedance for all branches. Amplifier gains either are identical or differ by calculated amounts, depending upon the types of circuit being fed. The volume indicator is connected to one of the branches through its own amplifier. It does not, therefore, affect the power transmitted to the various branches.

With equal pad values and with amplifiers #1 and #2 set for identical gains, the indication of the volume indicator is considered the volume at Point L.

Method 2-B

The volume indicator in the arrangement shown in Fig. 9 does not take any power from the main circuit.

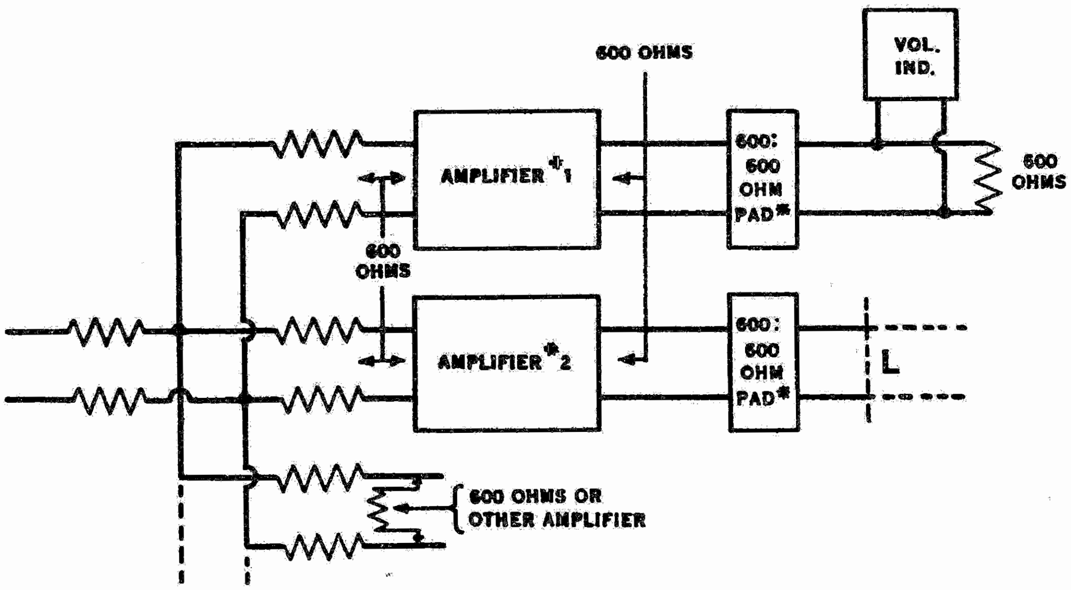


FIG. 8

The volume indicator reading minus the gain of amplifier No. 2, less the loss of the pad, gives the volume at Point L. (See Note under Method 1-B).

Method 2-C

Fig. 10 shows two ways of connecting volume indicators by means of bridge circuits.

The volume indicator reading, without any correction, is considered as being the volume at Point L. The loss introduced between the amplifier and Point L in either case is about 6db. The balance obtainable with an amplifier of 600 ohms nominal output impedance should be sufficient practically to eliminate any effect of the loop impedance upon the volume indicator readings. The entire wiring of the unbalanced circuit A should be shielded.

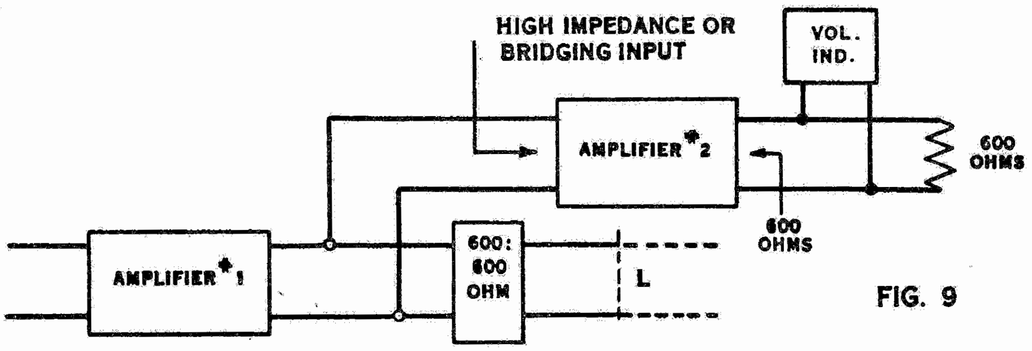


FIG. 9

* Pads may be omitted where not required for impedance reasons.

TRANSMITTING PADS

The action of a volume indicator on average program material is influenced mainly by the voltages developed at the point where it is connected, at the frequencies below 1000 cycles. The impedance presented by a loop below 1000 cycles, therefore, is of most importance in its influence on the readings, and, consequently, on the amount of isolation needed between the volume indicator and the loop for correct readings. For the usual loop of non-loaded cable this impedance varies with frequency, the range of variation depending upon the length, the gauge of the conductors, the equalizing arrangement applied (see Part 4 - "Program Loop Transmission"), and, if a transmitting coil be used, upon the ratio of this coil. If this be a 1:1 impedance ratio coil or if the coil be omitted

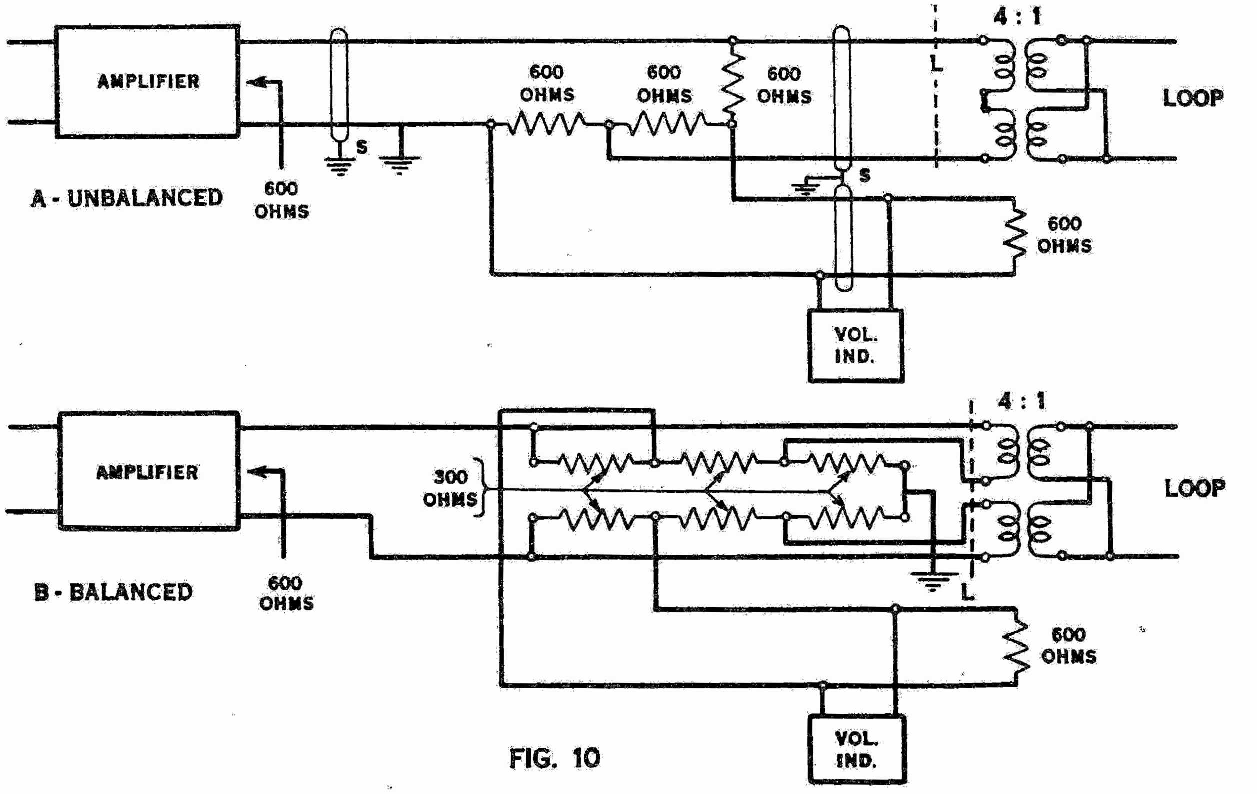


FIG. 10

altogether, a 6 db pad will normally be sufficient to make the readings of the volume indicator on average program material agree within two or three-tenths of a db with what they would be if the volume indicator faced a pure 600-ohm resistance in the direction of the loop. If, however, a 4:1 impedance ratio coil be used at the transmitting point, as is done in certain equalizing arrangements, the impedance faced by the volume indicator will be much higher than with a 1:1 impedance ratio coil and the deviations, even with a 6 db pad may be a db or more. Use of larger pads will reduce these deviations as shown in the APPENDIX, but this will increase the output requirements on the amplifier and alternative arrangements, as discussed subsequently, should be considered.

Most amplifiers now in use in broadcasting plants for transmitting into loops have adequate output capacity to permit use of 6 db isolation pads and still apply a +8 vu level to the loop without objectionable distortion.

MINIMUM VALUE OF TRANSMITTING PAD

Taking all of the foregoing factors into consideration, 6 db should be the minimum isolating value for a transmitting pad where transmitting coils of 1:1 impedance ratio are used, or where coils are omitted entirely.

SPECIAL ISOLATING MEASURES

Where transmitting coils of 4:1 impedance ratio are used, other measures will be required for obtaining a correct indication of the volume being transmitted to the loop. Among these may be mentioned -

(a) The use of pads larger than 6 db where practicable;

(b) The application of specially designed impedance adjusting pads;

(c) The use of pads which provide isolation between two branches of a circuit by application of the Wheatstone bridge principle, or

(d) The connection of the volume indicator to a paralleling branch of the circuit having a separate amplifier, as is shown in Fig. 8. This arrangement is one used quite generally by the telephone company in its offices.

Output circuits utilizing the Wheatstone bridge principle may be designed in various forms, both balanced and unbalanced, and with various amounts of loss.

An example of a balanced type output circuit is shown by Fig. 10B. The circuit in this case incorporates a 4:1 impedance ratio coil connected to the loop. The loss of this circuit is about 6 db and the isolation of the volume indicator will, as in the previous example, depend upon the match between the amplifier impedance and 600 ohms but will normally be several times the amount of loss introduced into the circuit by this arrangement.

CORRECTION OF VOLUME INDICATOR READINGS

Under "TRANSMITTING PADS," various measures are considered for reducing the influence of nonuniform loop impedance on the accuracy of volume indicator readings. Application of some of the arrangements discussed, particularly in the cases of Figs. 7 and 9, may still leave a residual error, of which it will be desired to dispose. The amount of this error can be determined by comparing the reading on a steady tone of 400 or 500 cycles, having the loop connected in the normal operating condition, with the reading obtained with a 600-ohm resistance substituted for the loop.

In this test the transmitting coil, if used, forms part of the loop, and should be disconnected with the loop when the 600 ohms is substituted. Tones of the frequencies mentioned may safely be transmitted at normal operating volumes without danger of interference with neighboring circuits, and their effect on volume indicators compares closely with that of average program material, for a test of this kind.

Where the difference between the two readings obtained in this test is not more than 0.3 db, it will usually be satisfactory to care for this by adjustment of the slide wire resistor in the volume indicator circuit. The procedure in this case is as follows: Make sure the volume indicator has been properly calibrated for use as in Fig. 7. Connect the 600-ohm resistance in place of the loop (and coil) and adjust the testing tone until the volume indicator shows the volume level to be transmitted (e.g. +14 vu with a 6 db pad). Disconnect the 600-ohm resistance and reconnect the loop (and coil). Adjust the slide wire until the volume indicator again reads +14 vu.

If the correction is found to be larger than 0.3 db, compensation by this method might disturb the dynamic characteristic of the volume indicator to an undesirable degree and other measures for reduction of the deviation, as discussed under "TRANSMITTING PADS" should be considered.

If a deviation of any appreciable magnitude is not to be corrected physically, the corrections should be applied algebraically in checking measurements with other points.

In the case of the method of use shown in Fig. 9, the correction may be determined by the same procedure as just described for Fig. 7. In this case, however, the gain of amplifier No. 2 is adjusted to obtain the desired compensation.

In the arrangements shown in Figs. 6, 8, and 10, no deviations due to the effect of loop impedance will be involved.

VOLUME INDICATOR SCALE FOR PEAK CHECKING

Peak checking between the telephone company and the broadcasters will normally be done by reference to the 0-100 scale on the volume indicator.

The broadcasters prefer the use of the 0-100 scale because it is applicable to direct indication of the per cent modulation of the radio transmitter, or the per cent utilization of the facilities involved.

Differences in volume should, preferably, be discussed in terms of db. The justification for this lies in the relationship to the need for changing amplifier gains or pad values which are designated in terms of db. The use of the term vu in this connection is permissible, although incorrect.

APPENDIX

EFFECT OF TRANSMITTING PAD LOSS ON VOLUME INDICATOR READINGS

A test was made for the purpose of demonstrating the relative effectiveness of different amounts of loss in a transmitting pad, in reducing the deviations of volume indicator readings when connected across a loop, from the readings when connected across a 600-ohm resistance, which is the reference load condition for the standard volume indicator.

The loop used consisted of about five miles of 19 gauge nonloaded cable conductors. The coil and equalizer arrangements were as shown in Part 4, Figs. 1, A, B, C, and D.

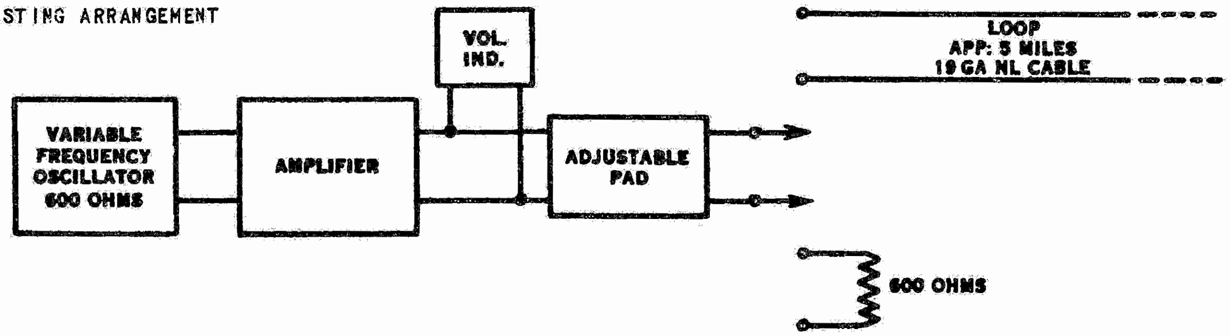
The Western Electric 23-A equalizer used was readjusted for each condition to obtain optimum equalization.

The coils were Western Electric Company No. 111-C.

TESTING PROCEDURE

1. With 0 db loss in the adjustable pad the output was connected to a 600 ohm resistance. The oscillator was adjusted until the volume indicator read +8 vu.
2. Without changing the oscillator the output was transferred to the loop (with coil, when used).
3. The volume indicator readings were recorded for the following amounts of loss in the adjustable pad: 0 db, 6 db, 10 db.
4. Steps 1, 2, and 3 were repeated at each testing frequency.

TESTING ARRANGEMENT



5. Steps 1, 2, 3, and 4 were repeated for each of four conditions of the loop equipment shown as A, B, C, and D, in Figure 1 (Part 4), except that receiving coil was omitted entirely in B and D.

RESULTS

The results of these tests are shown by the four accompanying sets of curves. Deviations identified by (+) indicate that the readings were higher for the loop than for the 600-ohm termination. It can be seen that the deviation can be reduced to a small amount (about .3 db) by use of a 6 db transmitting pad, if no coil (or a 1:1 impedance ratio coil) be used at the transmitting point, but that where a 4:1 impedance ratio transmitting coil is used a pad of at least 10 db will be required to obtain a comparable reduction.

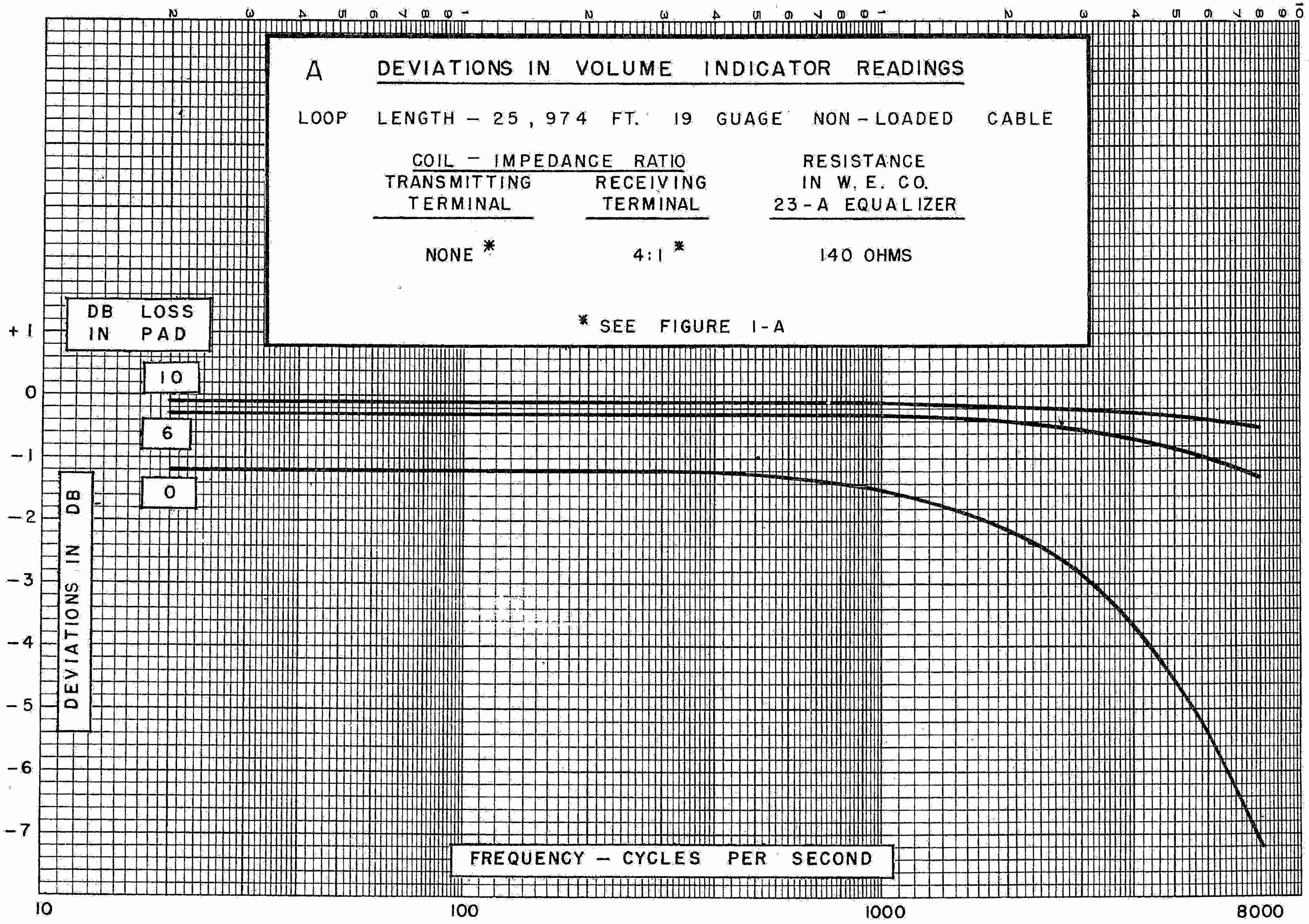
Note: The data obtained from these tests apply strictly to the specific loop tested. Loops of other makeups would show the same tendencies but the magnitudes of the effects might be different. For example, a loop of considerable length containing smaller than 19 gauge conductors would normally produce volume indicator readings greater than the 600-ohm termination, even with the transmitting coil omitted.

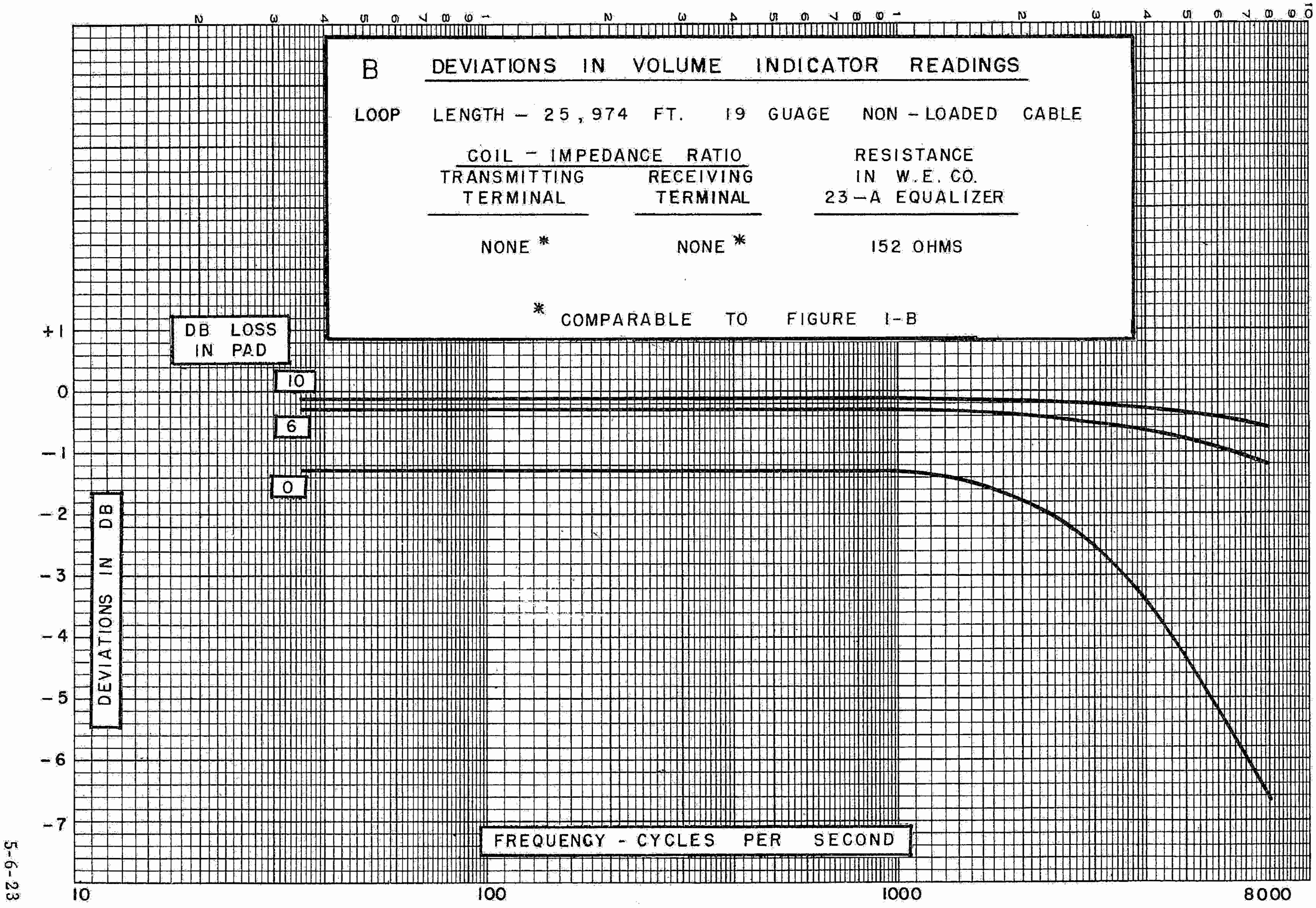
A DEVIATIONS IN VOLUME INDICATOR READINGS

LOOP LENGTH – 25,974 FT. 19 GUAGE NON-LOADED CABLE

COIL – IMPEDANCE RATIO		RESISTANCE IN W. E. CO. 23-A EQUALIZER
TRANSMITTING TERMINAL	RECEIVING TERMINAL	
NONE *	4:1 *	140 OHMS

* SEE FIGURE 1-A



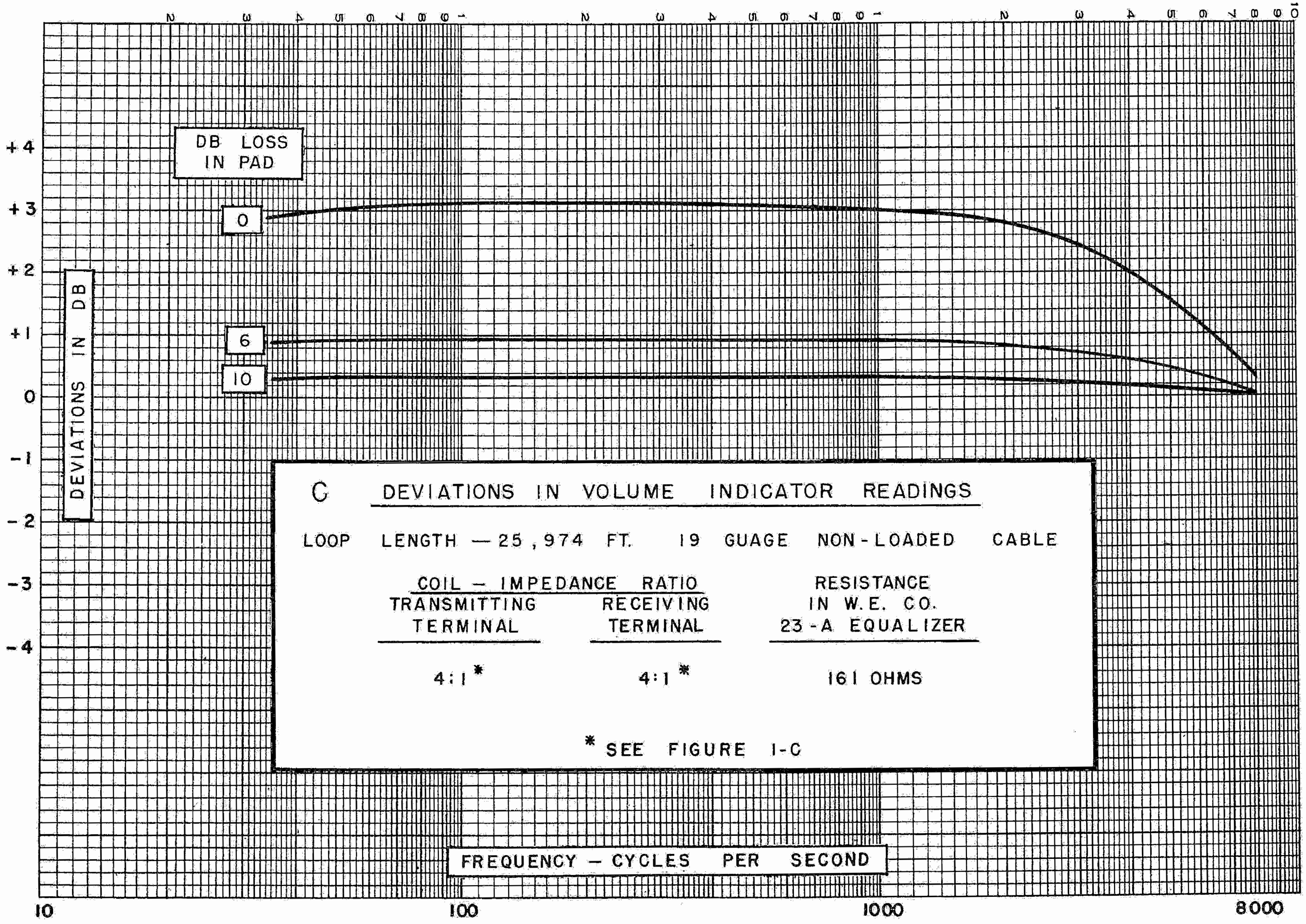


B DEVIATIONS IN VOLUME INDICATOR READINGS

LOOP LENGTH – 25,974 FT. 19 GUAGE NON-LOADED CABLE

COIL – IMPEDANCE RATIO TRANSMITTING TERMINAL	COIL – IMPEDANCE RATIO RECEIVING TERMINAL	RESISTANCE IN W.E. CO. 23–A EQUALIZER
NONE *	NONE *	152 OHMS

* COMPARABLE TO FIGURE 1–B

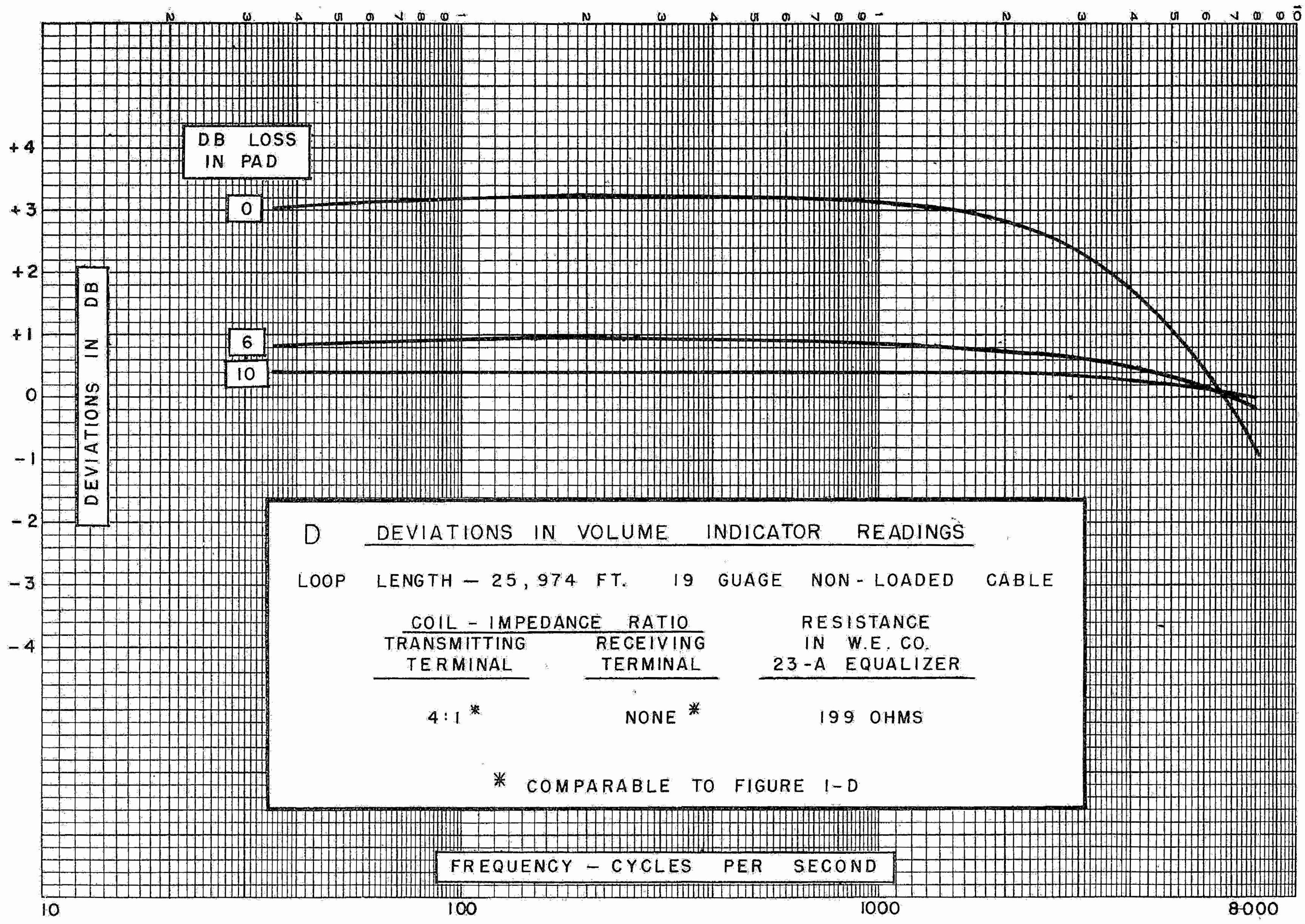


C DEVIATIONS IN VOLUME INDICATOR READINGS

LOOP LENGTH — 25,974 FT. 19 GUAGE NON-LOADED CABLE

COIL — IMPEDANCE RATIO TRANSMITTING TERMINAL	RECEIVING TERMINAL	RESISTANCE IN W.E. CO. 23-A EQUALIZER
4:1 *	4:1 *	161 OHMS

* SEE FIGURE I-C



D DEVIATIONS IN VOLUME INDICATOR READINGS

LOOP LENGTH — 25,974 FT. 19 GUAGE NON-LOADED CABLE

COIL - IMPEDANCE RATIO TRANSMITTING TERMINAL	COIL - IMPEDANCE RATIO RECEIVING TERMINAL	RESISTANCE IN W.E. CO. 23-A EQUALIZER
4:1 *	NONE *	199 OHMS

* COMPARABLE TO FIGURE 1-D

PART 6 - NETWORK OPERATION - AUDIO CHANNELS

PERFORMANCE CONSIDERATIONS

The interexchange audio program networks utilized in providing program transmission service are designed to afford the transmission performance necessary for the grade of service involved. If the expected results are to be obtained and detrimental reaction on or from other communication services is to be avoided, however, certain technical requirements must be observed in their use. This necessitates that all concerned have adequate information covering these requirements. The more general considerations relating to the operation of local program channels are covered in PART 5 of this Handbook. There remain some additional aspects of program channel operating, however, which apply specifically to interexchange networks. These are discussed in some detail in the following paragraphs.

The flexibility in application of the services available to the users may lead to unsatisfactory results in some cases if attempts are made to utilize the services beyond the limits of their capabilities. The probability of actual trouble from this, in the case of high quality services, is relatively slight since the influence of all factors limiting circuit performance has been greatly reduced in their design and since these services are given close supervision by the telephone company. In the case of medium quality service, however, such close supervision is not provided and, as the performance capabilities of the circuits are considerably less, and vary considerably with distance, they are much more susceptible to the ill effects of improper demands upon them.

VOLUME CONSIDERATIONS

Proper results from any broadcasting system are dependent upon having proper volume levels at every point in the system from pick-up to transmitter output, including intervening network connections. Insufficient volume results in more noise being heard with the program and excessive volume tends to increase distortion generally or produce overloading on the volume peaks.

Different parts of the system such as amplifiers, local channels, line circuits, etc., are designed to operate at different volume levels, depending on their functions, their positions in the circuit, or upon limitations due to interference considerations. For example, at amplifier points on open wire circuits the volumes are allowed to reach maximums of +14 vu. On long distance-type cable circuits comparable maximum volumes are +4 vu or +8 vu depending on the type of service involved.

It becomes readily apparent that an overall system comprising many component parts connected in series should be so "lined up" (the losses and gains so adjusted) that the proper maximum volume applied at the originating point will produce the proper maximum volume at all other points, such as amplifier outputs, in receiving local channels, etc.

The technique of controlling volume at originating points is based on one fairly obvious general principle, namely, keeping the average volume as high as possible without having to reduce too many volume peaks and thereby sacrifice desired volume range.

Program volume is controlled by attention, primarily, to the maximum levels. Consistent with this, engineering and operating practices applied to program networks by the telephone company are prepared with the assumption that maximum program volumes will be kept up to the proper level at the pick-up points, normally +8 vu, (except in a few special cases) into the transmitting local channel. Responsibility for the actual volume conditions throughout the system, including the networks, thus attaches itself to the control operator at the program source. No satisfactory substitute for this situation has been found, as attempts to compensate, at other points, for improper control at the originating point has been found by experience to lead to serious confusion and sometimes to upset the coordinated operation of the system.

A general principle can be evolved from this, which is to correct volume irregularities wherever they occur, only at their sources and not by compensating adjustments at circuit terminals. This requires locating the source of the irregularity by comparisons of volume peaks at successive points along a route toward the originating point. Obviously, efficient communication circuits between offices along the routes are necessary to permit doing this properly.

The considerations relating to the control of the volume at points on a network also apply to the amplifiers and other equipment at the broadcasters' premises at points where program material is received from one network and switched or retransmitted on to other networks. This and other factors involved in retransmission of programs are discussed later.

OPERATION OF MEDIUM QUALITY PROGRAM FACILITIES

As mentioned in PART 3 of this Handbook, medium quality program channels are available which are capable of transmitting a frequency band somewhat narrower than the 5 or 8 kc facilities. For this type of service, the facilities are usually of the type designed primarily for long distance telephone service but with their normal amplifier equipment adjusted to permit passing a somewhat wider band than for message purposes and to transmit at levels which will take full advantage of the controlled volume of the program material.

An important difference between medium quality and high quality transmission is that medium quality transmission deteriorates rapidly with distance, while high quality transmission suffers relatively little from circuit length. This is due to the fact that the medium quality circuits lack design and operating refinements present in the high quality networks for reducing objectionable effects which are cumulative with distance.

NON-AMPLIFIED MEDIUM QUALITY CIRCUITS

In a relatively few instances it may be found possible, temporarily, to provide short circuits for medium quality program service without line amplifiers at intermediate telephone offices. Under such circumstances, these short circuits have no intermediate equipment to restrict the frequency band transmitted and the only band limitation for the network is the "cutoff" of the line and local channel facilities. While this will vary somewhat between cases, the band will sometimes be wide enough to permit transmission approaching that obtainable from the regular high quality services, since delay distortion from such short lengths will normally be unimportant. In addition, these circuits afford the advantage of transmitting in either direction. It is important for the control of noise in such instances, of course, to arrange for switching equalizers and pads in and out of the circuits so that equalization will always take place at the receiving end of the channel. Taken at face value, these features appear to make "non-amplified" circuits very attractive by use in building up networks. This conclusion, however, fails to take into consideration the fact that the attractive features are primarily due to the short lengths of the circuits and not to their having different basic transmission characteristics. If used in tandem between studios to form long connections, the cumulative impairments characteristic of long lengths of circuit will make themselves apparent just as if only a single long circuit were involved. In fact, noise will tend to be somewhat higher in such a tandem arrangement than in a single circuit of equivalent length because of less favorable levels. The possibilities of operating irregularities and interference will also be increased because of routing the circuit through one or more retransmission points.

SUPPLEMENTARY EQUALIZATION

Supplementary equalization measures are sometimes applied to long medium quality circuits by broadcasters in an effort to widen the effective band width and so obtain additional benefits normally associated with wider band services. In many of these cases no serious difficulty is encountered in widening the band up to the cutoff of the line facilities. A comparable improvement in quality may not be obtained, however, as noise and distortion effects will tend to become more objectionable.

Attempts may be made to improve low frequency performance of medium quality circuits by application of low frequency pre-emphasis in material transmitted into the circuit. This is likely to result in trouble as low frequency levels considerably in excess of the 1,000 cycle reference levels may reach line amplifiers in the initial portion of the circuit and produce serious distortion on program material having high level low frequency components, such as pipe organ music, due to overloading. In specially designed program circuits, because of these considerations, equalization is distributed along the circuit and is applied at the receiving ends of the sections concerned only.

RETRANSMISSION OF PROGRAMS

In some cases the broadcasters receive programs from one network and switch or retransmit them to another. In these cases the broadcaster's retransmitting amplifiers and associated equipment become virtually units in a larger network. Their operation, consequently, becomes subject to the same requirements of other amplifiers in the networks, if they are to be kept from affecting all results disproportionately. Some of the technical requirements for the equipment which are of particular importance in this connection are as follows:

1. The amplifier should be stable in gain and have ample gain and volume capacity to apply +8 vu to the transmitting loop (through any necessary pads) with a few db of margin for safety and without introduction of objectionable noise or distortion. They should also make no appreciable change in the transmission-frequency characteristic of the transmitted band.
2. The amplifier should have a gain adjustment of positive type with which gain can be changed known amounts and set definitely at desired values. The steps should be 2 db or less. Mechanical detents are desirable so that gain adjustments will be protected against accidental change. Slide wire controls are not generally as suitable for this use.
3. A standard volume indicator should be available with arrangements to permit correct measurements of the volume fed to the outgoing loop.

4. Adequate input pads should be available, if needed to keep normal volumes received from the network from overloading any amplifier involved in retransmission.

5. The gain of the retransmitting amplifier should be adjusted so that normal (maximum) level from the receiving loop from the telephone company office will result in application of +8 vu to the transmitting loop at the broadcasting station. The method for doing this differs depending upon whether or not the circuit from which program is received employs line amplifiers. The procedures for both of the conditions mentioned are discussed in following paragraphs. These procedures apply basic principles which take into consideration the impedance characteristics of the local telephone circuits involved and should result in transmission values which can be coordinated with those of the telephone company. In the use of commercial testing equipment for such measurements it should be made sure that the same basic principles are applied.

6. The high and low frequency delay-frequency characteristics (sometimes referred to as delay distortion of phase distortion) of all equipment used (coils, amplifiers, equalizers, etc.) should be such as not to contribute any appreciable amount to the over-all network.

ADJUSTMENT OF GAIN OF RETRANSMITTING AMPLIFIERS

A. Where the incoming interexchange circuit utilizes amplifiers in the normal manner.

1. At the broadcasting station connect a 600-ohm resistance across the output of the retransmitting amplifier circuit in place of the transmitting (out-going) loop, and connect a standard volume indicator across this 600-ohm resistance. If a 600-ohm pad is normally used between the amplifier and the loop the 600-ohm resistance should be connected to the output of the pad, in place of the loop, and the volume indicator connected across the input of the pad.

2. Have the telephone office, at which the receiving (incoming) loop connects to the line circuit, transmit 1000-cycle test tone at a level of 0 vu (1 milliwatt) into the receiving loop.

3. Adjust the gain of the retransmitting amplifier until the volume indicator shows that 0 vu of test tone is being fed to the 600-ohm resistance. This is indicated by a scale reading of -4 with the attenuator set on +4 vu if no pad is involved. If there is a pad between the volume indicator and the 600-ohm resistance the volume indicator should read higher than 0 vu by the loss in db in the pad. If the volume indicator is to remain connected to the circuit for service it should be calibrated for use in this manner as brought out in Method 1 on Page 7 of the brochure mentioned earlier. If removed after the gain is adjusted calibration should be by method 2.

4. Replace the 600-ohm resistance by the loop. Note the reading of the volume indicator again. The algebraic quantity that must be added to this reading to obtain the reading when the 600-ohm resistance was connected, is the correction that should be added to the volume indicator readings under service conditions to obtain the actual volume fed to the loop (or pad if used). With actual program the normal corrected maximums should reach +8 vu into the loop.

B. Where the incoming interexchange circuit is of the non-amplified type (no amplifier at the telephone office, although one is required at the retransmitting point).

1. Communicate with the station transmitting on the interexchange circuit and request transmission of 0 dbm of 1,000-cycle test tone into the local circuit. (Oscillator should present 600 ohm impedance to local circuit.)

2. Adjustments should then be made at the retransmitting station as described for interexchange circuits utilizing amplifiers.

After establishing the correct normal setting of gain for the retransmitting amplifier at a broadcasting station this gain should be maintained at all times unless some change is made which will change the input to the amplifier. In this case a new normal setting should be established by repeating the procedure described for determining correct gain adjustments.

If transmission through the station concerned is sometimes reversed the proper gain for both directions of transmission should be determined. The necessary change in gain between the two directions may be made by insertion of different pads in the input circuit.

A testing frequency of 1000 cycles is specified for making the foregoing adjustments as this is the standard testing frequency utilized for "line-up" work on program and other circuits in the telephone plant and is the frequency at which amplifier gains and circuit losses are coordinated in obtaining proper transmission levels throughout the telephone plant.

Because of possibility of interference with other circuits frequencies as high as this can not safely be transmitted in local cable plant at levels greater than 0 dbm (1 milliwatt).

In the case of high quality program circuits 500 cycle test tone may be used for similar purposes, where it is desired to transmit full +8 dbm of test tone, (at a normal +8 vu point) as interference effects are much less at this frequency, and transmission loss at 500 cycles will be closely similar to that at 1000 cycles. In the case of medium quality circuits, however, equal uniformity in transmission loss at different frequencies can not be assured, and some over-all error might result from assuming 500-cycle test results to be equal to those at 1000 cycles if used for several points which might operate in tandem.

PROCEDURE IN CASE OF IMPROPER VOLUME RECEIVED FROM THE INTEREXCHANGE CIRCUIT

As indicated earlier, program network operating and maintenance procedures are based upon the assumption that the originating point will properly regulate the volume fed to its transmitting loop. The question, therefore, arises as to what should be done if this is not the case or if some network transmission irregularity develops which results in improper volume reaching the various tributary stations. This is of particular importance in the case of medium quality services since the closer supervision given the high quality services simplifies detection of the sources of volume irregularities.

If volume irregularities are noted, it should first be ascertained that this discrepancy is actually present on the incoming loop and that some irregularity in the station equipment is not accountable. Having determined this, the telephone company should be notified and will determine whether the circuit to the next interconnecting point toward the originating point is at fault. If not, it may either be assumed that the next station is also experiencing the trouble and is taking similar steps, or that station may be communicated with by the broadcaster to verify this.

AN EMERGENCY BROADCAST TIME SYSTEM*

(From the Engineering Notices of the National Broadcasting Company)

As network broadcasting continues to develop, it requires more and more careful and exact timing. The awkward pauses heard at the end of programs, cuts at the start of broadcasts, and many other similar troubles are usually traced directly to faulty timing.

In an attempt to overcome these troubles, in so far as is possible, a system has been devised to provide accurate and automatic time checks to all who might be concerned.

The system in its present form provides audible "beeps" three, two, and one minutes before each quarter hour. Three "beeps" indicates 3 minutes before the quarter hour, two "beeps", two minutes before the quarter hour, one "beep", one minute before. The start of the first "beep" in each case is exactly on the minute. Each "beep" is a 1000 cycle note for a duration of slightly more than 1/2 second.

In addition to providing accurate and automatic time checks, the system also provides an excellent warning to operating personnel that switching periods are "coming up." It is now recognized that the warnings have saved many switches that would have otherwise been overlooked.

The "beeper" time checks are supplied to all broadcast studio booths, superimposed over all announce delite** outgoing channel monitoring, connected to a house monitoring selector level, appears at the Master Control Desk, at Transmission Operating, the Division Engineer's office, the Maintenance Group Office, the Field Office, Air-Conditioning Office, and at Transmission arranged so that the "beeps" can be fed to radio and private lines.

The "beeps" are used in the broadcast studio booths by the Production Director and Engineer to check the accuracy of the booth clock. Experience has revealed that a large number of clocks fed from a common and accurate source are not necessarily exactly alike. Defects in the clocks sometimes cause errors that are not immediately noticed unless there is an auxiliary means of checking them. The audible "beeper" continuously available, results in clock errors being noticed and corrected before any harm is done. If a booth clock is wrong or not operating at all, the broadcast still starts on time from the audible time checks.

Some broadcast studios are operated without a Production Director. Others, usually repeater studios, are operated without either a Production Director or Engineer in the studio announce booth. The time checks superimposed over outgoing channel monitoring provides the correct time to the announcer at his delite** to check the clock there.

The "beeps" are available on a House Monitoring Selector Level to permit any office with a loudspeaker to obtain correct "broadcast time." It is also used by the Maintenance Engineers to set office clocks wherever loudspeakers are located. Sometimes it is used by office personnel as a warning to monitor a special program that they are particularly interested in. The loudspeaker is dialed to the "beeper" level and left there. The 3, 2, and 1 minute "beeps" serve as a warning that the program time is approaching. Before the actual broadcast time the loudspeaker is silent except for the "beeps" permitting concentration on work at hand without interference by broadcast program.

The time checks are used at Transmission Operating and at the Master Control Desk as warnings that switching periods are approaching.

Another important use is the feeding of time checks to remote pickup points over private lines and business phones. The business phone connections are received in the Master Control Room on a PLX Board from the building PBX. The "beeps" are fed to these lines in multiple so that normal conversation is not interferred with. The time checks are available on a spare PLX jack which is connected in parallel with all local private lines and PBX business phones that are being used for program coordination and "go aheads". The announcer receives the time checks at the pickup by listening to the engineer's private line receiver. The engineer lifts the receiver away from his ear slightly and the announcer hears the check by standing near the engineer.

Providing the automatic time checks frees the Transmission Operating Engineer in Master Control the last few minutes before switching time to make last minute patches, clear trouble, make changes, etc. The saving of time resulting from not tieing up personnel with giving verbal time checks is very appreciable and improves the overall operating efficiency.

It should be noted from the attached diagrams that a loudspeaker is automatically connected across all PLX and PBX lines receiving

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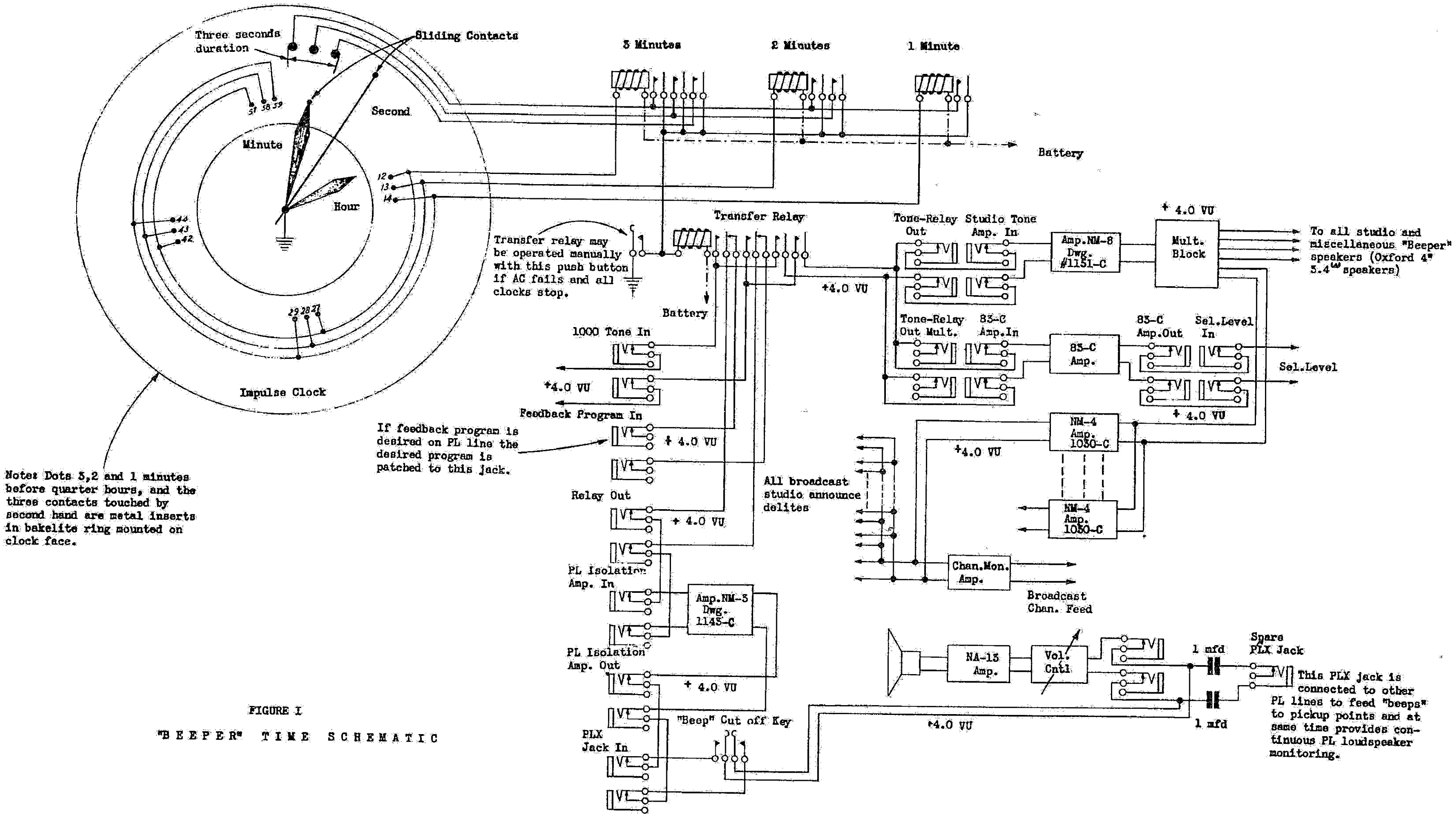
*System developed by Mr. Edwin Costello, New York NBC Maintenance Engineer, in cooperation with the Maintenance Staff.

**The word "delite" is used by NBC to identify a studio control position or console used by announcers.



Transfer relay may be operated manually with this push button if AC fails and all clocks stop.

If feedback program is desired on PL line the desired program is patched to this jack.

Notes Dots 3,2 and 1 minutes before quarter hours, and the three contacts touched by second hand are metal inserts in bakelite ring mounted on clock face.

To all studio and miscellaneous "Beeper" speakers (Oxford 4" 5.4" speakers)

This PLX jack is connected to other PL lines to feed "beeps" to pickup points and at same time provides continuous PL loudspeaker monitoring.

FIGURE I

"BEEPER" TIME SCHEMATIC

time checks. This loudspeaker provides a continuous monitor of lines without an engineer continually listening to a phone. Considerable operating time can be saved by this loudspeaker monitor alone.

Figure 1 shows the contacts added to an electric clock face, the relay system operated by the clock, and associated equipment used to feed the resulting "beeps" to monitoring points. Operation levels and notes make the diagram self-explanatory and no further discussion required.

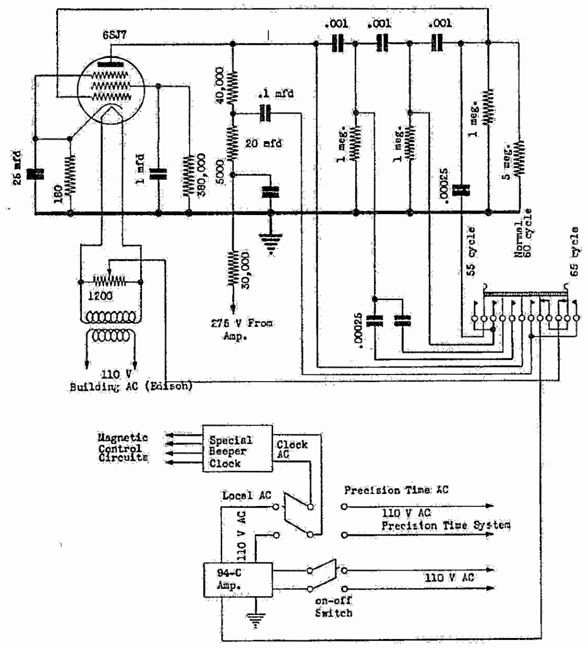


FIGURE 2

ALTERNATING CURRENT FEEDS FOR "BEEPER" CLOCK

Figure 2 shows the AC feed to the electric clock. Under the present normal operating conditions the switch is thrown to the Precision Time feed. If the Precision Time equipment fails or the clock requires correction the 94-C amplifier is turned on and the clock switch thrown to the local AC feed position. The "beeper" clock is then corrected by operating the oscillator switch in the 94-C input to change its driving frequency either faster or slower as required. Prior to the installation of the local Precision Time system, the clock was fed continuously from the 94-C. Due to poor 60 cycle frequency control it was found necessary to correct the "beeper" clock as often as once an hour.

If all AC feeds fail entirely the 3, 2, and 1 minute "beeps" can be supplied manually by

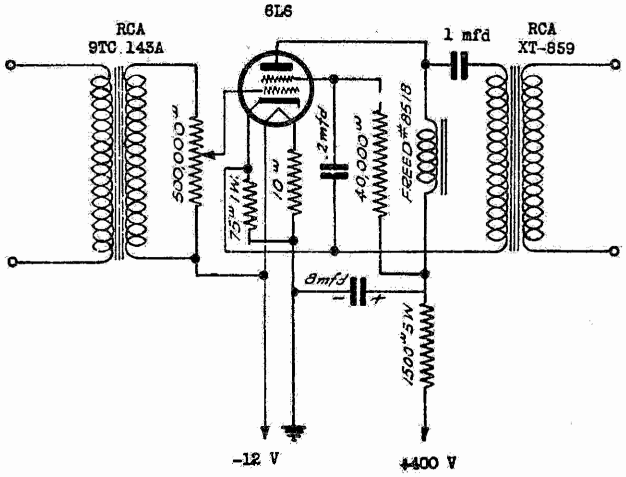


FIGURE 3

STUDIO "BEEPER" TONE AMPLIFIER

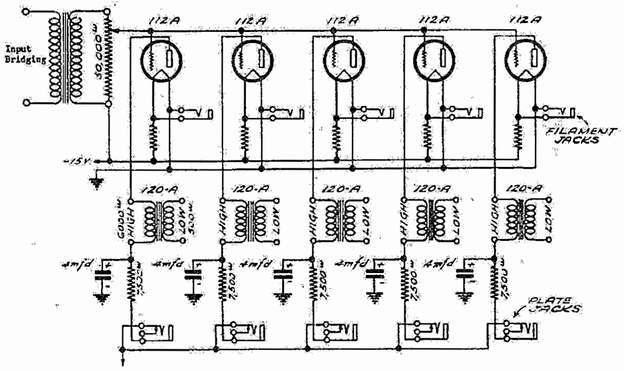


FIGURE 4

"BEEPER" TONE HEAD SET MONITORING ISOLATION AMPLIFIER

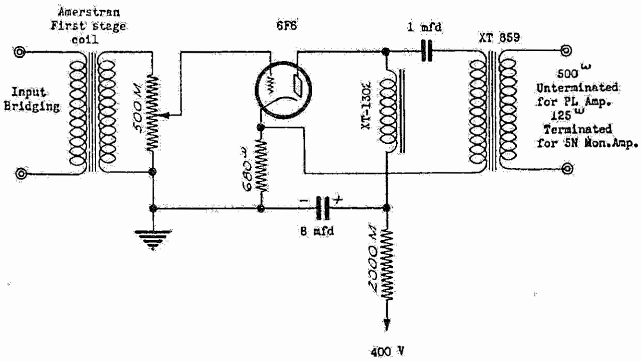


FIGURE 5

OFFICE MONITORING AND PRIVATE LINE ISOLATION AMPLIFIER

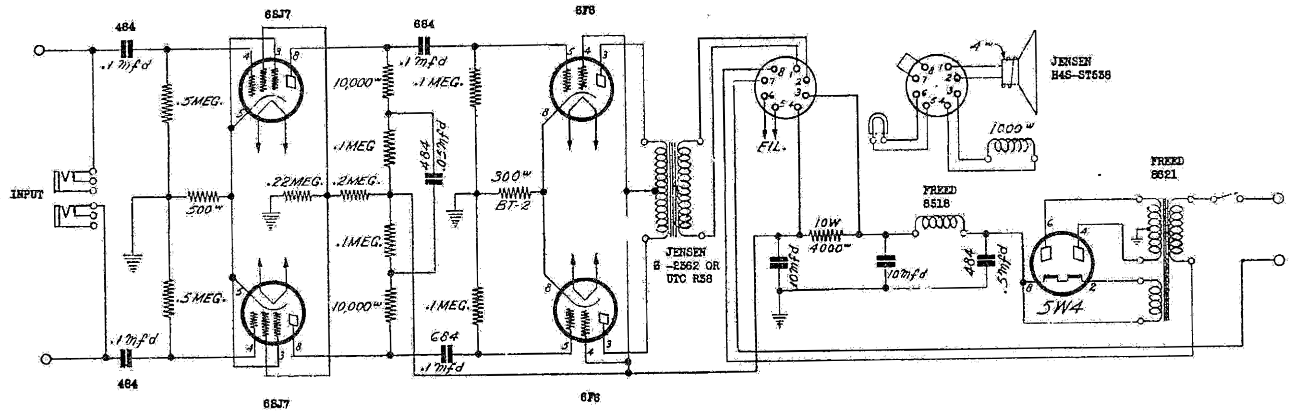


FIGURE 6

NA-13 MONITORING AMPLIFIER

FIGURE 7

PHOTOGRAPH VIEW OF MASTER CLOCK
FOR "BEEPER" SYSTEM

operating the push button associated with the transfer relay shown on Figure 1. The time to operate the relay manually is taken from a Western Union spring operated clock mounted beside the "beeper". The Western Union clock installation is inexpensive and provides an excellent emergency time system. The clock is corrected electrically from a central office once each hour. All equipment associated with the entire "beeper" system, except the clock itself and one monitor speaker, is DC operated in order to provide this emergency feature.

Figures 3, 4, and 5 are diagrams for the DC operated amplifiers. Some of the amplifiers are of an old design but are utilized here for economical reasons. Any amplifier that would accomplish the same purpose may, of course, be substituted.

Figure 6 shows the design of the AC operated NA - 13 amplifier. If AC fails, the loss of this amplifier will not interfere with the emergency DC operation of the system itself. The NA - 13 is used as a private line monitor and for "beeper" warnings at Transmission Operating.

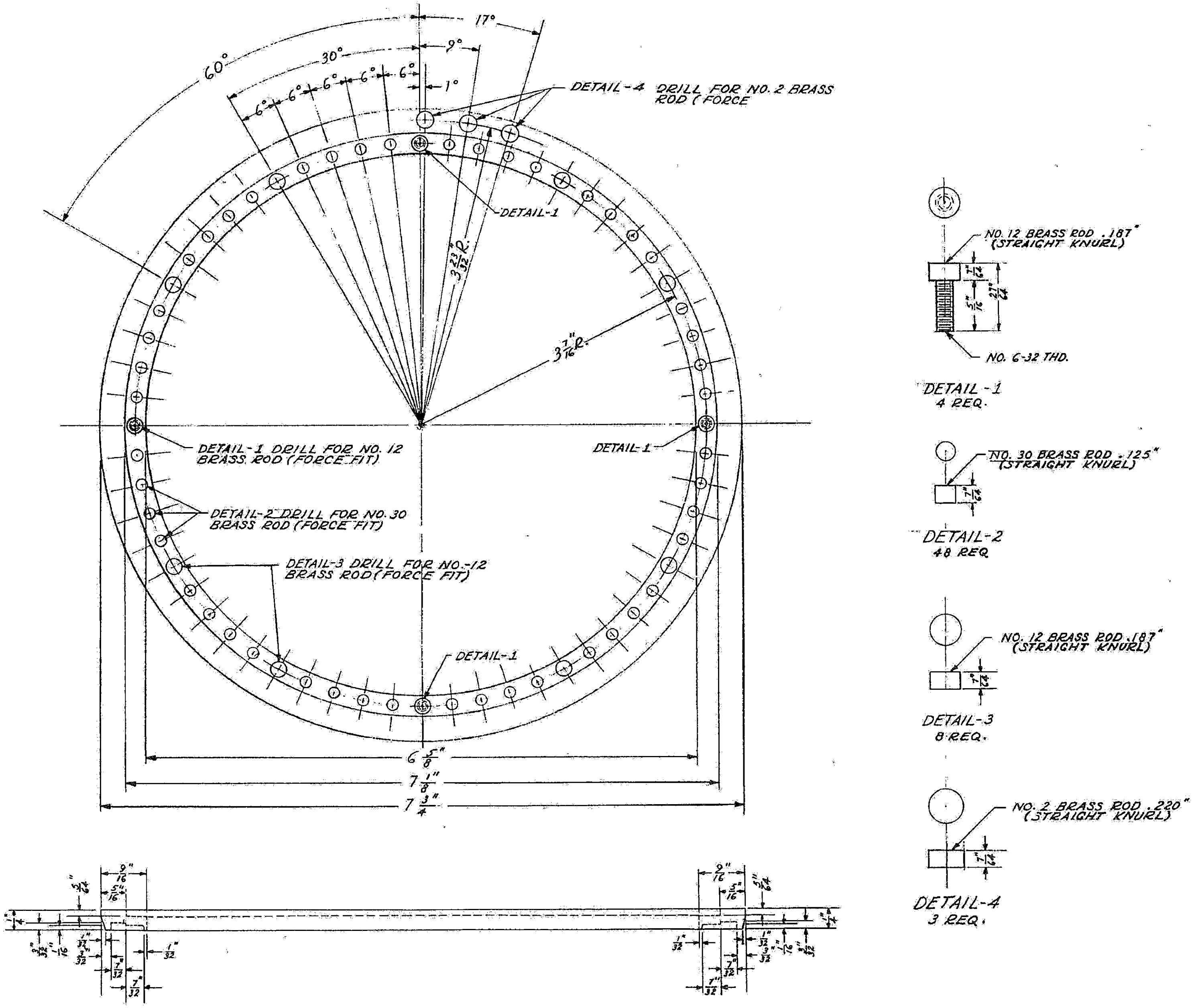

60°
30°
17°
9°
6°
6°
6°
6°
6°
1°
DETAIL-4 DRILL FOR NO. 2 BRASS ROD (FORCE
DETAIL-1
3 23/32" R.
3 7/16" R.
DETAIL-1 DRILL FOR NO. 12 BRASS ROD (FORCE FIT)
DETAIL-1
DETAIL-2 DRILL FOR NO. 30 BRASS ROD (FORCE FIT)
DETAIL-3 DRILL FOR NO.-12 BRASS ROD (FORCE FIT)
DETAIL-1
6 5/8"
7 1/8"
7 3/4"
9/16"
5/16"
5/64"
1/4"
3/32"
1/16"
1/32"
7/32"
NO. 12 BRASS ROD .187" (STRAIGHT KNURL)
7/64"
5/16"
27/64"
NO. 6-32 THD.
DETAIL-1
4 REQ.
NO. 30 BRASS ROD .125" (STRAIGHT KNURL)
7/64"
DETAIL-2
48 REQ
NO. 12 BRASS ROD .187" (STRAIGHT KNURL)
7/64"
DETAIL-3
8 REQ.
NO. 2 BRASS ROD .220" (STRAIGHT KNURL)
7/64"
DETAIL-4
3 REQ.

FIGURE 8

ELECTROACOUSTICS

Reprinted from Reference Data for Radio Engineers, Third Edition, by permission of the publisher, Federal Telephone and Radio Corporation, 67 Broad Street, New York, New York.

THEORY OF SOUND WAVES[1]

Sound (or a sound wave) is an alteration in pressure, stress, particle displacement, or particle velocity that is propagated in an elastic material; or the superposition of such propagated alterations. Sound (or sound sensation) is also the sensation produced through the ear by the above alterations.

Wave equation

The behavior of sound waves is given by the wave equation

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \qquad (1)$$

where p is the instantaneous pressure increment above and below a steady pressure (dynes/centimeter^2); p is a function of time and of the three coordinates of space. Also,

t = time in seconds

c = velocity of propagation in centimeters/second

∇^2 = the LaPlacian, which for the particular case of rectangular coordinates x, y, and z (in centimeters) is given by

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \qquad (2)$$

For a plane wave of sound, where variations with respect to y and z are zero, $\nabla^2 p = \partial^2 p/\partial x^2 = d^2p/dx^2$; the latter is approximately equal to the curvature of the curve showing p versus x at some instant. Equation (1) states simply that, for variations in x only, the acceleration in pressure p (the second time derivative of p) is proportional to the curvature in p (the second space derivative of p).

For a gas (as air), the velocity of propagation c is related to other parameters of the medium by the equation

$$c = \sqrt{\gamma p_0/\rho_0} \qquad (3)$$

where

γ = ratio of the specific heat at constant pressure to that at constant volume

p_0 = the steady pressure of the gas in dynes/centimeter^2

ρ_0 = the steady or average density of the gas in grams/centimeter^3

The range of variation of these parameters is given in Fig. 1 for typical substances at standard conditions (20 degrees centigrade, 760 millimeters of mercury).

Sinusoidal variations in time are usually of interest. For this case the usual procedure is to put p = (the real part of $\bar p \epsilon^{j\omega t}$), where $\bar p$ now satisfies the equation

$$\nabla^2 \bar p + (\omega/c)^2 \bar p = 0 \qquad (4)$$

The vector complex velocity $\bar v$ of the sound wave in the medium is related to the complex pressure $\bar p$ by the formula

$$\bar v = -(1/j\omega\rho_0)\ \mathrm{grad}\ \bar p \qquad (5)$$

The specific acoustical impedance $\bar Z$ at any point in the medium is the ratio of the complex pressure to the complex velocity, or

$$\bar Z = \bar p/\bar v \qquad (6)$$

The solutions of (1) and (4) take particularly simple and instructive forms for the case of one dimensional plane and spherical waves in one direction. Fig. 2 gives a summary of the pertinent information.

Fig. 1—Table of sound-propagation parameters in various substances.

substance	density ρ_0 grams/centimeter^3	velocity of propagation c centimeters/second	characteristic acoustic resistance $\rho_0 c$ grams/centimeter^2 /second
Air	0.00121	34,400	41.6
Hydrogen	0.00009	127,000	11.4
Carbon dioxide	0.0020	25,800	51.3
Salt water	1.03	150,400	155,000
Mercury	13.5	140,000	1,900,000
Hard rubber	1.1	140,000	150,000
Hard glass	2.4	600,000	1,440,000

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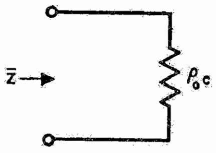
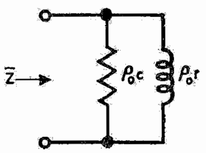
[1] Lord Rayleigh, "Theory of Sound," vols. I and II, Dover Publications, New York, New York; 1945. P. M. Morse, "Vibration and Sound," 2nd edition, McGraw-Hill Book Company, New York, New York; 1948.

Fig. 2—Table of solutions for various parameters.

factor	type of sound wave plane wave	 spherical wave
Equation for p	$\frac{\partial^2 p}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$	$\frac{\partial^2 p}{\partial x^2} + \frac{2}{r}\frac{\partial p}{\partial r} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$
Equation for $\bar{p}$	$\frac{d^2\bar{p}}{dx^2} + \left(\frac{\omega}{c}\right)^2\bar{p} = 0$	$\frac{d^2\bar{p}}{dx^2} + \frac{2}{r}\frac{d\bar{p}}{dt} + \left(\frac{\omega}{c}\right)^2\bar{p} = 0$
Solution for p	$p = F\left(t - \frac{x}{c}\right)$	$p = \frac{1}{r}F\left(t - \frac{x}{c}\right)$
Solution for $\bar{p}$	$\bar{p} = \bar{A}\epsilon^{-j\omega x/c}$	$\bar{p} = \frac{1}{r}\bar{A}\epsilon^{-j\omega r/c}$
Solution for $\bar{v}$	$\bar{v} = \frac{\bar{A}}{\rho_0 c}\epsilon^{-j\omega x/c}$	$\bar{v} = \frac{\bar{A}}{\rho_0 c r}\left(1 + \frac{c}{j\omega r}\right)\epsilon^{-j\omega r/c}$
$\bar{Z}$	$\bar{Z} = \rho_0 c$	$\bar{Z} = \rho_0 c / \left(1 + \frac{c}{j\omega r}\right)$
Equivalent electrical circuit for $\bar{Z}$		

where

p = excess pressure in dynes/centimeter^2

$\bar{p}$ = complex excess pressure in dynes/centimeter^2

t = time in seconds

x = space coordinate for plane wave in centimeters

r = space coordinate for spherical wave in centimeters

$\bar{v}$ = complex velocity in centimeters/second

$\bar{Z}$ = specific acoustic impedance in dyne-seconds/centimeter^3

c = velocity of propagation in centimeters/second

$\omega = 2\pi f$; f = frequency in cycles/second

F = an arbitrary function

$\bar{A}$ = complex constant

ρ_0 = density of medium in grams/centimeter^3

Fig. 3—Table of intensity levels.

type of sound	intensity level in decibels above 10^{-16} watts/centimeter^2	intensity in microwatts/centimeter^2	root-mean-square sound pressure in dynes/centimeter^2	root-mean-square particle velocity in centimeters/second	peak-to-peak particle displacement for sinusoidal tone at 1000 cycles in centimeters
Threshold of painful sound	130	1000	645	15.5	6.98×10^{-3}
Airplane, 1600 r.p.m., 18 feet	121	126	228	5.5	2.47×10^{-3}
Subway, local station, express passing	102	1.58	40.7	0.98	4.40×10^{-4}
Noisest spot at Niagara Falls	92	0.158	12.9	0.31	1.39×10^{-4}
Average automobile, 15 feet	70	10^{-3}	0.645	15.5×10^{-3}	6.98×10^{-6}
Average conversational speech 3¼ feet	70	10^{-3}	0.645	15.5×10^{-3}	6.98×10^{-6}
Average office	55	3.16×10^{-5}	0.114	2.75×10^{-3}	1.24×10^{-6}
Average residence	40	10^{-6}	20.4×10^{-3}	4.9×10^{-4}	2.21×10^{-7}
Quiet whisper, 5 feet	18	6.3×10^{-9}	1.62×10^{-3}	3.9×10^{-5}	1.75×10^{-8}
Reference level	0	10^{-10}	2.04×10^{-4}	4.9×10^{-6}	2.21×10^{-9}

For example, the acoustical impedance for spherical waves has an equivalent electrical circuit comprising a resistance shunted by an inductance. In this form, it is obvious that a small spherical source (r is small) cannot radiate efficiently since the radiation resistance, $\rho_0 c$ is shunted by a small inductance $\rho_0 r$. Efficient radiation begins approximately at the frequency where the resistance $\rho_0 r$ equals the inductive (mass) reactance $\rho_0 c$. This is the frequency at which the period ($= 1/f$) equals the time required for the sound wave to travel the peripheral distance $2\pi r$.

Sound Intensity

The sound intensity is the average rate of sound energy transmitted in a specified direction through a unit area normal to this direction at the point considered. In the case of a plane or spherical wave, the intensity in the direction of propagation is given by

$I = p^2/\rho c$ ergs/second/centimeter^2

where

p = pressure (dynes/centimeter^2)
ρ = density of the medium (grams/centimeter^3) and
c = velocity of propagation (centimeters/second)

The sound intensity is usually measured in decibels, in which case it is known as the intensity level and is equal to 10 times the logarithm (to the base 10) of the ratio of the sound intensity (expressed in watts/centimeter^2) to the reference level of 10^{-16} watts/centimeter^2. Fig. 3 shows the intensity levels of some familiar sounds.

ACOUSTICAL AND MECHANICAL NETWORKS AND THEIR ELECTRICAL ANALOGS[2]

The present advanced state of the art of electrical network theory suggests its advantageous application, by analogy, to equivalent acoustical and mechanical networks. Actually, Maxwell's initial work on electrical networks was based upon the previous work of LaGrange in dynamical systems. The following is a brief summary showing some of the network parameters available in acoustical and mechanical systems and their analysis using LaGrange's equations.

Fig. 4 shows the analogous behavior of electrical, acoustical, and mechanical systems. These are analogous in the sense that the equations (usually differential equations) formulating the various physical laws are alike.

LaGrange's equations

The LaGrangian equations are partial differential equations describing the stored and dissipated energy and the generalized coordinates of the system. They are

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_\nu}\right) + \frac{\partial F}{\partial \dot{q}_\nu} + \frac{\partial V}{\partial q_\nu} = Q_\nu, \; \nu = 1, 2, \ldots\ldots, n, \tag{7}$$

where T and V are, as in Fig. 4, the system's total kinetic and potential energy (in ergs), F is ½ the rate of energy dissipation (in ergs/second, Rayleigh's dissipation function), Q_ν the generalized forces (dynes), and q_ν the generalized coordinates (which may be angles in radians, or displacements in centimeters). For most systems (and those considered herein) the generalized coordinates are equal in number to the number of degrees of freedom in the systems required to determine uniquely the values of T, V, and F.

Example

As an example of the application of these equations toward the design of electroacoustical transducers, consider the idealized crystal microphone in Fig. 5.

This system has 2 degrees of freedom since only 2 motions, namely the diaphragm displacement x_d and the crystal displacement x_c, are needed to specify the system's total energy and dissipation.

A sound wave impinging upon the microphone's diaphragm creates an excess pressure p (dynes/centimeter^2). The force on the diaphragm is then pA (dynes), where A is the effective area of the diaphragm. The diaphragm has an effective mass m_d, in the sense that the kinetic energy of all the parts associated with the diaphragm velocity $\dot{x}_d$ ($=dx_d/dt$) is given by $m_d\dot{x}_d^2/2$. The diaphragm is supported in place by the stiffness S_d. It is coupled to the crystal via the stiffness S_o. The crystal has a stiffcess S_c, an effective mass of the m_c (to be computed below), and is damped by the mechanical resistance R_c. The only other remaining parameter is the acoustical stiffness S_a introduced by compression of the air-tight pocket enclosed by the diaphragm and the case of the microphone.

The total potential energy V stored in the system for displacements x_d and x_c from equilibrium position, is

$$V = \tfrac{1}{2}S_d x_d^2 + \tfrac{1}{2}S_a(x_d A)^2 + \tfrac{1}{2}S_c x_c^2 + \tfrac{1}{2}S_o(x_d - x_c)^2 \tag{8}$$

The total kinetic energy T due to velocities $\dot{x}_d$ and $\dot{x}_e$ is

$$T = \tfrac{1}{2}m_c\dot{x}_c^2 + \tfrac{1}{2}m_d\dot{x}_d^2 \tag{9}$$

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[2] E. G. Keller, "Mathematical Engineering," 1st ed., John Wiley, New York, New York; 1942. H. F. Olson, "Dynamical Analogies," 1st ed., D. Van Nostrand, New York, New York; 1943.

Fig. 4A—Table of analogous behavior of systems—parameter of energy dissipation (or radiation).

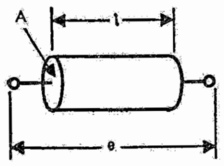
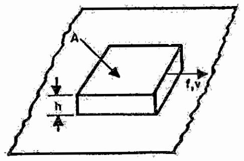
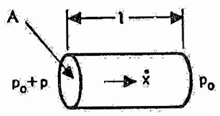
electrical	mechanical	acoustical
 current in wire	 viscous damping vane	 gas flow in small pipe
$P = Ri^2$ $i = \frac{e}{R} = \frac{dq}{dt} = \dot{q}$ $R = \frac{\rho l}{A}$	$P = R_m v^2$ $v = \frac{f}{R_m} = \frac{dx}{dt} = \dot{x}$ $R_m = \frac{\mu A}{h}$	$P = \dot{R}_a X^2$ $\dot{X} = \frac{p}{R_a} = \frac{dX}{dt}$ $R_a = \frac{8\mu\pi l}{A^2}$
where i = current in amperes e = voltage in volts q = charge in coulombs t = time in seconds R = resistance in ohms ρ = resistivity in ohm-centimeters l = length in centimeters A = cross-sectional area of wire in centimeters^2 P = power in watts	where v = velocity in centimeters/second f = force in dynes x = displacement in centimeters t = time in seconds R_m = mechanical resistance in dyne-seconds/centimeter μ = coefficient of viscosity in poise h = height of damping vane in centimeters A = area of vane in centimeters^2 P = power in ergs/second	where $\dot{X}$ = volume velocity in centimeters^3/second p = excess pressure in dynes/centimeter^2 X = volume displacement in centimeters^3 t = time in seconds R_a = acoustic resistance in dyne-seconds/centimeter^5 μ = coefficient of viscosity in poise l = length of tube in centimeters A = area of circular tube in centimeters^2 P = power in ergs/second

Fig. 4B—Table of analogous behavior of systems—parameter of energy storage (electrostatic or potential energy).

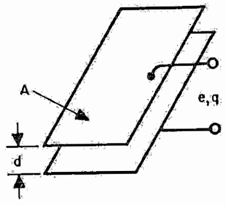
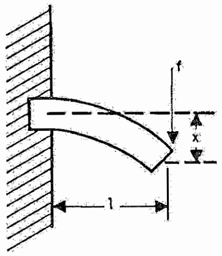
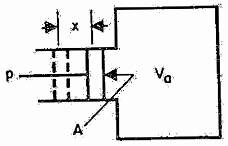
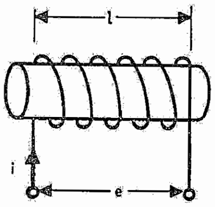
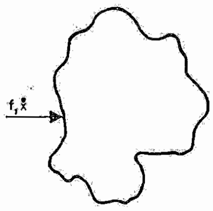
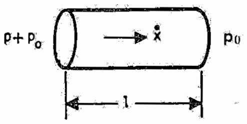
electrical	mechanical	acoustical
 capacitor with closely spaced plates	 clamped-free (cantilever beam)	 piston acoustic compliance (at audio frequencies, adiabatic expansion)
$W_e = \frac{q^2}{2C} = \frac{Sq^2}{2}$ $q = Ce = \frac{e}{S}$ $C = \frac{kA}{36\pi d} \times 10^{-11}$	$V = \frac{x^2}{2C_m} = \frac{S_m x^2}{2}$ $x = C_m f = \frac{f}{S_m}$ $C_m = \frac{l^3}{3EI}$	$V = \frac{X^2}{2C_a} = \frac{S_a X^2}{2}$ $X = C_a p = \frac{p}{S_a} = xA$ $C_a = \frac{V_o}{c^2 \rho}$
where C = capacitance in farads S = stiffness = 1/C W_e = energy in watt-seconds k = relative dielectric constant (= 1 for air, numeric) A = area of plates in centimeters^2 d = separation of plates in centimeters	where C_m = mechanical compliance in centimeters/dyne S_m = mechanical stiffness = $1/C_m$ V = potential energy in ergs E = Young's modulus of elasticity in dynes/centimeter^2 I = moment of inertia of cross-section in centimeters^4 l = length of beam in centimeters	where C_a = acoustical compliance in centimeters^5/dyne S_a = acoustical stiffness = $1/C_a$ V = potential energy in ergs c = velocity of sound in enclosed gas in centimeters/second ρ = density of enclosed gas in grams/centimeter^3 V_o = enclosed volume in centimeters^3 A = area of piston in centimeters^2

Fig. 4C—Table of analogous behavior of systems—parameter of energy storage (magnetostatic or kinetic energy).

electrical	mechanical	acoustical
		
for a very long solenoid	for translational motion in one direction m is the actual weight in grams	gas flow in a pipe
$W_m = \frac{Li^2}{2}$ $e = L\frac{di}{dt} = L\frac{d^2q}{dt^2} = L\ddot q$ $L = 4\pi l n^2 A k \times 10^{-9}$	$T = \frac{mv^2}{2}$ $f = m\frac{dv}{dt} = m\frac{d^2x}{dt^2} = m\ddot x$	$T = \frac{M\dot X^2}{2}$ $p = M\frac{d\dot X}{dt} = M\frac{d^2X}{dt^2} = M\ddot X$ $M = \frac{\rho l}{A}$
where L = inductance in henries W_m = energy in watt-seconds l = length of solenoid in centimeters A = area of solenoid in centimeters^2 n = number of turns of wire/centimeter k = relative permeability of core (= 1 for air, numeric)	where m = mass in grams T = kinetic energy in ergs	where M = inertance in grams/centimeter^4 T = kinetic energy in ergs l = length of pipe in centimeters A = area of pipe in centimeters^2 ρ = density of gas in grams/centimeter^3

(This neglects the small kinetic energy due to motion of the air and that due to the motion of the spring S_0). If the total weight of the unclamped part of the crystal is w_c (grams), one can find the effective mass m_c of the crystal as soon as some assumption is made as to movement of the rest of the crystal when its end moves with velocity $\dot x_c$. Actually, the crystal is like a transmission line and has an infinite number of degrees of freedom. Practically, the crystal is usually designed so that its first resonant frequency is the highest passed by the microphone. In that case, the end of the crystal moves in phase with the rest, and in a manner that, for simplicity, is here taken as parabolically. Thus it is assumed that an element of the crystal located y centimeters away from its clamped end moves by the amount $(y/h)^2 x_c$, where h is the length of the crystal. The kinetic energy of a length dy of the crystal due to its velocity of $(y/h)^2 \dot x_c$ and its mass of $(dy/h)w_c$ is $\frac{1}{2}(dy/h)w_c (y/h)^4 \dot x_c^2$. The kinetic energy of the whole crystal is the integral of the latter expression as y varies from 0 to h. The result is $\frac{1}{2}(w_c/5) \dot x_c^2$. This shows at once that the effective mass of the crystal is $m_c = w_c/5$, i.e., 1/5 its actual weight.

The dissipation function is $F = \frac{1}{2}R_c \dot x_c^2$. Finally, the driving force associated with displacement x_d of the diaphragm is pA. Substitution of these expressions and (8) and (9) in LaGrange's equations (7) results in the force equations

$$\left.\begin{aligned} m_d\ddot x_d + S_d x_d + S_0 A^2 x_d + S_0(x_d - x_c) &= pA \\ m_c\ddot x_c + S_0(x_c - x_d) + R_c\dot x_c &= 0 \end{aligned}\right\} \qquad (10)$$

These are the mechanical version of Kirchhoff's law that the sum of all the resisting

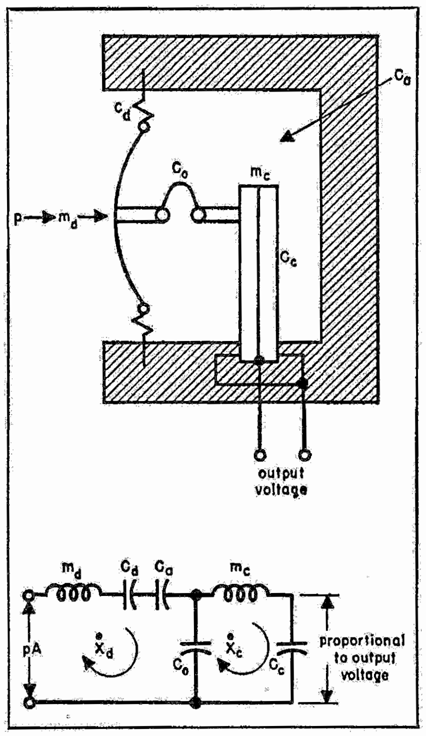


Fig. 5—Crystal microphone analyzed by use of LaGrange's equations.

forces (rather than voltages) are equal to the applied force. The equivalent electrical circuit giving these same differential equations is shown in Fig. 5. The crystal produces, by its piezoelectric effect, an open-circuit voltage proportional to the displacement x_c. By means of this equivalent circuit, it is now easy, by using the usual electrical-circuit techniques, to find the voltage generated by this microphone per unit of sound-pressure input, and also its amplitude-and phase-response characteristic as a function of frequency.

It is important to note that this process of analysis not only results in the equivalent electrical circuit, but also determines the effective values of the parameters in that circuit.

SOUND IN ENCLOSED ROOMS[3]

Good acoustics--governing factors

Reverberation time or amount of reverberation: Varies with frequency and is measured by the time required for a sound, when suddenly interrupted, to die away or decay to a level 60 decibels (db) below the original sound.

The reverberation time and the shape of the reverberation-time/frequency curve can be controlled by selecting the proper amounts and varieties of sound-absorbent materials and by the methods of application. Room occupants must be considered inasmuch as each person present contributes a fairly definite amount of sound absorption.

Standing sound waves: Resonant conditions in sound studios cause standing waves by reflections from opposing parallel surfaces, such as ceiling-floor and parallel walls, resulting in serious peaks in the reverberation-time/frequency curve. Standing sound waves in a room can be considered comparable to standing electrical waves in an improperly terminated transmission line where the transmitted power is not fully absorbed by the load.

Room sizes and proportions for good acoustics

The frequency of standing waves is dependent on room sizes: frequency decreases with increase of distances between walls and between floor and ceiling. In rooms with two equal dimensions, the two sets of standing waves occur at the same frequency with resultant increase of reverberation time at resonant frequency. In a room with walls and ceilings of cubical contour this effect is tripled and elimination of standing waves is practically impossible. The most advantageous ratio for height:width:length is in the proportion of $1:2^{1/3}:2^{2/3}$ or separated by 1/3 or 2/3 of an octave.

In properly proportioned rooms, resonant conditions can be effectively reduced and standing waves practically eliminated by introducing numerous surfaces disposed obliquely. Thus, large-order reflections can be avoided by breaking them up into numerous smaller reflections. The object is to prevent sound reflection back to the point of origin until after several re-reflections.

Most desirable ratios of dimensions for broadcast studios are given in Fig. 6.

Optimum reverberation time

Optimum, or most desirable reverberation time, varies with (1) room size, and (2) use, such as music, speech, etc. (see Figs. 7 and 8).

These curves show the desirable ratio of the reverberation time for various frequencies to the reverberation time for 512 cycles. The desirable reverberation time for any frequency between 60 and 8000 cycles may be found by multiplying the reverberation time at 512 cycles (from Fig. 7) by the number in the vertical scale which corresponds to the frequency chosen.

Computation of reverberation time

Reverberation time at different audio frequencies may be computed from room dimensions

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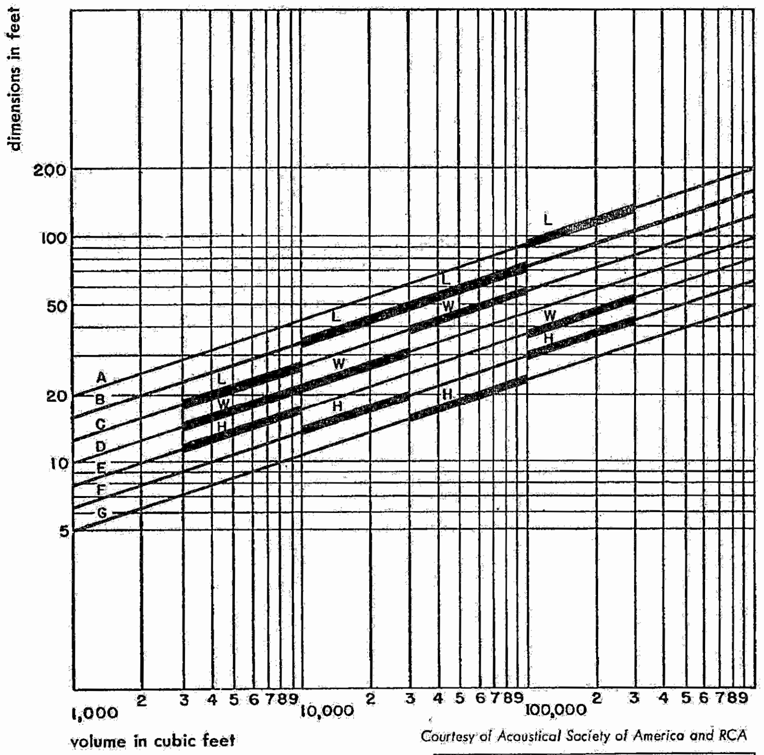
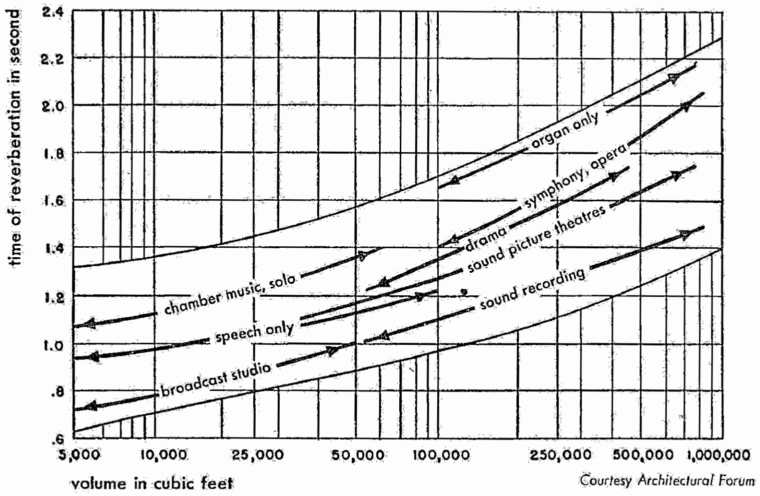
[3] F. R. Watson "Acoustics of Buildings," 1st ed., John Wiley and Sons, New York, New York; 1941.



Courtesy of Acoustical Society of America and RCA

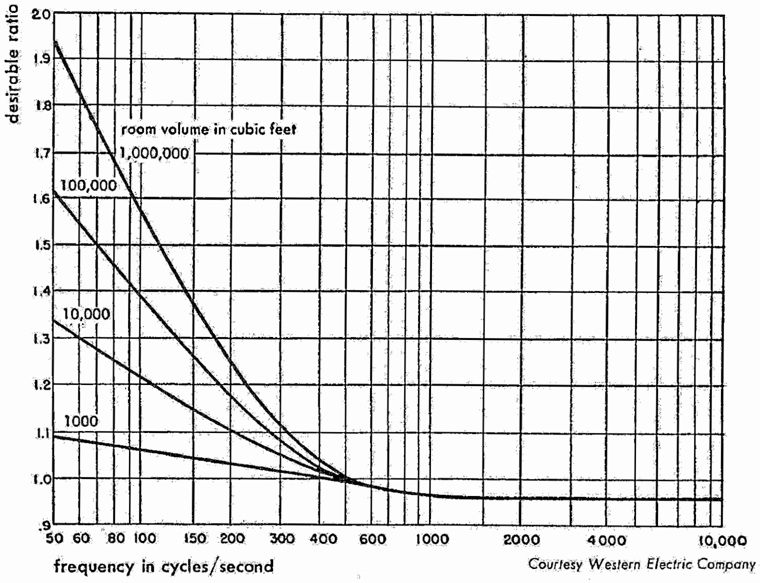
type room	H:W:L	chart designation
Small	1:1.25:1.6	E:D:C:
Average shape	1:1.60:2.5	F:D:B:
Low ceiling	1:2.50:3.2	G:C:B:
Long	1:1.25:3.2	F:E:A:

Fig. 6—Preferred room dimensions based on $2^{1/3}$ ratio. Permissible deviation ±5 percent.



Courtesy Architectural Forum

Fig. 7—Optimum reverberation time in seconds for various room volumes at 512 cycles per second.



Courtesy Western Electric Company

Fig. 8—Desirable relative reverberation time versus frequency for various structures and auditoriums.

Fig. 9—Table of acoustical coefficients of materials and persons*

description	sound absorption coefficients in cycles/second 128	256	512	1024	2048	4096	authority
Brick wall unpainted	0.024	0.025	0.031	0.042	0.049	0.07	W. C. Sabine
Brick wall painted	0.012	0.013	0.017	0.02	0.023	0.025	W. C. Sabine
Plaster + finish coat Wood lath—wood studs	0.020	0.022	0.032	0.039	0.039	0.028	P. E. Sabine
Plaster + finish coat on metal lath	0.038	0.049	0.060	0.085	0.043	0.056	V. O. Knudsen
Poured concrete unpainted	0.010	0.012	0.016	0.019	0.023	0.035	V. O. Knudsen
Poured concrete painted and varnished	0.009	0.011	0.014	0.016	0.017	0.018	V. O. Knudsen
Carpet, pile on concrete	0.09	0.08	0.21	0.26	0.27	0.37	Building Research Station
Carpet, pile on 1/8 in felt	0.11	0.14	0.37	0.43	0.27	0.25	Building Research Station
Draperies, velour, 18 oz per sq yd in contact with wall	0.05	0.12	0.35	0.45	0.38	0.36	P. E. Sabine
Ozite 3/8 in	0.051	0.12	0.17	0.33	0.45	0.47	P. E. Sabine
Rug, axminster	0.11	0.14	0.20	0.33	0.52	0.82	Wente and Bedell
Audience, seated oer sq ft of area	0.72	0.89	0.95	0.99	1.00	1.00	W. C. Sabine
Each person, seated	1.4	2.25	3.8	5.4	6.6	—	Bureau of Standards, averages of 4 tests
Each person, seated	—	—	—	—	—	7.0	Estimated
Glass surfaces	0.05	0.04	0.03	0.025	0.022	0.02	Estimated

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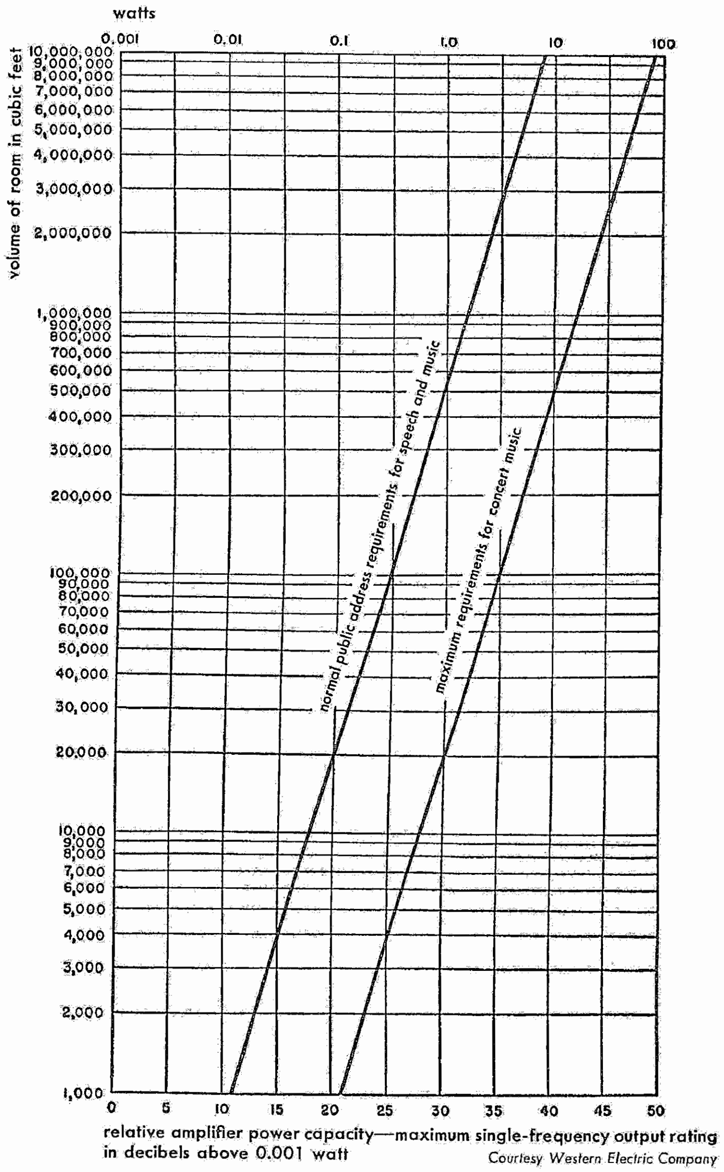
Fig. 10—Table of acoustical coefficients of materials used for acoustical correction

material	cycles/second 128	256	512	1024	2048	4096	noise-red coef *	manufactured by
Corkoustic—B4	0.08	0.13	0.51	0.75	0.47	0.46	0.45	Armstrong Cork Co.
Corkoustic—B6	0.15	0.28	0.82	0.60	0.58	0.38	0.55	Armstrong Cork Co.
Cushiontone A-3	0.17	0.58	0.70	0.90	0.76	0.71	0.75	Armstrong Cork Co.
Koustex	0.10	0.24	0.64	0.92	0.77	0.75	0.65	David E. Kennedy, Inc.
Sanacoustic (metal) tiles	0.25	0.56	0.99	0.99	0.91	0.82	0.85	Johns-Manville Sales Corp.
Permacoustic tiles 3/4 in	0.19	0.34	0.74	0.76	0.75	0.74	0.65	Johns-Manville Sales Corp.
Low-frequency element	0.66	0.60	0.50	0.50	0.35	0.20	0.50	Johns-Manville Sales Corp.
Triple-tuned element	0.66	0.61	0.80	0.74	0.79	0.75	0.75	Johns-Manville Sales Corp.
High-frequency element	0.20	0.46	0.55	0.66	0.79	0.75	0.60	Johns-Manville Sales Corp.
Absorbatone A	0.15	0.28	0.82	0.99	0.87	0.98	0.75	Luse Stevenson Co.
Acoustex 60R	0.14	0.28	0.81	0.94	0.83	0.80	0.70	National Gypsum Co.
Econacoustic 1 in	0.25	0.40	0.78	0.76	0.79	0.68	0.70	National Gypsum Co.
Fiberglas acoustical tiletype TW-PF 9D	0.22	0.46	0.97	0.90	0.68	0.52	0.75	Owens-Corning Fiberglas Corp.
Acoustone D 11/16 in	0.13	0.26	0.79	0.88	0.76	0.74	0.65	U. S. Gypsum Company
Acoustone F 13/16 in	0.16	0.33	0.85	0.89	0.80	0.75	0.70	U. S. Gypsum Company
Acousti-celotex type C-6 1 1/4 in	0.30	0.56	0.94	0.96	0.69	0.56	0.80	The Celotex Corp.
Absorbex type A 1 in	0.41	0.71	0.96	0.88	0.85	0.96	0.85	The Celotex Corp.
Acousteel B metal facing 1 5/8 in	0.29	0.57	0.98	0.99	0.85	0.57	0.85	The Celotex Corp.

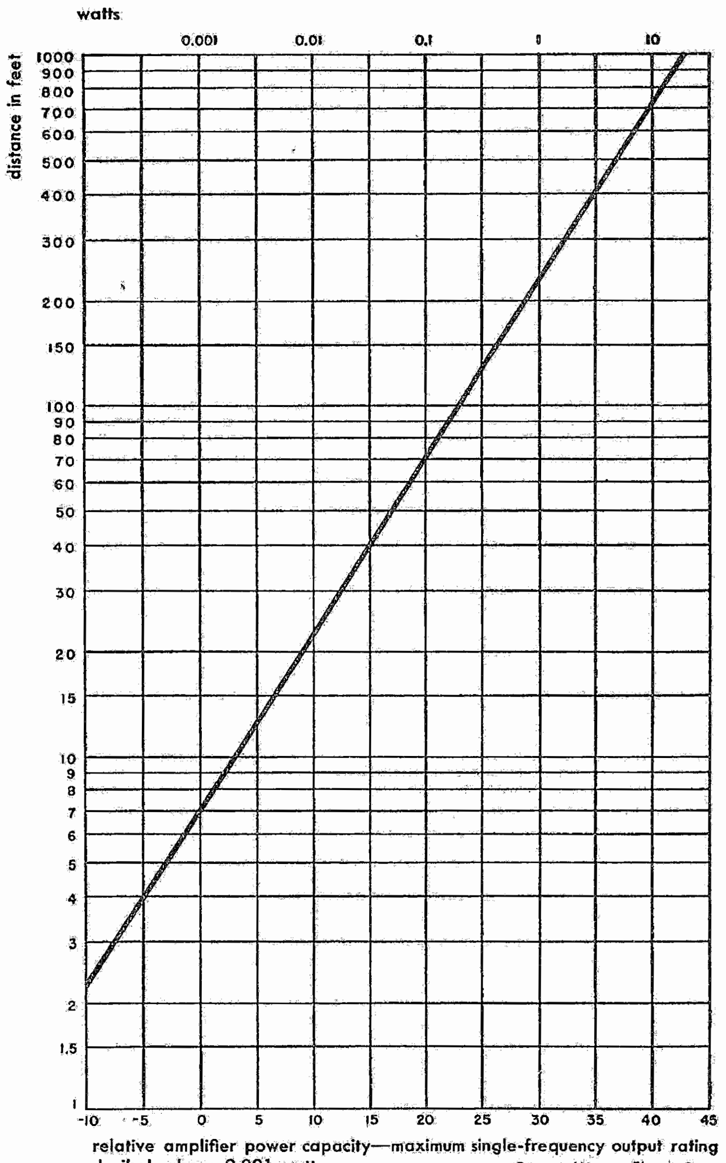
Courtesy Acoustics Materials Association

* The noise-reduction coefficient is the average of the coefficients at frequencies from 256 to 2048 cycles inclusive, given to the nearest 5 percent. This average coefficient is recommended for use in comparing materials for noise-quieting purposes as in offices, hospitals, banks, corridors, etc.



Courtesy Western Electric Company

Fig. 11—Room volume and relative amplifier power capacity. To the indicated power level depending on loudspeaker efficiency, there must be added a correction factor which may vary from 4 decibels for the most efficient horn-type reproducers to 20 decibels for less efficient cone loudspeakers.

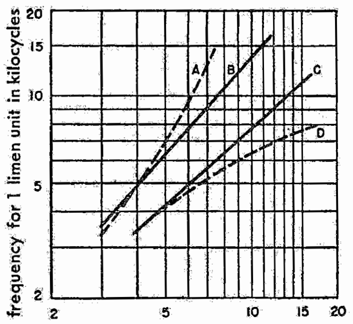


Courtesy Western Electric Company

Fig. 12—Distance from loudspeaker and relative amplifier power capacity required for speech, average for 30° angle of coverage. For angles over 30°, more loudspeakers and proportional output power are required. Depending on loudspeaker efficiency, a correction factor must be added to the indicated power level, varying approximately from 4 to 7 decibels for the more-efficient type of horn loudspeakers.

Fig. 13—Table showing bandwidth increases necessary to give an even chance of quality improvement being noticeable. All figures are in kilocycles.

minus one limen		reference frequency	plus one limen	
speech	music		music	speech
—	—	3	3.0	3.3
3.4	3.3	4	4.8	4.8
4.1	4.1	5	6.0	6.9
4.6	5.0	6	7.4	9.4
5.1	5.8	7	9.3	12.8
5.5	6.4	8	11.0	—
5.8	6.9	9	12.2	—
6.2	7.4	10	13.4	—
6.4	8.0	11	15.0	—
7.0	9.8	13	—	—
7.6	11.0	15	—	—



Courtesy of Bell System Technical Journal

Fig. 14 — Minimum-discernable-band-width changes. Curves show:

A—Plus 1 limen for speech
B—Plus 1 limen for music
C—Minus 1 limen for music
D—Minus 1 limen for speech

and average absorption. Each portion of the surface of a room has a certain absorption coefficient a dependent on the material of the surface, its method of application, etc. This absorption coefficient is equal to the ratio of the energy absorbed by the surface to the total energy impinging thereon at various audio frequencies. Total absorption for a given surface area in square feet S is expressed in terms of absorption units, the number of units being equal to $a_{av}S$.

$$a_{av} = \frac{\text{(total number of absorption units)}}{\text{(total surface in square feet)}}$$

One absorption unit provides the same amount of sound absorption as one square foot of open window. Absorption units are sometimes referred to as "open window" or "OW" units.

$$T = \frac{0.05V}{-S \log_e (1 - a_{av})}$$

where T = reverberation time in seconds, V = room volume in cubic feet, S = total surface of room in square feet, a_{av} = average absorption coefficient of room at frequency under consideration.

For absorption coefficients a of some typical building materials, see Fig. 9. Fig. 10 shows absorption coefficients for some of the more commonly used materials for acoustical correction.

PUBLIC-ADDRESS SYSTEMS[4]

Electrical power levels for public-address requirements

Indoor: Power-level requirements are shown in Fig. 11.

Outdoor: Power-level requirements are shown in Fig. 12.

Note: Curves are for an exponential trumpet-type horn. Speech levels above reference--average 70 db, peak 80 db. For a loudspeaker of 25-percent efficiency, 4 times the power output would be required or an equivalent of 6 decibels. For one of 10-percent efficiency, 10 times the power output would be required or 10 decibels.

SOUNDS OF SPEECH AND MUSIC[5]

A large amount of data are available regarding the wave shapes and statistical properties of the sounds of speech and music. Below are given some of these data that are of importance in the design of transmission systems.

Minimum-discernible-bandwidth changes

Figure 13 gives the increase in high-frequency bandwidth required to produce a minimum discernible change in the output quality of speech and music.

These bandwidths are known as difference-limen units. For example, a system transmitting music and having an upper cutoff frequency of 6000 cycles would require a cutoff-frequency increase to 7400 cycles before there is a 50-percent chance that the change can be discerned. (Curve B, Fig. 14.)

Fig. 14 is based upon the data of Fig. 13. For any high-frequency cutoff along the abscissa, the ordinates give the next higher and next lower cutoff frequencies for which there is an even chance of discernment. As expected, one observes that, for frequencies beyond about 4000 cycles, restriction of upper cutoff affects music more appreciably than speech.

Peak factor

One of the important factors in deciding upon the power-handling capacity of amplifiers, loudspeakers, etc., is the fact that in speech very large fluctuations of instantaneous level are present. Fig. 15 shows the peak factor (ratio of peak to root-mean-square pressure) for unfiltered (or wideband) speech, for separate octave bandwidths below 500 cycles, and for separate ½-octave bandwidths above 500 cycles. The peak values for sound pressure of unfiltered speech, for example, rise 10 decibels higher than the averaged root-mean-square value over an interval of 1/8 second, which corresponds roughly to a syllabic period. However, for a much longer interval of time, say the time duration of one sentence, the peak value reached by the sound pressure for unfiltered speech is about 20 decibels higher than the root-mean-square value averaged for the entire sentence.

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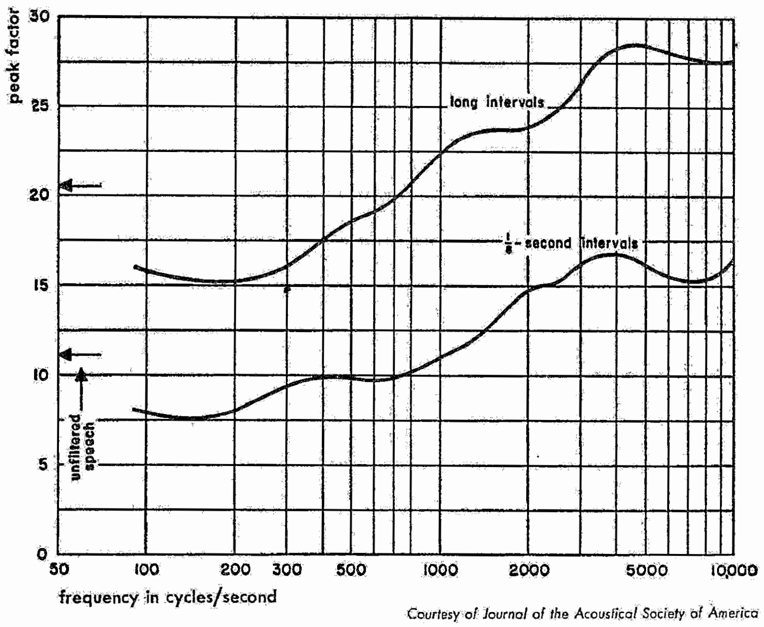
[4] H. F. Olson, "Elements of Acoustical Engineering," 2nd ed., D. Van Nostrand, New York, New York; 1941.

[5] H. Fletcher, "Speech and Hearing," 1st ed., D. Van Nostrand Company, New York, New York; 1929. S. S. Stevens, and H. Davis, "Hearing," J. Wiley and Sons, New York, New York; 1938.



Courtesy of Journal of the Acoustical Society of America

Fig. 15—Peak factor (ratio of peak/root-mean-square pressures) in decibels for speech in 1- and 1/2-octave frequency bands, for 1/8- and 75-second time intervals.

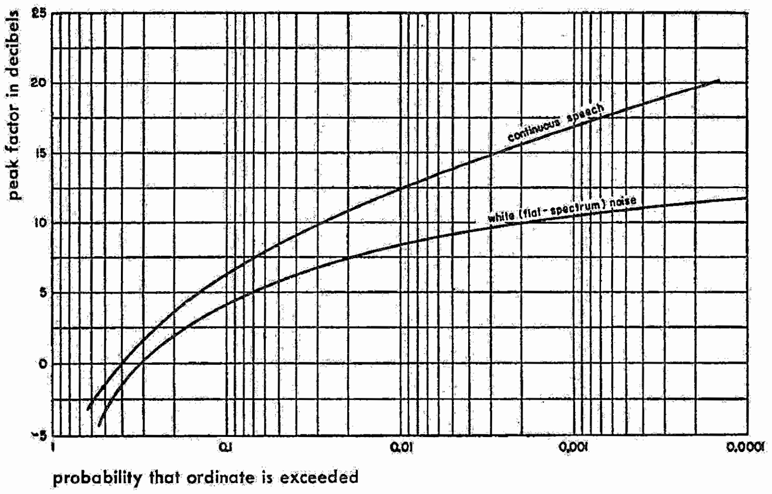


Fig. 16—Statistical properties of the peak factor in speech. The abscissa gives the probability (ratio of the time) that the peak factor in the uninterrupted speech of one person exceeds the ordinate value. Peak factor = (decibels instantaneous peak value) — (decibels root-mean-square long-time average).

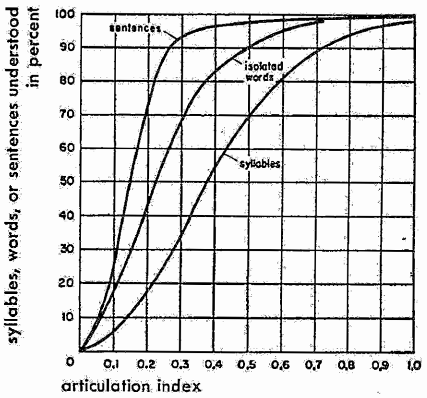
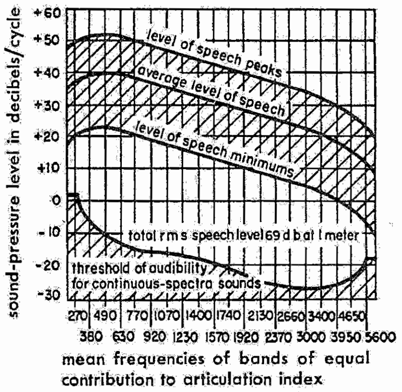


Fig. 17—Relations between various measures of speech intelligibility. Relations are approximate; they depend upon the type of material and the skill of the talkers and listeners.



Courtesy of Proceedings of the I.R.E.

Fig. 18—Bands of equal articulation index. 0 decibels = 0.0002 dyne/centimeter.

Thus, if the required sound-pressure output demands a long-time average of, say, 1 watt of electrical power from an amplifier, then, to take care of the instantaneous peaks in speech, a maximum-peak-handling capacity of 100 watts is needed. If the amplifier is tested for amplitude distortion with a sine wave, 100 watts of peak-instantaneous power exists when the average power of the sine-wave output is 50 watts. This shows that if no amplitude distortion is permitted at the peak pressures in speech sounds, the amplifier should give no distortion when tested by a sine wave of an average power 50 times greater than that required to give the desired long-time-average root-mean-square pressure.

The foregoing puts a very stringent requirement on the amplifier peak power. In relaxing this specification, one of the important questions is what percentage of the time will speech overload an amplifier of lower power than that necessary to take care of all speech peaks. This is answered in Fig. 16; the abscissa gives the probability of the

$\frac{\text{peak}}{\text{long-time-average}}$ powers exceeding the ordinates

for continous speech and white noise. When multiplied by 100, this probability gives the expected percent of time during which peak distortion occurs. If 1 percent is taken as a suitable criterion, then a 12 decibel ratio of

$\frac{\text{peak}}{\text{long-time-average}}$ powers is sufficient. Thus,

the amplifier should be designed with a power reserve of 16 in order that peak clipping may occur not more than about 1 percent of the time.

SPEECH-COMMUNICATION SYSTEMS

In many applications of the transmission of intelligence by speech sounds, a premium is placed on intelligibility rather than flawless reproduction. Especially important is the reduction of intelligibility as a function of both the background noise and the restriction of transmission-channel bandwidth. Intelligibility is usually measured by the percentage of correctly received monosyllabic nonsense words uttered in an uncorrelated sequence. This score is known as syllable articulation. Because the sounds are nonsense syllables, one part of the word is entirely uncorrelated with the remainder, so it is not consistently possible to guess the whole word correctly if only part of it is received intelligibly. Obviously, if the test speech were a commonly used word, or say a whole sentence with commonly used word sequences, the score would increase because of correct guessing from the context. Fig. 17 shows the interrelationship between syllable, word, and sentence articulation. Also given is a quantity known as articulation index.

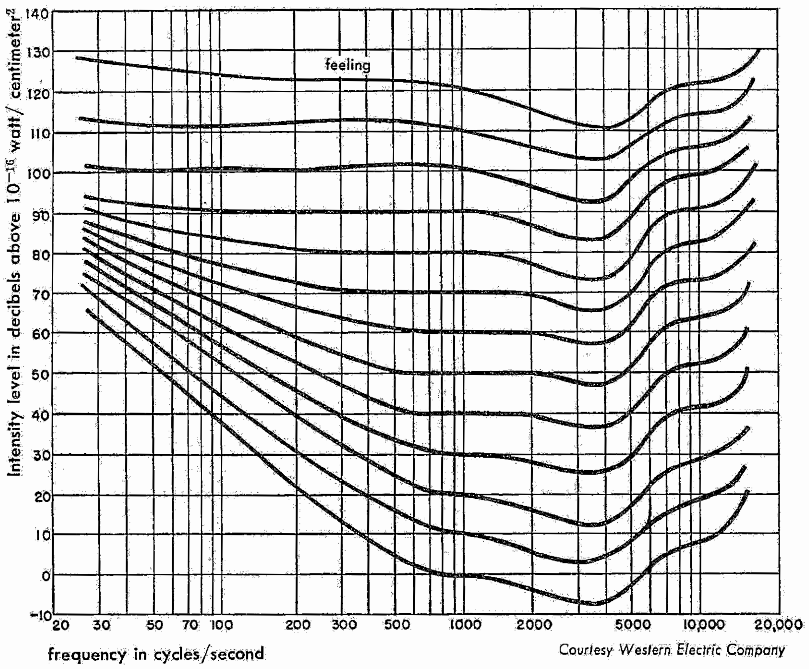
The concept and use of articulation index is obtained from Fig. 18. The abscissa is divided into 20 bandwidths of unequal frequency interval. Each of these bands will contribute 5 percent to the articulation index when the speech spectrum is not masked by noise and is sufficiently loud to be above the threshold of audibility. The ordinates give the root-mean-square peaks and minimums (in 1/8-second intervals), and the average sound pressures created at 1 meter from a speaker's mouth in an anechoic (echo-free) chamber. The units are in decibels pressure per cycle relative to a pressure of 0.0002 dynes/centimeter^2. (For example, for a bandwidth of 100 cycles, rather than 1 cycle, the pressure would be that indicated plus 20 decibels; the latter figure is gotten by taking 10 times logarithm (to the base 10) of the ratio of the 100-cycle band to the indicated band of 1 cycle.)

An articulation index of 5 percent results in any of the 20 bands when a full 30-decibel range of speech-pressure peaks to speech-pressure minimums is obtained in that band. If the speech minimums are masked by noise of a higher pressure, the contribution to articulation is accordingly reduced to a value given by 1/6 [(decibels level of speech peaks) - (decibels level of average noise)]. Thus, if the average noise is 30 decibels under the speech peaks, this expression gives 5 percent. If the noise is only 10 decibels below the speech peaks, the contribution to articulation index reduces to (1/6) x 10 = 1.67 percent. If the noise is more than 30 decibels below the speech peaks, a value of 5 percent is used for the articulation index. Such a computation is made for each of the 20 bands of Fig. 18, and the results are added to give the expected articulation index.

A number of important results follow from Fig. 18. For example, in the presence of a large white (thermal-agitation) noise having a flat spectrum, an improvement in articulation results if pre-emphasis is used. A pre-emphasis rate of about 8 decibels/octave is sufficient.

LOUDNESS

Equal loudness contours: Fig. 19 gives average hearing characteristics of the human ear at audible frequencies and at loudness levels of zero to 120 decibels versus intensity levels expressed in decibels above 10^{-16} watt per square centimeter. Ear sensitivity varies considerably over the audible range of sound frequencies at various levels. A loudness level of 120 decibels is heard fairly uniformly throughout the entire audio range but, as indicated in Fig. 19, a frequency of 1000 cycles at a 20-decibel level will be heard at very nearly the same intensity as a frequency of 60 cycles at a 60-decibel level. These curves explain why a loudspeaker operating at lower-than-normal level sounds as though the higher frequencies were accentuated and the lower tones seriously attenuated or entirely lacking; also, why music, speech, and other sounds, when reproduced, should have very nearly the same intensity as the original rendition. To avoid perceptible deficiency of lower tones, a symphony orchestra, for example, should be reproduced at an acoustical level during the loud passages of 90 to 100 decibels.



Courtesy Western Electric Company

Fig. 19—Equal loudness contours.

PRACTICAL DESIGN OF VIDEO AMPLIFIERS

By Elliott A. Henry

(Reprinted through the courtesy of the RCA Victor Division, Radio Corporation of America.)

Revised 1949 by Mr. Henry, now with Globe Products Corp., Bridgeport, Conn.

In the past few years many excellent articles and papers have been published in various technical magazines on the subject of video amplifiers and the many types of compensation used to extend the frequency range of resistance-capacity-coupled amplifiers. The majority of these articles have dealt with the mathematical analysis or have had primarily a theoretical approach. A few have presented a generalized introductory discussion of the subject. It seems that a wide gap exists in the published information on this subject. It is the intent of this article to attempt to bridge that gap by presenting practical design data for video amplifiers. The mathematics will be kept to simple algebra. Such other information as is pertinent to the subject, for example, some data on vacuum tubes, will be included for the sake of completeness.

If the underlying causes of trouble or limitations of performance are thoroughly understood, it will be easier to comprehend the methods of overcoming these limitations. We shall, therefore, commence this article with a discussion of the factors limiting the frequency range of the conventional R-C (resistance-capacitance) coupled amplifier.

As pentode tubes are almost universally used in video amplifiers, the following discussion will be based primarily upon their use and on the assumption that the value of the grid resistor is much greater than the plate load impedance, as is the case in video amplifiers. However, as triodes are occasionally used, sufficient data are included to cover the compensation of triode amplifier stages also.

In order better to understand the frequency response limitations of conventional R-C coupled amplifiers, let us examine the plot of output voltage versus frequency, Figure 2, of a typical amplifier stage, Figure 1.

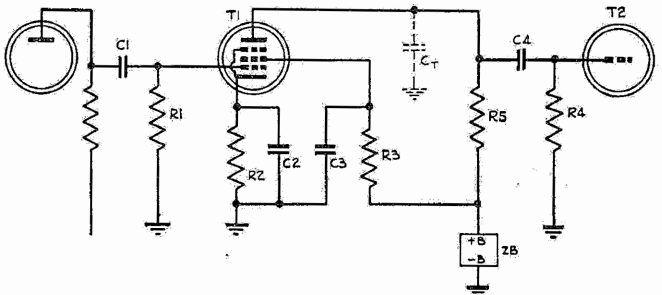


FIG. 1. *Conventional R-C coupled amplifier stage.*

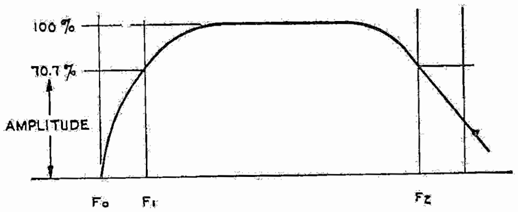


FIG. 2. *Gain-Frequency plot of Figure 1.*

At F_0, zero frequency, the output voltage is zero. As the frequency is increased, the output voltage rises to a maximum somewhat higher in frequency than F_1, remains essentially constant until the frequency is somewhat lower than F_2, and then continually decreases as the frequency is further increased. The two frequencies, F_1 and F_2, are considered the useful limits of the pass-band of an audio frequency amplifier and are the frequencies at which the output of the amplifier is 70.7% of the output at the mid-frequency range. This loss of response, or output, of the amplifier at F_1 and lower and at F_2 and higher both result from the change of reactance (X_c) of condensers with the change in frequency. Either the high or low frequencies will be attenuated, depending upon the location or function of the various condensers, including stray and circuit capacities. In order to demonstrate this more clearly, high and low frequency attenuation will be considered as separate problems.

Unequal gain in an amplifier is referred to as frequency distortion because a complex wave in passing through the amplifier will have its wave shape altered, or distorted, if all of its harmonic components do not receive the same degree of amplification. If the phase delay is not proportional to frequency, the wave may be further distorted. This is called phase distortion.

In the following discussion major emphasis has been placed on the frequency response rather than the phase characteristic of amplifiers. This has been done for two reasons: First, to keep the mathematics to simple algebra; second, an amplifier compensated in accordance with the design data herein presented will be corrected for both frequency and phase distortion and it is perhaps easier to visualize results in terms of frequency response rather than phase characteristic. The importance of the phase characteristic of a video amplifier cannot be over emphasized. For example, an amplifier stage with a response curve such as Figure 2 would not be suitable for video work as the phase angle would increase 45° at F_1 and decrease 45° at F_2 from the mid-frequency value and therefore a change in the phase angle of 90° over the operating range F_1 and F_2. General practice indicates that the frequency response should not drop more than 2% of F_1 and F_2 in a video amplifier if these frequencies are to be considered the limits of the useful pass band of the amplifier.

LOW FREQUENCY ATTENUATION

Low frequency attenuation, or low frequency distortion as it is sometimes called, may be introduced in any one of four places or any combination of the four. Referring to Figure 1, these four places or networks are: the grid resistor-condenser coupling network, R_1-C_1 or R_4-C_4; the cathode resistor by-pass condenser network, R_2-C_2; the screen resistor by-pass condenser network, R_3-C_3; and the internal impedance, Z_b, of the power supply. How the grid resistor-condenser combination acts to reduce the gain at low frequencies may be seen by referring to Figure 3.

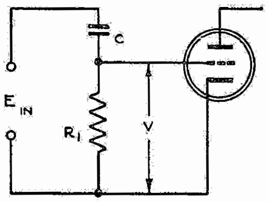


FIG. 3. *Grid coupling network.*

With E constant, the voltage, V, impressed across the grid to cathode may be expressed as $\frac{V}{E}$ and is equal to the resistance, R, divided by the impedance of R and C or:

$$\frac{R}{\sqrt{R^2 + X_c^2}} = \frac{V}{E} \qquad (Eq.\ 1)$$

As the reactance of a condenser is inversely proportional to frequency, the ratio of resistance to impedance, and thus $\frac{V_1}{E}$ decreases as the frequency decreases. This means the voltage available to drive the following stage is less at the low frequencies than at the high frequencies; and with the gain in the tube equal at both frequencies, the output voltage will be down in the same proportion as the input voltage. This ratio $\frac{V_1}{E}$ expressed in percentage, is the coupling efficiency of the grid resistor-condenser combination. For example, let us assign values to R and C, Figure 3, and with a constant voltage, E_{in}, see how V varies with frequency.

If
C = .05 ufd.
R = 250,000 ohms
E_{in} = 10 volts

and the two frequencies are

F_1 = 30 cycles
F_2 = 1000 cycles

then at F_2: $X_c = \frac{1}{2\pi\ FC} = 3184$ ohms.

From Equation 1:

$$\frac{V}{10} = \frac{25 \times 10^4}{\sqrt{625 \times 10^8 + 10.1 \times 10^6}} = \frac{250{,}000}{250{,}020} \cong 1$$

Therefore, V $\cong$ 10 volts or a coupling efficiency of practically 100% at 1000 cycles.

At F_1:

$$X_c = 10.6 \times 10^4 \text{ ohms}$$

$$\frac{V}{10} = \frac{25 \times 10^4}{\sqrt{625 \times 10^8 + 112 \times 10^8}} = \frac{25}{27.2} = .92$$

So V = 9.2 volts and the coupling efficiency is 92% at 30 cycles. Therefore, the output voltage of the stage will be 8% lower at 30 cycles than at 1000 cycles, other factors being equal.

Low frequency distortion may result from the cathode resistor-condenser combination, R_2-C_2 of Figure 1. This results from degeneration, as the impedance in the cathode circuit will vary with frequency, and the gain of a stage with cathode degeneration is reduced by the factor:

$$\frac{1}{1 + G_m Z_k} \qquad (Eq.\ 2)$$

In other words, the gain of a stage, other things being equal, is:

$$A = A_1 \times \frac{1}{1 + G_m Z_k} = \frac{A_1}{1 + G_m Z_k} \qquad (Eq.\ 3)$$

where A is the actual stage gain, and
A_1 is the stage gain without degeneration,
G_m is the mutual conductance in Mhos,
Z_k is the cathode circuit impedance (impedance of R_2-C_2 in parallel) in ohms.

This impedance, Z_k, is detailed in Figure 4 and is given by:

$$Z_k = \frac{R X_c}{\sqrt{R^2 + X_c^2}} \qquad (Eq. 4)$$

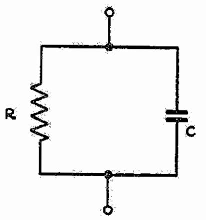


FIG. 4. *Equivalent cathode or plate load network.*

Thus if, in Figure 1, R_2 was 1000 ohms, C_2 was 10 ufd., G_m 5000 umhos, and the stage gain without degeneration 10, the actual gain at 1000 cycles would be:

$$X_{C2} = 15.9 \text{ ohms at } 1000 \text{ cycles}$$

$$Z = \frac{1000 \times 15.9}{\sqrt{10^6 + 253}} = \frac{15{,}900}{1000.125} \cong 15.9 \text{ ohm}$$

$$A = \frac{10}{1 + .005 \times 15.9} = \frac{10}{1 + .0795} = 9.25$$

or a loss of gain at 1000 cycles of 7.5%. Now let's see what the gain of the same stage is for a frequency of 20 cycles.

$$X_{C2} \cong 800 \text{ ohms at } 20 \text{ cycles}$$

$$Z = \frac{10^3 \times 800}{\sqrt{10^6 + 64 \times 10^4}} = \frac{8 \times 10^5}{\sqrt{164 \times 10^4}} = \frac{8 \times 10^5}{1280} = 625 \text{ ohms}$$

$$A = \frac{10}{1 + .005 \times 625} = \frac{10}{1 + 3.125} = \frac{10}{4.125} = 2.42$$

Thus, the output of the stage under these conditions will be only about one-fourth, at 20 cycles, of the output at 1000 cycles.

The effect of R_3-C_3, Figure 1, is similar in effect to the results of cathode degeneration mentioned above; but as the screen current is only about 10% of the plate current and the screenplate transconductance only about 12% of the control grid, or cathode, to plate transconductance, the effect is much smaller and can usually be made negligible by making the time constant of R_3-C_3 at least three times as long as the period of the lowest frequency it is desired to pass.

$$\text{Or, } TC = RC > 3 \frac{1}{F} \qquad (Eq. 5)$$

where C is in farads,
R is in ohms,
F is the lowest frequency in the pass-band.

The total impedance of the screen circuit is essentially the reactance of C_3; and, whereas in the case of cathode degeneration, if the product of G_m Z_k equals one, the gain will be reduced 50%, the effect of the screen is so much less that a reduction of gain, at the lowest frequency, of only 2% would result if G_m Z_s equaled 2 (G_m being the control grid-plate transconductance).

For example, a 6F6 is desired to pass 30 cycles (Figure 1).

$$Z_s \cong X_{C3} \quad \text{then } X_{C3}\, G_m = 2$$

$$X_{C3} = \frac{2}{G_m} = \frac{2 \times 10^6}{2500} = 800 \text{ ohms.}$$

$$X_{C3} = 800 \text{ ohms at } 30 \text{ cycles} - 6.64 \text{ ufd.}$$

We would use the next larger commercial size, or 8 ufd. To determine R_3:

$$RC = 3 \frac{1}{F} = \frac{3}{F} = \frac{3}{30} = .1$$

$$R = \frac{.1 \times 10^6}{8} = \frac{10^5}{8} = 12{,}500 \text{ ohms}$$

Therefore, we would use a value of 12,500 ohms or larger for R_3.

In the event that the value of the screen voltage dropping resistor, R as determined above, should be too large to allow the proper screen current, R may be set by screen requirements and the by-pass condenser C, determined from equation 5 using R as selected and solving for C.

The fourth place for low frequency distortion is the internal impedance of the power supply, Z_b. Unless a regulated power supply of the electronic type is used, the impedance is essentially the reactance of the output filter condenser and will vary with frequency as outlined previously. A method for making the effect of this impedance negligible is the use of R-C filters. These filters, if properly designed, may also provide correction for either R_1-C_1 or R_2-C_2, Figure 1, but not both at the same time. Design data for these correction networks is given in the section on low frequency compensation.

LOW FREQUENCY CORRECTION

Of the four places or networks at which low frequency distortion may be introduced, two, R_3-C_3 and Z_b, can be made negligible by proper design. In addition to making negligible the internal impedance of the power supply, we may correct for either R_1-C_1 or R_2-C_2 by the addition of an R-C filter, C_5-R_6, Figure 5.

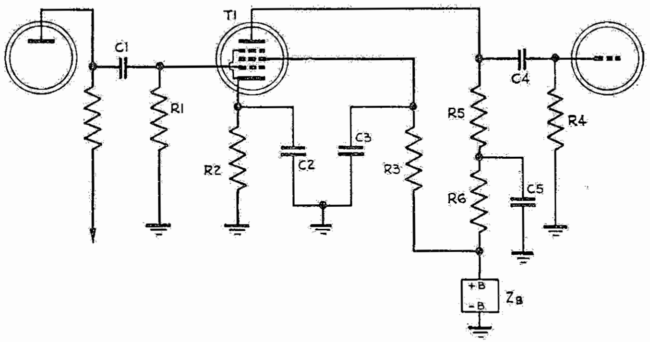


FIG. 5. *Amplifier stage with low frequency correction network (R_6-C_5).*

To correct for R_1-C_1 or R_4-C_4: Make the grid resistor (R_1 or R_4) as high as permissible; 500,000 ohms is a convenient value. Make the coupling condenser (C_1 or C_4) a nominal value such as .1 ufd. It is desirable to keep this value high but care must be taken to avoid making the capacity too large or trouble may be encountered from leakage and "hang over" effects. Now make the time constant of the grid resistor-condenser (R_1-C_1 or R_4-C_4) equal to the time constant of R_5-C_5 and make R_6 greater than 20 times the reactance of C_5 at the lowest frequency it is desired to pass. For example: If in Figure 5 we make R_4 equal 500,000 ohms, C_4 equal .1 ufd., R_5 equal 1000 ohms, and desire to provide correction to 30 cycles, then the time constant of R_4-C_4 will equal .05 seconds or 50,000 microseconds. Leaving the TC in u's, will give our answer directly in ufds.

$$TC = RC = .1 \times 500{,}000 = 50{,}000$$

$$\text{and } C_5 = \frac{50{,}000}{1{,}000} = 50 \text{ ufd.}$$

and $R_6 > 20\ X_{C5}$ at 30 cycles $= 20 \times 106 = 2120$ ohms or greater.

What actually happens is that as the voltage across R_4 decreases, as a result of the rising reactance of C_4 (as the frequency is decreased), the reactance of C_5 also increases and as a consequence, the parallel impedance of C_5-R_6 is added to R_5 as part of the plate load impedance. Where the plate load is small in comparison to the plate resistance, the gain from grid to plate is given by:

$$A = G_m Z_p \qquad (Eq.\ 6)$$

where A is the stage gain,
G_m is the transconductance in mhos,
Z_p is the plate load impedance.

As we have made the time constants of C_4-R_4 and C_5-R_5 equal, the voltage across the plate load impedance will rise in proportion to the loss of voltage across C_4 and the voltage across R_4 will remain constant.

It might be pointed out that although at times it is expedient to make either C_4 or R_4 somewhat lower in value, such as to use a standard size capacitor for C_5, this should be done with caution. If the values of C_4 or R_4 are reduced, the amount of correction necessary is increased and errors become magnified. Good practice demands good design first so that minimum correction need be used.

If it is desired we may use C_5-R_6 to compensate for the frequency distortion of R_2-C_2 instead of R_1-C_1. To see how this can be done refer again to Figure 5. It has been previously shown that the impedance in the cathode circuit varies with frequency; and therefore, the AC voltage developed across this impedance will be, according to ohms law:

$$E = IZ \qquad (Eq.\ 7)$$

and, therefore, a function of frequency. This voltage will appear across the plate load resistor, R_5, amplified by the stage gain. Now the plate current flows through both R_2-C_2 and R_6-C_5, so the same kind of distortion will be generated in both circuits if the time constants are equal; but as the current flows through these networks in opposite directions, the distortion across R_5, resulting from R_2-C_2, will be cancelled by the distortion from C_5-R_6, if the distortion components are equal in magnitude. This condition is met when:

$$R_2\ C_2 = R_6\ C_5 \qquad (Eq.\ 8)$$

$$\text{and } \frac{C_2}{C_5} = \frac{R_6}{R_2} = A$$

where A equals the stage gain as defined in Equation 6 for pentodes and Equation 11 for triodes. For example, if we assign values of 200 ohms to R_2 (Figure 5), a nominal value of 100 ufd. to C_2, and a stage gain of 10, and wish to determine the value of C_5 and R_6 then:

$$\frac{C_2}{C_5} = \frac{100}{C_5} = 10 \text{ so } C_5 = 10 \text{ ufd.}$$

$$\frac{R_6}{R_2} = \frac{R_6}{200} = 10 \text{ so } R_6 = 2000 \text{ ohms}$$

The second condition may be checked by substituting in Equation 8:

$$200 \times 100 = 2000 \times 10$$
$$1 = 1$$

Therefore, both conditions have been met. There will be no frequency distortion from plate to ground resulting from R_2-C_2 and the phase delay will be proportional to frequency. However, more about the phase delay later.

We now find ourselves in the position of being able to make two of the four circuits causing low frequency distortion negligible and being able to compensate for either of the other two but not both. Now without compensating, as previously explained, the only way of minimizing the effects of the coupling efficiency of R_1-C_1 or R_4-C_4, Figure 5, is by increasing the values of either the resistor, condenser, or both. There are limits as to how far this can be carried, and generally the reactance of the coupling condenser cannot be kept low enough, at the lowest frequency, to give completely satisfactory results. So it is generally good practice to utilize C_5-R_6 to compensate for R_1-C_1 or R_4-C_4 and use other means to minimize the effects of R_2-C_2, Figure 5.

There are three methods generally used to accomplish this. First, eliminate R_2-C_2, ground the cathode directly, and apply fixed bias to the tube through the grid resistor. Second, eliminate the cathode by-pass condenser, C_2, and accept the consequent loss in stage gain. The gain will be reduced by the factor given in Equation 2; but the reduction in gain will be constant at all frequencies, so with other factors being equal there will be no low frequency distortion. The third method is to make C_2 very large and accept what comes out. This is not as bad as it sounds, since 1000 ufd. low voltage electrolytics are available at reasonable costs and certainly cost less than an additional stage which might be required to bring up the overall gain of the amplifier. The reactance of a 1000 ufd. condenser at 30 cycles is 5.31 ohms and in the average circuit will cause negligible distortion.

HIGH FREQUENCY ATTENUATION

As we have seen from the foregoing, there are four places, or networks, in the conventional amplifier at which the low frequency output may be restricted, and actually only one place that correction may be applied (the others however being made negligible). The opposite is true for the high frequency limitations. We have only one (or what may be summed up and treated as one) place, or network, responsible for the reduction of output at the higher frequencies (F_2 and higher in Figure 2), but we have a choice of several correction circuits. For an explanation, let's take another look at Figure 4. We have a resistance, R, in parallel with a capacity, C. The impedance of this network is given by:

$$Z = \frac{R \times X_c}{\sqrt{R^2 + X_c^2}} \qquad (Eq. 9)$$

and, therefore, the impedance Z will be a function of frequency. Now if we let R, Figure 4, represent the plate load resistance of an amplifier stage such as R_5 in Figure 1 and C represent the total shunt reactance across this load resistor such as C_T in Figure 1, we can calculate the effective load impedance for any frequency. Equation 6 shows that where the plate load impedance is much less than the plate resistance of the tube, the gain of the stage is directly proportional to the plate load impedance. In other words, if the G_m of a tube is 9,000 umhos and the load impedance is 1000 ohms, the gain would be 9; while if the load impedance were raised to 2000 ohms, the gain would be 18. It is this shunt reactance in parallel with the plate load resistor that limits the high frequency response of the amplifier. This reactance is composed (Figure 1) of the output capacity of T_1 plus the input capacity of T_2 plus the stray circuit capacity, and summed up as C_T.

CIRCUIT AND STRAY CAPACITIES

Before taking up the problem of compensating for this condition, methods for determining C_T should be discussed, as all systems of high frequency compensation depend upon accurate knowledge of this capacity.

The input capacity, C_{in}, of a tube is defined as the capacity from the grid to all other elements and the output capacity, C_{out}, of a tube as the capacity from the plate to all other elements. This is emphasized because of the usual practice in tube manuals of listing the static inter-element capacities of triodes and summing the capacities up into C_{in} and C_{out} for multi-grid tubes. A good reason for this is that the dynamic capacities of triodes are more subject to variations than screen-grid tubes. Therefore, when dealing with triodes, remember to add the grid-place, C_{gp}, capacity to the plate-cathode, C_{pk}, capacity to determine the total output capacity, C_{out}; or for triodes,

$$C_{out} = C_{pk} + C_{gp}$$

In the case of a 6J5 where the tube manual lists C_{pk} as 3.6 uuf. and C_{gp} as 3.4, the output capacity will be 3.6 + 3.4 = 7.0 uuf.

In determining the effective, or dynamic, input capacity of a triode, the "Miller Effect" must be considered. When a triode is acting as an amplifier, the grid and plate voltages are out of phase. That is, if the grid voltage is changed one volt in the positive direction and the gain is ten, the plate voltage will decrease ten volts. This gives a net change of eleven volts between the grid and plate and results in a capacity current in the grid circuit eleven times above the normal capacity current. This is known as the "Miller Effect," and from the above it can be seen that the dynamic input capacity is a function of the stage gain. The dynamic input capacity of a triode is given by:

$$C_{in} = C_{gk} + \left[C_{gp} \; (1 + A) \right] \qquad (Eq. 10)$$

where C_{in} is the dynamic input capacity.
C_{gk} is the capacity from grid to cathode,
C_{gp} is the capacity from grid to plate,
A is the stage gain.

From Equation 10 it is evident that the stage gain must be known before the dynamic input capacity can be determined. The gain of a triode is given by:

$$A = \frac{u \; Z_L}{Z_L + R_P} \qquad (Eq. 11)$$

where A is the stage gain,
u is the amplification factor of the tube,
Z_l is the plate load,
R_p is the plate resistance of tube.

For example, determine the stage gain and dynamic input capacity of a 6J5 working into a 20,000 ohm plate load. From the tube manual the plate resistance is 6700 ohms, u is 20, C_{gk} is 3.4 uuf., and C_{gp} is 3.4 uuf.

From Equation 11:

$$(Z_L = R_L)$$

$$A = \frac{20 \times 2 \times 10^4}{2 \times 10^4 + 67 \times 10^2} = \frac{4 \times 10^5}{2.67 \times 10^4} \cong 15$$

From Equation 10:

$$C_{in} = 3.4 + \left[3.4 \; (1 + 15) \right] = 3.4 + 54.4 = 57.8 \text{ uuf.}$$

which is quite an increase from the static capacities.

Where the load of a triode is in the cathode instead of the plate circuit, cathode follower stage, the dynamic input capacity is given by Equation 31 in the cathode follower section. The grid to cathode capacity C_{gk} of any amplifier tube is modified, where cathode degeneration exists, by the factor $1 + G_m R_k$ where the cathode is unby-passed, and $1 + G_m Z_k$ where the cathode is partially by-passed and Z_k given by Equation 4. This reduction factor is seen to be the same as for the reduction of gain with cathode degeneration.

$$C_{eff} \cong C_{gk} \frac{1}{1 + G_m Z_k} = \frac{C_{gk}}{1 + G_m Z_k} \qquad (Eq. 12)$$

where C_{eff} is the effective capacity grid to cathode, C_{gk}
C_{gk} is the grid to cathode capacity without degeneration,
G_m is the transconductance in mhos,
Z_k is the cathode impedance.

In a pentode if the screen is by-passed to the cathode the entire input capacity may be degenerated. This, however, reduces the effective shielding of the screen grid. For example, determine the dynamic input capacity of an 1852 with an unby-passed 160 ohm cathode resistor ($Z_k = R_k$).

From Equation 12:

$$C_{eff} = \frac{11}{1 + .009 \times 160} = \frac{11}{1 + 1.44} = \frac{11}{2.44} = 4.52 \text{ uuf.}$$

With the screen by-passed to ground the effective input capacity would be about 10% higher.

Determining the stray capacity is perhaps the hardest job. There are no hard and fast rules for determining these strays. Sometimes the capacity of individual components to ground are measured and summed up but generally they are estimated as close as possible, which may involve a bit of "cut and try." Nominal variations are usually compensated for in critical or very wide band amplifiers by making the "peaking coil" with a variable hi-permeability iron core and adjusting the inductance during alignment of the amplifier. A close approximation of the stray capacity is 10 to 15 uuf. in a well-designed layout.

Another method of determining C_T is by measuring the gain of an uncompensated amplifier stage, Figure 1, in the mid-frequency range (between F_1 and F_2, Figure 2) and then measuring the frequency at which the gain drops to 70.7% of the mid-frequency gain. This will be F_2 in Figure 2. In an uncompensated amplifier the magnitude of C_T that, with a given plate load resistor, will cause the gain of the amplifier to drop to 70.7% of the mid-frequency gain, F_2, Figure 2, is given by:

$$C_T = \frac{1}{2\pi \; F \; R} \qquad (Eq. 13)$$

where C_T is in farads,
F is in cycles,
R is in ohms.

Essentially this states that when the shunt reactance across the plate load resistor and the resistor are equal, the response will drop to 70.7% of the mid-range value (Equation 4).

For example, by using the circuit in Figure 1, with R_5 1000 ohms, and a wide range vacuum tube voltmeter connected from plate to ground, we could determine C_T by measuring the voltage across R_5, with a constant voltage input to the grid of T_1, around 2500 cycles and then increasing the frequency until the voltage was 70.7% of the initial value. This frequency can then be substituted in equation 13, and we can solve for C_T. The C_T thus determined will include the input capacity of the vacuum tube voltmeter and this vacuum tube voltmeter input capacity must be subtracted from the calculated C_T. In order to minimize errors on the input voltage to the grid of T_1, resulting from shunt reactance across the grid, R_1 should be made very low in value, 50 to 100 ohms, while making the measurements.

As a practical example, if we proceed as above and measure 10 volts across R_5 at 2500 cycles and 7.07 volts at 2mc., then substituting in equation 36:

$$C_T = \frac{10^{12}}{6.28 \times 2 \times 10^6 \times 10^3} = \frac{10^3}{12.56} = 79.6 \text{ uuf.}$$

But we must subtract from this capacity the capacity of the vacuum tube voltmeter and assuming the vacuum tube voltmeter capacity to be 22 uuf., C_T will equal 79.6 minus 22 or 57.6 uuf. This value will include all circuit and stray capacity, and may be used as the basis for calculating the high frequency compensation networks, as outlined later. When the peaking coil is added to the circuit, care should be used in its mounting to disturb the circuit as little as possible. A good practice is to have a peaking coil of the same physical size mounted in place *but shorted out* during the above measurements. If the peaking coil is placed as in Figure 6, the effect of the capacity to ground of the peaking coil is minimum.

HIGH FREQUENCY COMPENSATION

In low frequency compensation we found it necessary to make the plate load impedance, and consequently the voltage gain, rise in proportion to the loss in voltage across C_4, Figure 5. In high frequency compensation, however, it is necessary to keep the plate load impedance, and thus the stage gain, constant over the desired frequency range.

One way of accomplishing this is to add an inductive reactance to the plate load network to counteract the effect on impedance, of the change of capacitive reactance with frequency, of the shunt circuit and stray capacity. Such a network is shown in Figure 6, and its impedance can be made essentially constant, from zero frequency up to any frequency where the network proportions are such that the reactance of C is equal to the resistance of R and twice the reactance of L. The impedance of this network is given by:

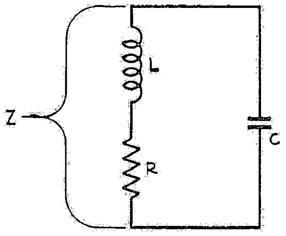


FIG. 6. *Basic shunt peaked network.*

$$Z = X_c \sqrt{\frac{R^2 + X_L^2}{R^2 + (X_c - X_L)^2}} \qquad (Eq. 14)$$

Actually if a plot of impedance versus frequency is made, using the proportions above, it will be found that the impedance begins to rise at a frequency .2F where F is the chosen correction frequency and gradually rises as the frequency is increased to approximately .6F and then decreases, becoming equal to the low frequency impedance at F. The magnitude of this increase is about .5% at .2F and 3% at .6F. For example, if we assume F to be 5 mc., C to be 31.8 uuf., L to be 15.9 uh, and R to be 1000 ohms, the impedance, Figure 6, will be:

At 5 mc. $X_c = 1000$ ohms

$X_L = 500$ ohms

$$Z = 1000 \sqrt{\frac{10^6 + 25 \times 10^4}{10^6 \ (1000\text{-}500)^2}} = 1000 \sqrt{\frac{1.25 \times 10^6}{1.25 \times 10^6}}$$

$$= 1000 \sqrt{1} = 1000 \text{ ohms}$$

At 4.5 mc. $X_c = 1112$ ohms

$X_L = 450$ ohms

$$Z = 1112 \sqrt{\frac{10^6 + .2025 \times 10^6}{10^6 + (1112\text{-}450)^2}} = 1112 \sqrt{\frac{1.2025 \times 10^6}{1.43825 \times 10^6}}$$

$$= 1112 \sqrt{.834} = 1112 \times .913 = 1016 \text{ ohms}$$

At 3 mc. $X_c = 1668$ ohms

$X_L = 300$ ohms

$$Z = 1668 \sqrt{\frac{10^6 + 9 \times 10^4}{10^6 + (1668\text{-}300)^2}} = 1668 \sqrt{\frac{1.09 \times 10^6}{2.87155 \times 10^6}}$$

$$= 1668 \sqrt{.37966} = 1668 \times 616165 = 1027 \text{ ohms}$$

At 1 mc. $X_c = 5000$ ohms

$X_L = 100$ ohms

$$Z = 5000 \sqrt{\frac{10^6 + 10^4}{10^6 + 24.01 \times 10^6}} = 5000 \sqrt{\frac{1.01 \times 10^6}{25.01 \times 10^6}}$$

$$= 5000 \sqrt{.040384} = 5000 \times .201 = 1005 \text{ ohms}$$

This plate load network is a parallel resonant circuit of very low Q and we are actually working along the resonance curve. By increasing the correction frequency, F, the linearity over a desired frequency range can be made almost perfect at a sacrifice of gain. Design data for this is covered under "Shunt Peaking."

Generally speaking, high frequency compensation of amplifiers is based upon wave filter theory, and the more complex the filter used, the higher the gain. The more complex types of filters are usually used where highest possible gain or very sharp cut-off characteristic are of prime importance. The most widely used types of high frequency compensation are:

1. Shunt Peaking
2. Series Peaking
3. Combination or Series-Shunt Peaking

The gain of the different types are in the order listed above, with series peaking giving 50% more gain than shunt peaking and combination peaking giving 80% more gain than shunt peaking. Combination peaking is widely used as the best compromise between maximum gain and simplicity.

SHUNT PEAKING

Referring to Figure 7, there are three components which we are interested in, in order to extend the high frequency range of the stage.

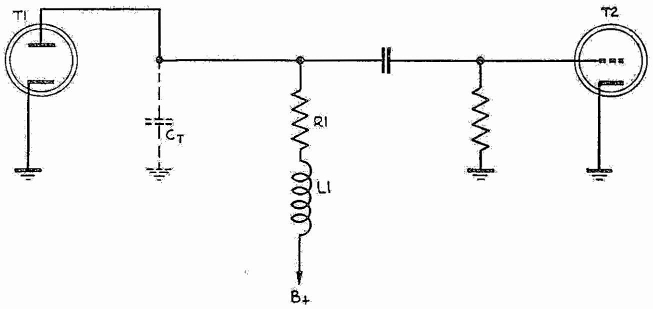


FIG. 7 *Shunt peaked stage.*

These are labeled C_T, R_1, and L_1. C_T can be determined by the methods previously outlined. R_1 is made equal to the reactance of C_T at the highest frequency of correction. Let us label this frequency F_c; then:

$$R_1 = X_{C_T} \text{ at } F_c \qquad (Eq. 15)$$

And L_1 is such that its reactance at F_c is one-half of X_{C_T} at F_c, or:

$$X_{L_1} = \frac{X_{C_T}}{2} \text{ at } F_c \qquad (Eq. 16)$$

or

$$L_1 = \frac{R_1}{4\pi\ F_c} \qquad (Eq.\ 17)$$

For example, suppose it is desired to extend the bandwidth of the stage in Figure 7 to 5 megacycles and C_T was 25 uuf. Then:

$$X_{C_T} = \frac{1}{6.28 \times 5 \times 10^6 \times 25 \times 10^{-12}} = \frac{10^6}{785} = 1273 \text{ ohms}$$

Therefore, R_1 equals 1273 ohms (Equation 15) and:

$$L_1 = \frac{1273}{12.56 \times 5 \times 10^6} = \frac{1273}{62.8 \times 10^6} = 20.3 \times 10^{-6} \text{henries}$$

$$L_1 = 20.3 \text{ uh.}$$

The stage gain, given by Equation 6, assuming T_1 to be an 1852, will be 1273 times .009 or 11.45. Equations 15, 16 and 17 are satisfactory for shunt peaking where only one or two stages are required. Actually the response, using these formulae, at F_c is the same as the low frequency response, but there is about a 3% rise in output somewhat lower in frequency than F_c. Shunt peaking can be made nearly perfect if F_c is made about 40% greater than the highest correction frequency desired. As this would result in a reduction in gain of 30%, an accepted compromise is to design for a reduction in gain of 15%.

If a conservative design is desired, or several stages are to be cascaded, the following formulae may be used. Still referring to Figure 6, Equation 15 may be replaced by:

$$R_1 = .85\ X_{C_T} \text{ at } F_c \qquad (Eq.\ 18)$$

and Equation 17 may be replaced by:

$$L_1 = \frac{.3}{(2\pi\ F_c)^2 C_T} \qquad (Eq.\ 19)$$

If we recalculate the previous example, R_1 and L_1 would be:

$$R_1 = .85 \times 1273 \cong 1080 \text{ ohms}$$

$$L_1 = \frac{.3}{(6.28 \times 5 \times 10^6)^2 25 \times 10^{-12}} = \frac{.3}{(3.14 \times 10^7)^2 25 \times 10^{-12}}$$

$$= \frac{3 \times 10^5}{9.85 \times 2.5 \times 10^3} = \frac{300}{24.6} = 12.2 \text{ uh.}$$

and the stage gain will be .009 x 1080 = 9.72.

SERIES PEAKING

The basic circuit of a series peaked stage is shown in Figure 8.

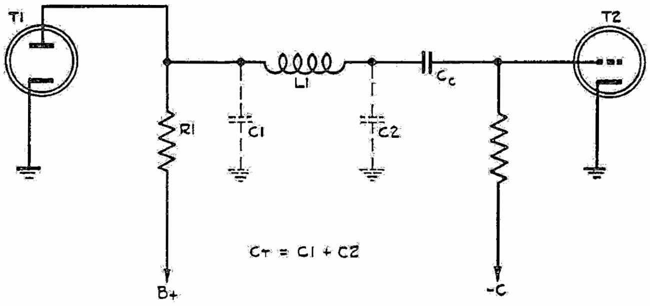


FIG. 8. *Series peaked stage.*

Here again we are interested in three components, L_1, R_1, and C_T, broken down into C_1 and C_2. C_T can be determined by the methods previously outlined; but in addition to knowing C_T, we want a 2/1 ratio between C_1 and C_2, although the ratio may be reversed by moving R_1 to the opposite side of the coil L_1, Figure 8. The rule is to keep the load resistor on the low capacity side of the filter. (See Figure 9.)

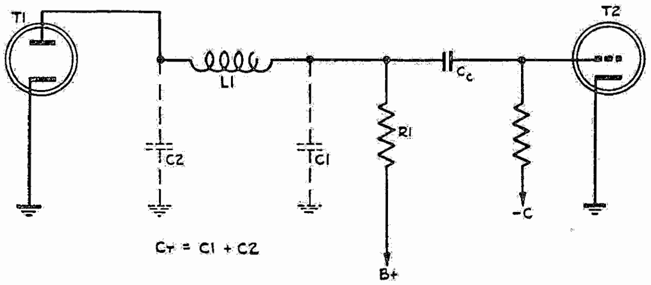


FIG. 9. *Series peaked stage.*

Usually, with a bit of juggling, the ratios may be kept close to 2/1. For instance, the coupling condenser, C_c, could be moved to the plate side of L_1, Figure 8, thus shifting the capacity to ground of C_c from C_2 to C_1. Referring to Figures 8 or 9:

$$C_T = C_{out} \text{ of } T_1 + C_{in} \text{ of } T_2 + C_{stray} = C_1 + C_2 \qquad (Eq.\ 20)$$

$$C_2 = 2C_1 \qquad (Eq.\ 21)$$

$$R_1 = 1.5 \times \ X_{C_T} \text{ at } F_c \qquad (Eq.\ 22)$$

$$L_1 = \frac{1}{2(\pi\ F_c)^2 C_1} = .67\ C_T\ R_1^2 \qquad (Eq.\ 23)$$

In using Equation 23, it is suggested that the second portion be used, that is, where C_T is used to determine L_1, because C_T is more important than the division of C_1 and C_2 in the compensation network and in all probability less error will be made in determining C_T than C_1.

For example let us calculate R_1, L_1, and the stage gain of Figure 8, assuming T_1 to be an 1852, F_c to be 5 mc., and C_T to be 30 uuf., with $C_2 = 2C_1$.

Then from Equation 22:

$$R_1 = 1.5\ X_{C_T} = 1.5 \times 1060 = 1590 \text{ ohms}$$

And from Equation 23:

$$L_1 = .67 \times 30 \times 10^{-12} \times 1590 = 51 \times 10^{-6} \text{ henries}$$
$$L_1 = 51 \text{ uh.}$$

And the stage gain will be:

$$A = G_m Z_p = .009 \times 1590 = 14.3$$

The series peaked network is characterized by a sharper cutoff and a more linear phase characteristic than the shunt peaked network.

SERIES-SHUNT OR COMBINATION PEAKING

Combination peaking, as its name implies, is a combination of shunt and series peaking and has a still sharper cutoff than series peaking. Here again our problem is similar to series peaking in that a 2 to 1 division of the capacity C_T is required for best performance of the stage. The same rule applies on the location of the load resistor; that is, place the load resistor on the low capacity side of L_2. (See Figures 10 and 11).

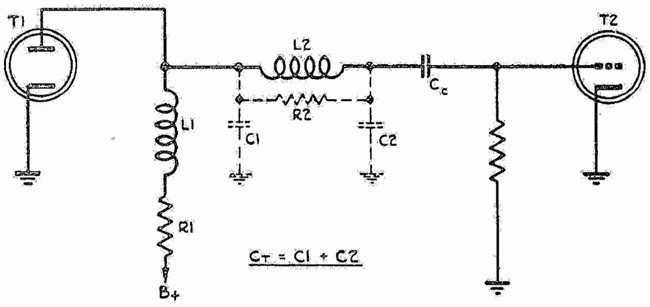


FIG. 10. *Combination peaked stage.*

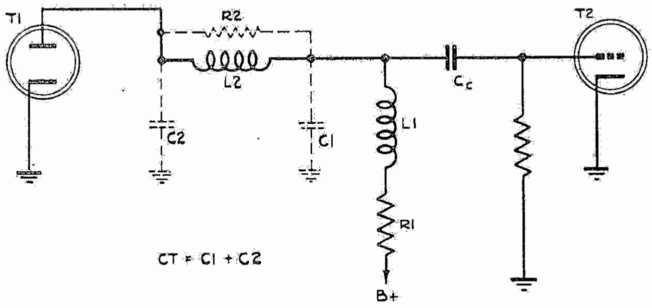


FIG. 11. *Combination peaked stage.*

R_1 and L_1 may be reversed, and usually it is desirable to do this as the stray capacity, which composes part of C_1 and C_2, would be smaller with a resistor connected to either side of L_2 than if L_1 were so connected (smaller physical size, primarily).

Referring to Figures 10 or 11, the design criteria for combination peaking is:

$$C_T = C_1 + C_2$$

$$C_2 = 2C_1$$

$$L_1 = .12 \times C_T \times R_1^2 \qquad (Eq. 24)$$

$$L_2 = .52 \times C_T \times R_1^2 \qquad (Eq. 25)$$

$$R_1 = 1.8\ X_{C_T} \text{ at } F_c \qquad (Eq. 26)$$

If required, start with $R_2 \cong 5R_1$ by experiment.

A high distributed capacity in coil L_2 or improper ratio between C_1 and C_2 may cause a rise in response in the higher frequency portion of the pass-band. This rise can usually be flattened out by the addition of the resistor R_2, Figures 10 and 11, to lower the Q of L_2. The exact value will have to be determined by experiment in each case. A good starting value is about five times the value of the plate load resistor.

As an example, suppose we use the same specifications we used in the example for series peaking, in calculating L_1, L_2, and R_1, Figure 10.

From Equation 26:

$$R_1 = 1.8 \times 1060 = 1908 \text{ ohms}$$

From Equation 24:

$$L_1 = .12 \times 30 \times 10^{-12} \times 3.64 \times 10^6 = 13.1 \times 10^{-6} \text{ H.} = 13.1 \text{ uh.}$$

From Equation 25:

$$L_2 = .52 \times 30 \times 10^{-12} \times 3.64 \times 10^6 = 56.7 \times 10^{-6} \text{ H.} = 56.7 \text{ uh.}$$

And the stage gain is:

$$A = .009 \times 1908 = 17.17.$$

THE HIGH PEAKER STAGE

One problem usually encountered in transferring the video voltage output of an Iconoscope into the grid of the first amplifier stage is that of getting the maximum signal to noise ratio. The most satisfactory method for accomplishing this is to provide the highest possible signal input into the grid of the first amplifier stage without regard for frequency distortion, then carefully preserve

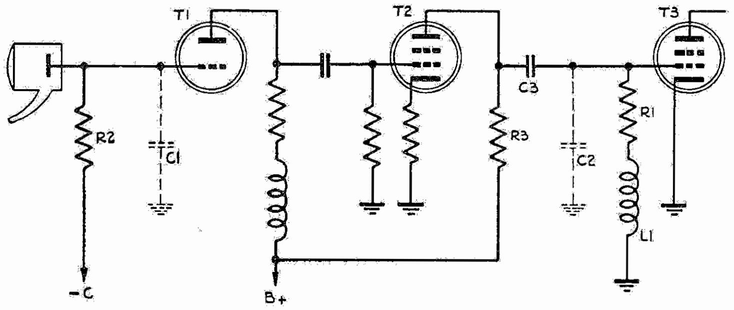


FIG. 12. *"Hi-Peaker" stage.*

this distorted signal while it is being amplified in one or two stages, and finally introducing a complementary network that gives equal and opposite distortion to that generated by the input network. With frequency components from 30 cycles to about 4 mc. in the output signal of an Iconoscope, developed across R_2 in Figure 12, it is readily seen that the shunt reactance of C_1 will severely limit the high frequency components.

If the linearity is preserved, that is, compensating as previously outlined between T_1 and T_2, to keep intact this distorted waveform, we can insert the network R_1-L_1 as the load for T_2. This network is complementary to the network R_2-C_1, and has the opposite impedance and phase characteristic, provided the time constants are equal. The time constants will be equal when:

$$R_2\,C_1 = \frac{L_1}{R_1}$$

A stage with this type of correction is called a "High Peaker" stage, and the design data are:

C_1 = total ckt. and stray capacity (input stage)
C_2 = total ckt. and stray capacity (hi-peaker stage)
R_2 = nominally 100,000 ohms

$$R_3 > 10 \times X_{L_1} \text{ at } F_c \qquad (Eq. 27)$$

$$X_{C_3} < .1\ R_3 \text{ at lowest frequency} \qquad (Eq. 28)$$

$$R_1 = \frac{L_1}{R_2\,C_1} \text{ where } R = \text{ohms}, L = \text{uhenries}. C = \text{ufds}. \qquad (Eq. 29)$$

$$L_1 = \frac{25.33 \times 10^3}{(2\,F_c)^2 \times C_2} \qquad (Eq. 30)$$

where L is in uh.,
C is in uuf.,
F is in mc.

Thus, with Equations 27, 28, 29 and 30, we can design a satisfactory compensating network. Equation 30 shows that the resonant frequency of L_1-C_2 is twice the cutoff frequency, F_c.

For an example let's determine L_1, R_1, R_3, and C_3 of Figure 12, assuming C_1 to be 12 uuf. and C_2 to be 30 uuf., F_c is 5 mc., and 30 cycles the lowest frequency.

From Equation 30:

$$L_1 = \frac{25.33 \times 10^3}{10^2 \times 30} = \frac{253.3}{30} = 8.43 \text{ uh.}$$

From Equation 29:

$$R_1 = \frac{L_1}{R_2 \times C_1} = \frac{8.43}{10^5 \times 12 \times 10^{-6}} = \frac{843}{12} = 7.25 \text{ ohms}$$

From Equation 27:

$$R_3 > 10 \times 6.28 \times 5 \times 10^6 \times 8.43 \times 10^{-6} = 2650 \text{ ohms}$$
or greater

From Equation 28:

$$X_{C_3} = < .1 \times 2650 = 265 \text{ ohms or less}$$
$$C_3 = 20 \text{ ufd. or more}$$

And the stage gain, if T_2 is an 1852, will be:

$$A = .009 \times 7.25 = .06525$$

From this it is apparent that the stage is operating at a loss, but the actual overall voltage output will be greater than if we had used a much lower value for R_2 in an attempt to preserve the high frequency response into T_1; also the signal to noise ratio will be better.

PHASE CHARACTERISTICS

These correction circuits will provide essentially flat frequency response to F_c and a phase shift proportional to frequency; or saying it another way, the time delay is independent of frequency. Up to now little has been said of the phase characteristic of amplifiers. The phase characteristic is relatively unimportant in amplifiers designed for audio work, as the human ear is very insensitive to phase distortion, but becomes very important in video work or wherever complex waves are to be amplified without distortion. Without going too deeply into the subject of complex waves, which is beyond the scope of this article, every complex wave is composed of the fundamental frequency and any number of harmonics, having various phase relationship with each other, and whose amplitude and phase may be expressed by a Fourier Series. To see why it is important that the phase shift be proportional to frequency, that is, the second harmonic should be delayed twice as much as the fundamental, the third harmonic three times, etc., let's take a look at Figure 13.

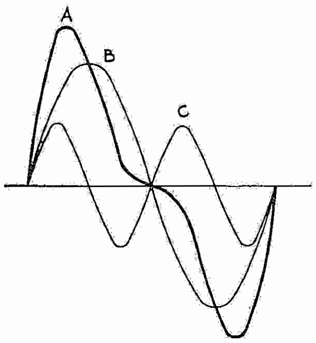


FIG. 13. *Complex wave with components in phase.*

Wave **A** is a complex wave composed of the fundamental wave **B** and the second harmonic **C** in phase. If the wave **A** is passed through an amplifier that delayed waves **B** and **C** the same amount, for instance 30°, the wave shape would be as shown in Figure 14.

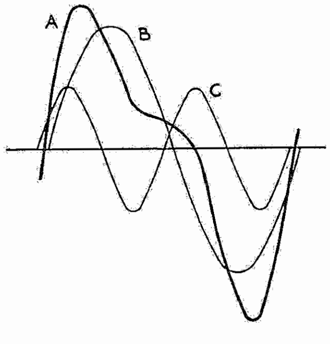


FIG. 14. *Complex wave after both component waves are delayed 30°.*

Wave **C** goes through two cycles, 720 electrical degrees, while wave **B** goes through one cycle, 360 electrical degrees; or to put it another way, with respect to time, wave **C** is traveling twice as fast as wave **B**. Therefore, if both waves are delayed 30°, wave **C** will be ready to repeat its cycle 50% sooner than wave **B**; or with respect to wave **B**, wave **C** will be advanced in phase. When these two waves are summed up, with the altered phase relationship, we will get wave **A** in Figure 14. Compare this with wave **A** in Figure 13. Both are composed of the same two frequencies, only the phase relationship has been changed. If the phase characteristic of the amplifier is proportional to frequency, the wave coming out of the amplifier would be the same shape as the input wave, provided the frequency response is uniform. As a point of interest, the shorter the pulse, the greater the number of harmonics present and the wider the bandwidth of the amplifier required to pass the pulse without distortion. A single impulse of infinitesimal duration contains all frequencies from zero to infinity of equal amplitude.

CATHODE FOLLOWERS

Cathode follower is the name given to a stage when the load is in the cathode instead of the plate circuit. This type of circuit finds its widest use in video work as an impedance changing device. As the output voltage of an amplifier taken from the plate circuit is at a comparatively high impedance, unless changed by an impedance changing device such as a transformer, securing a proper match into a transmission line of nominal impedance is therefore somewhat of a problem. This is especially true in video work where a wide frequency range is encountered, and the design of a transformer with flat output from 30 cycles to 4 or 5 mc. presents quite a few difficulties. The simplicity and low cost of the cathode follower is primarily responsible for its popularity. Either pentodes or triodes may be used and a conventional circuit for each is shown in Figures 15 and 16 respectively.

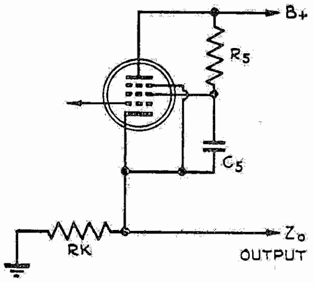


FIG. 15.
Pentode cathode follower.

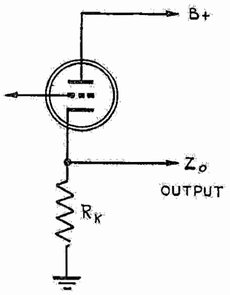


FIG. 16.
Triode cathode follower.

Both the input conductance and the grid to cathode capacity of the tube in a cathode follower stage are modified by the factor

$$\frac{1}{1 + G_m R_k}.$$

The pentode cathode follower stage is used in preference to the triode in applications where the lower input capacity or a higher output voltage is desired. The effective internal impedance of the tube is the reciprocal of the grid to plate transconductance in mhos and must be added in parallel to the cathode resistor to determine the output impedance, Z_o, Figures 15 and 16.

In a triode cathode follower stage, Figure 16, the dynamic input capacity is given by:

$$C_{eff} = \frac{C_{gk}}{1 + G_m R_k} + C_{gp} \qquad (Eq.\ 31)$$

and if a pentode is used, as in Figure 15, the dynamic input capacity will be:

$$C_{eff} = \frac{C_{in}}{1 + G_m R_k} \qquad (Eq.\ 32)$$

And the stage gain is given by:

$$A = \frac{G_m R_k}{1 + G_m R_k} \qquad (Eq.\ 33)$$

The effective output impedance, Z_o, is given by:

$$Z_o = \frac{\frac{1}{G_m} \times R_k}{\frac{1}{G_m} + R_k} \qquad (Eq.\ 34)$$

From Equation 33 it can be seen that the stage always operates with a gain of less than 1 and the higher the value of R_k the closer to unity the gain becomes. The circuit in Figure 17 is sometimes used to secure higher output voltages.

In this circuit R_k is divided into two parts, R_1 and R_2, arranged so the dc voltage drop across R_1 is equal to the required grid bias, and as the grid is returned to the junction of R_1 and R_2, the correct bias will be obtained; the G_m will not change, but R_k will be increased and thus the voltage output (Equation 33). Similarly Z_o will be changed (Equation 34).

For example let's determine the effective input capacity, stage gain, and effective output impedance of an 1852 cathode follower stage with a 160 ohm cathode resistor. From the tube manual, C_{in} is 11 uuf. and the G_m is 9,000 umho's (.009 mho).

From Equation 31:

$$C_{in} = \frac{11}{1 + .009 \times 160} = \frac{11}{2.44} = 4.52 \text{ uuf.}$$

From Equation 33:

$$A = \frac{.009 \times 160}{1 + .009 \times 160} = \frac{1.44}{2.44} = .59$$

From Equation 34:

$$\left(\frac{1}{G_m} = \frac{1}{.009} = 111\right) Z_o' = \frac{111 \times 160}{271} = 65.7 \text{ ohms}$$

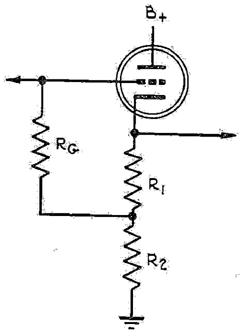


FIG. 17. *Cathode follower with Z_o matched to load.*

By using the arrangement in Figure 17, we could get a perfect match into a 72 ohm line by leaving R_1 equal to 160 ohms and by making R_2 equal to 45 ohms. The gain, A, and Z_o would be then:

$$\text{unloaded— } A = \frac{.009 \times 205}{1 + .009 \times 205} = \frac{1.845}{2.845} = .648$$

$$\text{loaded— } A = \frac{.009\frac{72 \times 205}{72 + 205}}{1 + .009\frac{72 \times 205}{72 + 205}} = \frac{.009 \times 54.7}{1 + .009 \times 54.7} = \frac{.492}{1.492} = .33$$

With a normal bias of 3 volts on the grid, the maximum voltage output would be 3 x .33 or .99 peak volts. In terms of peak to peak voltage, and assuming the grid swing was from 0 to 6 volts, the output would be 1.98 volts peak to peak.

The output impedance will be:

$$Z_o = \frac{111 \times 205}{316} = \frac{22755}{316} = 72 \text{ ohms}$$

DESIGN HINTS

It is evident, from the foregoing design data, that the limiting factor, in securing good high frequency response, is the shunt reactance across the plate load resistor and that this shunt reactance has a direct bearing on the gain of the amplifier. Therefore, good practice demands that every effort be made to keep the stray and circuit capacity at a minimum. A well-designed layout and careful planning will pay big dividends.

The practice of placing a small paper or mica condenser across a large electrolytic by-pass condenser to by-pass the high frequencies is sometimes dangerous, as far as flat frequency response is concerned. The inductance of the electrolytic and the paper or mica condenser may form a parallel resonant circuit; and this may cause either an increase or decrease in the gain, depending on the location of the network, at its resonant frequency.

Care should be used in selecting resistors as there is a wide variation in the high frequency characteristics between the products of different manufacturers. Wire wound resistors for plate loads should be used with extreme caution. The inductance and distributed capacity may be quite high and upset the network.

When triodes are used in wide band amplifiers where the required plate load is comparable to the plate resistance of the tube, the plate resistance should be considered in selecting the plate load resistor value. The plate load resistor should be of such a value that when it is in parallel with the plate resistance of the tube, the resistance of the combination will equal the calculated value. For example, if a 6J5 is used and the calculated load resistance is 1000 ohms, a plate load resistor of 1175 ohms would be used.

$$R = \frac{1000 \times 6700}{6700 - 1000} = 1175 \text{ ohms}$$

Test and Alignment

As it is a general practice to design video peaking coils with movable powdered iron cores in order to adjust their inductance to compensate for minor variations in circuit and wiring capacities, a rapid method of adjustment is desirable. Although this adjustment may be accomplished and the gain-frequency characteristic determined by the use of a radio frequency signal generator and a wide range vacuum tube voltmeter to monitor the output, this method requires so much time that it has been generally discarded in favor of visual techniques.

The low-frequency response, below 100 Kcs., phase shift, and transient response are tested by applying square-waves to the amplifier input and observing the resulting pattern on an oscilloscope screen. For this test it is desirable to couple the output of the amplifier directly to the CRO deflecting plates as this prevents errors from being introduced by the CRO amplifier. Overshoot, ringing, phase shift, and frequency response are readily determined from the distortion to the original square-wave by the amplifier. The input signal level should be kept low to prevent one or more of the amplifier stages from being driven to cut-off and thus prevent a true picture of the amplifier characteristic.

A typical arrangement for visual alignment or test of the amplifier response above 100 Kcs. is shown in block form in figure #19. The use of a sweep-generator of the type normally used for television I.F. amplifiers will be very satisfactory and in addition will readily allow detail examination of small portions of the amplifier pass-band, especially when used with the "Baseliner," essentially a mechanical DC restorer used to blank, or discharge the input condenser of, the CRO for 180 degrees of the modulation cycle. The use of the linear detector makes the response pictured on the CRO screen independent of the characteristic of the CRO amplifier. The CRO time base will, of course, be governed by the type of modulation used in the sweep generator. Where sinusoidal modulation is used, a sinusoidal time base will be required to produce a linear gain-frequency trace.

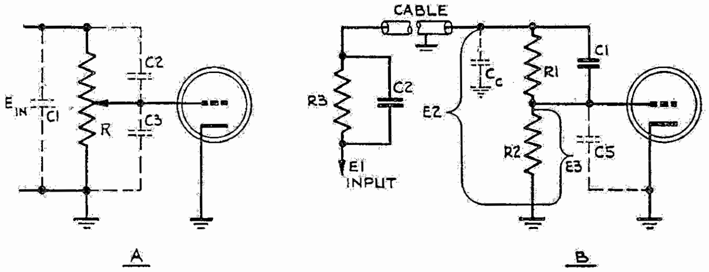
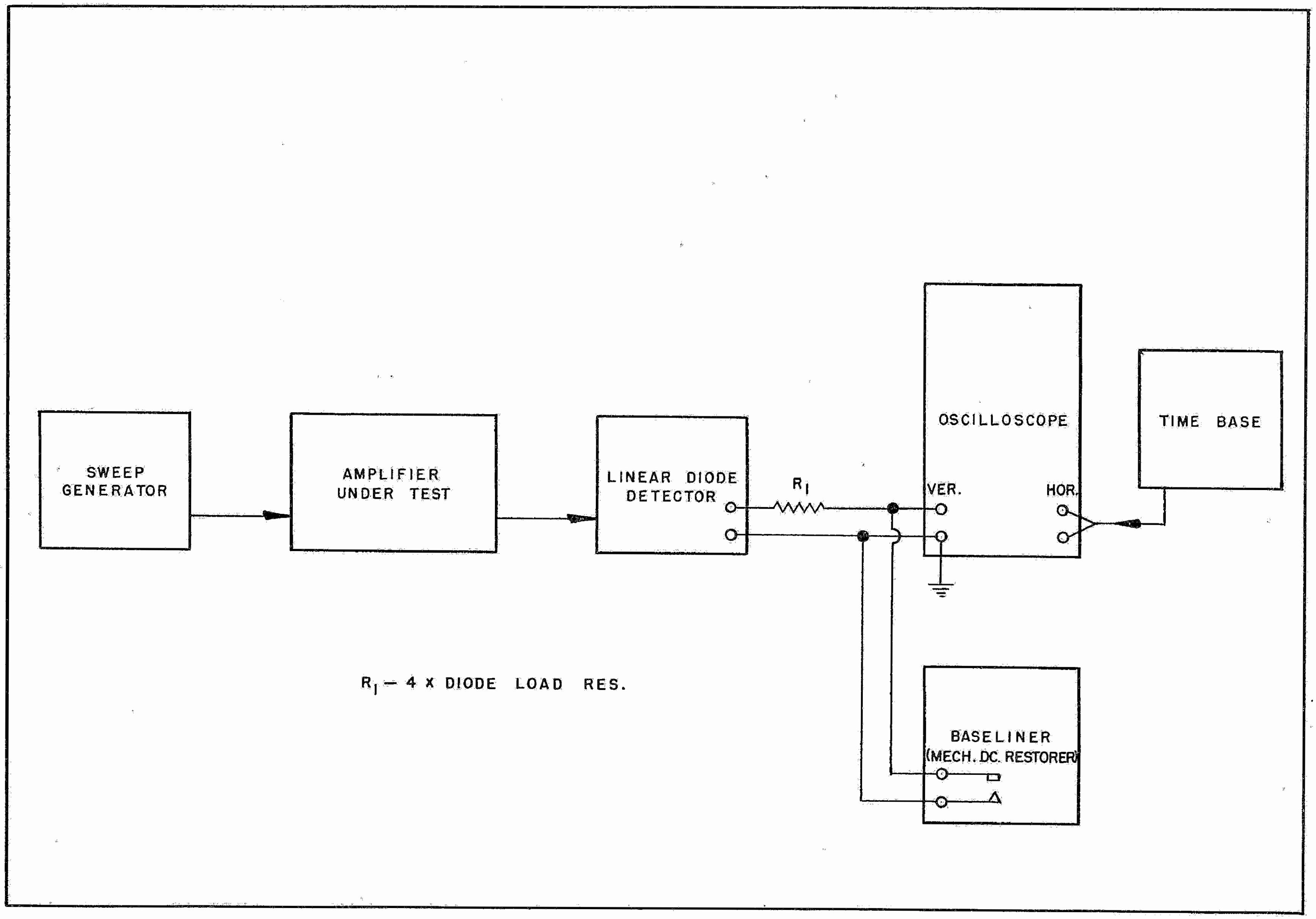


FIG. 18. *Attenuating systems.*
A. *Uncompensated.* B. *Compensated.*



R_1 — 4 x DIODE LOAD RES.

FIG. 19

Alignment is completed by adjustment of the inductance of the peaking coils until a uniform response is obtained over the pass-band.

ATTENUATORS

The effects of the circuit and stray capacities, C_1, C_2, and C_3 in Figure 18a are negligible at audio frequencies but become increasingly important as the frequency is increased. At video frequencies they cause reduced input impedance as well as frequency and phase distortion. The frequency and phase distortion, and to a certain extent, the input impedance will vary with the position of the slider on R. This condition can be remedied by use of a compensated step type attenuator. Figure 18b is a schematic of the basic circuit of an input cable and attenuator system generally used on wide range oscilloscopes.

Ignoring the input cable for the moment, the ratio of output voltage, E_3, to the input voltage of the attenuator, E_2, will be independent of frequency if the time constants of R_1-C_1 and R_2-C_S are made equal. As C_S is the sum of circuit and stray capacities, and thus fixed, the design procedure is to set the values of R_1 and R_2 for the voltage ratio desired, and then make C_1 such value that:

$$TC = R_1 C_1 = R_2 C_s \text{ or } C_1 = \frac{R_2 C_s}{R_1} \quad \textit{(Eq. 35)}$$

This means that a different value of C_1 will be required for each step of the attenuator; and since, as will be explained below, it is desirable to keep the total resistance of R_1 and R_2 constant, these values will have to be changed for each step also.

It is generally desirable to load the circuit supplying the signal voltage as little as possible. Yet means must, however, be provided for making connection to the signal voltage source, and a low capacity cable with an isolation resistor in the probe is usually satisfactory. Even with so-called low capacity cable, the capacity of a five foot section plus fitting and circuit capacity is considerable at video frequencies.

The voltage division can be made independent of frequency in the same manner as outlined for the attenuator. That is, by considering R_1 and R_2 as one resistor and summing up the cable and fitting capacity together with the effective capacity of C_1 and C_S in series, as one capacity, C_c, and then adding the capacity C_2, across the isolation resistor, R_3, making its value such that the time constants of R_3-C_2 and $(R_1 + R_2)$-C_c are equal. This is the same as Equation 35. This will mean, of course, that E_2 will become

$$\frac{R_1 + R_2}{R_1 + R_2 + R_3} \times E_1$$

but by making the reduction a factor of 10 and increasing the gain of the amplifier by the same factor, our overall gain remains the same and we have secured a coupling and attenuating system that has a high input impedance and gives minimum distortion of the wave shape of the signal. The effective input impedance will be a resistance equal to $R_1 + R_2 + R_3$ with a parallel capacity equal to C_2 and C_c in series and may be calculated for any frequency by Equation 4. For example, if we wished to have E_3, Figure 18b, one-tenth of E_2, and E_2 one-tenth of E_1, and C_s is 50 uuf. with C_c being 200 uuf., we could proceed with design by making:

$R_2 = 10{,}000$ ohms

$R_1 = 90{,}000$ ohms

$R_3 = 900{,}000$ ohms

$$C_1 = \frac{R_2\,C_s}{R_1} = \frac{10^4 \times 50}{9 \times 10^4} = \frac{50}{9} = 5.56 \text{ uuf.}$$

$$C_2 = \frac{(10^4 + 9 \times 10^4)200}{9 \times 10^5} = \frac{2 \times 10^7}{9 \times 10^5} = \frac{200}{9} = 21.1 \text{ uuf.}$$

And the input impedance will be one megohm with 19 uuf. in shunt (21.1 and 200 uuf. in series). By always keeping the total resistance of R_1 and R_2 equal to 100,000 ohms one setting of C_2 would be correct for any setting of the attenuator.

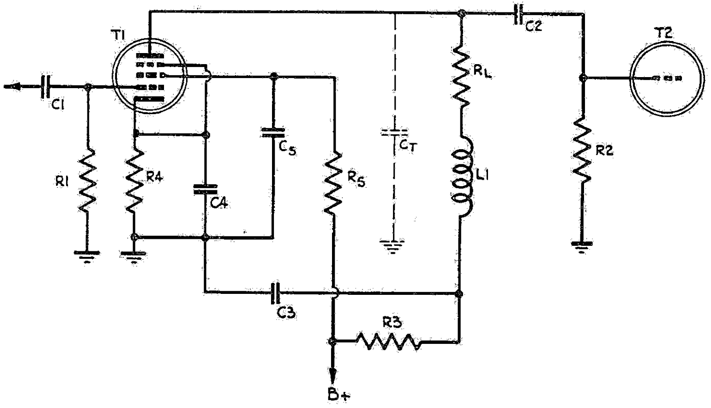
SUMMARY

As a final summary, the following three design charts have been prepared. There is one chart for compensated stages using Shunt high frequency peaking, one for Series high frequency peaking, and one for Combination high frequency peaking. Low frequency compensation data is included on each to keep each chart complete in itself.

Of the numerous reference sources used in writing this article, the author desires to give special mention to lecture notes of Mr. T. M. Gluyas of RCA, on the subject of "Generation and Application of Non-Sinusoidal Waves."

DESIGN CHART NO. 1

Compensated stage with shunt high frequency peaking.



$$\text{Gain} = G_m R_L$$

$$C_T = C_{pk} + C_{gk} \text{ of } T_1 \text{ and } T_2 \text{ respectively} + \text{wiring capacity}$$

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$$\left.\begin{array}{l} R_L = X_{C_T} \text{ at } F_C \\ L_1 = \dfrac{R_L}{4\pi F_C} \end{array}\right\} \text{General}$$

$$\left.\begin{array}{l} R_L = .85\, X_{C_T} \text{ at } F_C \\ L_1 = \dfrac{.3}{(2\pi F_C)^2 C_T} \end{array}\right\} \text{Conservative}$$

$$X_{C_S} < \frac{2}{G_m} \quad \text{at } F_1$$

$$R_S > \frac{3/F}{C_S} \quad \text{at } F_1$$

To compensate for R_1—C_1 or C_2—R_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

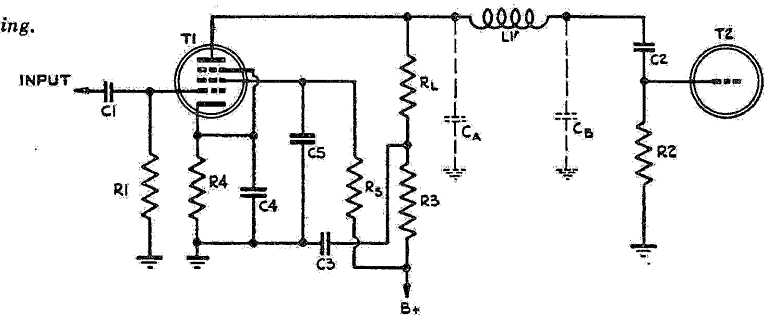
$$R_3 > 20\, X_{C_3} \text{ at } F_1$$

To compensate for R_4—C_4

$$R_4 C_4 = R_3 C_3 \text{ and } \frac{R_3}{R_4} = \frac{C_4}{C_3} = G_m R_L$$

DESIGN CHART NO. 2

Compensated stage with series high frequency peaking.



$$\text{Gain} = G_m R_L$$

$$C_T = C_A + C_B$$

$$C_B = 2\, C_A$$

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$$R_L = 1.5\, X_{C_T} \text{ at } F_C$$

$$L_1 = .67\, C_T R_L^2$$

$$X_{C_S} < \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

To compensate for R_1—C_1 or R_2—C_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

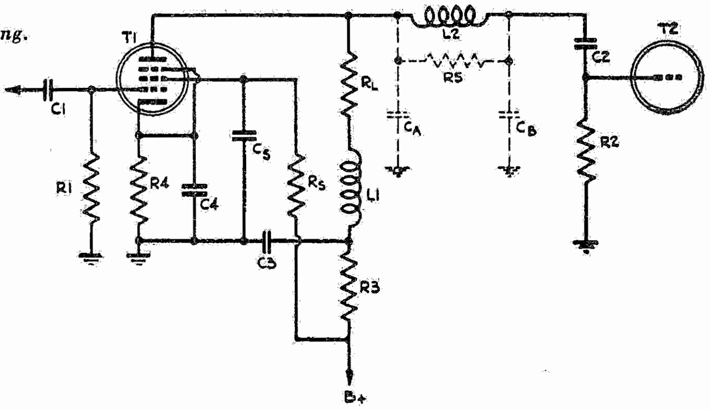
$$R_3 > 20\, X_{C_3} \text{ at } F_1$$

To compensate for R_4—C_4

$$R_4 C_4 = R_3 C_3 \text{ and } \frac{R_3}{R_4} = \frac{C_4}{C_3} = G_m R_L$$

DESIGN CHART NO. 3

Compensated stage with combination high frequency peaking.



Gain $= G_m R_L$

$C_T = C_A + C_B$

$C_B = 2 C_A$

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$R_L = 1.8 \ Xc_T$ at F_C

$L_1 = .12 \ C_T R_L^2$

$L_2 = .52 \ C_T R_L^2$

$$Xc_3 = \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

$R_5 \cong 5 R_L$ by experiment

To compensate for R_1—C_1 or R_2—C_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

$R_3 > 20 \ Xc_3$ at F_1

To compensate for R_4—C_4

$$R_4 C_4 = R_3 C_3 \text{ and } \frac{R_3}{R_4} = \frac{C_4}{C_3} = G_m R_L$$

UHF COIL DESIGN

(Reprinted from Electronic Industries, August 1943)

The design of ultra-high-frequency circuit components frequently calls for the computation of inductances that are outside of the rules, tables and charts that have been found useful for coils for use at lower frequencies.

The following analysis deals with inductances of a size useful in the highest frequency ranges at which the usual negative-grid triode oscillator will work. In other words, the coils described are about as small as a coil can be, in practical design and still be called a "coil."

The problem has two parts--the first, to determine the dimensions to give a certain inductance--and second, to compute the resulting inductance from a given set of dimensions. At first it might seem that these problems are identical, but unlike computations of many-turn single layer coils, the inductance formula that takes into consideration the wire size and turn-spacing so complicates the design that a rigid method that will give a predetermined inductance is not always practicable. The easiest way out is that suggested in the following analysis: use a system that will give the nearest approximation and still is simple enough to permit several dimensional variations to be determined by comparison, to be followed by a more rigorous determination when the rough set of values has been indicated.

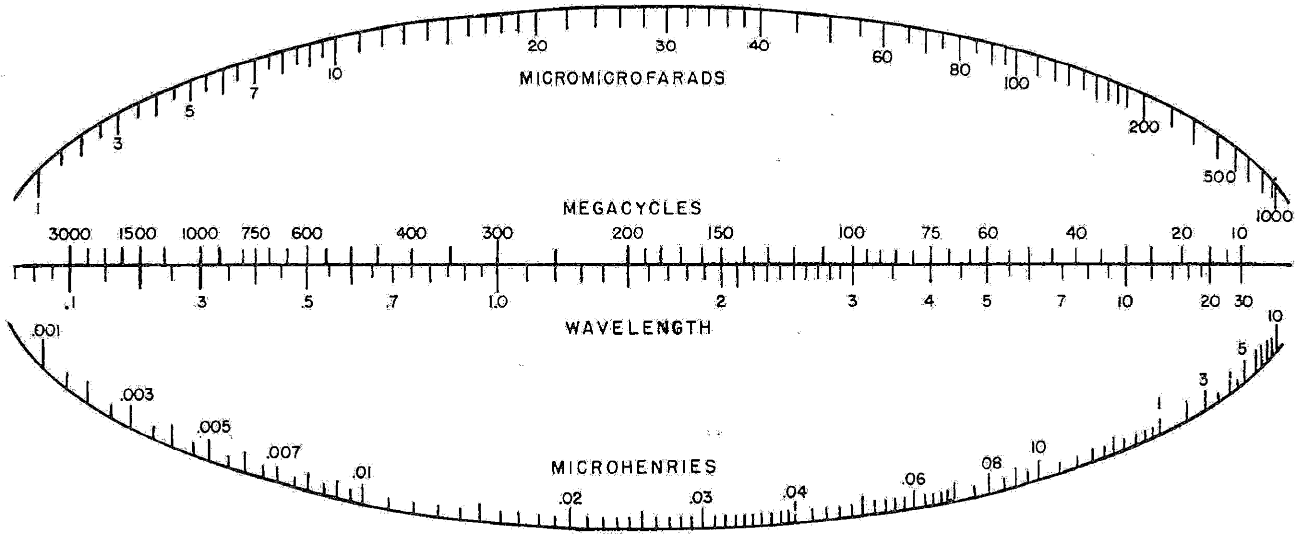
Chart I is first referred to, if it is not known just how much inductance is needed in a certain set-up for a given frequency. This is the well-known LC relation but is extended to the particular inductance range useful at 30-3000 megacycles. While this chart is arranged to cover the usual values of L and C, many unusual values of L/C are found in modern circuits, so in case it does not fit, multiply or divide the L scale by 10 and do the reverse to the C scale.

Of course, both L and C refer to the total values present, and not those of the coil and condenser alone.

Coil Dimension Factors

Chart II provides an easy method of finding out constructional details when a given inductance is needed. It is based on a "current sheet" formula, as is usual in such charts, and while it may be in error 5-10 per cent in some remote cases, it does give an easy way of determining how big a certain coil should be. The method of using this chart is illustrated by an example on the chart itself. At the left is a scale which takes care of the factor of winding pitch, or "turns per inch" in practical units. The family of curves at the right end of Chart II determines the "shape factor." It is to be noted that coils with small diameters have a considerable inductance shift with a slight change of that diameter, as evidenced by the steepness of the curves. In using these curves, take note that the diameter of a coil is equal to the diameter of the winding form plus the diameter of one wire. The length of a coil is equal to number of turns times the distance between centers of adjacent turns. In selecting the shape values for a proposed coil, it is suggested that the wire size and pitch be selected first, so that the "turns-per-inch" value

CHART I -- Nomographic chart of LC values in the short wave range



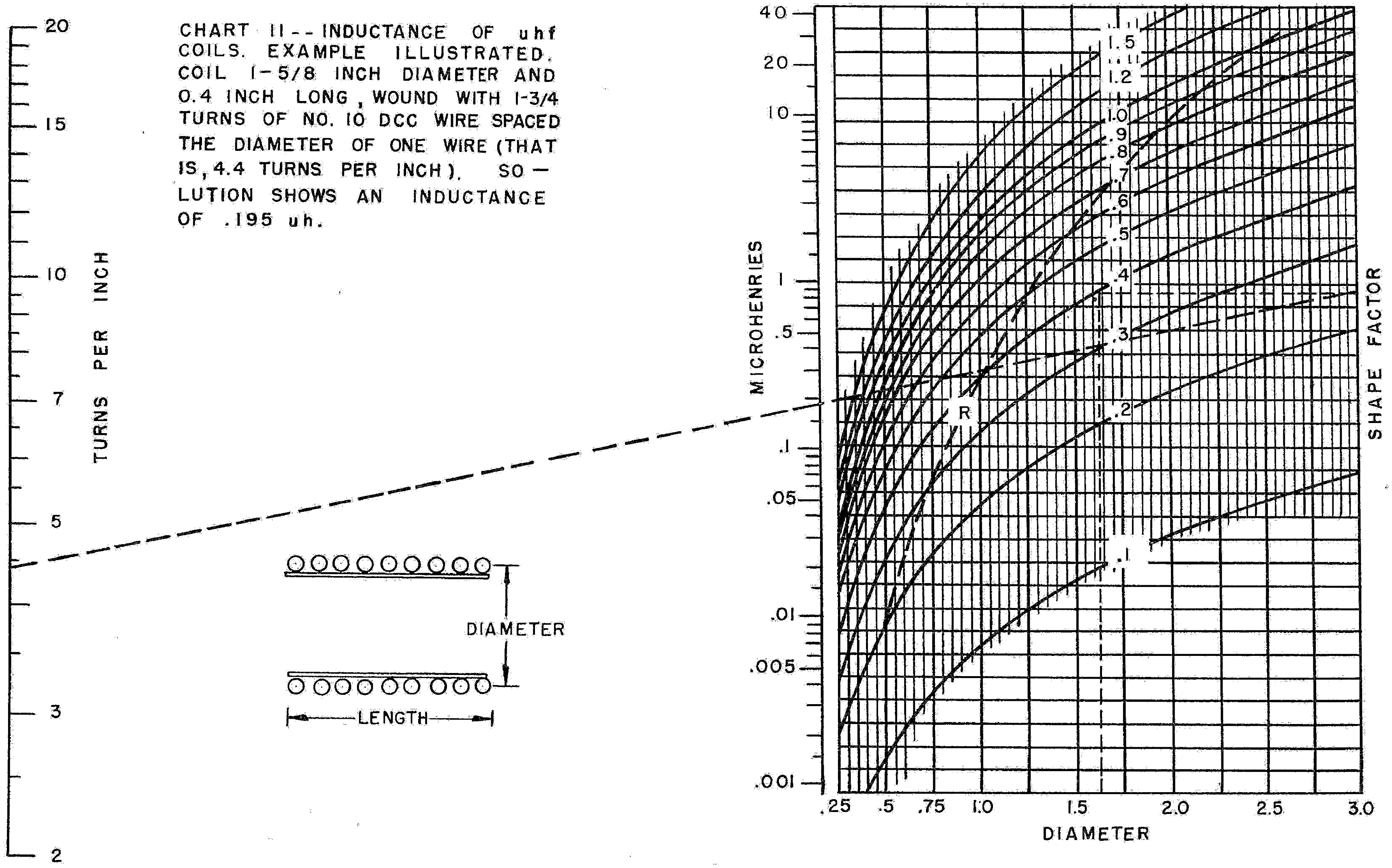


CHART 11--INDUCTANCE OF uhf COILS. EXAMPLE ILLUSTRATED. COIL 1-5/8 INCH DIAMETER AND 0.4 INCH LONG, WOUND WITH 1-3/4 TURNS OF NO. 10 DCC WIRE SPACED THE DIAMETER OF ONE WIRE (THAT IS, 4.4 TURNS PER INCH). SOLUTION SHOWS AN INDUCTANCE OF .195 uh.

can be indicated on the left scale. A dotted line from this point through the inductance value on center scale is extended to the Shape Factor scale at extreme right. It will be noted that several different diameter-to-length ratios can be used to give a certain inductance, giving considerable leeway in design. Pairs of values that can be used are on the same horizontal line extending toward the left from the required Shape Factor point.

Opinions differ somewhat as to the best shape ratio and there is no single universal rule that covers all cases. A value of D/1 equals 2.46, has been suggested by Bull. No. 74 of the Bureau of Standards as giving the maximum inductance with a given length of wire. The locus of points bearing this relation is shown as the broken line (R).

Some designs will be based on purely physical details--the winding form must have a certain diameter, so that it will fit into a given shield. Other designs must be based on obtaining the highest possible Q. Still again, the design might be based on temperature drift considerations.

In the latter case, it will be seen that if all dimensions of a coil change linearly due to temperature, a first order change is noted in the inductance—the greater the expansion, the greater the inductance. However, few coils follow this simple rule in practice: sometimes the diameter changes according to the expansion coefficient of copper, and the length according to the expansion of the material in the winding form. A material that expands twice as far as copper would seem to offer the best solution.

However, in the range of frequencies under discussion, many other effects enter into the problem, and when all is said and done, it is probable that very few uses for a zero-coefficient coil are found anyway, since the usual tuned circuit requires the coil shift to partially make up for the capacitance shift as well if it is at all possible.

Chart II is not complete inasmuch as it gives no indication of the inductance of a single turn. Rather than to complicate the basic chart, Chart III takes care of this special case. While the inductance of a single turn is mainly dependent on the turn diameter, the wire size also has some effect. The central scale of Chart III takes care of this, based on factor (turn diameter/wire diameter).

Other factors of importance that alter the inductance are, the change in the resistance of the coil with both frequency and temperature shifts, and the change in the amount of inductance in the circuit as the variable condenser is rotated, caused by a shift of the physical point where the center of capacitance is located as the plates become more or less enmeshed.

This brings up the question of how much the length of the leads from the coil to the rest of the circuit increases the inductance. This is a simple factor to figure, according to the rules, but actually, the shorter the leads the closer the coil is to other metallic objects that alter the field pattern and therefor the inductance. Tests have shown that it is hardly possible to improve the accuracy of the inductance computations as determined by the chart, in practical cases, and in fact it is just as difficult to predetermine the circuit capacitance when all factors are considered. It is possible, however, to strike pretty close to what is wanted and it will be found that these circuits are easy to trim to the desired frequency.—R.R.B.

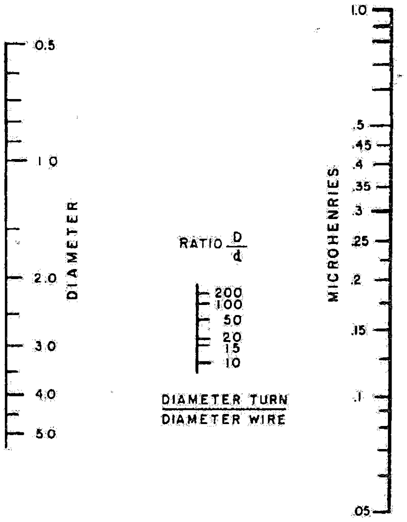


CHART III -- Nomographic charts showing inductance of single turn loops

SINGLE JACKS FOR BROADCAST APPLICATION

Howard A. Chinn[1] *and Robert B. Monroe*[2]

(Reprinted from Audio Engineering, Vol. 31, No. 6, July 1947)

A bank of Telephone-Type Jacks, known as a jack field, is employed in essentially every broadcasting, recording, or public-address audio system. It is the usual practice to connect the input and output of the important circuits and components of the system to these jacks. The connections are made in a manner which permits access to the circuits by placing a plug or patch cord into the proper jacks. Furthermore, auxiliary "make" contacts are employed on each jack so that when there are no patch cords in the jack field, the components and circuits are connected together in their *normal* sequence, see Fig. 1. These auxiliary contacts are called "normals", for obvious reasons.

A jack field, incorporated in an audio system, provides a high degree of operational flexibility. By the use of patch cords various operations may be quickly performed, as for example:

(a) A defective component may be readily replaced by another similar unit, or may be removed completely from the circuit by patching around the unit.

(b) Whenever necessary, the program circuits may be rearranged as desired.

(c) Special-effect devices, such as filters or reverberation facilities, may be inserted in any desired program channel.

In addition to the operational conveniences made possible by the jack field, test and measurement of the facilities are greatly simplified as it is possible to make direct connection to the terminals of various components of the system. Location of a defective unit is thereby greatly facilitated.

The plugs currently employed in the majority of professional audio systems are the "twin" type, Fig. 2. With these twin-type plugs it becomes necessary to employ jacks in pairs. This arrangement of twin plugs and jack pairs has been in use in broadcast plants since the early days of radio broadcasting. Their introduction to radio work was a carry-over from the practice on "Long Line" circuits used for network program distribution at telephone exchanges. The performance of these plugs and jacks over a period of many years has always been reliable. However, the following points, which may be considered disadvantages, have been noted:

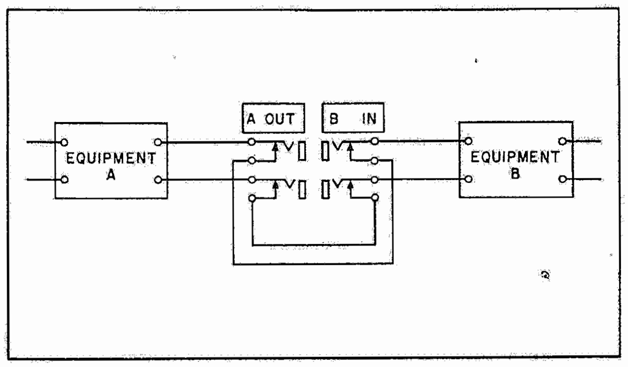


Fig. 1. Jacks incorporated in an audio system permit access to the input and output of the various equipment units by placing a plug or patch cord into the proper jacks. When no patch cords are in use the components are automatically connected in their normal sequence by means of the auxiliary jack contacts shown. These contacts and the associated wiring are called circuit "normals".

(a) Care must be exercised to insert the plug correctly polarized. If this is not done the polarity of the circuit may be reversed.[3]

(b) A relatively large amount of panel space is required for the jack field.

(c) The cost of the jack field and associated patch cords is high.

Inasmuch as the trend in the design of audio facilities is to reduce the size of installations, a study was made to determine the possibility of employing single plugs and jacks without sacrificing any of the features of the traditional twin units. The successful application of single jacks would overcome the shortcomings of the double units mentioned above; that is, less panel

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[1] Chief Audio Engineer, Columbia Broadcasting System.

[2] Engineer, Columbia Broadcasting System.

[3] This may lead to several undesirable consequences. In unbalanced-to-ground arrangements reversal of the plug will ground the wrong side of the circuit. If this does not short circuit the program material (depending on grounding arrangement employed) it will place a ground on the high side of unbalanced elements. In most cases, particularly in the case of filters and attenuators, the characteristics of the unit may be considerably altered. Polarity reversal in both balanced and unbalanced-to-ground arrangements causes loss of phasing, if employed.

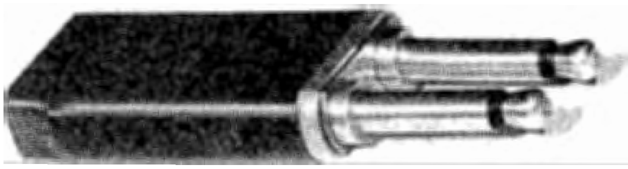

Fig. 2. The "twin" type of plug currently employed in the majority of audio systems. Jacks are used in pairs with this type of plug.

space would be required for a given number of jack circuits; the cost would be lower; and all possibility of reversing the circuit by improper insertion of the plug would be eliminated.

SINGLE PLUGS AND JACKS

To perform the same operations now accomplished by twin plugs, it is necessary that the single plug accommodate three conductors; two for the program circuit and one for ground. This requirement can be met by the "tip, ring and sleeve" type plug of the general type used on telephone switchboards.

It must be pointed out, however, that the usual telephone-type single plugs (such as the W.E. type 110) are *not* satisfactory for broadcast use, Fig. 3. This can be readily observed by visual inspection of the operation of these units. As this type of plug enters the jack, a point is reached where the tip of plug momentarily touches both program springs of the jack. During this period, the plug short-circuits program material on the jack. For this reason, these telephone-switchboard plugs cannot be considered for broadcast use.

This difficulty can be avoided by employing a different type of tip, ring and sleeve plug constructed with a shorter tip. Such plugs have been made for telephone applications and are available. An example of a plug of this type is the W.E. type 291-E which was employed in this study, Fig. 4.

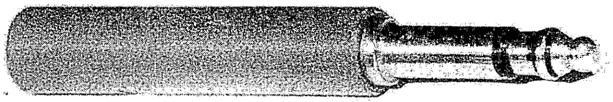

Fig. 3. A tip, ring, and sleeve type of single plug often used in telephone switchboard work. This type of plug is not satisfactory for use in audio systems as explained in text.

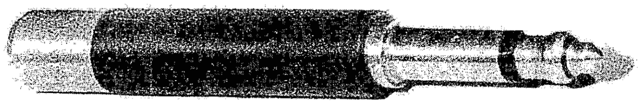

Fig. 4. This type of single plug, constructed with a shorter tip than the plug of Fig. 3, is satisfactory for use in audio systems. It is used in conjunction with the jack in Fig. 5.

The single jacks employed were the W.E. type 239-A. These jacks are designed to operate with the W.E. type 291-A plug and contain the necessary contact springs for two program circuits, each of which is provided with a "normal" contact. The ground circuit is carried in the usual manner, through the frame of the jack which is equipped with a terminal lug, Fig. 5.

It is often necessary in the design of audio systems to employ a few jacks equipped with auxiliary "make" or "break" contacts to accomplish some special circuit changes when a plug is placed in the jack. Jacks of the type under discussion are also available with these auxiliary contacts.

EXPERIMENTAL TESTS

As part of the early study of single plugs and jacks, an audio jack field consisting of 24 single jacks mounted on a conventional jack mounting panel was set up for the purpose of checking the operational performance of single plugs and jacks. Various amplifiers and other components were connected to this jack field, which was then normalled to simulate a conventional studio audio channel complete from microphone input circuits to program line output. Visual and aural monitoring facilities were included in this experimental set-up to make it resemble as closely as possible an actual installation.

The plugs and jacks in this experimental system were associated with both balanced-to-ground and unbalanced-to-ground circuits. In the case of the balanced circuits both the tip and the ring of the plugs, as well as the corresponding contacts of the jacks, were high with respect to ground; however, the wiring was so

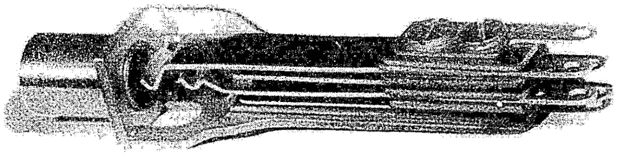

Fig. 5. The type of single jack shown above was used in all the measurements, investigations, and applications described in this text.

arranged that in the case of unbalanced circuits the tip was high and the ring low.

Patch cords, equipped with single plugs, were employed to check the ability of this jack field to perform all the usual jack field operational requirements, such as substituting amplifiers, patching out various components and making multiple connections.

It was found that the operation of these single jacks and plugs was entirely satisfactory and equivalent in all respects to the performance of the conventional double units.

Tests were made to determine the cross-talk introduced in audio circuits by single jacks as compared with that introduced by the more conventional "double" jacks. These tests were made on a balanced-to-ground, terminated, 600-ohm circuit by applying a sine wave of 15,000 cps to a jack, or in the case of double jacks to a pair of jacks, and measuring the signal crossing into adjacent jacks. The results of these tests are tabulated below:

Cross-Talk To:	Single Jacks	Double Jacks
Adjacent Left-Hand Jack(s)	–139 db	–132 db
Adjacent Right-Hand Jack(s)	–137 db	–128 db
Jack(s) Immediately Above	–140 db	–114 db

It will be noted that cross-talk is lower in the case of single jacks. *This is an important consideration in the design of audio facilities for present-day standards.*

SHUNT CAPACITY

Inasmuch as shunt capacity is an important factor in audio systems, measurements were made of the shunt capacity of both single jacks and pairs of jacks. The measured values are as follows:

SHUNT CAPACITY IN MICROMICROFARADS

Single Jacks

Tip-Spring to Ring-Spring	10
Tip-Spring to Ground	14
Ring-Spring to Ground	10

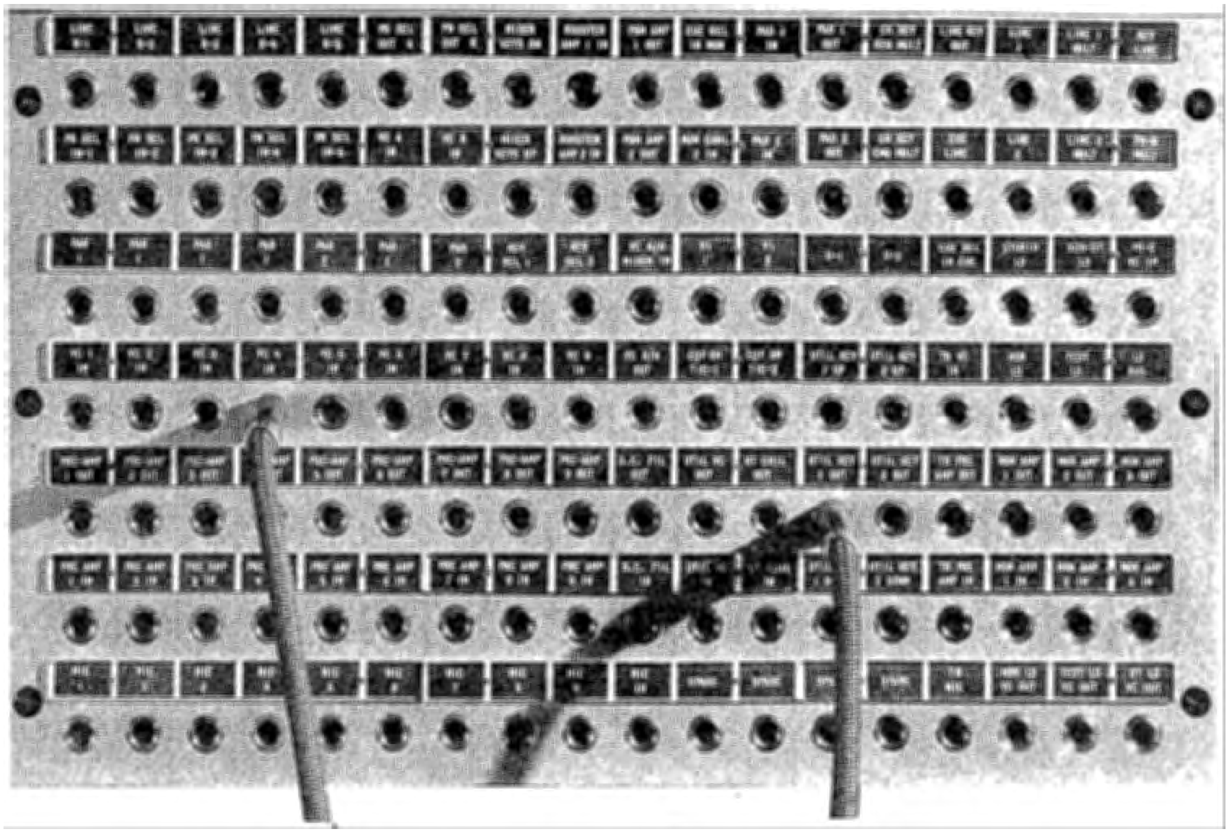

Fig. 6. The jack field of the CBS 3-B studio control console. 126 jack circuits are mounted on a panel only 9 by 14-1/2 inches in size. The spacing between jacks is 3/4 inches, the spacing between rows 1-1/4 inches.

Double Jacks

Tip-Spring to Tip-Spring	5.5
Jack 1 Tip-Spring to Ground	13
Jack 2 Tip-Spring to Ground	13

It is seen that the shunt capacity between program springs is slightly higher in the case of single jacks. It is not believed, however, that this will cause any difficulty in new audio facilities, inasmuch as 150-ohm circuits will probably be used in most future systems designed for wide-band transmission. The reduction of circuit impedance by a factor of four will more than offset any effect of the slightly greater shunt capacity on the higher audio frequencies.

PRACTICAL APPLICATION

Audio installations employing single plugs and jacks have now been made at CBS stations in New York, St. Louis, and, presently, in Hollywood. Three of these installations are shown in Figs. 6, 7, and 8. In addition, Station WWL at New Orleans has incorporated these jacks in a post-war studio control console.

As a result of the experience which has been gained with these installations, it has become evident that single jacks offer several advantages over the twin units. These advantages include: (a) smaller space requirement, (b) lower cost, (c) lower cross-talk, and (d) impossibility of incorrect patch cord insertion.

Fig. 7. A modified W.E. 25-B studio control console. The use of single jacks permitted 32 jack circuits to be mounted in the panel space originally accommodating 20; an increase of 60 per cent.

It is believed that the use of single jacks of the type that retain all the advantages of double units marks a step forward and will find wide application in the future.

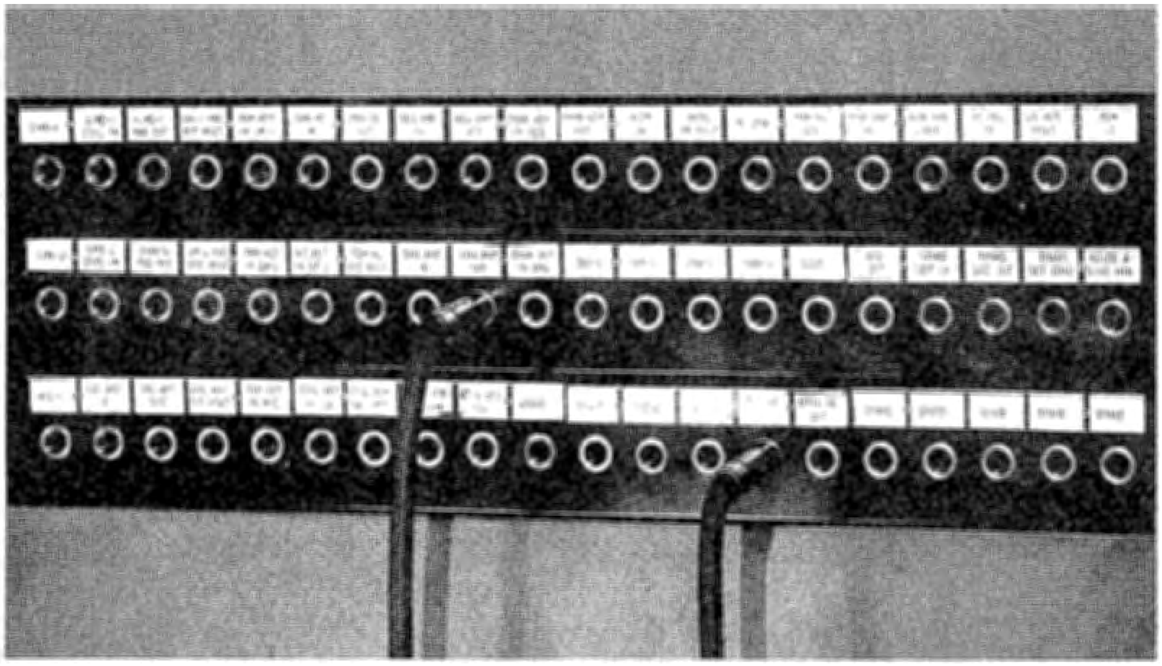

Fig. 8.

Supplement No. 1

to

NAB (NARTB) ENGINEERING HANDBOOK

(Fourth edition, 1949)

Maintenance of Television Equipment

(Although this article has been prepared primarily for television stations, much of the material will be found useful in AM and FM radio stations as well)

INSTRUCTIONS FOR FILING

To open binder, pull up on the ring and slide the cover of the binder upwards. Lift up on the metal bar, and the posts are open for insertion of the punched Supplement pages.

Supplement No. 1 should be filed at the end of Section 5, "General Engineering" immediately ahead of the division tab for Section 6, "Charts-Graphs-Tables-Notes".

MAINTENANCE OF TELEVISION EQUIPMENT

PREVENTIVE VS CASUAL MAINTENANCE

Many prospective television broadcasters will come into the field from AM/FM broadcasting bringing with them the same theories of operations which they followed in aural broadcasting. In a large number of areas, this thinking will serve admirably—certain techniques will be similar or, at most, require only such changes as come from adding sight to sound. There are fields, however, where the change experienced in transferring from audio to video seems to present much greater problems. One of these is maintenance. A study made by NARTB in the early part of 1952 reveals that, of the 108 television stations then operating, a typical medium sized station employed 61 people. Twenty-two of these were in the Engineering Department, and of the 22, two were full-time maintenance engineers. That is, two men were scheduled full time to check equipment in an attempt to prevent equipment failures. Hereafter, when the term "preventive maintenance" is used, it is this type of operation we mean. "Casual maintenance" is considered to be only routine checks, or repairs made after equipment failures. The prospective television broadcaster may wonder at first why a regular preventive maintenance schedule should be necessary for television when he has been getting along very well with casual maintenance in aural broadcasting. The answer lies partly in the far more complex equipment needed for television, and partly in the higher expense and income associated with television.

As an illustration of the latter reason, the failure of a single relay or contact in a switching system could result in the loss of a commercial spot announcement. Going back to the typical medium sized station mentioned above, this means a loss in the neighborhood of $100, this loss being a little more than the amount needed to pay the maintenance man's salary for a week according to the same NARTB survey mentioned above.

In all fairness to those broadcasters who firmly believe casual maintenance is enough in the television station, it must be pointed out that some highly successful operations have no maintenance engineers as such. An examination of their methods will reveal, however, that transmitter and studio technicians spend a certain amount of their time checking equipment not in use while the station is on the network, or in other ways fitting some maintenance into their daily working schedules. Furthermore, these technicians will be found to be highly experienced men who are familiar with the circuitry of the equipment, and excellent "trouble-shooters". It will thus be seen that while no formal preventive maintenance schedule is in force in the station, a larger percentage of the working day is being spent in maintenance in the television station than is usually spent in maintenance in an FM or AM station. It remains a problem requiring a decision to be made by each broadcaster as to whether he will hire maintenance men who can keep the equipment in good operating condition and be able to use less experienced men at the transmitter and studio, or whether he will hire technicians who have the experience, knowledge and "feel" for maintenance and who can get the station back on the air quickly in the event of equipment failure. It may be mentioned, too, that his decision may have to be based on union classification.

In a number of articles and panel discussions by practical television broadcast engineers, the need for preventive maintenance has been stressed, but due to the present highly flexible state of the art, very little of a definite nature can be prepared. In this article, a suggested preventive maintenance schedule is shown, and a few suggestions of a general nature are listed, in the hope it may provide the prospective broadcaster with a beginning to which he may add such procedures as are pertinent to his particular type of equipment. Each piece of television equipment will have its own individual characteristics, and specific operating procedures for each equipment item are furnished by the manufacturer. It is suggested that a collection of all the instruction books for the equipment in the new station be gathered together and from this collection, specific details can be drawn to supplement the general material which follows.

The object of any maintenance program, whether it be preventive or casual maintenance, is to keep the equipment operating at optimum—to satisfy the regulations set forth by the FCC—and to keep operating costs down. Although the most careful and thoughtful maintenance program cannot always prevent occasional equipment failures, the symptoms of impending failure may often be observed during the day's operation and a well-defined system of reporting to the regular maintenance crew should be developed. At the transmitter, the log is the logical place. At the studio, the workshop should have a regular place to put notices of equipment troubles. After the maintenance man checks the item noted as being faulty, he makes such adjustments or repairs as are necessary, and initials the notice with the notation "Adjusted", "Tube changed" or whatever work was done. The sheets or logs are kept on file after completion of the work, and over a period of time they provide a good source of study for the idiosyncracies of each equipment item. From a collection of this nature, conclusions can be drawn as to what type of trouble to expect from each piece of equipment and in many cases equipment failures can be foreseen and corrected in advance of failure.

In the following pages, a general outline of preventive maintenance is given. Complete details applicable to all kinds and makes of equipment naturally cannot be given, nor is it the purpose of this article to replace the specific instructions given by the manufacturer for the care and maintenance of each equipment item. The purpose of the article is rather to supplement these specific instructions by a few notes and suggestions made by station operators as a means of gathering together in one place the beginning of a maintenance manual. The value of such a manual to each station depends entirely on supplementation by recommendations drawn from (1) the manufacturer's instruction manuals, and (2) the experience of the chief engineer and his staff as the station develops.

STUDIO PREVENTIVE MAINTENANCE SCHEDULE

Daily

Dusting.

Check for signs of overheating on all equipment.

Check pick-up equipment for abnormal conditions such as position of control knobs and poor picture quality which may not have been reported.*

Check cameras for geometric distortion, alignment and resolution.

The film photographic sound track scanning system must be checked. The exciter lamp condition should be noted and, in addition where provided, the adjustment of the lamp filament alignment with the optical assembly should be checked. Optical assemblies and any apertures in the light path should be cleaned. Dust can be removed by blowing air across the lens faces with a syringe bulb and wiping with lens tissue. Photo cells should be examined for oil on the glass.

Projection lenses should be wiped with lens tissue. Coated lenses should be cleaned very carefully in accordance with the manufacturer's instructions.

Check need for unusual control knob settings on synchronizing generator.

Clean film projectors in accordance with manufacturer's instructions, checking especially for accumulations of dust, lint and emulsion on gate, pressure shoe rollers, teeth, picture aperture, etc.

Visually check microphone and other cables for serious abrasions from pinching, kinks, etc., which may lead to broken wires internally.

Weekly

Thorough internal and external cleaning of cameras, camera controls, monitors, and power supplies. Check insulation on lead wires to power lines and replace lines if necessary. (NOTE: On delivery or after a major repair job or change in equipment, a thorough inspection should be made of all connections, checking for rosin joints and poorly soldered connections by firmly pulling on wires and leads. Connections incapable of passing the required electrical current can be corrected before equipment failures.)

Check and record cable socket voltages on cameras.

Run test checks on cameras and projectors using test charts, slides or films such as those recommended by RTMA or SMPTE.

Check amplitude and pulse widths of synchronizing generator.* Aging of tubes may cause some small variations which can be overcome by adjustment.

Oil film projectors.

Check and clean fader controls on both audio and video equipment.

Check microphones for proper output. WARNING: Do not use an ohmmeter or other circuit checker, since they may damage the ribbon or diaphragm.

Check air filter on power supply and clean or replace if clogged.

Lubricate wheels and moving parts of camera dollies and booms, microphone booms, pulleys for studio lights and mechanical parts of studio cameras (pan and tilt and optical focusing mechanisms, etc.)

Monthly

Record and compare cable socket voltages on all equipment.

Check adjustment of all control knobs and readjust where necessary.

Tube checks on all equipment using a good mutual-conductance tube tester. Generally, tubes should be replaced in the same sockets from which they were removed. Tubes with weak emission should be replaced with spares known to be good. After tube checks, equipment should be operated and tests run to insure that no unusual conditions have resulted from tube removals and replacements.

Check and clean relays and switch contacts in all equipment. Some relays in more recent systems are protected sufficiently from dust and dirt and may not need such frequent inspection.

Low level audio tubes and audio amplifiers with "plug-in" chassis should be moved in and out a few times to renew the contact between fins and sockets.

(NOTE: Voltage and waveform charts for each type of equipment will be furnished by the manufacturer and should be regarded as standards by which to compare test checks.)

After 1000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by manufacturer.

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* During camera set-ups, need for unusual control settings should be observed by the operator and reported.

* Some manufacturers recommend this be done daily.

FIELD PICKUP (REMOTE) PREVENTIVE MAINTENANCE SCHEDULE

(This is also applicable to S-T-L)

NOTE: These daily, weekly and monthly schedules will naturally be revised in accordance with usage given equipment.

Daily

Check switching system for abnormal conditions such as poor picture output when compared to input.

Check cameras for geometric distortion, alignment and resolution.

Check pick-up equipment for abnormal conditions. (See "Studio" schedule.)

Check all equipment for overheating.

Dusting.

Weekly

Internal and external cleaning of cameras and power supplies. (See notes on "Studio" schedule.)

Check and readjust controls.

Inspect and tighten cable connectors and clamps.

Check amplitude and pulse widths of synchronizing generator. (Some manufacturers recommend this be done daily.)

Lubrication of moving parts of cameras. See studio preventive maintenance schedule.

Check and clean fader controls on both audio and video equipment.

Visually check weatherproofing of cables, connectors and other parts of equipment subjected to weather.

Check batteries on audio equipment.

Monthly

Tube checks on all equipment. (See "Studio" schedule.)

Record and compare cable socket voltages.

Check air filter on power supply and clean or replace if clogged.

Check and clean relays and switch contacts in all equipment. (See "Studio" schedule.)

After 1000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by manufacturer.

If a field power generating system is used, the internal combustion engine and the generator should be given equal weekly and monthly attention. See manufacturer's instructions on this.

TRANSMITTER PREVENTIVE MAINTENANCE SCHEDULE

NOTE: In connection with the following schedules, reference should be made to the FCC Rules Governing Television Stations. The RTMA "Electrical Standards For Television Broadcast Transmitters, Channels 1-13—TR-104-A" will also be found helpful.

Daily

Check filament line voltages every hour and adjust if required. FCC Rules governing transmitter logs (Sec. 3.663) require that operating constants of last radio stage of the aural transmitter (total plate current and plate voltage), transmission line meter readings for both transmitters, and frequency monitor readings be observed and recorded half-hourly.

Check visual and aural monitoring circuits, observing both voltage and current meters. Changing current or voltage indicates either deteriorating tubes or equipment. If the operator observes any rapid changes, a sufficient note should be left with the log as instructions for the maintenance crew.

Dusting and general inspection for overheating or other signs of abnormal operation.

Weekly

Tube checks on all tubes which are not metered in the transmitter.

Clean internal parts of transmitter (insulators, etc.)

General performance check of noise, distortion and frequency characteristics of aural transmitter.

General performance check of visual frequency and broadband characteristics of visual transmitter.

(On the last two mentioned checks, spot checks will ordinarily suffice on a weekly basis—however, in this case, a more thorough check should be made monthly.)

Inspection of blowers and flowmeters. Clean and/or lubricate if required.

Test door-interlocks and disconnect-switches being certain they result in interruption of high voltage when access doors and windows are opened.

Check and operate all relay contacts. Observe closely for heating.

Check transmission lines for tightness by observing gas or air pressure.

Add distilled water to cooler unit if required.

Correct all meter needles to normal non-energized readings.

Monthly

Inspection and lubrication of small blower motors.

Test spare tubes required by FCC.

Clean socket contacts if necessary.

Service relay contacts if necessary.

Check air filters and clean or replace as necessary.

Visually check condition of water in cooling system.

Quarterly

Operate all spare mercury vapor tubes for 30 minutes (See instructions furnished by manufacturer.)

Detailed inspection of every unit in transmitter using tests recommended by manufacturer.

Service all power contactors if necessary after inspection.

Flush and refill water-cooling system.

Make visual inspection of physical condition of antenna tower and transmission line.

Inspect and test tower lighting equipment according to Part 17 of FCC Rules.

Semi-annually

Tighten all connections, both electrical and mechanical, in transmitter and associated equipment.

Lubricate exhaust fans.

Lubricate high-pressure blowers and check operation of air interlocks.

Lubricate water cooling system.

Check outdoor protection to water cooler intake before cold weather, and for free circulation before summer.

SAFETY

Every possible means of affording maximum protection to personnel working in the television station should be considered. Television equipment has been designed to operate safely so long as reasonable care and judgment are exercised, but it cannot be too strongly impressed on every person coming into contact with the equipment that the safety rules for handling each item must be observed, since the high voltage of certain components is sufficient to endanger life. Some general safety precautions are given below and more will probably suggest themselves to the station operator and can be added.

1. Regular inspection of safety interlocks for proper functioning. Check leads and connections to grounding hooks.
2. Check ground connections for tightness.
3. Check insulation on all leads regularly. Never use leads with broken insulation.
4. All high-voltage capacitors should be discharged before they are touched by the operator. Although "bleeder" resistors do discharge capacitors after a reasonable time, in consideration of the voltages used, it will still be safer to discharge the capacitor with a shorting bar. Due precaution must be observed in the removal of the shorting bar.
5. Rubber gloves should be worn when working on high-voltage equipment, and a rubber sheet should be placed over the sill of the transmitter compartment, or over any place where it is possible for the employee to come into contact with live equipment.
6. Before making repairs on high-voltage areas of equipment, instruction books and schematics should be closely studied so that the maintenance man is thoroughly acquainted with the equipment before starting work. It may also be pointed out here that *high-voltage sometimes appears at unexpected points in defective equipment.*
7. Ground leads of oscillographs should not be connected to a high-voltage point, since the ground lead of most instruments is connected internally to the case.
8. When measuring high-voltages, consideration should be given to both A-C and D-C voltages present, and peak voltages should be taken into account when selecting voltmeters and multipliers.
9. Rubber gloves and blankets will not afford protection against high radio-frequency voltages. When working on circuits carrying high R-F voltages, the circuit should be inoperative before work is begun.
10. Extreme care must be used when touching tubes that have been in operation for a considerable length of time since serious burns can result. This is true even of small tubes.
11. Pressure developed on the envelope of large vacuum tubes is extremely high and when the tube envelope is broken, it must be remembered that the tube will implode—not explode. This means there is a possibility of the tube base being projected through another portion of the tube. For this reason, tubes should be kept in cartons until time for their actual use—safety goggles and gloves should be worn when handling large vacuum tubes. Spectators should be kept at a safe distance whenever a tube is outside its carton.

A means of disposition of these tubes must be found, bearing the above hazards in mind, to prevent the scattering of shattered glass and the possibility of the tube elements and base flying free. One suggestion is that the tube should be placed in a shipping container, the container sealed, and a crowbar or similar instrument driven through its top. Another suggestion is that the tube should be placed in a shipping container, leaving the neck or gun end of the tube exposed. A tarpaulin or burlap bag is thrown over the neck to deflect any glass and the neck is struck sharply with a hammer.

12. It is not generally known that carbon tetrachloride is a strong toxic chemical and that continued breathing of the fumes is cumulative and can become injurious to health. Its use as an open cleaning agent is not recommended. The Navy has discontinued its use for projector cleaning and recommends that alcohol be used wherever possible.

    It must be remembered, however, that alcohol and naptha are both inflammable, and proper precautions must be taken in using either.

GENERAL

In the following pages, some amplification of the preventive maintenance schedules will be found. In some cases, it may seem that the emphasis has been shifted from "preventive" to "casual" maintenance, or from maintenance to operation principles. These are the areas where experience of presently operating stations has indicated a need for calling special attention of the new station's technical staff.

Certain principles of maintenance are common to all types of equipment. For example, throughout this article, frequent mention is made of the removal of dust from equipment. This is extremely important because, among other things, excessive dust may lead to current leakage or arc-over between high voltage points. Obviously, dust will do more damage to open equipment than to completely enclosed equipment, but daily efforts must be made to keep the collection of dust at a minimum on all equipment. We are reminded of the story of a government agency which was said to have employed both "high dusters" and "low dusters", each having specified areas of work and each employing different tools and practices of dusting. The problem of dusting in the television station requires tools ranging from soft lint-free cloths and absorbent pads to vacuum cleaners. A small hand-type vacuum which can be reversed and used as a blower may be a wise investment for the station. Various sizes of paint brushes will be helpful in removal of dust and lint from small equipment items. When cloths and brushes are used, they should be absolutely dry or moistened with a volatile liquid such as carbon tet, alcohol, naptha, etc.*—never with oil.

All equipment tests should be made as soon as possible after the close of the day's programming, or after the last use of the equipment item during the day. After tests or checks are completed, the equipment should be placed in operating condition to be sure that it is functioning properly. Before beginning any tests, instruction books and schematics should be closely studied and safety precautions observed. Inspection may be made by feel (for overheating), smell (this often locates an overheated part such as a transformer or reactor), and visual inspection for loose, broken, warping or cracked connections, broken parts, insulations or wires.

Before dismantling any part of the equipment, be certain the correct input signals and voltages are being applied. (In other words, there is no use dismantling the engine of a car if it's just out of gas.) The correct input signals and voltages are supplied by the manufacturer as part of the operating instructions.

Be Logical—Check the Obvious First

In the section relating to the Synchronizing Generator, it is pointed out that personnel should be briefed at least semi-annually on the possible causes of failure. This same procedure may well be used with all other major equipment items in the station. Also, as mentioned above, instruction books, schematic drawings and other technical data on the equipment should be readily available to all technical personnel.

The notes on "Tube Checks" found in the Camera Chains section apply to all tubes used in the television station, as do the notes on regular cleaning and inspection of cable connectors and the measuring of cable socket voltages.

TESTS AND TEST EQUIPMENT

Many television stations upon first going on the air have underestimated the need for appropriate test equipment, only to find themselves later on faced with the need for purchasing more such equipment. In addition to the more common test equipment such as tube testers, volt-ohm meter, etc., normally associated with aural stations, television stations require one or more good oscilloscopes, video sweep generators, audio oscillators, noise and distortion meters, and a device for checking scanning linearity such as a grating or bar generator. Depending upon the complexity of the installation more or less equipment may be required. The FCC requires that certain standards with respect to the overall attenuation characteristics of the visual transmitter must be maintained, the aural transmitter and entire audio system must meet certain well defined operational characteristics with respect to distortion and frequency response. The scope of this article at the moment does not permit us to list all of the FCC Rules and Regulations pertaining to the required tests and operating practices, but these will more appropriately be included in subsequent articles. The matter of so called "proof of performance" on video transmitters is not altogether as well defined at the moment as the "proof of performance" required for the aural transmitter. We hope at a later date to have information on this subject. It is therefore necessary for us to confine the

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* See Note 12 in "Safety" section.

material in this article to that maintenance required for the uninterrupted functioning of all mechanical items and the electrical portions containing expendable parts or where trouble more commonly occurs. In other sections of this Handbook will be found data on video amplifiers, terminal equipment, etc., which will prove helpful in understanding the design, operation and line-up of various segments of the television system.

FILM PROJECTORS

Specific details for the operation and maintenance of each of the many types of film projectors will be furnished by the manufacturer. These instructions should be carefully read by every operator who handles the projector, and kept handy for ready reference at all times. There are, however, a few general remarks that can be made on the subject of film projectors:

1. *Cleanliness.* The projector film path should be cleaned thoroughly daily and accumulations of emulsion or other dirt removed with a tooth brush or flat pointed tooth pick and cloth moistened with carbon tetrachloride or alcohol * which must not leak into the mechanism. In cleaning lens surfaces, do not blow on the surface of the lens as this may force vapor back into the lens mount. The lens tissue may be moistened with the breath or lens cleaning fluid.
2. *Oiling.* Always use the type of oil recommended by the manufacturer. Different weights of oils are recommended for different parts of the projector, and substitutions can cause trouble. Oils flows more freely and penetrates faster when the machine is hot. Be extremely careful not to over-oil the projector since the oil may leak onto the film. For the same reason, be careful not to spill oil about the projector.
3. *Handling lamps.* Before placing a new lamp in the projector, wipe off lamp surface with a clean, lintless cloth. Fingerprints left on the surface of the lamp will bake into the glass and be difficult to remove later.
4. *Spares.* A complete set of tested spare lamps, tubes, fuses, belts and other parts subject to wear should be kept on hand at all times. In replacing fuses, be sure that the new fuse does not have a higher power rating than the old one.

Following are some of the major "troubles" which occur in the film projector. It will be noted that many of these troubles arise from the presence of dirt, improper control settings, or tube failures—all of which can be anticipated to some extent by a sound preventive maintenance schedule.

Loses film loops—tears sprocket holes: Feed sprocket or film pressure shoe out of adjustment. Adjust as explained in manufacturer's instructions. Other possible causes are dirty or worn claws, claws out of adjustment, torn film or bad splices. Daily cleaning will prevent accumulation of dirt and emulsion on claws, sprockets and pressure shoes—proper splicing and pre-editing will save time and trouble in the long run.

Noisy projector mechanism: Check adjustment of claws, roller chain, drive chain and gears. Adjust as recommended by manufacturer.

Travel ghosts and picture jump: Check projector synchronization of the shutter with the pull-down mechanism. Trouble may be shutter out of adjustment, improper threading, claws worn or out of adjustment, worn rails or cam shaft. Bad or poorly made film causes the same symptom—it is well to check the projector with standard film selected for this purpose.

Indistinct picture or low illumination: Projection lens, condenser lens, or reflector dirty, or projection lamp may need replacement. Dense film may cause the trouble—check with the standard film.

Film scratched: Film shoe, pressure roller, aperture plate or guide rollers dirty or emulsion coated. On 35 mm projectors, check fire rollers in upper and lower magazines for accumulations of fuzz and grit which will scratch film.

NOTE: The last three troubles mentioned may be on the film in use. Pre-viewing of all film is recommended.

Picture, but sound weak or distorted or no sound: First, check audio level control and threading system. These are the principle causes. Open or shorted cables, burnt out fuses or lamps, improper seating of photoelectric tubes, improperly adjusted sound mirror are also frequent causes. Check for obstruction of light beam by foreign matter. If trouble is still not located, check further by manufacturer's instructions.

Sound, but no picture: Burnt out projection lamp.

Oscillation in preamplifier: Loose ground wires, output leads too near the input leads, or defective by-pass capacitor.

Hum level high: Check shield on audio line or photoelectric cell, filtering of photoelectric cell voltage or bad tubes.

No photoelectric cell voltage: A-C power may be off. Also check filter capacitors and rectifier tubes in preamplifier, fuse in A-C line to preamp, and for open resistors and broken or shorted wires.

Microphonics: Loose connections, poor contact between plug and socket, loose elements in PEC, or oil soaked wiring. Also check projector mechanism for excessive vibration. (Pre-amplifier tubes are often microphonic.)

Distortion: Most often found to be tube trouble or defective PEC or sound optics out of adjust-

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* See Note 12 in "Safety" section.

ment. Other causes are due to leakage in speech lines or open coupling capacitor.

Tone unsteady—Wows: Check tension of pressure roller. Sound drum may be dirty or damaged. Check also for dirty pressure rollers, and dirty guide rollers. Sound drum shaft or bearings may be loose or worn. Defective motor or drive mechanism could cause unsteady tone.

Motor Repairs

All adjustments and repairs to the film projector motor should be made with *POWER TURNED OFF*. Try to avoid loosening shutter from the rotor shaft as this will require readjustment of the shutter for proper synchronization. Failure of drive motor to start, not running at proper speed, acceleration time too long, or drive motor starting then stopping, usually indicate excessive loads or improper line or field voltages. Check for open switches, loose connections or breaks in power wiring. Regular maintenance schedules should include proper cleaning and oiling to prevent overheating of bearings in blower motor and drive motor. Check and tighten motor coupling and attachment of motor to bed plate. (In tightening screws, avoid forcing screws and damaging threads. If necessary, remove screw and replace with a new one.) Included in the regular maintenance schedule should also be repairs and replacements of brake resistors and relays on projector mechanism.

The following section on Precision Adjustments was provided through the courtesy of the Society of Motion Picture and Television Engineers.

Precision Adjustments

TELEVISION TEST FILM

This film is designed to indicate the condition of operation of those portions of the television film reproducing system which depend upon the relation between the film projector and the television system.

Use of the test film on a routine operational basis is recommended since it will indicate errors of adjustment and equipment malfunction before they might otherwise be detected, and before they adversely affect the quality of the transmitted picture.

Several test sections and a selection of scenes comprise the complete film which is available in 16 and 35mm widths. The test sections are a series of geometrical patterns intended to present information on the factors most likely to be degraded in television film reproduction. The test targets appear in the following order; alignment and resolution, low frequency response, medium frequency response, storage characteristic, gray scale and brightness control. Each section is preceded by an explanatory title. 16mm test films are used for the following tests:

SOUND OPTICAL ASSEMBLY ADJUSTMENT

Two types of film are available, a 7000 cycle record for precision adjustments following overhaul and a 5000 cycle record for quick service adjustment. Both films are original recordings, rather than print. Each carries a special square wave track which was chosen because its output changes more rapidly with changes in the focus of the assembly than the output from the usual sine wave high frequency track, and also gives a sensitive indication of the errors in azimuth adjustment. Films are used as loops and adjustments are made for maximum output meter readings.

ALIGNMENT OF THE SOUND RECORD WITH THE SCANNING BEAM

Buzz track test film is used for this purpose. The track consists of an .076 in. opaque center with a square wave signal frequency of 300 cycles recorded just outside that area on the picture side and another of 1000 cycles just outside that area on the side nearest the film edge. Guides should be adjusted so no sound is heard from either frequency.

Standard sound record widths are .060 in. to .072 in. Some sound optical assemblies produce a light of sufficient length to reproduce both frequencies when the assembly is only slightly out of adjustment.

Buzz track film is an original recording made on a special machine built for that purpose.

UNIFORMITY OF SCANNING BEAM ILLUMINATION

This film requires the use of an output meter and a picture projected light on the screen. A narrow sound track .005 in. wide, modulated at constant level, by a 1000 cycle tone sweeps across the scanning light beam from one end to the other at a uniform rate, the position of the sound track relative to the ends of the light beam at any instant being shown by an animated diagram appearing in the picture area.

If the scanning beam illumination were absolutely uniform across the width of the scanned area, the output of the 1000 cycle tone would be constant. In practice, however, some variation of the meter reading will always be observed. The film is made up into loops of 34 ft. for the laboratory type and 3½ ft. for the service type. By running a loop continuously and observing the indications of the output meter while adjustments are made it is usually possible to correct unevenness of illumination and bring the variations of output within a limit of ± 1.5 db. Sometimes a new exciter lamp will correct uneven meter readings.

FLUTTER

The 3000 cycle flutter test film is a direct positive original recording and carries a 3000 cycle tone having extremely low flutter content for use in measuring the flutter introduced by sound reproducers. A flutter meter is required to make this measurement. The total flutter content of the film at the time of shipment is less than 0.1%.

SYSTEM FREQUENCY RESPONSE

The multifrequency test film is a direct positive original recording and is used to obtain the electrical frequency response at the output of the power amplifier. Each film is individually calibrated and contains 14 frequencies each preceded by a spoken announcement. The deviation of the test film record from the intended flat response characteristic is stated as a correction for each frequency which will give a true level when it is added algebraically to the output level measurement obtained when using the film.

Calibration data and instructions are packed with each film.

SYSTEM GAIN TEST

The 400 cycle signal level test film is a direct positive original recording designed to furnish as nearly as is practicable an absolute standard of recorded signal level for use in measuring the effective amplification and output of sound systems, taking into account the sound optical system and photo tube as well as the amplifier.

TRAVEL GHOST TEST

Travel ghost is a blurring effect in the picture as seen on the screen and evidenced by vertical tails or light streaks added to the projected images of the transparent area on the test film. It is caused by the projector shutter being out of synchronism with the intermittent mechanism.

The test film travel ghost target shows improper timing of the shutter quite readily and gives a clear indication of the correct adjustment.

PICTURE STEADINESS TEST

This film permits the unsteadiness of a projected film image to be measured. As a steadiness reference there are three round holes punched in the picture area. The two lower holes are produced by a single punch stroke that is indexed from the adjacent standard film perforation, the one that locates that particular frame in the aperture on many projectors. The upper hole is produced by the succeeding stroke. Relative motion between the upper hole and the lower pair is a direct indication of inherent unsteadiness of the film resulting from expected inaccuracies in the perforating of the film because it is a plastic material.

Simultaneous motion of the upper hole with the lower pair permits the image unsteadiness produced by the projector under test to be observed. Residual unsteadiness of films approved for sale is no greater than 0.05% of picture width.

CHECK OF FINAL RESULTS

A film containing picture and sound of known quality should be selected.

The Research Council sound projector test film contains three dialogue samples, a female solo sample, orchestral and piano music.

The Society produces a sound service test film which contains title music, buzz track, sound focusing test, constant frequencies from 50 to 6000 cycles, dialogue and piano music. This film is intended to provide an inexpensive overall quick test of projector performance.

A complete list of 35mm and 16mm test films is shown in the catalog of the Society and Research Council and is available for the asking. See final section, "Test Charts, Slides and Films" for availability.

CAMERA CHAINS

The most frequent cause of trouble here is small tube failure which can be prevented to a large extent by regular tube checks. Tubes with weak emission can be replaced by ones known to be good. Spares should be kept at hand at all times for quick replacement if trouble occurs while the camera chain is operating. In making replacements, be certain that power is OFF, and that capacitors are DISCHARGED. Here, as in most constantly operating equipment, serious burns can result from carelessly touching tube envelopes.

Another frequent source of improper operation is failure to check control settings. It is suggested here that the approximate control settings be written or typed on a small card to be fastened to the camera for the benefit of inexperienced personnel.

Tube Checks

One simple method of testing the tubes in a circuit for the presence of microphonics is to tap each tube lightly with the eraser end of a pencil. A "noisy" tube can be located by observing the raster of the picture monitor during the test.

In making tube checks, tube testers of the emission type should be avoided, using mutual-conductance tube testers instead where applicable. A permanent log of the usage on all image orths, iconoscopes, etc., is suggested. Experience has shown that such logs (or card files) will often point out tubes likely to go bad in the near future, and may often show up repeated failures of a certain tube which can then be traced to defective or partially defective circuitry, or possibly to a defective lot of tubes.

Waveform and voltage charts will be furnished by the manufacturer of each type of camera, and should be regarded as standards to be used in tests on each individual camera.

In addition to the monthly tube checks suggested in the preventive maintenance schedule, frequent checks on cameras for geometric distortion are suggested. These may be effected by use of test pattern charts, slides and film as recommended by RTMA and SMPTE.

When faulty operation of the camera occurs, the four major circuits of the camera ordinarily can be checked quite easily as follows:

Vertical deflection: Check waveform.

Horizontal deflection: Check waveform.

Operating potentials of picture tube: Remove the tube and check voltage and control ranges.

Picture amplifier. Touching the grid terminal of the input stage with a screwdriver or other small "antenna" will usually produce oscillations if the amplifier is all right. If no activity is indicated, checking for lighted heaters in all stages, or for cathode bias voltages will often lead to the trouble point.

With these relatively simple checks, the defective area can be isolated and a more detailed examination made. It will be found that the manufacturer's instructions in each case are very explicit.

SYNCHRONIZING GENERATOR

The timing, formation and shaping of a television picture signal which will conform to the standards set by the FCC starts with the proper functioning of the synchonizing generator. Fortunately, the newer types of synchronizing generators give very little trouble over long periods of time. It has been suggested that since this is the case, an effort be made at least semi-annually to acquaint personnel with the possible causes of failure so that when trouble is experienced, the operator will have some idea where to look for the cause.

Two of the most common causes of failure of the synchonizing generator are variations in the power supply and tube failures.

Deviations in the power supply will, among other results, cause the picture to "roll". This can be guarded against by regular checks on power supplies and tolerances in voltage regulation equipment which, in most cases, is required to insure reliable operation.

As the tubes in the synchronizing generator grow old, they may cause small variations in the amplitude and pulse widths of the output signals, or may cause unwanted pulses to appear in the positive region of the output signal. Unless tubes or voltages vary greatly from normal, pulse shapes can be returned to standard by adjustment of external controls.

The small vacuum tubes used in this equipment item are relatively stable, but quite often slight variations in operating characteristics of similar type tubes dictates that each tube be replaced in its former socket after it has been removed for testing. (This may be found to be good practice throughout all other equipment in the station.) After a tube has completely failed, or as a result of the tube tests is expected to fail soon, and is replaced, the synchronizing generator should be checked for proper operation and adjustments made immediately, rather than wait until the next day's operation begins only to find that, due to the change of one small tube, the generator is not functioning properly.

It has been considered a good policy in many stations to have a second synchronizing generator for use as a spare, and to test both before beginning the day's programming to be certain they are both operating properly.

In all equipment of this nature where a large number of small tubes is employed, a large number of stations have found it profitable from a standpoint of economics, as well as trouble-free operation, to keep the equipment running on a 24-hour basis. This practice is applicable in many sections of the station's equipment where the daily thermal cycles definitely cause deterioration of tubes and parts.

FIELD PICKUP (REMOTE) EQUIPMENT

Periodic inspection and cleaning of equipment used outside the studio is especially important since it is constantly subjected to jolting and to conditions of excessive dust and moisture, and possibly to wide variations in primary sources of power.

Particular attention should be paid to the removal of dust which may cause current leakage or arc-over between high-potential points. Needless to say, all surface dust should be removed before beginning internal cleaning to prevent dust particles from falling inside where they may be hard to dislodge. All bushings and terminal boards should be kept free of dust.

Frequent visual electrical and physical inspection of wires and terminals becomes even more important on field equipment where connections may become strained from jolting during moving from one location to another. Good, firm (but careful) pulls on lead wires may reveal high resistance or broken connections which can then be repaired before failure occurs.

When fuses are renewed, fuse cartridge caps should be clean and dry to insure good contact and to prevent fuse heating due to contact resistance.

One of the more frequent causes of trouble in field equipment is the improper setting of controls. Controls can be properly set before the equipment leaves the station, but it may be also found helpful to record the approximate settings on a small card which can then be attached to the equipment item and referred to at the remote point. This is particularly true when the equipment is operated by several different technicians, rather than one man who always has the responsibility for remote set-ups.

Camera lenses should be removed before leaving the station, covered with the lens caps, and stored in felt-lined carrying cases. Such cases should be both moisture- and dust-proof.

The remote vehicle should have spare tubes, cables, fuses and other parts subject to wear within instant reach of the technicians.

TUBES

It has been found that a television station equipped for both film and live telecasting employs around 1800 tubes in the overall system of studios and transmitter. These tubes range from the inexpensive miniature type to the image orthicons which cost about $1200 each. Naturally, it is impossible in an article of this type to completely cover the idiosyncrasies of such a variety of tubes, but since tube failure is one of the major causes of equipment failure, it may be well to point out a few general precautions to be observed in their handling.

To begin with, the same life expectancy of a tube used in video circuitry is not always as great as that of the same tube when used in audio equipment. However, many tubes may be transferred to audio service when they are found to be no longer useful in video, provided of course, that the length of service in video has not been too great. A supply of pre-tested tubes should be instantly available to the operator for quick substitution when necessary. It may be found desirable to have certain tubes pre-marked for location.

A record of test readings and hours in use on all critical tubes is considered desirable. In addition to revealing tubes which are likely to fail in the near future, such a record may also reveal types of tubes which are not giving satisfactory service and which should be studied closely to determine the cause of failures. (See notes on camera chains.) Either a card file or a loose leaf notebook will be suitable for tube records.

Spare tubes, particularly of the transmitting, cathode ray and image orthicon type should be operated regularly to prevent them from becoming "gassy".

When transmitter tubes are first received at the station, they should be tested at a time outside the regular hours of operation, or into a dummy antenna if this is available. The "tube biography" is then begun with the date of test and condition in which the tube was received being the first entries. Transmitter tubes are guaranteed for a period of 1000 hours and a pro-rated rebate is made by the manufacturer if failure occurs before the completion of the guarantee. Therefore, a record of the number of hours in operation and other pertinent data is essential for each tube until the tube is eliminated from service since hundreds of dollars are involved.

Water-Cooled Tubes

The proper care and maintenance of water-cooled tubes is of primary importance in insuring good service. These suggestions are made as a general outline. They should be checked against the instructions given for different types of water-cooled tubes by the manufacturer since such instructions will vary. See especially the notes from RCA on the 8D21.

1. Installation of the water-cooling system, and of each new tube placed in service should be in strict accordance with the manufacturer's instructions. Improper operation for only a few minutes can ruin a tube.
2. Always use distilled or water of equal purity in the system. Tap water or even the spring water used for office water coolers often contains impurities which become electrostatically precipitated and form scale which interferes with the proper operation of the system.
3. Remove filter strainer regularly and clean out any sludge that has formed. This should be done quite frequently during the run-in period, and periodically thereafter.
4. After cleaning the system, water should be circulated for a short time and then the entire system refilled with fresh distilled or equally pure water. Never allow chlorinated water to enter the system as it greatly increases the corrosion rate of the pipes and ducts in the tubes.
5. Regular oiling and greasing of the system motor should be a part of the maintenance routine.
6. Avoid operating the water-cooling system at too high a pressure, since this will cause excessive water turbulance in the tube passages with the possibility of an increase in microphonics.
7. It is highly important to protect outside intake of the water-cooling system before cold weather begins. (In one station, the intake system was installed in the basement of the transmitter house with no further protection. The first night the temperature dropped below freezing, the intake system froze causing a great deal of damage and expense before the situation could be corrected.)

Air-Cooled Tubes

In general, the maintenance of air-cooling systems is relatively simple. Air filters should be regularly inspected and cleaned or replaced when necessary. Small strips of cloth tied to the blower will give an instant visual check on whether or not the system is working. A suggestion has been made than when the system is first placed in operation, the temperature of the intake air and out-go air should be noted and the differential established as an operating standard for the system. (Each system will be found to have its own differential.) The same temperature measurements may be made monthly, and as soon as a wide departure from the standard appears, a check on the system can be made to determine the cause. In making such a check, try the filters first. The cause will usually be found in a clogged filter. Periodically, jackets should be removed from the tubes and fins cleaned with a soft, lint-free cloth. Fins, of course, should be perfectly clean on initial installation. Fan and motor bearings must not be overlooked. Lubrication will depend on whether the bearings are sealed or open, sealed bearings requiring attention only every few years.

The Image Orthicon

If improper operation is experienced, make as many checks on the adjustment of all controls on the camera as possible before attempting to dismantle the equipment. In many cases, dismantling can be prevented if these precautions are taken. The correct input signals and voltages should be available before beginning any work on the camera.

As with all tubes, the life of the image orthicon will be greatly increased by its proper operation:

1. The tube should be allowed to warm up before operation—if it is being used outdoors, the target heater may be used to shorten the warmup time and to keep the operating temperature at the correct level. Check the correct operating temperature limits recommended for each tube and be certain that they are maintained throughout the operation. Operating at temperatures lower than those recommended will result in "sticking"; excessive temperatures lead to migration of the photosensitive material among the elements of the tube, resulting in improper operation such as loss of resolution and possible permanent damage to the tube. Listen occasionally during the operation to be sure the blower is functioning.
2. Failure of scanning for even a few minutes when light is incident on the photocathode may permanently damage the surface of the target. If the camera must be left unattended for any reason, possible damage due to scanning failure may be avoided by capping the lens and biasing off the target. It is good insurance to avoid cutting off the beam current, since a small percentage of image orthicon tubes may be damaged by such a practice. The beam current should be kept as low as possible to give the best picture quality. The target should always be scanned to full size, and overscanned during rehearsal and stand-by periods.
3. The tube should never be allowed to focus on a stationary bright scene for more than a few seconds. Here again, the result will be "sticking" of the picture. If the retained or "sticking" picture persists, it can usually be removed by focusing the camera on a rough, white surface; in other words, by flooding the photocathode with light.
4. Continued operation of an image orthicon having an ion spot will eventually cause permanent damage to the target.
5. Check the scene illumination and use correct lens stop.
6. Use lowest beam current with proper target voltage for best signal-to-noise and gray scale reproduction.
7. New image orthicons should be tested immediately upon receipt and operated for several hours before being set aside as spares. Spares should be operated for several hours at least once a month to keep them free of any traces of gas which may be liberated during prolonged storage.

   At one time, a practice of "shelf rest" and/or rotation of image orthicon tubes was recommended. It has been found, however, that this does not necessarily result in longer tube life or improved operational quality and, in fact, once a tube has been placed in a camera, it is better to leave it there until it becomes defective.

MISCELLANEOUS

A few other general suggestions on studio equipment maintenance may be mentioned here.

Switching Systems

If a switching system is properly installed and adjusted, little or no maintenance is required. Most modern relay systems are enclosed and have a self-cleaning feature for contacts. Such systems should be tampered with as little as possible. Covers are to be kept dust-free so that, should it become necessary to open them, dust will not fall into the relays. A daily routine of operating each relay will be found of great use in improving the operating record of the equipment and in showing up other equipment failures. Switches in a push-button electronic system require the same care. This should, of course, be done after regular operation hours. Audio faders must be wiped clean frequently, using a soft lint-free cloth moistened by carbon tet. * If relay contacts in either audio or video circuits must be cleaned, this should be done with a blower using clean air and use of a burnishing tool made for the purpose.

Monoscope Camera

Other than dusting and cleaning and the regular tube checks, little maintenance is required for the monoscope. Checks on its non-linearity are easily made during the time the camera is being used to show test pattern.

Monitors

The monitors are of extreme importance to studio personnel; both technical and production people depend on them for producing programs of optimum quality. In addition to the regular dusting, cleaning and tube checks, frequent tests should be made for non-linearity as well as tests for resolution and gray scale. It has been observed in some stations that monitors are poorly maintained as to linearity and focus, and are very often made of broken-down or cast-off receivers. Such practice is deemed improper, not only from the technical standpoint, but the psychological standpoint on producers, directors, actors and others who may not have the technical knowledge to evaluate the resultant picture.

Stabilizing Amplifier

Improperly adjusted controls and tube drift account for most of the troubles here. Correct signal voltages (as recommended by the manu-

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* See Note 12 in Safety section.

facturers) should always be available at the input jacks. Regular cleaning and inspection of cable connectors and tube checks will avoid most failures. In addition to the tube checks, cable socket voltages should be regularly measured.

Capacitors

Dust must be removed regularly from high-voltage capacitors since its accumulation tends to cause arc-overs and increases chances of equipment failure. If the method of cleaning with lint-free cloths is used instead of a bellows, extreme caution must be exercised to see that the capacitor is inoperative and DISCHARGED before handling. Leads and terminal connections must be regularly checked for loose or broken connections and the insulators checked for cracks.

An excessive rise in the temperature of a high-voltage capacitor may be detected by placing the palm of the hand against it after a long period of operation. Be certain that the capacitor is inoperative and DISCHARGED and that the case is grounded before touching these capacitors. High resistance paths to ground have been known to develop and a normally "grounded" case conductor can become very "hot" electrically. This may be an indication of impending failure from dialectric leakage or improper ventilation. Prompt replacement will avoid loss of air time from over-heated capacitors.

Low-voltage capacitors do not require as much care as those of the high-voltage type, but should be kept free of dust, oil deposits and other foreign matter. Since the leads used here are not as rugged as those in the high-voltage type, greater care is necessary in inspection for loose or poorly soldered connections.

Different organizations have found widely differing lengths of service for electrolytic units. Twelve to thirty months seems to be the minimum and maximum periods of service. Dried out capacitors are one cause of hum bars in the television image. Excessive temperature rises often result in nonlinear scanning, since the capacitance is known to vary with temperature changes.

Resistors

Check load resistors and terminating resistors at least once each year, and replace if there is a critical deviation. Dust should not be permitted to collect on any resistor, especially in high-voltage circuits. Snap-in resistors should have firm, clean contacts to prevent heating at the terminals. If a resistor is removed for cleaning, be certain to follow through making sure that it is properly replaced, otherwise damage may result to the equipment when it is energized.

Patch Panels and Cables

In both video and audio systems, jacks and plugs should of course be maintained in perfectly clean condition. If a faulty cable develops, it should be removed from service and sent to the repair shop immediately. Plugs in audio equipment should be polished regularly. Visual inspection of the connections is very important.

TEST CHARTS, SLIDES AND FILMS

Reference has been made in this article to test pattern charts, slides and films recommended by SMPTE and RTMA.

The Society of Motion Picture and Television Engineers (SMPTE), 40 West 40th Street, New York 18, N. Y. has test films available in both 16 mm and 35 mm sizes. The SMPTE "Test Film Catalog" which lists descriptions and prices of all test films produced and sold by the Society and the Motion Picture Research Council can be obtained free of charge by addressing SMPTE.

Radio Television Manufacturers Association (RTMA), 777 Fourteenth Street, N.W., Washington 5, D.C. furnishes a resolution chart which was prepared by its TR4 Committee on Television Transmitters for the purpose of standardizing resolution measurements. The cost is $2.00 per copy. RTMA does not furnish slides or test films, but its resolution chart has been prepared on slides, motion picture films (both 16 mm and 35 mm), film strips and photo paper sensitives by Loucks and Norling Studios, Inc., 245 West 55th Street, New York 19, N. Y. A copy of the current price list may be obtained from Loucks and Norling.

A television station may design its own personalized test pattern built around the ones recommended either by RTMA or SMPTE, or some completely different idea of its own which may then be reproduced on slides, films or opaques. At least one manufacturer can furnish a custom-built monoscope with a personalized pattern. Some stations use two different test patterns— one of the RTMA or SMPTE type which is used to check the alignment, resolution, etc. of pickup and projection equipment; and for "on the air" use, a much less complicated one which provides identification of the station and some engineering information for the use of servicemen in installing and adjusting receivers in the viewer's home. The designer of the second type of test pattern should remember that its primary purpose is to enable the viewer or serviceman to adjust the television receiver for maximum detail and not solely for its artistic possibilities.

Part 3 of the FCC Rules and Regulations, "Radio Broadcast Services" which includes the Standards of Good Engineering Practice for Television Stations may be ordered for 20¢ per copy from:

Superintendent of Documents
Washington 25, D.C.

RTMA "Electrical Standards for Television Broadcast Transmitters Channels 1-13, TR-104-A" may be ordered for 90¢ per copy from:

Radio Television Manufacturers Association
Wyatt Building
Washington 5, D.C.