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DEPARTMENTS

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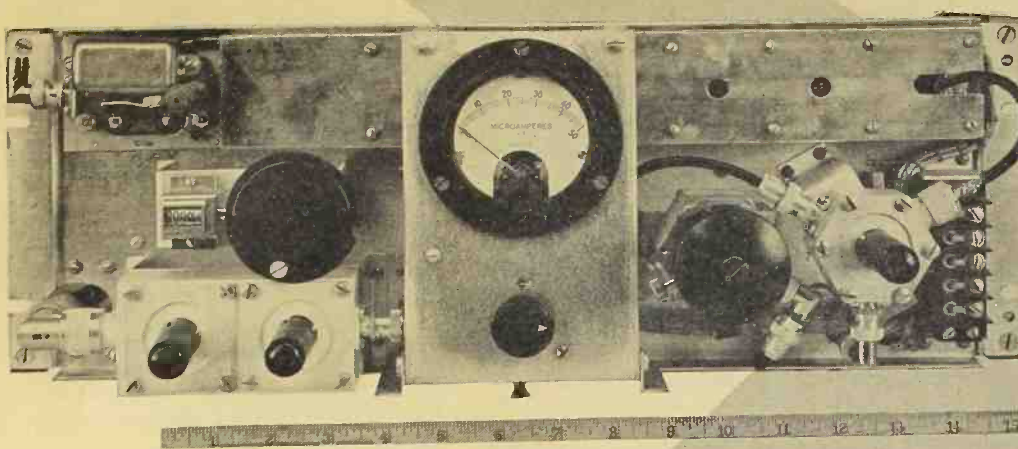

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By J. RACKER

Federal Telecommunication Laboratories, Inc.

MICROWAVE RECEIVERS

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the receiving system. The first, known as the Johnson noise, appears across the antenna. The antenna noise power, assuming that it is matched into a resistance equal to its radiation resistance, is equal to:

$$N_a = k\,T\,B \qquad (1)$$

where k is Boltzmann's constant $= 1.37 \times 10^{-23}$ joules/degree

T is the absolute temperature of antenna

B is receiver bandwidth in cycles per second

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where: F is the noise factor of the receiver

S_{IN} is available signal power from the antenna

N_a is antenna noise power

S_o available signal power applied to demodulator

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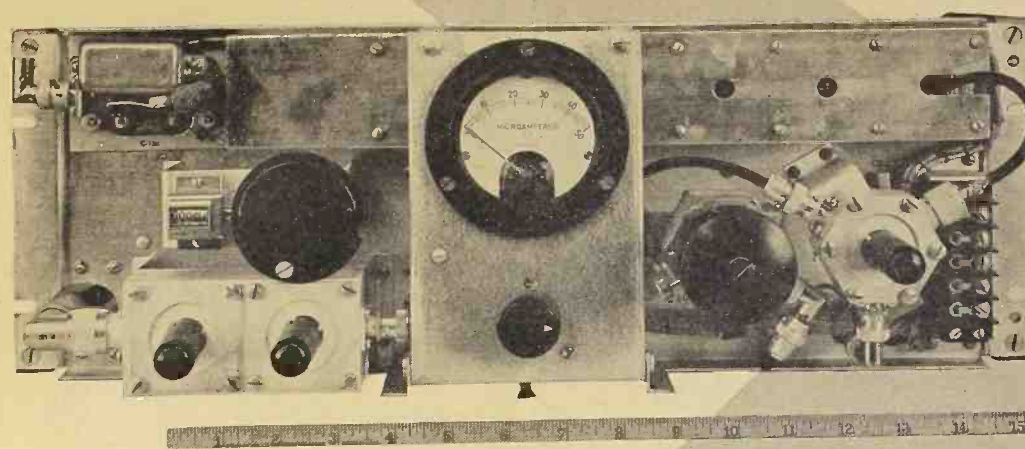

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MICROWAVE RECEIVERS

Part I. A discussion of front-end design with particular emphasis on noise figure.

NOISE introduced in the receiver, while always of some interest at lower frequencies, becomes a primary design factor in microwave equipment. In many cases the receiver noise places a limitation on the entire system and sometimes this parameter alone will determine the type of transmitter, method of modulation, and system bandwidth to be used. Because of its importance, many authors have redefined the term receiver "sensitivity" to include its "noise factor" since specification for a given receiver sensitivity actually indicates the maximum noise that can be tolerated.

There are a number of reasons why receiver noise has become so important at microwaves. One fact is that the level of atmospheric noise is very low at these frequencies and hence a major part of the noise in the system originates in the receiver. Secondly the noise introduced by most practical networks is proportional to the frequency of operation so that microwave amplifiers and mixers are inherently more noisy. Finally, as will be noted subsequently in this article, most of the noise appearing at the receiver output originates in the first and second stages which, of course, will generally be operated at microwave frequencies. At lower frequencies with the atmosphere introducing more noise and the r.f. amplifier less, the effect of the receiver on the over-all signal to noise system was small. But from the foregoing it is obvious that the signal to noise ratio of a microwave system is very much affected by the design of the first two receiver stages and hence the statements made in the opening paragraph.

For economic reasons as well as the noise factor, most microwave receivers employ a superheterodyne circuit in which the incoming signal is dropped to an i.f. frequency as soon as design parameters such as local oscillator radiation, image sensitivity, and antenna "pulling" effects permit. In most receivers, the incoming signal is fed directly to a mixer and more than one r.f. amplifier is rarely employed.

Noise Factor

There are three sources of noise in the receiving system. The first, known as the Johnson noise, appears across the antenna. The antenna noise power, assuming that it is matched into a resistance equal to its radiation resistance, is equal to:

$$N_a = k\,T\,B \qquad (1)$$

where k is Boltzmann's constant $= 1.37 \times 10^{-23}$ joules/degree
T is the absolute temperature of antenna
B is receiver bandwidth in cycles per second

This antenna noise sets a definite limit on the improvement of usable sensitivity which can be obtained by perfecting the receiver and provides a basis for defining the noise factor. Noise generated in the receiver itself will be due to two factors, thermal and shot noises. These noise sources are primarily functions of the type of tube and circuit used and will be discussed when individual circuits are described.

The noise factor, also called the noise figure, is a measure of the amount of noise power introduced by the receiver. For reasons outlined above, the antenna noise should be distinguished from that introduced by the receiver and hence noise factor is defined as:

$$F = \frac{S_{IN}/N_a}{S_o/N_o} \qquad (2)$$

where: F is the noise factor of the receiver
S_{IN} is available signal power from the antenna
N_a is antenna noise power
S_o available signal power applied to demodulator
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It should be noted that the noise fac-

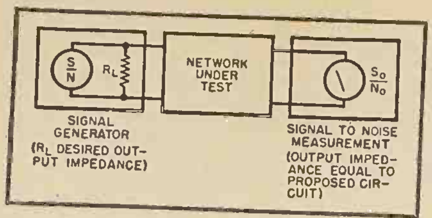


Fig. 1. Test setup for measuring the noise figure of a network.

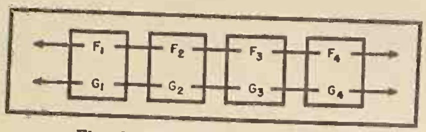


Fig. 2. Networks in cascade.

tor covers all stages of the receiver up to but not including the demodulator. This distinction is made because the signal-to-noise ratio at the output of the demodulator is a function of the method of modulation and hence is not directly a measure of the receiver performance.

The ratio S_o/S_{IN} in Eqt. (2) is of course the signal amplification of the receiver. If we denote this amplification by G (Power Gain) and express F in terms of db., Eqt. (2) becomes:

$$F_{db} = 10 \log \frac{N_o}{G\,k\,T\,B} \qquad (3)$$

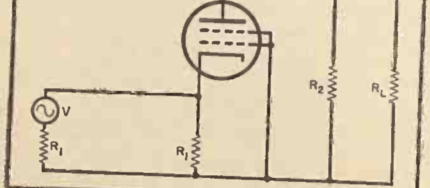
The receiver is comprised of a number of stages and it is convenient to be able to calculate the total noise figure due to the individual noise figures for each stage. Fig. 1 shows the test setup for determining the noise figure of each network. Given the noise figures F_1, F_2, F_n for each network the noise figure of all networks in cascade F_{1n} as shown in Fig. 2, is equal to:

$$F_{1N} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots \frac{F_{n-1} - 1}{G_1 G_2 \ldots G_{n-1}} \qquad (4)$$

It should be noted that F_n is the noise figure of network N under the condition that it is fed from a source whose impedance is equal to the output impedance of network N-1.

Eqt. (4) brings out two important factors. To simplify it let us consider a two stage receiver. In this case Eqt. (4) reduces to:

Fig. 4. Equivalent circuit for grid-separation amplifier with both input and output circuits tuned to resonance.



$$F_{12} = F_1 + \frac{F_2 - 1}{G_1} \qquad (5)$$

It is readily seen that when network 1 amplifies the signal (G_1 greater than 1) the effect of noise generated in network 2 is much smaller than that generated in network 1. This can readily be seen by considering a typical problem. Assume that all of the noise in a given bandwidth introduced in each of the two stages is equivalent to 10 microvolts of noise introduced at the grid of the tube, and that the gain of the stage is 10. The total noise of the two stages may be accounted for by adding the amplified noise of the first stage; i.e., 10 x 10 = 100 microvolts, to the equivalent noise of the second tube at its grid. Since noise voltages are composed of many different frequency components, the r.m.s value of the sum of two such voltages is the square root of the sum of the squares of the individual r.m.s values. Thus the total noise of the two stages is equivalent to $\sqrt{100^2+10^2}=100.5$ microvolts. Thus the noise at the grid of the second tube is only 0.5 per-cent greater than the noise caused by the first stage alone. Of course the effect of any succeeding stages (if they existed) is even further reduced. This il-

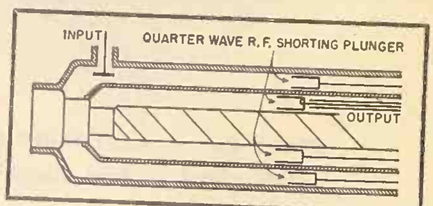


Fig. 3. Simplified schematic of typical grid-separation circuit for lighthouse tubes.

lustrates the importance of the first several stages in a receiver.

A second factor brought out by Eqt. (5) is that when the network attenuates the signal, so that G is less than one, as in a crystal mixer circuit, the noise present in network 2 is amplified. To illustrate this effect, consider the design of a mixer-amplifier system in which each amplifier has a noise figure of 30 and a gain of 12, and the mixer has a noise figure of 5 and a conversion loss of 0.2. If the signal is fed directly into the mixer the noise figure is:

$$F = 5 + \frac{30-1}{0.2} + \frac{30-1}{(0.2)\,12} + \cdots = 163 \qquad (6)$$

If one stage of amplification is used before mixer, the noise figure becomes:

$$F = 30 + \frac{4}{12} + \frac{29}{12\,(0.2)} + \cdots = 43.5 \qquad (7)$$

and for a two stage amplifier before the mixer:

$$F = 30 + \frac{29}{12} + \frac{4}{12^2} + \frac{29}{12^2 \times (0.2)} + \cdots = 33.5 \qquad (8)$$

For three stages of amplification very little improvement will be effected (F= 32.7). Of course, as is the case in many practical design problems, if it is possible to design an amplifier after mixing (usually about 30 mc.) with a much smaller noise figure than that possible at microwave frequencies, then use of r.f. amplifiers may not be justified. For example, if after mixing it is possible to design an i.f. amplifier with a noise figure of 6, then equation (6) would become equal to 15 and it obviously would not be useful to employ r.f. amplifiers (with noise figures of 30)—at least from the viewpoint of improvement of noise figure.

R.F. Amplifiers

It has previously been indicated that receiver sensitivity has been redefined to include noise power. In many cases the noise factor is given as a measure of sensitivity for microwave receivers. As a result of the discussion on noise factor, the reason for this should now become clear. It is always possible to amplify the signal as much as desired through the use of a sufficient number of stages. However the signal may not be of value if it is accompanied by excessive noise. At microwaves this noise will be encountered to a large degree in the first few stages of the receiver because of the small amount of atmospheric noise and the relatively large amount of noise introduced by microwave amplifiers. As a consequence, if sensitivity is defined as the smallest r.f. signal that can be picked up to provide the desired intelligence, the sensitivity of a microwave receiver will be dependent upon the magnitude of signal necessary to override noise in the first two stages, or more specifically the noise factor.

At conventional frequencies this difficulty is not encountered to an appreciable degree because one or two stages of r.f. amplification (desirable for many other reasons) prior to the mixer stage provides the effect indicated by Eqts. (6), (7), and (8). As the frequency of operation increases to beyond approximately 1000 megacycles, the noise introduced by the i.f. is so small in comparison to that developed in an r.f. amplifier, that a smaller noise factor can be evolved by feeding the r.f. signal directly to a mixer than to use any stages of r.f. amplification. Of course there is an additional factor to be considered and that is that an r.f. amplifier, because of the special tubes required, is far more costly than an i.f. amplifier. Hence economic factors alone would dictate using a mixer stage at the input even if some gain in noise factor could be attained.

As a result of these considerations very few microwave receivers employ r.f. amplifiers. However there are some applications, either because of operation at 1000 mc. or below where improvement can be obtained, or due to need for isolating the antenna from the mixer and local oscillator, that an r.f. amplifier is used. Furthermore the recently developed traveling wave tube, as will be shown, shows promise of being a useful amplifier.

As described in previous articles [1, 2] covering the design of microwave transmitters, special tubes must be used for operation at about 900 mc. and above. These tubes, with the exception of the magnetron, can also be used for r.f. amplification. Actually only the lighthouse triode and traveling wave tube are employed in this manner, while the klystrom is very rarely used as an amplifier —particularly in receivers.

A lighthouse triode is used as an amplifier in much the same manner as it is used as an oscillator (previously covered[1]) except that the feedback loop is either omitted or reduced. The input is applied to the grid-cathode cavity and the output obtained from the plate-grid cavity. This circuit, shown in Fig. 3, is known as a grid-separation amplifier (sometimes called a "grounded grid" amplifier) because the grid actually separates the input and output circuits physically.

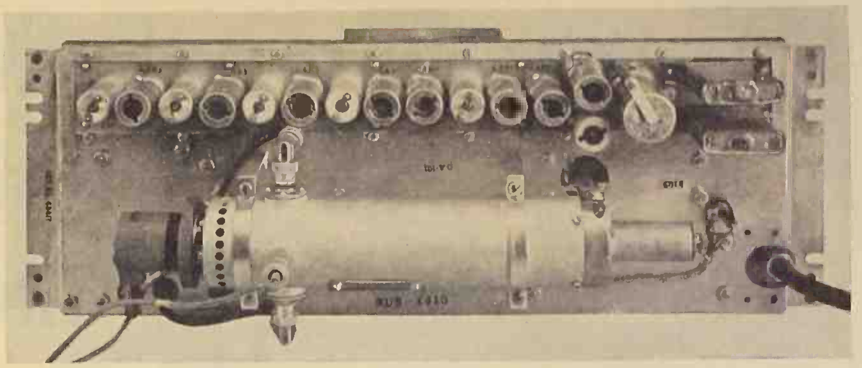
When such an amplifier has its input and output circuits tuned to resonance, so that they appear as pure resistances, and when the input circuit is matched to the antenna (or previous stage output impedance). The equivalent circuit is as shown in Fig. 4. The tube is drawn as a tetrode to emphasize the separation of input and output circuits. The input line is assumed to be matched so that no standing waves are set up. This is done physically by varying the position of the probe until no standing waves are noted on the line (the term 'no standing waves' is used in the sense that the mismatch is so small that it is safe to assume that all the power transmitted down the line is dissipated in resistor R_1). If an r.f. power P_1 is applied to the line, an r.m.s voltage V_1 is developed between cathode and grid where:

$$V_1^2 = R_1 P_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

This voltage produces an r.f. current in passing through the first grid having a value:

$$i = g_m V_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where g_m in this case is the effective transconductance which includes transit time effects.[1] If V_2 is the r.f. voltage developed across the output circuit, the total power delivered by the beam is:



Rear view of typical microwave receiver operating in the 2000 mc. range.

$$P_2 = V_2^2\left(\frac{1}{R_2} + \frac{1}{R_L}\right) \quad . \quad . \quad . \quad . \quad . \quad (11)$$

and the useful power P_L, is V_2^2/R_L. If the full current, i, arrives in the output circuit, V_2 is given by:

$$V_2 = i\frac{R_2 R_L}{R_2 + R_L} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

and therefore:

$$P_2 = \frac{i^2}{R_L}\left(\frac{R_2 R_L}{R_2 + R_L}\right)^2 = i^2\frac{R_2^2 R_L}{(R_L + R_2)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

By combining Eqts. (9) and (10) and substituting for i in Eqt. (13), the following relation for power gain is obtained:

$$G = \frac{P_2}{P_1} = \frac{g_m^2 R_1 R_2^2 R_L}{(R_L + R_2)^2} \quad . \quad . \quad . \quad . \quad (14)$$

For a constant-current generator such as this amplifier, the maximum value of P_L is obtained when $R_L = R_2$, in which case

$$G_{max} = \frac{g_m^2 R_1 R_2}{4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

From this it is clear that the maximum gain obtainable is dependent not only on the transconductance, but also on the shunt resistances of the input and output circuits, which are partly functions of the tube and partly of the cavities. The shunt impedance of the cavities can be determined through the use of relationships developed in earlier articles [1, 2], while the tube parameters can be obtained from the manufacturer.

The gain of an amplifier has little meaning unless the bandwidth is specified. In most grid separation amplifiers the loading on the input circuit is so heavy that the bandwidth of the output circuit is the determining factor. If C_2 is the effective capacity across the output circuit, the bandwidth $2\Delta f$ between half power points is given by:

$$2\Delta f = \frac{f}{Q} = \frac{R_2 + R_L}{2\pi C_2 R_2 R_L} \quad . \quad . \quad . \quad . \quad (16)$$

Combining this result with that of Eqt.

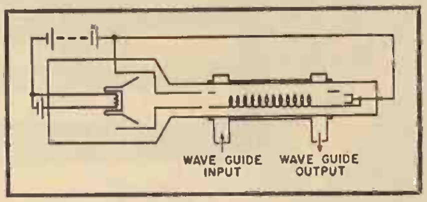


Fig. 5. Schematic diagram of a traveling wave amplifier tube.

(15), an expression for a figure of merit is obtained which is the power gain multiplied by the bandwidth or:

$$G \cdot 2\Delta f = \frac{g_m^2 R_1}{2\pi C_2} \cdot \frac{R_2}{R_L + R_2} \quad . \quad . \quad (17)$$

If the amplifier is loaded for maximum gain, $R_L = R_2$, the figure of merit is:

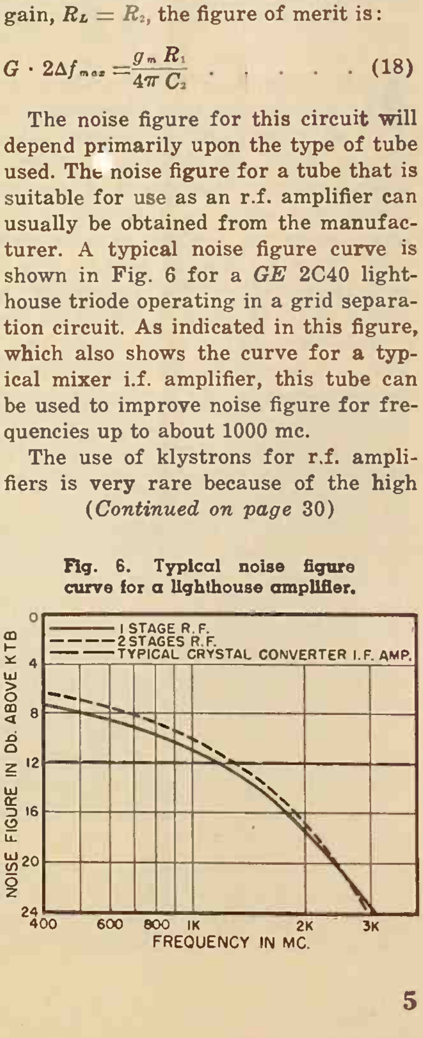
$$G \cdot 2\Delta f_{max} = \frac{g_m R_1}{4\pi C_2} \quad . \quad . \quad . \quad . \quad . \quad (18)$$

The noise figure for this circuit will depend primarily upon the type of tube used. The noise figure for a tube that is suitable for use as an r.f. amplifier can usually be obtained from the manufacturer. A typical noise figure curve is shown in Fig. 6 for a *GE* 2C40 lighthouse triode operating in a grid separation circuit. As indicated in this figure, which also shows the curve for a typical mixer i.f. amplifier, this tube can be used to improve noise figure for frequencies up to about 1000 mc.

The use of klystrons for r.f. amplifiers is very rare because of the high

(*Continued on page* 30)

Fig. 6. Typical noise figure curve for a lighthouse amplifier.



Helical Coils as TRANSMISSION LINES and Radiators

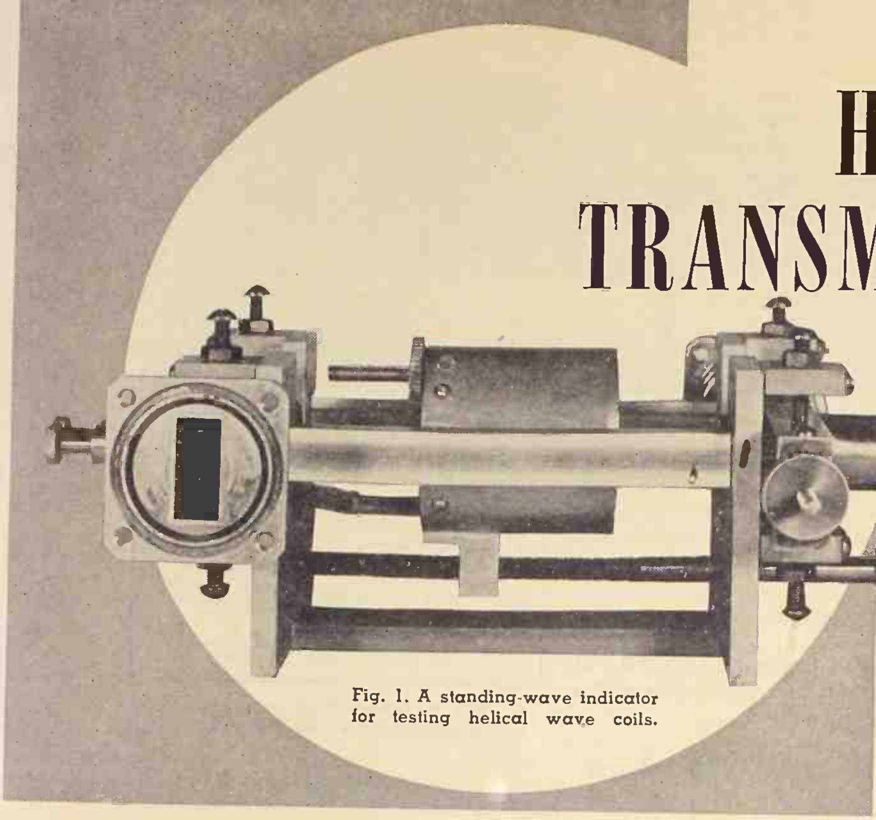


Fig. 1. A standing-wave indicator for testing helical wave coils.

By SAMUEL FREEDMAN
Technical Products & Services Co.

Construction, application, and testing of helical coils for use in the ultra-high frequency range.

ELECTROMAGNETIC wave propagation can take place along a solenoidal coil or simple coiled spring. Such helical wave coils comprising no more than a coil of wire or spring may serve as a substitute for wave guide or coaxial transmission lines. They can also be used as a coupling device in lieu of a transformer, a rotary joint transition, a substitute for flexible wave guide, as an actual radiator or antenna device, or as a single device possessing all or some of these capabilities.

A combination of imagination, initiative and experimentation can result in very ingenious and rather revolutionary developments for the microwave art when the helical wave coil techniques are employed. This can be particularly true in connection with u.h.f. developments (frequencies below 3000 megacycles), where dimensions have been inconveniently large for the utilization of super-high wave guide techniques.

As a transmission line, the coil or spring terminates or enters into a coaxial cable inner conductor directly or to the inner conductor of the coaxial fitting of a wave guide.

As a radiator, the same coil or spring terminates into an unwound section as shown in Fig. 6A for a non-directional type or Fig. 6B for a directional type.

The coils themselves are very simple in physical appearance and are not frequency sensitive. Only the terminations or the parts to which they may connect have that characteristic, particularly where the dimensions are appreciable with respect to the wave length.

Helical wave coils are tested with equipment similar to that of any microwave test bench in which unknown transformations are to be investigated. The general layout of the test bench is blocked in Fig. 3 with the exception of one additional non-standard unit. This is the standing wave indicator for helical wave coils as illustrated in Fig. 5.

The coupling sections at each end of the helix represent a transformation of unknown characteristics. It would be quite possible to have flat line characteristics within the rectangular guide on each side of the helix and still have a high standing wave ratio along the helix itself.

Fig. 2. Coupling test for helices of minimum attenuation.

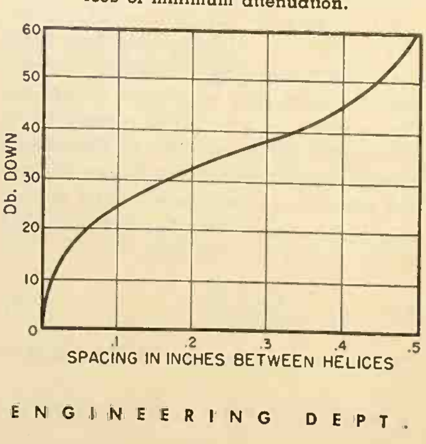


Fig. 7 illustrates a coupling section between the standing wave indicator (Fig. 5) and the wave guide termination at either end. The internal constructional details of the coupling section are shown in this figure.

Any helical wave coil has a reduced phase velocity. It is less than that of the velocity of light by approximately the ratio of coil length to wire length. Thus far, its most important use has been in the traveling wave amplifier tubes developed for the microwave region. Its use in lieu of a wave guide or a radiator is much more novel, particularly where it has no cut-off frequency or cut-off wavelength as a transmission line. Persons of limited qualifications and with a minimum of facilities can build such coils out of wire and get a variety of results from the way the coil ends are tapered or ended.

Referring to the standing wave indicator (Fig. 5), normal probe or loop measurements are not feasible due to the relatively weak field about the helix at a feasible coupling distance. To assure maximum coupling with minimum field interference, a tunable re-entrant cavity is placed circumferentially about the helix. Energy is electrostatically coupled through an open annular ring at the inner radius of the re-entrant section. This section is so tapered as to be effectively coupled to only a small area of the helix. This assures proper field indication and minimum effect on the helix's field by allowing a maximum clearance between its main body and the test section.

In practice, there will be some interaction between the helix and the re-entrant cavity which will tend to introduce reflections. This effect can be reduced by enlarging the coupling hole. The cavity is tuned to resonance to assure maximum coupling. Tuning is accomplished by moving a choke type plunger along the coaxial section of the cavity. The choke plunger is designed with a center wavelength of 3.2 centimeters and is made slightly broadband by choosing a large characteristic impedance ratio between quarter-wave sections. The cavity will tune to both quarter-wave and three-quarter wave resonances.

Monitoring energy can be magnetically coupled from the cavity by a loop at the plunger face. This in turn is connected to the input of a spectrum analyzer through a coaxial cable. Since the spectrum analyzer is inherently a power device, standing wave power ratios are measured.

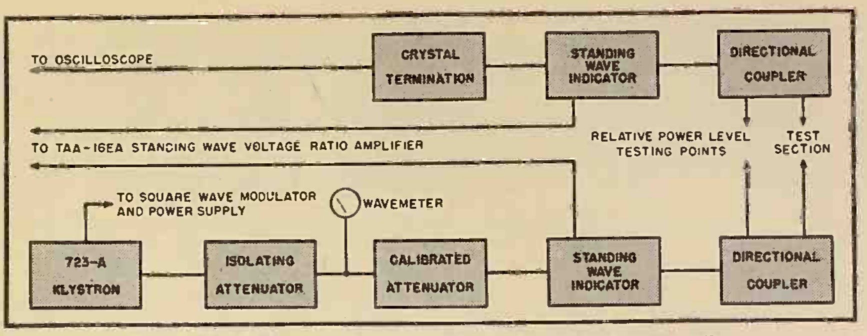


Fig. 3. Block diagram of test setup for testing helical wave coils.

Transformation Section

The development of a transformation section between the helical wave coil and rectangular wave guide may be accomplished through the use of either a resonant section or a tapered section. Only the latter has been used by the authors. To obtain proper coupling between two transmission media of dissimilar physical characteristics, it is necessary that their corresponding fields be properly positioned. This can be done either electrostatically or magnetically. For coupling between helical wave coils and rectangular wave guides, electrostatic coupling is more readily obtained. Such a coupling is referred to as an "E" type coupler (Fig. 7).

The transition can be considered as consisting of three steps.

1. A rectangular wave guide to coaxial line.
2. Coaxial line to a coaxial line whose center conductor is a helix.
3. Finally, from the helical type of coaxial line to a helical wave coil.

The straight section of the helix is parallel with the "E" field of the rectangular wave guide for a distance a little greater than half the wave guide width. The wire is then tapered in both pitch and helical diameter for two to two and a half turns to the final helix size in the remaining distance across the guide. It is brought out through a hole in the rectangular wave guide. The end plate of the wave guide is approximately a quarter of a guide wavelength from the coupling, so that it reflects radiation in phase with that radiated directly down the guide.

Even with variation of physical parameters such as post diameter, helix to post termination and exponential transition section for various "E" couplings, a double stub tuner on the transmitter side of the junction has made it possible to match any reasonable configuration of the coupler to a low standing wave ratio. A match has not been found possible, however, if the helix is simply passed through the guide and terminated on the far side. Best results have been obtained by the configuration shown in Fig. 7, and at the left in Fig. 6, top and bottom.

The helix is terminated by smoothly decreasing its pitch for the last two turns and by spiraling the same two turns inward to a point where the helix becomes a straight wire. This is then soldered into a hole drilled at the apex of the coupling stub. The band pass characteristics of a given coupler critically depend upon the exact configuration of the coupling. If the exponential section is eliminated, the coupler becomes extremely frequency sensitive. Small differences can be corrected by use of a double stub tuner. However, movement of the coupling stub itself is far more effective and easier to adjust.

The stub is mounted within a half-wave coaxial choke section in such a manner that a short is reflected at the wave guide's inner surface. A quarter-wave radial choke circumferentially about the helix of the coupling hole is advantageous since it eliminates any direct radiation from that area and at the same time discourages a $TE_{1,1}$ mode from forming. That mode might exist when the mean circumferential distance around the coupling hole between the

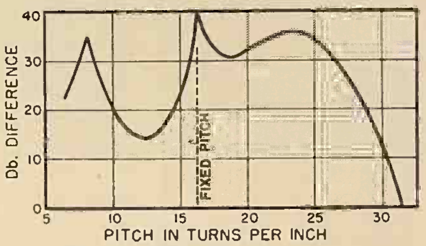


Fig. 4. Coupling between two helices of different diameters.

rectangular wave guide and the helix is approximately equal to or greater than one wavelength.

With both chokes in place and the helix properly terminated at the apex of the stub, the coupler is easy to adjust. It can be adjusted to have a standing-wave ratio of unity at any given wavelength and has considerable bandwidth depending upon the fineness of adjustment of the transition section. A typical coupler with a mean wavelength of 3.2 centimeters (X band) may have a standing wave ratio of 1.13 at 3.15 centimeters and 2.4 at 3.4 centimeters.

Coupling

Maximum coupling occurs with helices of equal diameter and pitch. Mini-

Fig. 5. Standing wave indicator for helical wave coils.

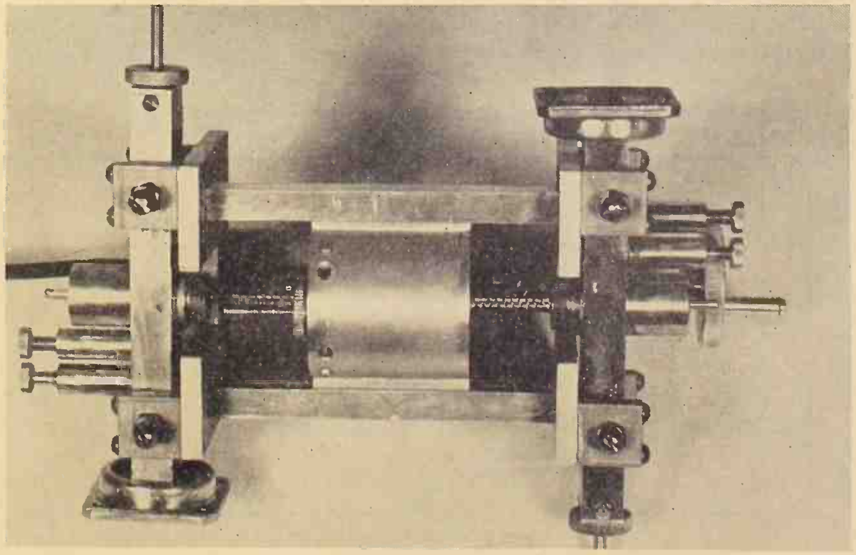


Fig. 6. (Top) Helix unwound and terminated in a radiating section. (Bottom) Unwound radiator driven by wound helical coil section.

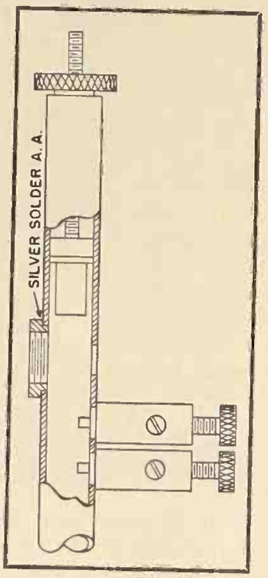


Fig. 7. Internal details of coupling section.

mum coupling occurs when the helices have a pitch ratio of approximately two to one. This indicates a change in the relative amount of constructive and destructive coupling between the two helices due to their differences in phase velocity. With helices of equal pitch and diameter, all coupled components are in the same direction; thus, a maximum power transfer. Helices with comparative values of half or double pitch have an equal number of constructive and destructive coupled field components; thus, a condition of minimum power transfer.

This leads one to deduce that if a phase velocity difference of two to one can be introduced between parallel helices in any manner, a similar result will be obtained. Such phase velocity difference can also be introduced by a change in helix diameter. For minimum coupling between two parallel helices, it is therefore desirable to choose a combination of turns and diameter ratios such that their phase velocities will be in the ratio of two to one as shown in Figs. 2 and 4.

Comparing both attenuation characteristics and coupling characteristics of the helix, two helices .177" outside diameter wound with a .040" wire, one with a pitch of 8 turns per inch and the other with a pitch of 4 turns per inch, would represent optimum conditions from a standpoint of minimum attenuation and coupling for a dual feed system. At a spacing of ½ inch, the power difference was found to be 60 db. between them.

The peak power input at breakdown for several helices of .37", .177" and .269" outer diameter, wound with .040" diameter copper wire was noted as a function of pitch. The helices were terminated in the *E* type coupler shown in Fig. 7. The r.f. power was obtained from a pulsed Type 725-A magnetron and measured by means of a Johnson Bridge type r.f. wattmeter. The wave guide at the receiving end was terminated in a dry sand load. All helices had similar characteristics. The power at breakdown varied linearly with pitch from approximately 7 kilowatts peak at a pitch of 20 turns per inch to 25 kilowatts peak at a pitch of 9 turns per inch. At this time, arcing would occur within the coupler rather than between the turns of the helix. The smaller diameter helices have somewhat greater power capabilities than the large diameter helices. With a safety factor of two, the power limit of a normal helix (4-10 turns per inch) would be approximately 12 kilowatts at atmospheric pressure. This can be increased by pressurization. The average power approaches peak power because breakdown is not due to heating. It is due to voltage arc-over.

In addition to being able to terminate a helix in a dry load consisting of aquadag or some similarly absorbing substance, it can be directly terminated in a radiator. The characteristics of the slow speed helical mode are such that its termination in a radiator will result in a linearly polarized wave.

The helix, exponentially unwound and terminated in a straight section of wire one half-wave in length, is an effective radiator. Such a termination is similar to the transformation section of the "E" type coupler. This type of termination can be slightly varied by bringing the straight half-wave section off at a tangent to the helix as shown in Fig. 6A. A quarter-wave termination has proved ineffective.

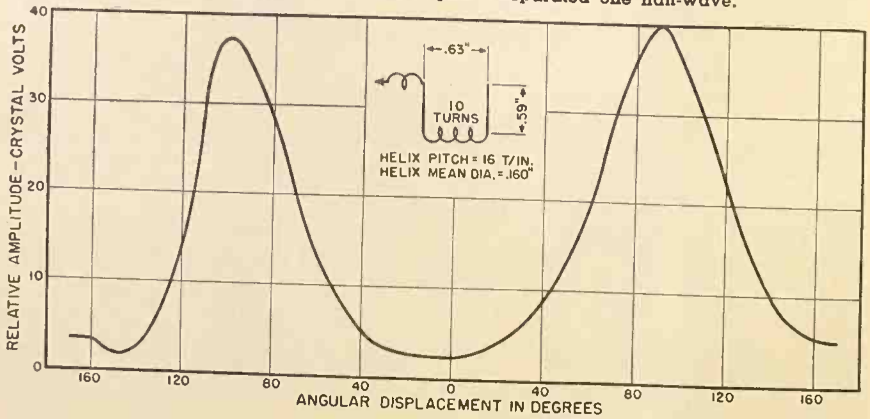
In addition to a simple half-wave termination, the helix offers an excellent method for forming directional arrays. This is effected by properly winding and unwinding the helix. The unwound section represents the radiation surface driven by the wound surface and is shown in Fig. 6 (bottom). Its primary radiation pattern is shown in Fig. 8.

For proper phasing of the various elements forming an array, it is necessary to maintain a proper number of turns within the helices forming the transmission lines between them. For a given size helix and spacing between elements, the turns required for physical reasons will, in general, not be in integral agreement with electrical phasing requirements. This difficulty can be eliminated by introducing a dielectric within the coupling helices in the form of a phase shifter.

In applications where back to front ratios and beam widths obtainable from simple arrays will suffice, it is felt that a helical array may offer a solution.

The major difference in field distribution between helical wave coils and more standard types of wave guides is that the field is not enclosed between conducting boundaries. This results in considerable loss due to radiation and can also be a means of coupling between two parallel helices. A helix is good mechanically for two-dimensional flexibilities and has characteristics identical with those of a normal spring.

Fig. 8. Field pattern for a helical broadside array — two half-wave radiating sections in phase separated one half-wave.



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CURVE GENERATOR for ELECTRON TUBES

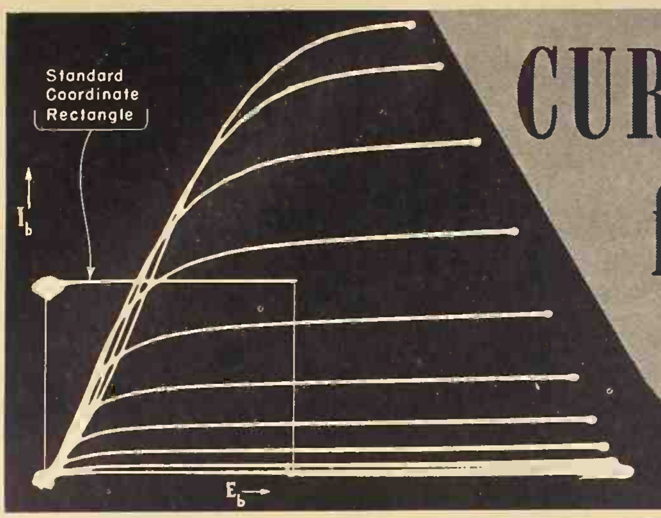


Fig. 1. Typical display (6AC7 plate characteristics).

A device developed at NBS for plotting tube characteristic curves directly on the screen of a cathode-ray oscilloscope.

An instrument which gives an instantaneous display of electron tube characteristics has been developed by Milton L. Kuder at the National Bureau of Standards. The curve generator plots directly on the screen of a cathode-ray oscilloscope the family of plate current versus plate voltage curves for any receiving tube. A standard rectangle is displayed along with the characteristic curves to provide a direct scale of voltage and current readings. In cases where the tube characteristics are not known or where an unusual combination of supply voltages is to be used, the curve generator can provide the necessary tube data at a great saving in time and labor.

The plate voltage applied to the tube under test is swept continuously from zero to predetermined positive values. The voltage drop appearing across the plate load resistance is then a measure of the plate current. This voltage drop is applied to the vertical deflecting plates of a cathode-ray oscilloscope and the plate voltage itself to the horizontal plates. The combined voltages generate a plate current—plate voltage curve on the oscilloscope screen for the entire sweep interval. The sweep sequence is repeated automatically for several values of grid bias, forming the family of plate characteristic curves. A series of bright dots appearing at the end of each curve in the family gives a useful representation of the load line of the tube for the operating conditions selected.

In addition to producing plate characteristic curves, the new instrument can provide a visual representation of plate current versus grid voltage. In this case the oscilloscope display is particularly convenient since grid voltage increments are directly defined by calibrated vertical bars appearing on the oscilloscope screen; a standard current reference is given by a horizontal bar. All of the possible displays are produced by the curve generator without overloading the tube under test. Over-all accuracy of voltage and current readings from the oscilloscope screen is within plus or minus five per-cent.

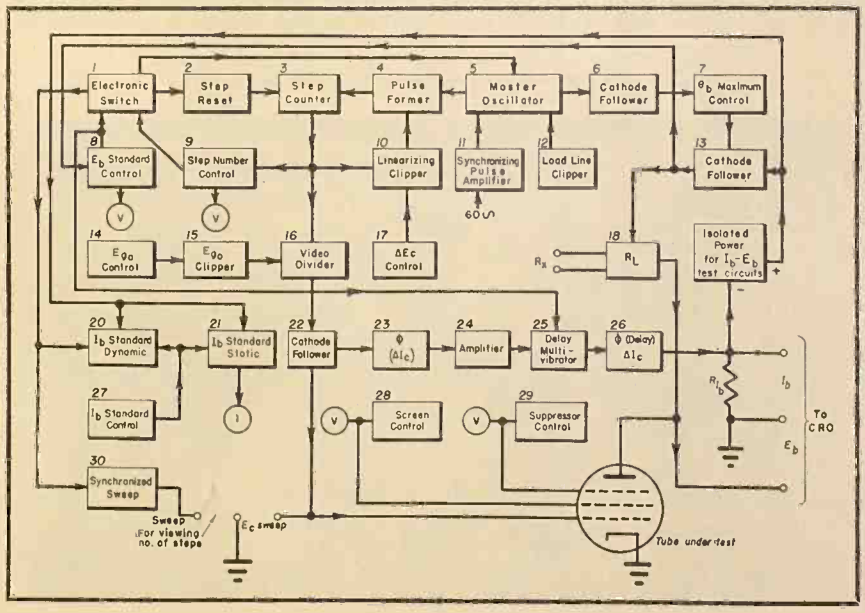
A complete family of curves is retraced sixty times a second; the resulting image is stationary and free from flicker. Characteristic curves may be quickly obtained in permanent form by photographing the screen image with a regular oscillograph camera. Electronic research and development organizations would find this procedure extremely valuable on many occasions.

All of the driving signals are produced in the generator by a single master oscillator. Voltage excursions for the tube under test are obtained from the oscillator in the form of a rising sawtooth wave whose magnitude is controlled without any oscillator loading effect. A cathode follower isolates the power supply for the tube under test from the rest of the generator circuit, so that only the plate current of the tested tube is plotted on the oscilloscope.

When the sawtooth plate sweep signal is most negative, the master oscillator sends a pulse into a pulse former. Pulses

(*Continued on page* 30)

Fig. 2. Block diagram of the curve generator.



A Compact GEIGER COUNTER

By RONALD L. IVES
Indiana University

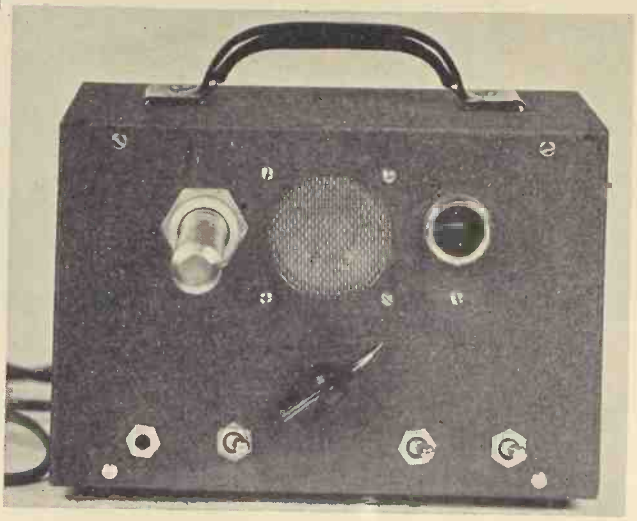


Fig. 1. Panel view of the compact counter in its case.

Design and construction of a cheap, easily-built counter incorporating a novel high-voltage power supply.

LARGE bulk and high cost of most line-powered laboratory Geiger counters has resulted in the use indoors, and within easy access of power lines, of portable instruments, even though battery replacement costs are very high.

Chief obstacle to the construction of a compact and inexpensive device for determining roughly whether or not a substance is radioactive has been the bulk and cost of power transformers, or the complexity of substitutes for them.

By use of a "voltage adding" rectifier circuit, related to the familiar "voltage doubler" used in "transformerless" radio receivers, cost and bulk of power supply is brought within reasonable limits, so that a very compact and inexpensive Geiger counter can be constructed almost entirely from standard radio receiver components.

General Description

This instrument consists of a standard beta-gamma tube (1 B 85 Thyrode), two stages of audio frequency amplification, a speaker and flasher output device, and a power supply. Dimensions are small, so that the entire device, constructed for 24-hour operation, can be housed in a standard 5″ by 6″ by 9″ radio utility cabinet. Weight is only ten pounds, and power consumption is about 50 watts.

General appearance of this Geiger counter is shown in Fig. 1.

Wiring diagram of this counter is shown in Fig. 4, and is quite conventional except for the power supply and output circuits.

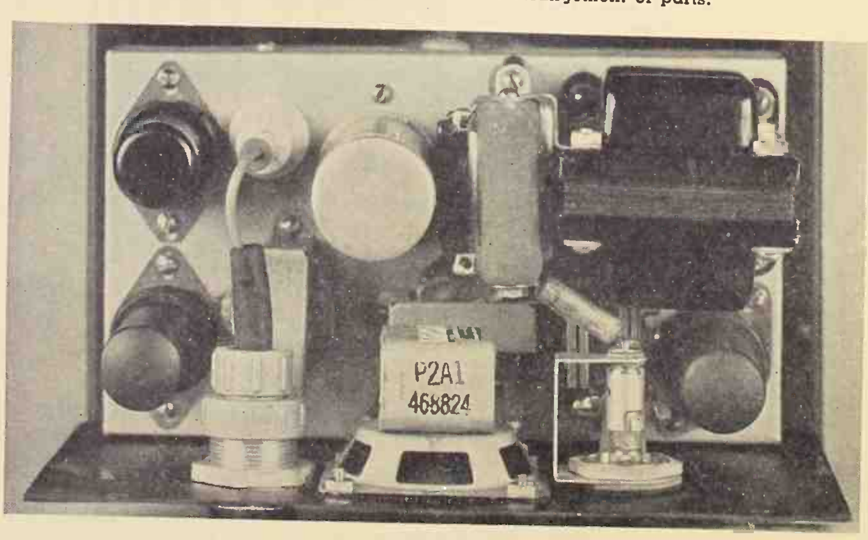
Power supply for this counter is a "voltage adding" device. 300 volts at about 40 ma. is produced by one-half of the transformer, through the selenium rectifiers, and the low-voltage filter consisting of C_{12}, L_1 and C_{13}. Additional filtering for the 6SJ7 is provided by the choke L_2 and condenser C_6. This is necessary not only to prevent hum, but also for circuit isolation. If this additional filter is omitted, the circuit will tend to oscillate violently at about 5000 cycles.

High voltage is provided by the whole transformer winding, through a half wave rectifier tube, 5Z4, and *R-C* filter consisting of C_{10}, R_{11}, and C_{11}. This high voltage, which is about 650 volts, is added to the potential of the other supply circuit to produce the 950 volts, approximately, required by the G-M tube. Note that the high voltage filter condensers do not have their negatives grounded, but are connected to the "hot side of the low-voltage filter condensers. This connection makes unecessary the use of 1000 volt filter condensers, resulting in a saving of cost and space.

Output voltage of the high potential portion of the power supply can be regulated with great precision by varying either the bleeder resistor (R_9) or the filter resistor (R_{11}), the current drain of the G-M tube being substantially zero.

The amplifier is an entirely conventional two-stage unit, with a 6SJ7 first stage and a 6F6 output stage. Standard resistance—capacitance coupling is used, but both coupling and bypass condensers are smaller than in voice amplifiers, not only to lower hum response, but to permit greater sensitivity. In a surge amplifier, tone quality is unimportant.

Fig. 2. Back-of-panel above-chassis arrangement of parts.



Values of resistors R_1 and R_2 in the input circuit are made as large as possible, and tendency to oscillate at high frequencies is reduced by use of a small output bypass condenser (C_6), and by use of a two-step filter in the first stage plate supply. Shielding or isolation of the 6F6 plate lead and of the high voltage lead to the G-M tube is desirable.

A jack is provided to permit headset operation of the counter from the first stage of the amplifier. Output of the second stage is dual—sonic output is by the 2" PM dynamic speaker on the panel, visual output is by means of a neon flasher tube (NE-30) in series with a condenser (C_9) shunted across the primary of the output transformer.

A switch (SW_3) is provided to turn off the speaker if desired. Should the visual output circuit tend to motorboat at a very slow rate, this can usually be prevented by reversing the neon bulb in the socket, or by shunting the bulb with a very high resistance, such as 10 megohms.

Input of this counter is designed to work from a *Victoreen* type 1B85 Thyrode, or similar 900 volt Geiger-Muller tube. To protect the tube against warmup surges, and to lengthen its life when counting is unnecessary, a switch is provided so that the high voltage can be removed when desired. This (SW_2), in the "ON" position, connects the input resistor to the tube. In "OFF" position, the input resistor is grounded, partially draining the high voltage filter, and disconnecting the tube. The other side of the switch turns on a small pilot light, mounted behind the neon tube bezel, when the G-M tube is out of service. When the tube is in service, the intermittent flashes of the neon tube in the output serve as an "ON" indicator.

Internal electrical parts are mounted on a 1½" by 4" by 8" open end chassis, firmly bolted to the panel. Exact arrangement of parts is not important, except that heat-sensitive parts should be as far as possible from heat-producing elements, such as the tubes. One satisfactory arrangement is shown in Fig. 2.

Under-chassis arrangement is also not critical except that input and output components should be separated as far as possible. Careful planning, plus use of tie strips in strategic places, makes possible access to any sub-chassis component with ordinary tools. Under-chassis appearance of this counter is shown in Fig. 3. To prevent chafing of insulation, with resultant later breakdown, all wires going through the chassis are protected by rubber grommets. High voltage wiring is protected by use of spaghetti.

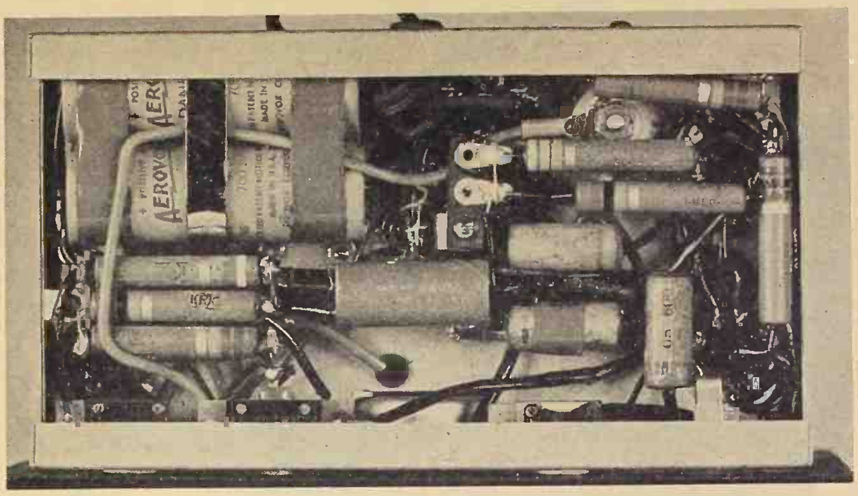


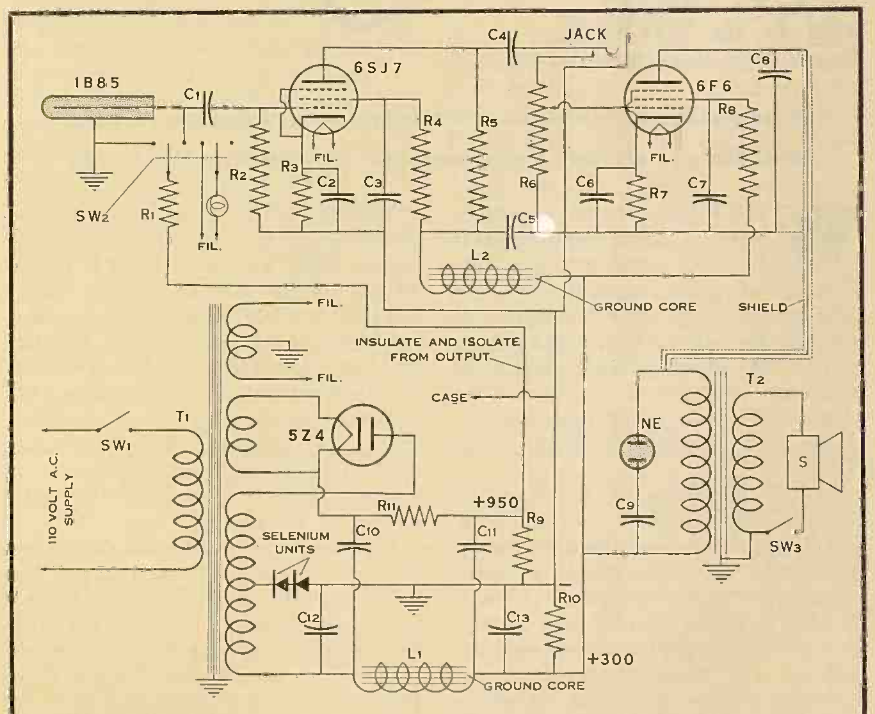
Fig. 3. Under-chassis view of the counter.

Life of many electronic components is a function of the temperature at which they are operated, and is markedly shortened if the operating temperature is too high. For this reason, some consideration should be given to ventilation, even of a small device such as a small Geiger counter.

With no ventilation, and the case tightly closed, this counter stabilizes at an internal temperature about 130° F. above room temperature, and requires almost an hour to stabilize. Under most conditions, internal temperatures will be too high for long component life.

(*Continued on page* 29)

Fig. 4. Wiring diagram and parts list of the counter.



R_1—2-10 megohm, 2 w. res.
R_2—2-5 megohm, 2 w. res.
R_3—600 ohm, 2 w. res.
R_4—500,000 ohm, 2 w. res.
R_5—100,000 ohm, 2 w. res.
R_6—250,000 ohm, 1 w. pot
R_7—500 ohm, 2 w. res.
R_8—5000 ohm, 2 w. res.
R_9—1 megohm, 2 w. res.
R_{10}—50,000 ohm, 5 w. res.
R_{11}—50,000 ohm, 2 w. res.
C_1—.0005 μfd., 2500 v. mica cond.
C_2, C_3, C_6, C_7—.06 μfd., 600 v. paper cond.
C_4—.002 μfd., paper cond.
C_5, C_{12}, C_{13}—40/40/10 μfd., 450 v. dry elec. cond. (all parts of a triple common-ground unit)
C_8—.0001 μfd., or less, 600 v. paper cond.
C_9—.5 μfd., 600 v. paper cond.
C_{10}, C_{11}—10 μfd., 700 v. dry elec. cond.
L_1—8 hy., 40 ma., filter choke
L_2—35 hy., 15 ma., filter choke
T_1—Power trans. 240-0-240 @ 40 ma.; 5 v. @ 2 amps; 6.3 v. @ 2 amps (Thordarson TS-24R00-U or Stancor P-6297)
T_2—Universal output trans. to match tube to speaker (Stancor A-3856 or Thordarson T-22S86 or T-22S87)
S—2" PM dynamic speaker
Selenium Units—65 ma., 130 v., half-wave rectifier
SW_1, SW_3—S.p.s.t. toggle sw.
SW_2—D.p.d.t.—toggle sw. (good insulation)

Fig. 1. Front view of YCL-1 Capacitometer.

Improved R. F. Capacitometer

By E. F. TRAVIS
and T. M. WILSON
General Engineering & Consulting Lab., G. E.

A negative resistance oscillator provides increased stability. Other refinements improve accuracy.

WHILE there are many inexpensive instruments on the market to make rapid measurements of capacitance and inductance, most of them are too inaccurate for industrial use. On the other hand, a laboratory setup which gives accurate results requires an experienced operator, takes considerable time to operate, and includes several pieces of expensive equipment.

At the beginning of the war the *General Electric* R.F. Capacitometer was developed to meet the need for an instrument to make rapid, accurate measurements of capacitance from 0 to 1000 micromicrofarads and inductance from 0 to 1000 microhenries. The original r.f. capacitometer provided accurate results and was rapid in operation, but it was soon found that the limited range was a handicap.

To meet the need for an instrument to measure wider ranges, the original unit was redesigned to extend its range and increase the ease of operation. The improved r.f. capacitometer shown in Fig. 1 has a measurement range of 0 to 20,000 micromicrofarads capacitance and 0 to 10,000 microhenries inductance, while retaining the same accuracy as the original instrument.

The simplicity of the new unit is shown by the few controls on the front panel. These are the ON-OFF power switch, range selector switch, SENSITIVITY CONTROL for the tuning indicator, ZERO SET control and the main tuning control and dial. The ease of adjustment of the main tuning control is increased by the use of the large lucite disc integral with the tuning knob. This is designed for use as a vernier, permitting exceptionally close setting of the control.

Two ranges are provided for capacitance measurements and three for inductance measurements. The desired range is selected by the RANGE SWITCH located on the front panel. The first capacitance range (0 to 1000 μμfd.) is direct reading with an accuracy of ±(0.2% + 0.5 μμfd.). On the second capacitance range (1000 to 20,000 μμfd.) a calibration curve is used, and the accuracy is ±(0.2% + 30 μμfd.). It should be noted that these accuracy specifications are not in terms of per-cent of full scale but in terms of per-cent of the value being measured.

The inductance ranges are 0 to 1250, 1250 to 4000 and 4000 to 10,000 microhenries. Calibration curves are furnished for each of those ranges and the accuracy is ±(0.5% + 0.5 microhenries) on all ranges.

The speed of operation of the capacitometer results from the use of the simple principle of comparing the frequency of two stable radio frequency oscillators. One oscillator operates at a fixed frequency of 75 kc. while the other, called the variable oscillator, is tuned to this same frequency before and after the unknown element is connected in its tank circuit. The electron ray tube indicates when the two frequencies are equal or zero beat. The change in oscillator tuning capacity necessary to compensate for the insertion of the unknown element is a measure of the value of the unknown.

The elementary diagram (Fig. 4) shows the important circuit elements of the Capacitometer. A Type 6SA7 tube is used as a combined oscillator-buffer amplifier for both the fixed and variable oscillator circuits. The output of the fixed oscillator is applied to one grid and the output of the variable oscillator is applied to the other grid of a 6SA7 mixer. The difference frequency which appears at the plate of the mixer tube is applied to the grid of a 6E5 electron ray tube so that the rate of opening and closing of the shadow represents the difference frequency between the two oscillators.

The measurement procedure to be followed in measuring capacitance is simple. With the main tuning control dial set at zero, the variable oscillator frequency is adjusted to zero beat with the fixed oscillator by the zero set control. During this operation only the ground or low side of the unknown capacitor is connected to the Capacitometer using the shielded cable furnished. Next, the high side of the unknown is connected and the frequency of the variable oscillator is again adjusted by the main tuning control until the indicator tube shows that the frequency is the same as that of the fixed oscillator. Since the main tuning control dial is marked to indicate the capacitance removed from the tuned circuit the dial reading is the value of the capacitor being measured for the 0 to 100 μμfd. range. Between 1000 and 20,000 μμfd. the actual value is obtained from calibration curves.

For inductance measurements the zero adjustment is made with the inductance shorted. After the unknown is connected, the variable oscillator is returned to its original frequency by means of the main tuning control. The scale reading is translated to inductance by means of a chart.

As mentioned before, the original Capacitometer was redesigned to provide wider measurement range, and ease of operation. These additional requirements necessitated considerable redesign even though the original principle was still retained.

A two terminal negative resistance type of oscillator circuit was selected for use in the Capacitometer because:

1) The circuit has good frequency stability with respect to fluctuations in tube element voltages.

2) It will maintain oscillation over a wide range of circuit impedance.

3) The range switching circuit is less complicated than with the ordinary *L-C* type.

The conditions to produce oscillation in the circuit (Fig. 2) are: (1) the feed back capacitor (C_F) must have negligible reactance compared to the grid circuit resistance, and (2) the tuned circuit must have a parallel resonant impedance greater than the absolute magnitude of R_n. The frequency of oscillation will be very nearly equal to the resonant frequency of the tuned circuit. Over a limited range the grid to screen transconductance of the 6SA7 is negative; that is, the screen current (i_{SG}) increases as the grid voltage (e_g) decreases. Since more electrons are deflected to the screen as the grid voltage decreases, the plate current is correspondingly reduced. Therefore, a decrease in voltage causes an increase in current (looking in at the grid), and the tube acts like a negative resistance ($-R_N$).

The cathode resistor (R_K) and capacitor (C_K) provide self bias for the oscillator tube. Grid No. 1 is operated at ground potential. The output load rather than being directly connected to the oscillator circuit is in the plate circuit of the 6SA7 which acts as a "buffer" amplifier so that changes in load have very little effect on the oscillator frequency. Thus an oscillator possessing good frequency stability with respect to changes in element voltages and load changes is obtained by the use of only one tube.

During the development, it was discovered that changes in oscillator transconductance (g_m), due to heater voltage fluctuations or actual tube changes affected readings obtained on the capacitometer when the impedance of the tuned circuit was high. It was noted that tubes of different g_m in the variable oscillator circuit gave different dial readings for the same unknown inductance. This effect was finally reduced to a negligible amount by decoupling the oscillator tube from its tuned circuit by the network C_g, R_g, and R_f (Fig. 3). This made the oscillator frequency less dependent upon changes in tube transconductance (g_m) and more dependent on the tuned circuit constants.

To maintain the accuracy of the instrument over long periods of time, it was necessary that the fixed oscillator frequency be stable. It was found that the expense of the crystal controlled oscillator used in the original Capacitometer was not necessary as the negative resistance type of oscillator with a regulated plate supply and temperature compensation would give the required stability. The drift in the frequency of the fixed oscillator was measured over a five day period. The unit was turned on in the morning, was operated for 8 hours and was turned off at night. During the period of the test the frequency never deviated more than 25 c.p.s. from its original frequency. This would cause a maximum error of .06% in measurements.

The frequency stability of the variable oscillator does not affect the accuracy to any great extent. However, since any shift in the variable oscillator necessitates resetting the zero its frequency should be as constant as possible for convenience in making measurements.

When two closely associated oscillators are operating at nearly the same frequency, there is a tendency for one oscillator to be pulled into synchronism with the other. In the RF Capacitometer this effect would seriously limit the instrument's precision and accuracy. Special precautions were therefore taken to prevent this so called "locking."

The *Q* of the oscillator coils was made as high as possible to reduce the tendency for the oscillators to shift in frequency. In addition, the two oscillators were decoupled as shown in Fig. 2 by the dividing network (R_{p1} and R_{p2}) the ratio being approximately:

$$R_{p2}/(R_{p1}+R_{p2}) = 30$$

Also, special shielding and wiring precautions were taken: the tank coil of the fixed oscillator was mounted on top of the chassis and shielded, while the coil for the variable oscillator was placed under the chassis. The components of the fixed oscillator were further isolated by a shield on the under side of the chassis and the plate supply leads to the two oscillators were decoupled.

The effectiveness of these methods is shown by the fact that it is possible to approach the correct tuning point and tune to zero beat without any noticeable pulling effect. Any perceptible motion of the main tuning dial in either direction can also be detected on the indicator tube.

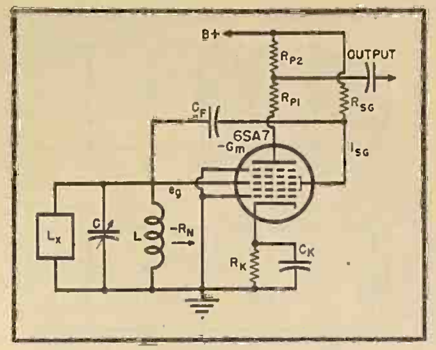


Fig. 2. Elementary circuit of the 6SA7 negative resistance oscillator.

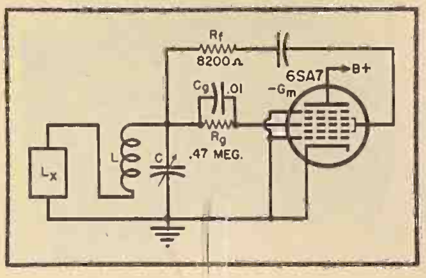
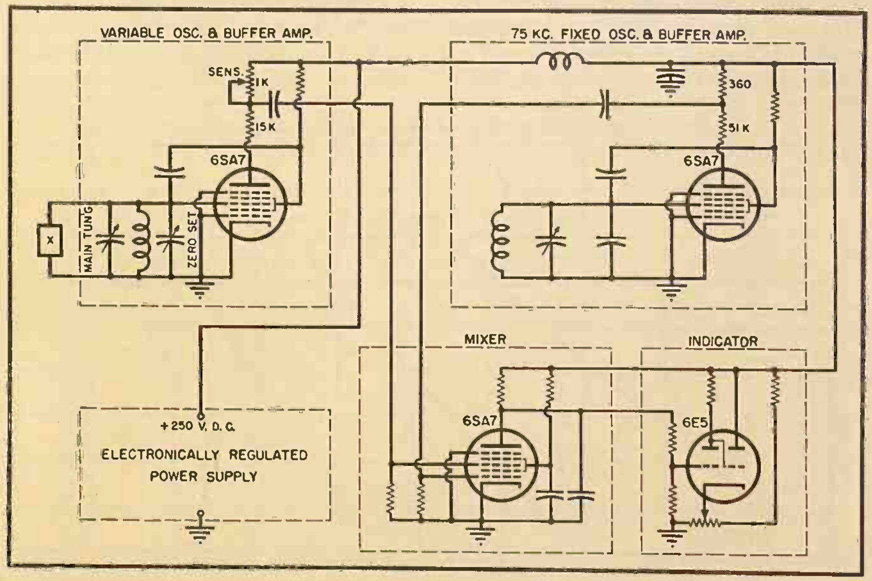


Fig. 3. 6SA7 negative resistance oscillator showing decoupling network.

Fig. 4. Elementary diagram of the R.F. Capacitometer.



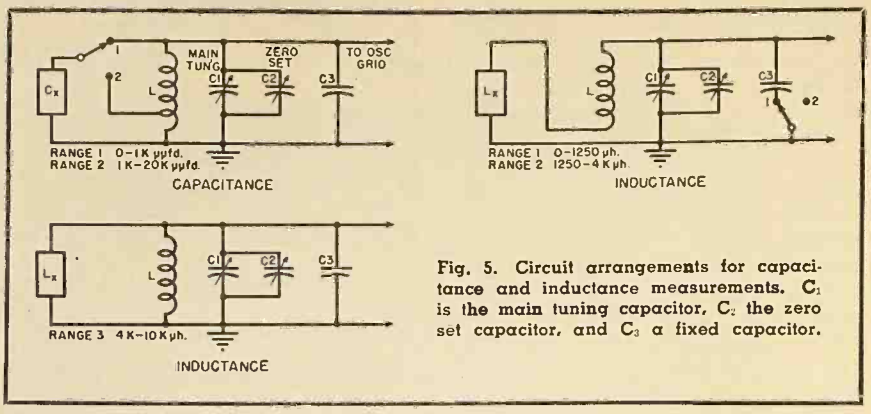


Fig. 5. Circuit arrangements for capacitance and inductance measurements. C_1 is the main tuning capacitor, C_2 the zero set capacitor, and C_3 a fixed capacitor.

Photograph showing front panel arrangement of the original capacitometer.

To maintain oscillations over such a wide measurement range the circuits were arranged as shown in Fig. 5. For the first capacitance range the tuned circuit consisted of coil L and capacitors C_1, C_2 and C_3. The unknown capacitance C_x was added in parallel with the tuned circuit. On the second capacitance range, the unknown is connected to a tap on the coil to reduce the effect of C_x at the oscillator grid approximately 20 to 1, so that capacities up to 20,000 μμfd. can be measured by means of the 1000 μμfd. tuning control. For measurements on the first and second inductance ranges, the unknown L_x is inserted in series with the coil L; C_1, C_2, C_3 again being the capacitances for the lowest inductance range. For the second range C_3 is removed from the circuit. In order to keep the tuned circuit resonant impedance down to a low enough value, the unknown is connected across the tuned circuit rather than in series for the highest or third range of inductance, which covers 4000 to 10,000 microhenries.

To meet the high accuracy requirement, careful selection and calibration of capacitance and inductance standards was necessary. The most precise 1000 μμfd. variable capacitor available was selected as a standard and was calibrated at the U. S. Bureau of Standards. The calibration accuracy on this type of capacitor is ±(.05% + 0.2 μμfd.) for values of capacitance difference between any two settings. This is the manner in which the capacitor is used and so furnished a satisfactory calibration.

A decade capacitor with 1000 μμfd. steps was made for calibrating the Capacitometers on the 1000 to 20,000 μμfd. range. Each step was calibrated against the 1000 μμfd. secondary standard capacitor just described. Intermediate points to aid in plotting the calibration curves were furnished by paralleling the decade capacitor with the 1000 μμfd. variable capacitor which had previously been calibrated.

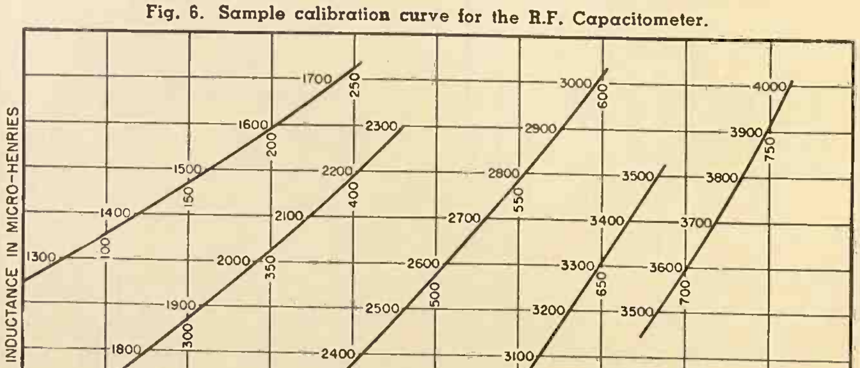
Special inductance standards were made for calibrating the Capacitometer. The inductance of these coils was measured at 75 kc. by the frequency comparison method using the 1000 μμfd. secondary standard capacitor. As a further check, several of these inductances were calibrated by the National Bureau of Standards, which provided very accurate standards.

Since the main tuning dial is calibrated directly in capacitance removed from the circuit, the capacitance may be read directly from the dial for the range of 0 to 1000 μμfd. Above this and on the inductance ranges, calibration curves are furnished to convert dial readings into actual values of capacitance or inductance. Here, the problem of supplying graphs of sufficient reading accuracy in a reasonable size was overcome by breaking each graph up into segments and overlapping. Five curve sheets were supplied with each Capacitometer, two for capacitance and three for inductance. A typical calibration curve for a Capacitometer is shown in Fig. 6. This particular curve is for the 1250 to 4000 microhenry inductance range, but the other ranges are similar. Circles represent calibration points. To avoid confusion all of the graph divisions are not shown in this figure. Although not shown in this figure, the graph is so divided that the smallest division represents two microhenries. Points on the curve can easily be read closer than the smallest division. This means the reading accuracy is at least within 0.1% which is five times better than the guaranteed over-all accuracy on inductance.

The precision of measurement with the R.F. Capacitometer, that is, the agreement between readings of the same quantity, is limited by (1) the error in reading the dial, (2) backlash in the main tuning capacitor drive mechanism, (3) the sensitivity of the indicator, and (4) stray effects caused by shifting of leads. It was found that with care measurements could easily be made, even by non-technical workers, with a precision of 0.2 μμfd., one part in 500, which is the smallest division on the main tuning dial.

For comparative measurements where indication of deviations from a standard capacitor rather than absolute value is desired, the R.F. Capacitometer also proves to be a useful instrument. In measuring small deviations, of the order of two or three μμfd., the accuracy is approximately equal to the precision of the instrument (0.2 μμfd.) on the 0-1000 μμfd. range.

Fig. 6. Sample calibration curve for the R.F. Capacitometer.



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Design of Acoustic Systems by Electromechanical Analogies

By D. FIDELMAN

Part I. The design of equipment for converting electrical impulses to sound and vice versa.

Dual-cone loudspeaker having a uniform output from 30 to 15,000 cycles.

THE reproduction of sound by any method must always involve, somewhere in the system, the conversion of mechanical vibrations to electrical energy or of electrical to mechanical vibrations. Sound itself is a mechanical vibration, while all present amplification and transmission systems operate upon electrical signals—therefore the incident sound must be converted into an electrical signal, and the final electrical signal must again be converted into sound. If the signals are to be recorded for reproduction at a later time, the recording process is also likely to involve the conversion of electrical to mechanical energy.

At the present stage of audio system development, the performance of the electrical systems is generally much better than that of the units which involve mechanical motions. Much of the current development and research in sound reproduction is therefore being directed toward the improvement of the electromechanical components. When these have been properly perfected, it will then be possible to obtain even better fidelity of reproduction than the best we have today.

The fundamental requirements of a system which will give good sound reproduction may be summarized briefly:

(a) It must be able to reproduce a wide frequency range — the entire range of human hearing would be the ultimate goal.

(b) The response should be uniform over the entire frequency range.

(c) It should not introduce detectable distortion or noise into the reproduced sound.

(d) Transient sounds should be reproduced exactly as they occur.

(e) It should be able to reproduce the entire dynamic range of the original sound.

Present systems of sound reproduction meet these requirements to a large degree—but not completely. The difficulties exist mainly in the electromechanical components of the system.

The basic difficulties are better understood when the problem is considered closely. For example, a loudspeaker is required to be able to reproduce accurately all the sounds, both singly and in combination, which can be produced by all musical instruments. The degree to which this has been accomplished is one of the successes of modern engineering. This article will describe the methods which are used to design electromechanical devices for the reproduction of sound, to show the basis of practical designs using these methods, and how they are used for the improvement and perfection of existing designs.

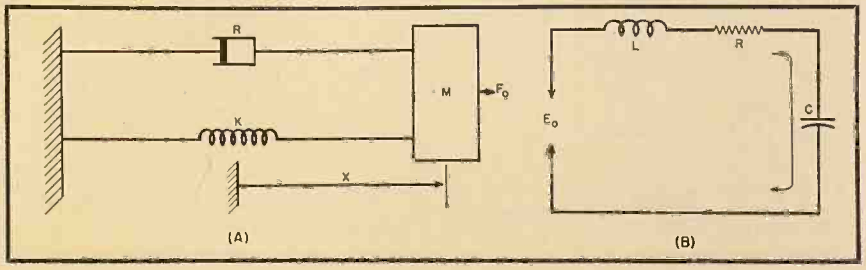
Electromechanical Analogies

Essentially, the performance of mechanical systems is analyzed by writing the differential equation of the system and obtaining the response to some applied force. However, the mechanical systems which are used in sound reproduction are usually too complex to permit direct calculation of the response, and the most direct method is to measure it.

This measurement, and any calculations which are to be performed, are best done by making use of the differential equation instead of the actual mechanical system. This makes it possible to make use of the fact that mechanical systems are represented by the same differential equations as electrical networks, so that the method of electromechanical analogies can be used. Thus all the results of network theory are available for the design of mechanical systems, and the operation of a proposed new design can be measured by setting up the analogous electrical circuit, saving the expense and time required to construct mechanical models.

The theoretical basis of the method can best be understood by consideration of the simple mechanical system shown in Fig. 1A. It consists of a mass, a spring, and a dashpot connected to-

Fig. 1. (A) Simple mechanical system consisting of a mass, a mechanical resistance, and an elastic spring, caused to move by an external applied force. (B) Mathematically equivalent electrical circuit consisting of an inductance, a resistance, and a capacitance, with an applied voltage.



Actual electrical circuit	Electrical analogy circuit
$L' = \frac{aL}{n}$	$L' = \frac{aM}{n}$
$C' = \frac{C}{an}$	$C' = \frac{1}{anK}$
$R' = aR$	$R' = aR$

a is arbitrary constant, n is ratio of frequencies in analogous circuit to those in actual system.

(1) If known excitation function is represented by a voltage E'_0, actual voltages or quantities they represent are given by equations

$$e_n = \frac{E_0}{E'_0} e'_n \qquad f_n = \frac{F_0}{E'_0} e'_n$$

and currents or their analogies by equations:

$$i_n = \frac{a E_0}{E'_0} i'_n \qquad v_n = \frac{a F_0}{E'_0} i'_n$$

(2) If known excitation junction is represented by current I'_0

$$i_n = \frac{I_0}{I'_0} i'_n \qquad v_n = \frac{V_0}{I'_0} i'_n$$

$$e_n = \frac{I_0}{aI'_n} e'_n \qquad f_n = \frac{V_0}{aI'_0} e'_n$$

gether. The motion is then given by Newton's second law, and is represented by the differential equation:

$$F_0 = M \frac{d^2x}{dt^2} + R \frac{dx}{dt} + Kx$$

If the simple LCR circuit of Fig 1B is considered, the electrical charge (and therefore the current) in the circuit is given by the well-known differential equation derived from Kirchhoff's second law:

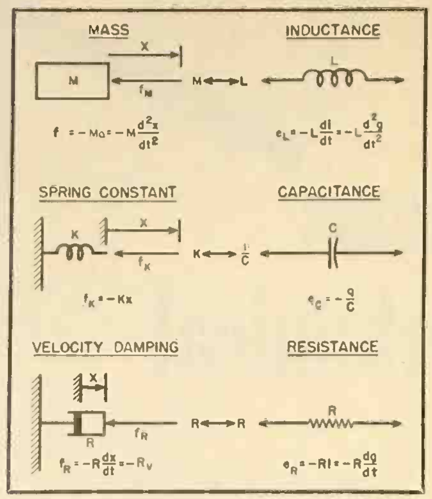


Fig. 2. Methods of representing mechanical elements by equivalent electrical circuit elements, when using the force-voltage analogy.

Fig. 3. Conversion formulas for determining the various circuit constants.

$$E_0 = L \frac{d^2q}{dt^2} + R \frac{dq}{dt} + \frac{1}{C} q$$

It is obvious that the equations for the electrical and the mechanical system become identical if the following substitutions are made:

charge (q)	←→	displacement (x)
voltage (E_0)	←→	force (F_0) $\left(\frac{1}{K}\right)$
capacitance (C)	←→	compliance
inductance (L)	←→	mass (M)
resistance (R)	←→	damping, friction (R)

This identity between the mathematical equations holds true for mechanical and electrical systems of any degree of complexity, therefore the electromechanical analogous circuits may always be set up without any further investigation into the exact mathematical solution to the equations of the mechanical system. All the known methods of circuit and network analysis can then be applied to the electrical circuit, and the results will be completely valid for the mechanical system.

It may be noted that when the electromechanical analogous circuit is set up as indicated, the basis for the analogy is fundamentally the differential equation, even though it is not explicitly used. (Another analogous circuit may be set up by considering a force-current analogy, and using Kirchhoff's first law. Both systems are equally valid, but the force-voltage analogy is much more widely used.) The details of application of this method are given graphically in Figs. 3 and 4 which give the basic analogies together with the dimensions of the various factors.

When setting up the analogous circuit, if the mechanical system gives impractical values the circuit constants and the time base can readily be changed by any desired scale factor to obtain the most practical circuit values, without affecting the accuracy with which the mechanical system is represented. A consistent set of formulas for accomplishing such conversions is given in Fig. 2. When testing the circuit it is generally best to set the applied voltage at some convenient value, and then record the solutions as ratios of this value according to these conversion equations.

In the design of any electromechanical transducer, perhaps the most important information which must be known about it is its response to an applied signal. The electromechanical analogous circuit is not only much faster, easier and cheaper to set up than the original mechanical device, but it offers additional advantages in ease of measurement and adjustment of constants. Sound measurement on transducers requires calibrated microphones, specially treated listening rooms, and sources of sound designed to minimize standing waves and other spurious effects. The electrical circuit, on the other hand, is measured by the standard methods and no special equipment is needed.

The electromechanical equivalent circuit is also valuable in showing that acoustic and mechanical "networks" can be constructed, and that these can be designed and analyzed on the same basis as electrical networks. The elements which make up mechanical and acoustic networks are shown in Fig. 5, which also shows which elements are analo-

Fig. 4. Analogous quantities in the two systems, and their corresponding dimensions.

Mechanical Systems			Electrical Circuits		
Symbol	Quantity	Dimensions	Symbol	Quantity	Dimensions
v	Velocity	cm./sec.	i	Current	amperes
f	Force	dynes	e	Voltage	volts
x	Displacement	cm.	q	Charge	coulombs
M	Mass	grams	L	Inductance	henries
$\frac{1}{K} = C_M$	Compliance = $\frac{1}{\text{Stiffness}}$	cm./dyne	C	Capacity	farads
Z_M	Impedance	mechanical ohms (dynes/cm./sec.)	Z_E	Impedance	ohms
R_M	Resistance	"	R_E	Resistance	"
$X_M \begin{cases} j\omega M \\ \frac{1}{j\omega C} \end{cases}$	Reactance	"	$X_E \begin{cases} j\omega L \\ \frac{1}{j\omega C} \end{cases}$	Reactance	"
$\frac{1}{2\pi\sqrt{M/K}}$	Resonant frequency	cycles/sec.	$\frac{1}{2\pi\sqrt{LC}}$	Resonant frequency	cycles/sec.

gous in the various systems. The analogue of electrical resistance is sliding friction which causes dissipation in mechanical systems, and the dissipation caused by viscosity when fluid is forced through narrow slits is the analogue in acoustic systems. The analogue of electrical inductance is mass in mechanical systems, and in an acoustic system is represented by the fluid contained in a tube in which all the particles move with the same phase when actuated by a force due to pressure. The analogue of capacity is a spring in the mechanical system, and a volume which acts as a stiffness or spring element in the acoustical system.

Another analogy which is valid with certain restrictions is the transformer as shown in Fig. 6. The lever in the mechanical system is analogous to the transformer; however, the transformer operates only for alternating current, while the lever performs its function for static as well as for alternating forces. There is no d.c. electrical analogue for the transformer, but this is not important in acoustic design since only audio frequencies are of interest. The acoustic analogue of the transformer is the exponential horn, which transforms large pressures and small volume velocities to small pressures and large volume velocities above the cutoff frequency. The equation of the taper of such a horn is:

$$L_x=\frac{2.302}{m}\log_{10}\frac{A_x}{A_t}$$

where L_x is the length (in cm.) from the throat, A_t is the area of the horn throat, A_x is the area at L_x, m is the rate of taper$=A\pi f_c/c$, c is the velocity of sound in air$=$34,400 cm./sec., and f_c is the theoretical low-end cutoff frequency.

An example of the use of these principles in the design of acoustic and mechanical networks is the low-pass acoustic filter shown in Fig. 8. This consists of three sheets of perforated metal to form a number of two-section filters. The mass of the air in the openings acts as the series inductance, and the compliance of the air between the sheets acts as the capacity to ground—thus the network has the configuration shown in 8B, which is the standard type of low-pass filter circuit. A typical frequency response of such a filter is shown in 8C.

Applications to Specific Designs

An indication of the method of application of the method of electromechanical analogies in the design of audio systems may best be obtained by considering its application to the design of several specific devices.

Loudspeaker Design. The application to the design of a simple direct-radiator loudspeaker is shown in Fig. 11. The diagram in 11A shows the constructional details of a standard single-coil, single-cone dynamic loudspeaker. Consideration of this structure shows that its mechanical characteristics are determined mainly by: M_c, the mass of the cone and voice coil; K_s, the compliance of the cone suspension; R_s, the mechanical resistance of the cone suspension; M_a, the mass of the air load on the cone; and R_a, the mechanical resistance of the air load. These factors are indicated in the diagram. There are, of course, several other factors which haven't been indicated—such as the stiffness of the voice coil form, the mass and compliance of the air in back of the voice coil, and the fact that most of the constants are distributed rather than lumped—but these do not usually have too great an effect upon the accuracy of the representation, if their efforts are properly taken into account. (This is the same approximation which is commonly made in electrical circuit calculations, where small-order stray capacitances, resistance and inductance are usually neglected, and distributed parameters are considered as lumped.)

The electrical circuit which supplies driving power to the voice coil is shown in Fig. 11B. The voltage e is supplied by a generator having an internal impedance Z_G, in the voice coil having a resistance R_{VC} and an inductance L_{VC}. The effect of the coupled mechanical system appears in this circuit as the impedance Z_{EM}.

The electromechanical analogue circuit which represents the mechanical system can also be written as shown in Fig. 11B. The effect of the electrical circuit appears here as an impedance Z_{ME}, which is therefore the internal impedance of the generator that supplies the signal. Thus the "mechanomotive force" of the generator is f_{MO}, and the force supplied by the voice coil is f_M. By the principles of electromechanical analogies which have been described, the mechanical circuit representing the loudspeaker can then be drawn as indicated. This gives a series circuit, with the mass of the cone, and the compliance and resistance of the suspension all in series with the load, consisting of the mass and resistance of the air load on the cone.

This gives two circuits for the loudspeaker, which contain the unknown impedances Z_{EM} and Z_{ME}. Since the force in the mechanical system due to the current in the voice coil and the inverse e.m.f. in the voice coil due to its motion in the magnetic field are related by the same factor, the circuit can be simplified by eliminating these unknown impedances. The mechanical impedance is obtained from the electrical impedance by the relation:

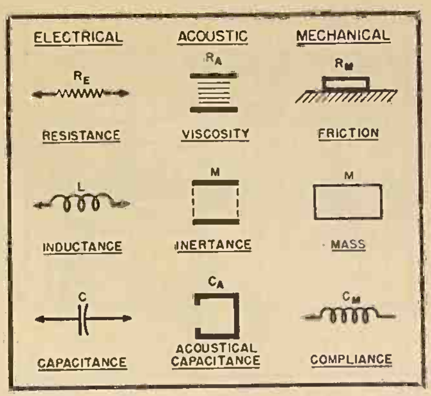


Fig. 5. Elements which can be used in the construction of electrical, acoustic, and mechanical networks.

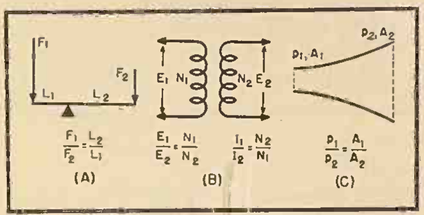


Fig. 6. Analogy between the lever, the transformer, and the exponential horn.

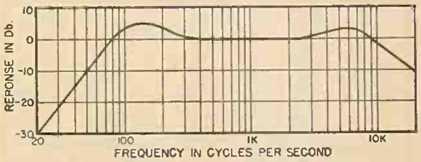
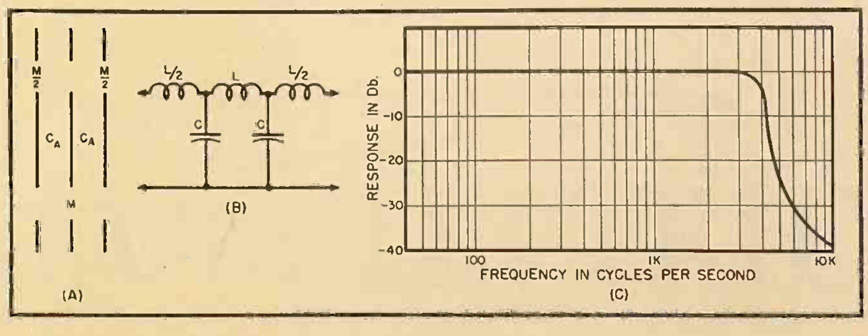
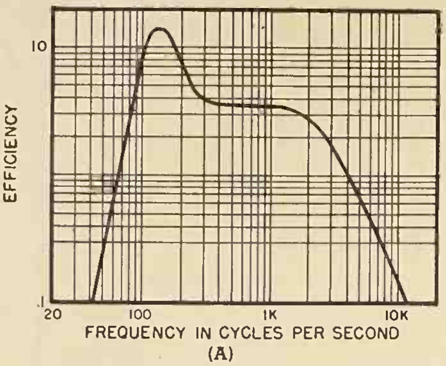


Fig. 7. Frequency response on the axis of the loudspeaker shown in Fig. 9.

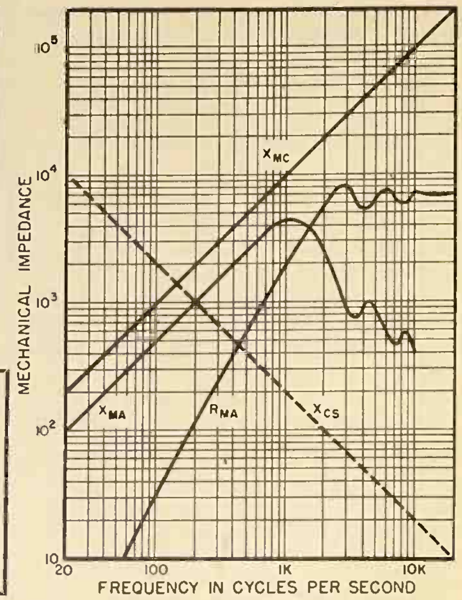
Fig. 8. Design of a low-pass acoustic filter. (A) Low-pass acoustic filter. (B) Equivalent electrical filter. (C) Typical frequency response of above filter.





Cone diameter	4 in.
Mass of cone	1 gm.
Mass of voice coil	9.35 gm.
Compliance of suspension	8.0 x 10⁻⁷
Mech. res. of suspension	200
Voice coil material	copper
Air gap flux	10,000 gauss

(B)



(C)

Fig. 9. Practical application of the electromechanical equivalent circuit of Fig. 11 to the design of a loudspeaker. (A) Efficiency characteristics of loudspeaker. (B) Mechanical characteristics. (C) Various mechanical impedance components as a function of frequency.

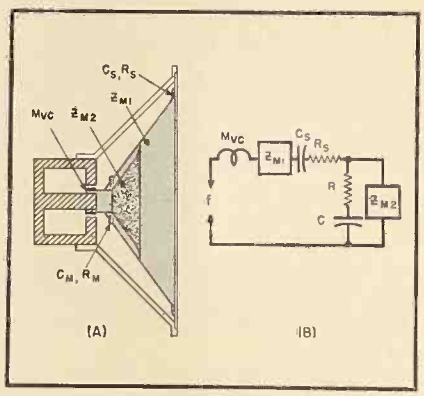


Fig. 10. (A) Mechanical system of double-cone single-coil loudspeaker. (B) Equivalent electrical circuit of the double-cone speaker.

$$Z_{EM}=\frac{(Bl)^2}{Z_M}\times 10^{-9}$$

where B is the magnetic flux density, and l is the length of wire in the voice coil. This relation shows that the entire system can be represented as a single network, if the proper transformer is inserted between the two sections, the actual turns ratio of the transformer will depend upon the electromagnetic structure of the specific loudspeaker.

The final circuit then becomes that shown in Fig. 11C. This circuit can be analyzed by any of the standard methods of circuit analysis, or it can be set up with ordinary coils, condensers and resistors, and its response measured. It is basically a band-pass circuit, giving good response at the center frequencies, and dropping off at the high and low frequencies.

The manner in which this circuit applies to a practical loudspeaker design is shown in the graphs of Fig. 9. The characteristics of the speaker which are being considered are shown in 9C, and the various impedance components as a function of frequency in 9A. The efficiency, which is the ratio of the sound power output to the electrical power input, is shown in 9B. If the loud speaker were nondirectional, the efficiency characteristic would be the frequency response characteristic. However, the response is measured on the axis, and the directional effects give a proportionately greater sound pressure on the axis at the higher frequencies. If this is taken into account, calculations show the sound pressure response on the axis to be as shown in Fig. 7, and this is very close to the actual measured frequency response characteristic.

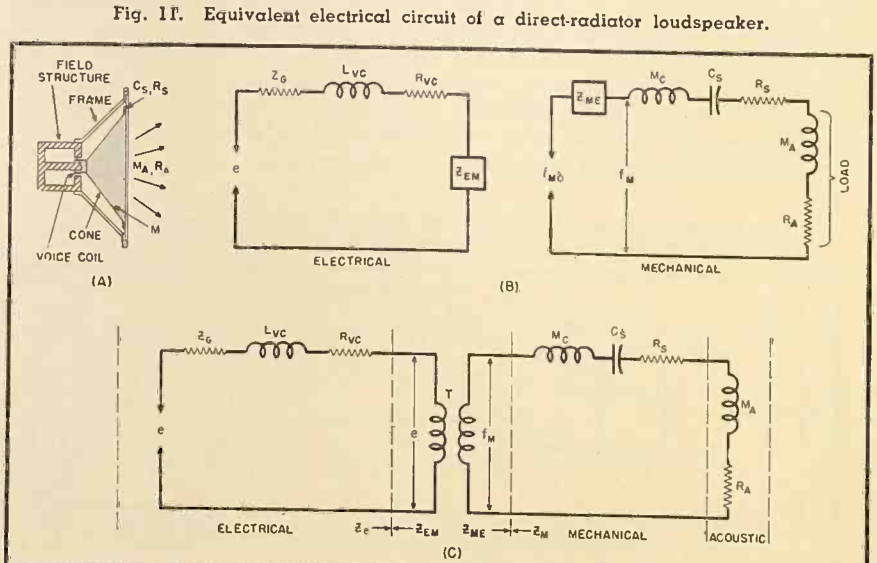
The curves in Fig. 9 show that a loudspeaker with a small and relatively lightweight cone and voice coil is capable of giving good response and efficiency over a wide frequency range. However, a loudspeaker with a small cone is not able to deliver much acoustic power at low frequencies because the required amplitude of vibration is too great. One method of avoiding this difficulty is by use of the dual-cone system, in which the use of a mechanical network makes it possible to obtain the advantages of the small cone at high frequencies, and of the large cone at low frequencies.

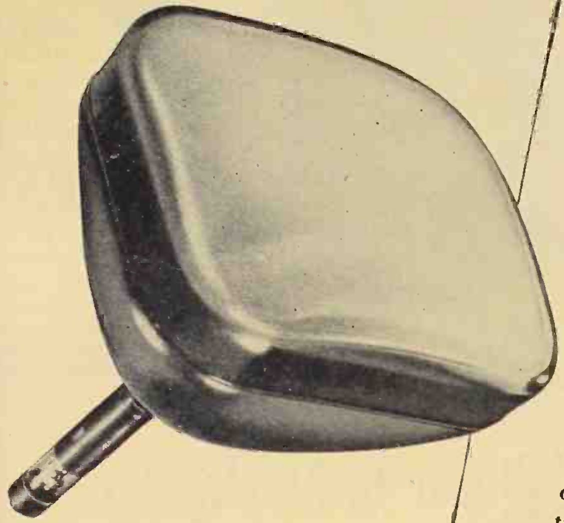
This system is illustrated in Fig. 10. It consists of a single voice coil coupled to two cones as shown in (A), with the two cones coupled together by a compliance. The operation can be understood by reference to the analogue circuit in (B). At low frequencies the reactance of the compliance is large compared to the mechanical impedance Z_{M2} of the large cone, therefore the entire current flows through Z_{M2} and the entire system moves as a whole. At high frequencies the reactance C_M is small compared to Z_{M2} and shunts it, therefore the small cone moves while the large one remains stationary. A system of this type makes it possible to extend the frequency range of the loudspeaker by almost a full octave, depending upon the mass and electrical characteristics of the voice coil.

This article has been concerned primarily with the design of loudspeakers by means of electromechanical analogies. Part 2, which will appear next month, will deal with microphone design incorporating these same principles.

(To be continued)

Fig. 11. Equivalent electrical circuit of a direct-radiator loudspeaker.





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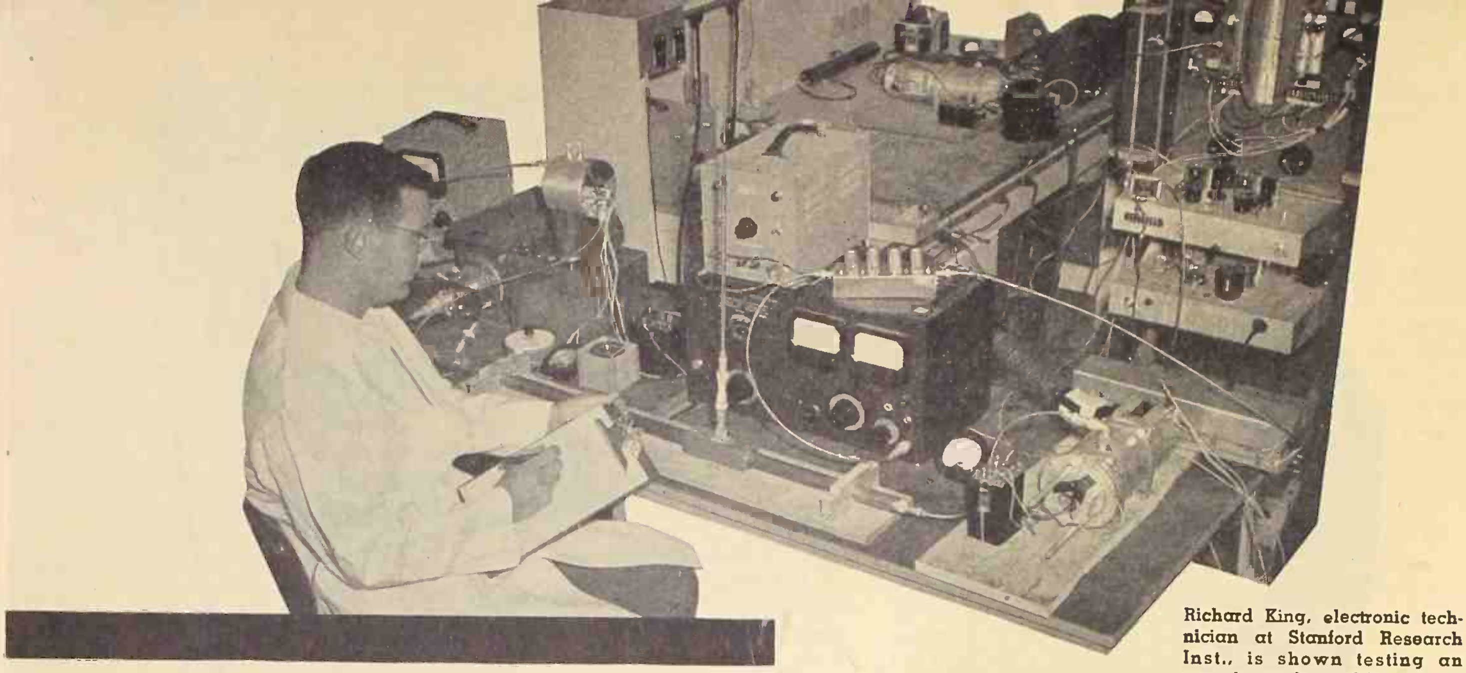


Richard King, electronic technician at Stanford Research Inst., is shown testing an experimental amplifier chain.

P.T.A. (Phase to Amplitude) MODULATION

This novel system of modulation has been successfully applied to television for the first time by Stanford engineers at KM2XAZ.

IT HAS been evident for some time that the present v.h.f. band is entirely inadequate for a truly nationwide television service. The logical solution is to move to the u.h.f. band above 300 mc., where many more television channels would be available. To stimulate research at these higher frequencies, the FCC has alloted experimental licenses to several stations for operation between 500 and 1000 mc.

One of the stations so licensed is KM2XAZ, at Long Beach, Calif., owned by Mr. John H. Poole. Stanford Research Institute has been carrying on a development program for u.h.f. television transmitters and receivers under the sponsorship of Mr. Poole, and Mr. W. E. Evans, Jr. of Stanford described the transmitter at the Cincinnati Spring Television Conference, April 29.

This television transmitter, which operates at 530 mc., uses a type of modulation called P.T.A. (phase to amplitude), or sometimes referred to as "outphasing" modulation. The system is not new, having been used quite extensively in foreign countries, but has not until recently been developed to any great extent in this country. It permits the amplitude modulation of large amounts of power using small receiving tubes as modulators.

The system consists basically of two identical phase modulated transmitters driven from the same oscillator and fed into the same antenna. The phase modulation is so arranged that on modulation peaks the two channels are in phase and, when combined, give maximum amplitude of the carrier, while on modulation troughs, the two channels are out of phase, giving minimum modulation of the carrier. From this it can be seen that the phase modulation of the two channels must be kept equal and opposite—that is, if one channel is phase modulated by $+15°$, the other channel must be modulated *exactly* $-15°$ at the same instant.

This system of modulation permits the use of high-efficiency nonlinear class C amplifiers following the modulator. Since modulation takes place at a very low level, large modulation transformers and reactors are eliminated, along with the need for high modulating powers. Modulation is possible practically down to d.c., and the upper frequency is limited only by the bandwidth of the power amplifiers. This makes the system ideal for a television transmitter, particularly in the u.h.f. range.

The transmitter at station KM2XAZ has a power output of 150 watts peak at 530 mc. A crystal oscillator output is multiplied up to a power level of about 4 watts at 265 mc., where it divides and goes through the two halves of a twin-channel phase modulator, each side of which is capable of linear modulation up to ± 22.5 degrees. This output is then passed through identical doublers and power amplifiers to give an output of 75 watts peak from each channel at a phase modulation up to ± 45 degrees. Two 4X150A coaxial cavity stages are used to provide this amplification. The outputs of these two channels, constant in amplitude but varying in phase, are then fed into the antenna, where they combine to produce an output which is constant in phase but varying in amplitude—in other words, the output is amplitude modulated.

The output combining network consists of a configuration of quarter-wave transmission lines having the property that when two equal r.f. voltages are fed into the input terminals, the impedance that each channel sees is resistive and constant, regardless of the relative phase between the two voltages. The network feeds into the antenna and a dummy load, thus the distribution of power varies smoothly between these two loads, depending upon the phasing of the inputs.

The relationship between "volts output" and the relative phase angle is sinusoidal. It would seem that this nonlinearity would introduce a great deal of distortion, but a sine wave departs from a straight line by only 4 per-cent over the first 75 per-cent of its total amplitude. In a television signal, the picture information is contained in the lower 75 per-cent of the waveform and the upper 25 per-cent is devoted to sync pulses, making this sinusoidal characteristic ideal. The sync pulse amplitude may be restored by sync stretching.

As mentioned before, the r.f. power amplifier sections are of the conventional coaxial cavity type. Each channel uses one 4X150A as a straight-through amplifier on 265 mc. followed by another **4X150A** which doubles the frequency to 530 mc. A bandwidth of 9 mc. is maintained in this power amplifier.

The phase modulator, which could well be called the heart of this type of transmitter, poses several difficult problems, not the least of which is that of providing linear modulation at carrier frequencies of 265 mc. A network similar to that used in the output for converting phase modulation to amplitude modulation can be reversed to provide amplitude to phase modulation. The total linear modulation range is about ±25°, so to obtain the necessary ±45° shift at 530 mc., the phase modulator must be operated at 265 mc.

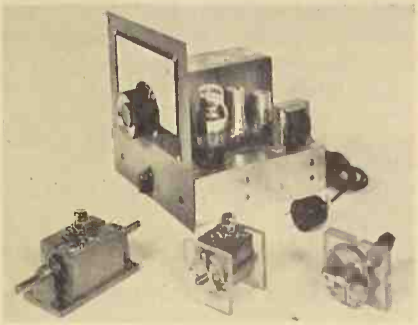
A special twin-channel phase modulator tube has been developed at Stanford to do the entire job of phase modulation with practically no adjustments. The maximum power output thus far obtained from such a tube has been in the milliwatt region, which prevents its use in the present transmitter because of the extra amplification required. Development is continuing, and if a tube can be built to provide an output in the order of one to ten watts, the problem of a simple phase modulator will have been solved.

Tests have indicated that the performance and stability of the transmitter now in use are adequate to meet the most stringent requirements. The video response of the complete system is flat within 1 db. to 4.8 mc., and a horizontal resolution in excess of 400 lines has been realized.

It is apparent that this system of modulation will have very little, if any, advantage at low power levels, but will be superior to conventional systems at higher power levels. Above 500 to 1000 watts, distinct advantages in physical size, initial cost and efficiency may be realized over grid-modulated systems.

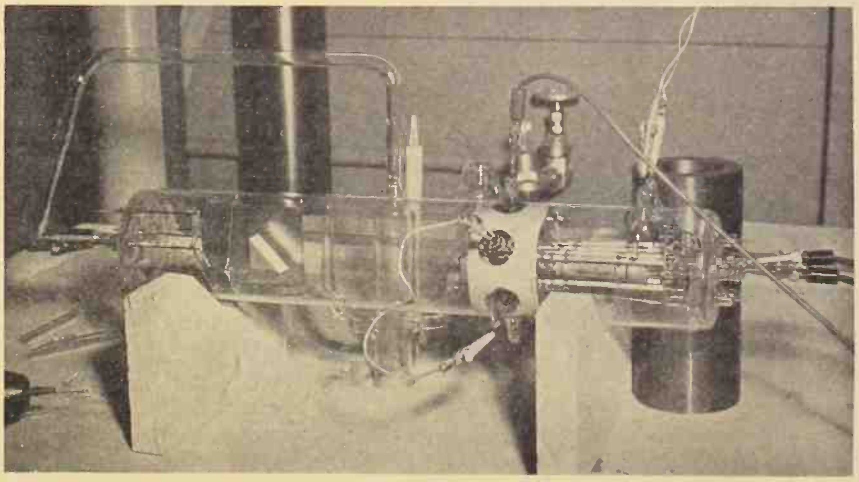
With a basic unit of the type now in use at KM2XAZ, additional power output may be obtained merely by the addition of class C amplifiers designed for operation at 530 mc. Use can be made of such tubes as klystrons, resnatrons and traveling wave tubes.

The development of this transmitter has been one long-sought step toward the opening of the u.h.f. region for commercial broadcasting. Another is the development of converters for bringing u.h.f. signals down to the v.h.f. level of standard commercial TV receivers. Such a prototype converter has been designed and built by engineers at Stanford Research Institute, also under Mr. Poole's sponsorship. Several tunable versions have been built, thus completing the necessary steps for the development of a truly nation-wide, competitive television broadcasting system. It is expected that the FCC will complete its hearings sometime this fall, and shortly thereafter will probably open the u.h.f. band for TV broadcasting. In the meantime, intensive research for the development of additional techniques, antennas, etc. is continuing in all branches of the industry. Other experimental u.h.f. television stations have been in operation for some time, and a great deal of data has been collected regarding propagation characteristics, shadow effects, ghosts, etc. Preliminary results indicate that radiated powers considerably in excess of those used at v.h.f. will be necessary for equivalent coverage at u.h.f.



Chassis view of the TV converter for the u.h.f. band developed by Stanford Research Institute for John H. Poole of Long Beach, Calif. In the foreground are special circuits, which are, left to right: cylinder oscillator with acorn tube, modified semi-butterfly type of oscillator, and a special crystal mixer.

The 200-watt phase to amplitude transmitter is being subjected to exhaustive tests before being delivered to experimental TV station KM2XAZ. William E. Evans, research engineer, is shown with some of the testing instruments.



Special phase-modulator tubes have been designed by the laboratory staff to incorporate the modulating jobs of several conventional u.h.f. tubes into one. The model is shown connected to the vacuum pumps during processing. Work is continuing on the development of a tube having from one to ten watts output, rather than the milliwatts output of preliminary experimental models.

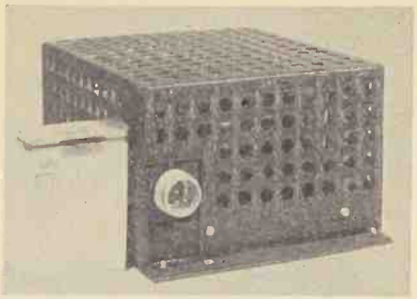
REFERENCES

1. *Chireix, Henri, "High Power Outphasing Modulation," Proc. I.R.E., Vol.* 23, *No.* 11, *p.* 1370, *November,* 1935.
2. *Villard, O. G. Jr., and Evans, W. E., Final Report to Air Materiel Command, Watson Laboratories, Red Bank, N. J., on Project* W-28-099-ac-121, *August,* 1947.
3. *Terman, F. E., "Radio Engineers Handbook," McGraw-Hill, p.* 546.

NEW PRODUCTS

ELECTRONIC PHASE ADAPTER

Varo Manufacturing Co. Inc., Box 638, Garland, Texas has announced its



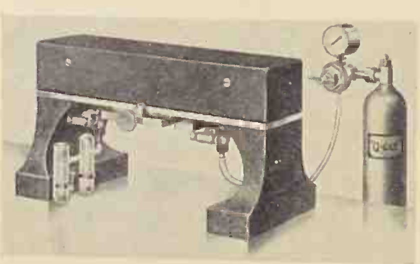
Model 160 Electronic Phase Adapter which is an electronically controlled phase splitting network capable of dividing single phase 400 cycle current into balanced three phase current over a large range of power up to 100 va.

This device consists of a reactor and capacitor in series directly across the line, the third phase terminal being their common connection. Output voltage on all phases is equal to input voltage ±3% over wide ranges of input voltage, frequency, load, power factor, temperature, and altitude.

Designed for maximum resistance to fungus, salt spray, sand, dust, and humidity, this phase adapter has no moving parts and has a life expectancy of 1000 hours.

FLOW COUNTER

Nuclear Instrument & Chemical Corporation, 223 West Erie St., Chicago, Illinois, has announced a low background gas flow counter using the famous Q-gas mixture. Known as Model D46A, this new counter has the long plateau and low voltage operation which were obtainable with the former

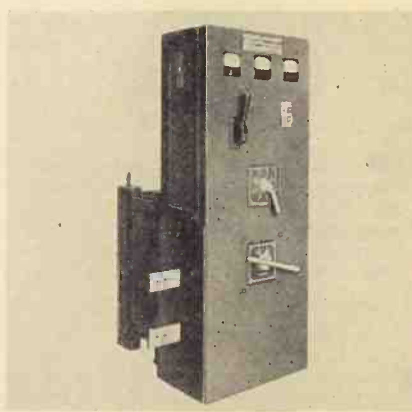


counter.

In addition, this instrument has a shielded background of only 17-18 counts per minute at Chicago elevation and a still lower background may be expected at sea level. The counter now has a flush time between samples of only ten seconds. Resolution time is approximately 100 microseconds, and a sample as large as 1¼" in diameter may be used. Starting potential is 1025 volts, and the plateau is 400 volts long with a slope of less than 3% per hundred volts.

TRANSFORMER FOR HEATING

Eisler Engineering Co., Inc., 750 So. 13th St., Newark 3, N. J., has developed a low voltage heavy current transformer for heating applications, com-



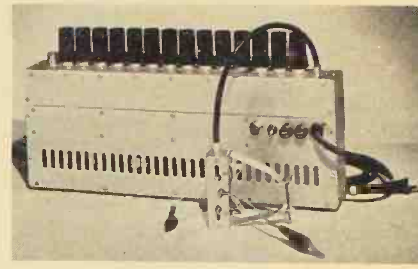
plete with control panel. Available in a wide variety of kva. capacities up to 500 and in any required combination of voltages and frequencies, the unit shown is of 40 kva. capacity for 440 volt supply and has secondary voltages ranging from 25 to 100 volts with secondary current up to 1600 amperes.

The control equipment includes, in addition to the tap switches, a magnetic contactor and suitable indicating meters for voltage and current. In other cases, additional equipment such as recording meters, safety entrance switches and various arrangements of tap switching are supplied.

CHAIN PULSE AMPLIFIER

A chain pulse amplifier designed to amplify very fast pulses and transients and employing fourteen 6AH6 vacuum tubes in a traveling wave circuit is now offered by *Spencer-Kennedy Laboratories, Inc.*, 186 Massachusetts Ave., Cambridge 39, Mass.

Model 214 has a bandwidth of 40 kc. to 100 mc. and a gain of 30 db. The input impedance of 180 ohms is de-



signed to match the output impedance of the Series 200 Wide-Band Chain Amplifiers for additional gain up to 60 db. A special termination at the end of 15" of cable is provided for convenient use with a *DuMont* 5XP cathode-ray tube for the viewing of high speed pulses.

Housed in an aluminum chassis, this amplifier can be supplied for either table or rack mounting. Further information may be obtained by addressing inquiries to Dept. RT.

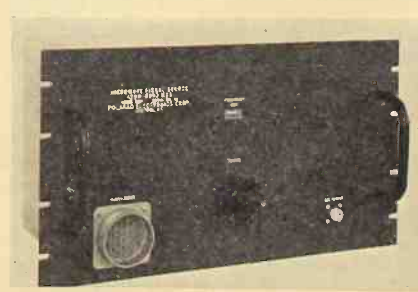
PORTABLE RADIATION DETECTOR

A long-probe radiation detector which permits the operator to measure radioactivity from a safe distance has been developed by the Special Products Division of the *General Electric Company*, Schenectady 5, N. Y.

This instrument can be used for monitoring areas in which radioactivity is suspected, or for other types of radiation metering. A detector located at the tip of a 4 ft. probe converts radioactive emanations into electrical energy. This detector consists of an electronic tube and a phosphor; and light from the phosphor acts upon the electronic tube which converts the light energy into electrical energy and amplifies its magnitude.

SIGNAL SOURCES

A series of microwave signal sources, covering the range of 634 mc. to 8340 mc. in four units, is now available from *Polarad Electronics Corp.*, 100



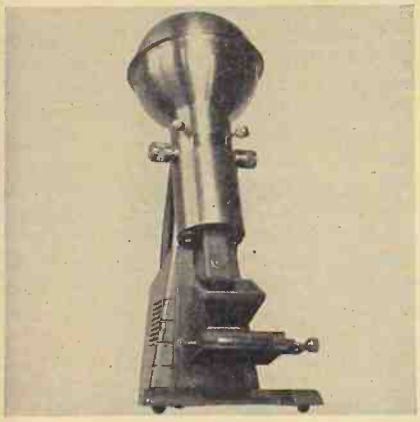
Metropolitan Ave., Brooklyn 11, N. Y.

These reflex klystron signal sources are controlled by one dial only and frequency is read directly from a linear indicator to accuracies of ½%. The reflector voltage is automatically tracked with the cavity tuner. Non-contacting shorts are used to eliminate noise and reduce mechanical wear, and terminals are provided for applying modulation to either the grid or reflector.

Model SSR covers the range from 634 to 1174 mc.; Model SSL—1140 to 2184 mc.; Model SSS—2145 to 4310 mc.; and Model SSM—4290 to 8340 mc. The signal sources are supplied complete with tube.

ELECTRON MICROSCOPE

RCA Victor, Camden, New Jersey, has announced a table or bench model of the famed Universal electron microscope, standing only 30 inches high and



expected to sell for less than $6000.00.

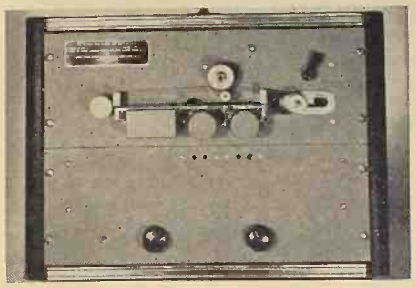
Revolutionary in design and employing for the first time permanent magnet lenses requiring no stabilization circuits and controls, the *RCA* Permanent Magnet Electron Microscope will provide useful magnifications up to 50,000 diameters by photographic enlargement with direct magnification in the instrument ranging up to 6000 diameters. It has the same 50,000 volt accelerating potential as the Universal model.

According to *RCA*, the simplicity of operation achieved in the new design makes it safe for operation in the hands of a high school student or unskilled laboratory personnel. The lower cost and smaller size of this instrument make available the benefits of electron microscopy to most colleges, high schools, hospitals, and industrial laboratories.

REVERBERATION GENERATOR

A new unit for the addition of reverberation to radio, video, and recorded sound channels is announced by the *Audio Facilities Corp.*, 608 Fifth Avenue, New York 20, N. Y.

The Artificial Reverberation Generator uses a magnetic tape delay system combined with a new reentrant electronic system. The basic unit consists of two seven inch rack panels and will work in conjunction with most broadcast type audio consoles. Input and out-



put levels are at zero VU, and the frequency response is suited to wide range live program material.

For use in other services, the unit is available with its own microphone preamplifier, isolation amplifier, control panel, VU meter, and sound effects filter.

SEALING FOR TIMERS

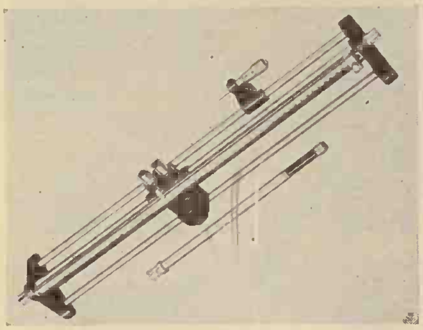
A. W. Hayden Company, Waterbury, Conn., is now furnishing hermetically sealed enclosures for its timers to give maximum protection against fungus growth, salt spray, humidity, oil spray, sand and dust, explosive atmospheres, and climatic changes.

All enclosures are evacuated to 100 microns and filled to one atmosphere with dry nitrogen so that full switch ratings can be used even at extremely high altitudes where contact capacity is normally reduced. Deterioration of motor brushes is completely eliminated.

COAXIAL MEASURING EQUIPMENT

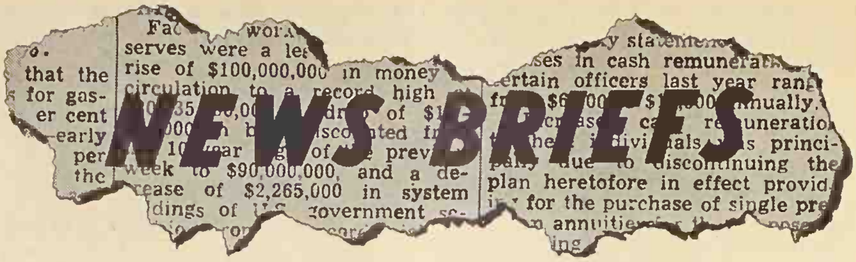
The Type 874-LB Slotted Line and Type 874 Coaxial Elements announced by *General Radio Company*, 275 Massachusetts Ave., Cambridge 39, Mass., provide a convenient and accurate system for impedance, standing-wave, voltage and power measurements at ultra-high frequencies.

This equipment uses the Type 874 Co-



axial Connectors previously announced. Adaptors are avaliable for connecting

(*Continued on page* 31)



PLAN THEATRE TV

Spyros P. Skouras, President of the *20th Century-Fox Film Corporation,*

has announced that the company will proceed immediately with plans for installation of theatre television equipment in twenty theatres in the Los Angeles area.

Mr. Skouras disclosed these plans when addressing members of the Society of Motion Picture and Television Engineers at their 67th Semi-Annual Convention in Chicago recently.

STATIC CONTROL

Now available for the control of fire or explosion hazards in industry due to static electricity is equipment called the Takk Static Control marketed by *The John Hewson Company*, 106 Water St., New York, N. Y. Many industrial companies are now using this equipment successfully to control the hazard in locations where static-caused fires were frequent and where the danger of static-caused explosions was constant.

Takk equipment will control static on any type of material and on most types of machines, even at speeds in excess of 2000 feet per minute. It will control both mild and intense static charges. Operating cost is negligible as current consumption is less than 15 watts per bar.

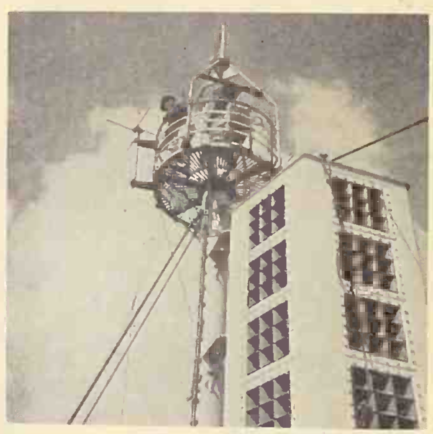
DR. COOK RECEIVES AWARD

The Washington Academy of Sciences Award for distinguished scientific achievement in the engineering sciences by researchers under forty years of age has been awarded to Dr. Richard K. Cook, chief of the sound section of the National Bureau of Standards.

Dr. Cook joined NBS in 1935 in the Bureau's engineering mechanics section where he took part in the design of apparatus for producing longitudinal vibrations in airplane wing beams and assisted in the calibration of proving rings, testing machines, and strain gages. After transferring to the sound section in 1938 he conducted research on methods for securing absolute pressure calibrations of microphones and also worked on the Bureau's proximity fuse project during the period of the war.

ROBOT LIGHTSHIP

The U. S. Coast Guard disclosed in Washington recently that a robot lightship manned only by an electronic crew is nearing completion at Curtis Bay,



Maryland. The 91-foot-long lightship "EXP-99" will be given a two months' dock trial at Curtis Bay and will be given further tests under actual service conditions near Scotland Lightship, one of three lightships marking the approaches to New York Harbor.

A single operator at the Sandy Hook, New Jersey, Coast Guard Station will have complete control over the lightship's signalling system. W. A. Derr, *Westinghouse* engineer, who helped plan the installation for the Coast Guard, explained that the key to the successful operation of the crewless lightship is the remote control system, called Visicode, developed by *Westinghouse.* This equipment uses short radio waves to send orders from the shore station to the ship. There the waves are picked up by a receiver, executed by sensitive relays, and a return signal is sent to the operator.

With a mast height of 40 feet above the water, the lightship will throw out a 10,000-candlepower beam of light, visible for 10 to 15 miles.

TESTS PLASTICS

At the Johns Hopkins University's Institute for Cooperative Research a high voltage transmitter goes on the air, but its signals go only six feet, subjecting samples of plastic materials to tests that have uncovered new data of both practical and scientific importance.

The power of the high frequency oscillator has been bridled by lining the 7 by 15 foot room with copper sheathing. When the equipment is at work, no one can remain in the red-walled room, yet a sensitive receiving set in an adjacent workshop is unable to pick up the faintest signal from the oscillator.

According to Dr. R. K. Witt, Associate Professor of Chemical Engineering of The Johns Hopkins University, who heads the team investigating plastics for use in electronic equipment, the information now being made available on the various makes and types of plastics will enable electronic equipment to be redesigned with a realistic safety factor in mind. Those on the scientific team with Dr. Witt include: Dr. John J. Chapman, John W. Dzimianski, and Dr. C. Frank Miller.

NEW DEVELOPMENT IN COMPUTERS

Bell Telephone Laboratories has developed an apparatus for modern computers which makes it possible for these machines not only to detect their own mistakes but actually to correct them. The discovery is regarded as one of the most important and fundamental advances in computer techniques and is expected to be of significance in the general communication field where transmission is on a code basis.

The basic concepts underlying the new technique are the result of mathematical research carried out by Dr. R. W. Hamming (left), *Bell Laboratories* mathematician, and apparatus incorporating

the mathematical discovery has been constructed under the direction of B. D. Holbrook (right), *Bell Telephone*

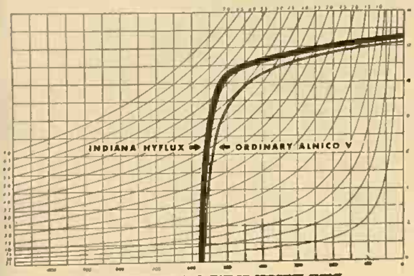
Lab's. switching research engineer.

A general discussion of the theory is contained in the Bell System Technical Journal for April 1950 and the Bell Laboratories Record for May 1950.

PERMANENT MAGNETS

The Indiana Steel Products Company of Valparaiso, Indiana has just announced new permanent magnets with a guaranteed energy product of at least 5¼ million BHmax, yet priced on a par with Alnico V.

According to F. A. Hayden, vice-president, the energy product for many types of these magnets will average 5½ million BHmax, or even more. Since



DEMAGNETIZATION AND ENERGY PRODUCT CURVE

these new magnets are not a new alloy but the result of a wholly new production technique applied to dependable Alnico V, the *Indiana Steel* designation for this product is "Hyflux Alnico V."

Graph shows increase in strength guaranteed for Hyflux.

NEW PLANT FOR POTTER INSTRUMENT

Operations of the *Potter Instrument Co. Inc.*, have been transferred to a

newly constructed plant at 115 Cutter Mill Road, Great Neck, L. I.

Of modernistic design, the new plant contains double the floor area of the former location at Flushing, N. Y. The sales, research and manufacturing departments will all be centered at this new location.

MILLI-MICROSECOND PULSE GENERATOR

The announcement of an electronic device capable of the generation of pulses of energy existing for only 1,000th of 1,000,000th of a second has been received from the U. S. Signal Corps. This development of the Signal Corps Engineering Laboratories at Fort Monmouth, N. J. is expected to provide the basis for many advancements in military electronic equipment, particularly in the field of radio communications.

Similar circuits are currently being embodied in various preliminary experimental models of radio communications equipment ranging from the short range portable and vehicular equipment up through the trunk microwave radio relay stations. In the v.h.f. spectrum these narrow-pulse-generating circuits appear to make possible the simplification of wide-frequency-band stabilizing-circuits to a point where in the not too distant future a signal officer may have a much wider choice of highly stable radio frequency channels incorporated into a single package.

SOUND CHANNEL EQUIPMENT

Federal Telecommunication Laboratories, Inc., 500 Washington Ave., Nutley 10, N. J., American research and development unit of the *International Telephone and Telegraph Corporation*, has announced a new system for transmitting television programs in which both high-quality sound and picture can be relayed simultaneously over a common radio link.

A departure from existing techniques, this system may be used with FM radio links and repeaters or with video cable circuits, thus eliminating the need for high-quality telephone lines. It can be employed to relay television programs between cities, between studio and transmitter location, and from remote pickup points to studio.

A bulletin describing the FTL 38-A Sound Channel Equipment may be obtained by writing *Federal Telecommunication Laboratories, Inc.*

ELECTRONIC COMPUTERS

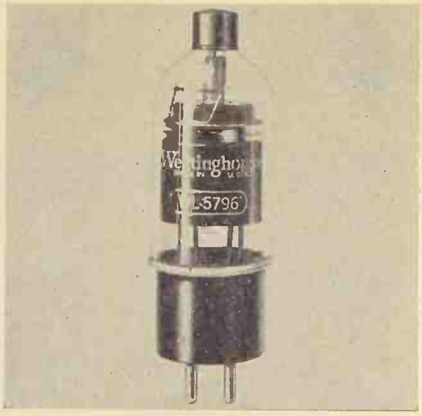
Members of the American Institute of Electrical Engineers recently heard five staff members of an M.I.T. research program in digital computer development sponsored by the Office of Naval Research predict that electronic computers will take over routine bookkeeping jobs as well as other tasks far more complex in their logic, and that they will be both fast and accurate and will be serviced so that most errors are eliminated before they occur.

C. Robert Wieser spoke on computers as engineering control mechanisms and George C. Sumner described "marginal checking," a new technique for servicing such computers to eliminate errors. Ways to lengthen the life of computer parts were discussed by Edwin S. Rich and new developments in pulsed circuit test equipment were described with movies by Robert Rathbone. Stephen H. Dodd, Jr. described the electrostatic storage tubes developed at M.I.T. for digital computer "memory."

NEW TUBES

GAS THYRATRON

A grid-controlled, inert-gas rectifier, the type WL-5796 thyratron, is available from the *Westinghouse Lamp Division*, Bloomfield, N. J. Designed for industrial control and ignitor firing service, the WL-5796 is a three-electrode, temperature-free tube.



Maximum peak anode voltage, both inverse and forward, is 1500. For general control service, maximum cathode current is 20 amps. peak, 1.6 amps. average. In ignitor firing applications, the tube's maximum cathode current peak is 30 amps., and the average 0.5 amps. For both types of applications, the maximum negative control grid voltage before conduction is 250; after conduction, 10. The maximum commutation factor rating is 10 and therefore, the tube can be used in polyphase rectifiers on inductive loads with very small or no cushioning circuits. The cathode voltage is 2.5 v. and the cathode heating time is 10 seconds.

The tube utilizes air convection cooling and can be operated in any position. It has a net weight of 3 ounces.

NEUTRON COUNTER TUBE

The Special Products Division of the *General Electric Co.*, Schenectady 5, N. Y., has announced a new proportional counter tube sensitive to thermal neutrons designed by the *GE* General Engineering and Consulting Laboratory.

The boron lined neutron counter tube will enable measurements of slow neutron intensities for nuclear scientific purposes. The cathode cylinder is made from seamless steel tubing. The internal surfaces of the cylinder are coated with metallic boron enriched in the isotope Boron 10 which has a large effective area for the capture of the slow neutrons.

The counter is so constructed as to have all external high voltage points shielded electrically and physically. Tubes of 8-inch and 12-inch sensitive length are available.

SYLVANIA TUBES

Heater-Cathode Rectifier

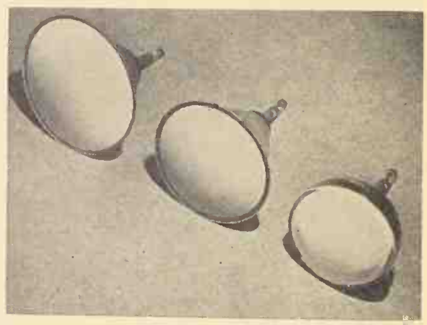
A full wave heater-cathode type rectifier which does not require a special filament transformer has been announced by the Radio Tube Division, *Sylvania Electric Products Inc.*, 500 Fifth Ave., New York 18, N. Y.

The tube, type 6AX5GT, when used with other heater-cathode types in a receiver complement, requires the same heating time as the other tubes, thus preventing excessive voltages across filter capacitors. High d.c. output also makes the tube suitable for rectifier replacement in automobile radio receivers.

19" Metal TV Tube

A nineteen inch metal television picture tube which provides useful video image measuring 11¾ x 15¾ inches with high brilliance and definition is announced by the Television Picture Tube Division of *Sylvania*.

The 19AP4 is designed for magnetic focus and deflection and utilizes an electron gun with bent structure for use with a single external magnetic field to eliminate ion spot screen blemish.



Type 19AP4, shown at left, contrasts with 16 inch tube in center and 12¼ inch all-glass tube at right.

Double-Triode Tube

Also available from *Sylvania* is the new double-triode subminiature tube providing high performance for a wide range of applications in television receivers, industrial electronic applications, servomechanisms, and radio communications receivers.

Available with pigtail leads as type 6BF7, and with short pins for socketing as type 6BG7, this subminiature tube is supplied in a T-3 bulb measuring only 0.400" in diameter and 1½" long. These tubes are supplied with separate cathodes for each triode section so that each section may be operated independently and to provide flexibility in circuit and equipment designs where compactness is essential.

LOW-CURRENT PENTODE

A low-current beam pentode of the remote cutoff type intended particularly for the voltage regulation of high voltage d.c. power supplies has been announced by *RCA's* Tube Department, Harrison, N. J. Designated the *RCA*-5890, it has a maximum plate dissipation rating of 30,000 volts, a maximum d.c. plate current rating of 500 microamperes, and a maximum plate dissipation rating of 10 watts.

Tubular in shape, the 5890 has a length of 6½ inches and a diameter of 1½ inches. It is provided with a small-shell duodecal 7-pin base.

TWIN TRIODE

A double triode having semi-high perveance units has been announced by *Hytron Radio & Electronics Corporation* of Salem, Mass.

Type 12BH7 is intended for use in television receivers and other applications where the use of two similar triode sections in a single envelope is desirable from the viewpoint of space saving and lower cost.

SUBMINIATURE ELECTRON TUBE

The CK5889 subminiature electrometer pentode having several new mechanical design features has been announced by the Special Tube Section of *Raytheon Manufacturing Co.*, 55 Chapel Street, Newton 58, Mass.

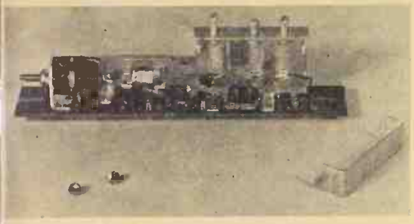
The new features include the 7.5 milliampere low microphonic filament, the double-ended construction, and the guard ring. The maximum grid current is 3X10^{-15} amperes but the nominal value will be 1X10^{-15} amperes. In the single-stage type of circuit, where the tube must actuate the indicating or recording device, the CK5889 has sufficient reserve emission, notwithstanding the extremely low filament current, to provide operation for

(*Continued on page* 28)

Television

V.H.F. — U.H.F. TV TUNER

Mr. J. F. Bell of *Zenith* described a turret tuner with a special u.h.f. channel strip at the 1950 Cincinnati Television Conference. This strip converts the con-



ventional turret tuner to a conventional superheterodyne with a mixer operating on a local signal which is derived from a harmonic of the v.h.f. oscillator already in the receiver.

The antenna problem is solved by a special filter which effectively isolates the u.h.f. and v.h.f. antennas, making it possible to feed both signals down a single transmission line.

The u.h.f. channel strip incorporates a preselector, crystal mixer with its local signal derived from a crystal multiplier placed between the mixer and v.h.f. oscillator, and circuits converting the r.f. and converter tubes to i.f. amplifiers. The u.h.f. tuned circuits are helical coils wound with flat strip, and have an unloaded *Q* of 500 to 600. Turret strips have been built and appear quite practical for frequencies as high as 900 mc.

Oscillator drift cannot be detected on intercarrier receivers, and actual use in the field has shown the oscillator stability to be entirely adequate on the u.h.f. band.

VIDICAM SYSTEM

Tests have been completed on the new Vidicam system which is a radical departure from any system now in use, and which is expected to definitely revitalize the motion picture industry for television. The idea for this system was conceived by *Television Features, Inc.*, a division of *Larry Gordon Studios*, and is a direct application of the *RCA Victor* Vidicon tube.

The Vidicam system utilizes a new and unique camera chain, unit controlled, with the monitoring done off the set in the director's booth. The TV cameras are synchronized with specially adjusted 35 mm. or 16 mm film cameras and *RCA Victor's* new industrial television camera chain, the three cameras acting simultaneously in perfect unity.

William Van Praag, vice-president of *Television Features, Inc.* announced that preliminary productions using Vidicam will be filmed in their newly acquired studios where they will also augment it by the use of Filtelite, the new lighting system they have just perfected.

TRAVELING WAVE TUBE

A weird looking vacuum tube like the one being held by S. E. Webber in the *General Electric* Research Laboratory

is expected to be used when color television comes into common use. An electron beam is fired through the tube, and action of the beam on current flowing through the spiral causes a large increase in the power of the current.

Color television will have to be broadcast at very high frequencies over a wide band, and this coiled spring in a vacuum, called a "traveling wave tube," is one of the most promising types of tubes for handling these special requirements. The tube would serve as an amplifier in color TV transmitters.

This type of tube was developed during the war by the British for use in radar. *General Electric* scientists have modified the original designs radically to make the device into a tube capable of remarkably high power output.

INDUSTRIAL TELEVISION

Mr. R. W. Sanders of the *Capehart-Farnsworth Corp.* described a closed-circuit TV system suitable for many industrial uses at the 1950 Cincinnati TV Conference. The unit, originally developed for the *Diamond Power Specialty Corp.*, is called the Utiliscope.

The Image Dissector pickup tube is used, and only 15 standard receiving types and the cathode-ray tube are required in addition. Horizontal and vertical resolution of 300 lines is obtained and a standard aspect ratio of 4 to 3 is used. A 6L6 Beam Relaxor circuit oscillating at 21.5 kc. provides the high voltage as well as the horizontal deflection voltage.

The transmitter and receiver are connected by three coaxial cables which may be as much as 1000 feet in length. The camera unit is connected to the power unit by a multiple conductor cable which may be up to 25 feet in length.

Some of the proposed uses for this equipment include watching plant gates, furnace ignition, combustion and slag, infrared observation, and underwater observation.

TELEVISION TUNER

Just announced by the *Radio Corporation of America*, Harrison, N. J. is a 12-channel television tuner employing printed circuit coils, rotary turret switching, and a circuit offering outstanding advantages in performance. The 206E3 is for use with a stagger-tuned picture i.f. system having a carrier of 25.75 mc. and a sound i.f. system having a carrier of 21.5 mc. as employed in the 630TS type of television receiver.

This new tuner provides a voltage gain of between 28.7 and 34.9 db. for all channels under typical operating conditions.

TV VISUAL DEMODULATOR

Now available for commercial use is *General Electric's* television visual demodulator, Type TV-21, which allows the transmitter operator to measure accurately the transmitted signal.

The new unit feeds both picture and waveform monitors simultaneously and

is easily installed in a standard equipment rack. It is crystal controlled, eliminating the need for tuning, and is practically impervious to stray r.f. fields. In addition to its primary use as a transmitter monitor, the new demodulator can be used as a double sideband detector or a transient demodulator.

Further information on this unit may be obtained from the Commercial Equipment Division, *General Electric Company,* Syracuse, N. Y.

SPECIAL TV STUDY

An investigation of transmitter requirements for u.h.f. and color television broadcasting is now being conducted by a special panel of electronics engineers headed by P. J. Herbst of the *RCA Victor* Division of the *Radio Corporation of America,* according to an announcement from the National Television System Committee. The panel's final report will recommend any modifications in existing transmission standards which may be needed; will specify additional requirements applying specifically to u.h.f. or color transmission; and will summarize existing information on available and anticipated equipment and components.

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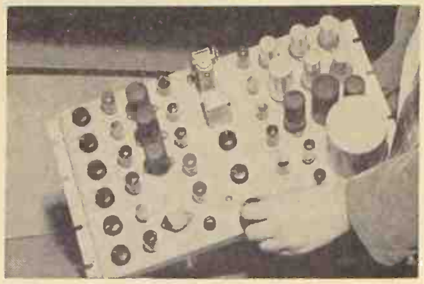
The *General Electric Company,* Syracuse, N. Y., has announced an electronic television mixer for automatic and manual fading, lapping and dissolving of television pictures. When combined with *GE* control panels TC-21-A or TC-31-A, the Type TV-19-A mixer will provide split second timing between channels. It is built for both portable and studio use.

The power input of this electronic mixer is 117 volts at 50/60 cycles and 275 volts d.c. regulated. The signal input: four non-composite, 1 volt black negative—75 ohms; signal outputs are 2 volts composite, black negative—75 ohms, and 1.4 volts non-composite black negative—75 ohms. The monitor output level is .2 volts or .8 volts. The mixer



has a frequency response which is flat to 6 megacycles and is about 1 db. down at 8 megacycles.

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New Tubes

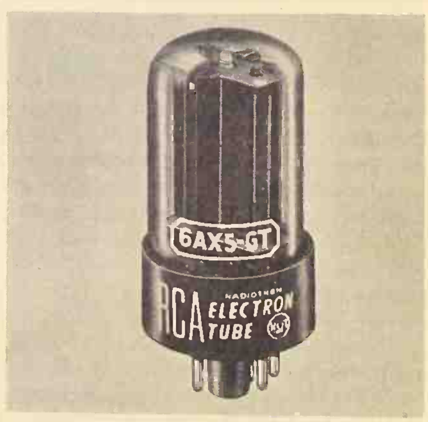
(*Continued from page* 26)

several thousand hours. In multi-stage circuits, where the tube is operated at low space currents in the high-gain, pentode connection, the filament power may be reduced to 5 milliwatts, or approximately 6 milliamperes at 0.85 volts.

The electrical characteristics are similar to those of the CK5886/CK571AX, including high transconductance, good emission stability, low drift and low microphonics.

VACUUM RECTIFIER

RCA Tube Department, Harrison, N. J., has announced the 6AX5-GT, a full-wave rectifier especially designed to provide for the economical design of



a.c. receivers and to facilitate the design of automobile receivers having high power output.

This tube features a unipotential cathode having a 6.3-volt heater and a relatively wide plate-cathode spacing chosen to minimize sputter and yet provide good regulation. The heater can be operated from the same transformer winding that supplies other 6.3-volt heater types in the receiver.

TECHNICAL BOOKS

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Geiger Counter

(Continued from page 11)

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Service Life and Performance

Service tests of three counters of this type show that component life is somewhat longer than factory ratings, and that no operational vagaries are to be expected.

Sonic output is a direct function of count frequency up to 1000 counts per second, where output into a resistive load is approximately 6 watts. At higher rates, power output falls off, as might be expected. As most laboratory tests are in the range from background (40 counts per minute approximately) to 100 counts per second, power output is adequate for ordinary test needs.

Operational tests show that a counter of this type is ideal for use in a laboratory where most of the measurements are made in answer to the question "Professor, is this radioactive?", and for rough determinations of the amount of radioactivity.

Cost of construction of a counter of this type is about $50.00 for components (at 1950 retail prices) and four hours of work. Current drain being only 50 watts (or less), cost of operation is negligible. Component depreciation is estimated at about two cents per hour on the basis of rated life of the various components.

Alternative Designs

Several alternative designs are entirely workable, but in general, do not produce any great change in operation. If current drain is important, reduction by about eight watts is possible by replacing the rectifier tube (5Z4) with a high-voltage selenium unit. This change reduces the current drain, but raises first cost of the device considerably. Likewise, a small reduction in bulk is possible by use of miniature or subminiature tubes, but this saving in bulk and weight is offset by a small loss in power output, and a probable decline in ruggedness.

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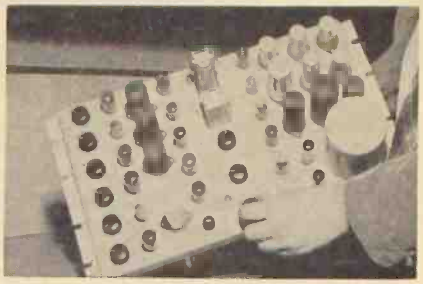

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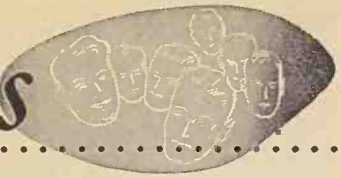

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Microwave Receivers

(*Continued from page 5*)

noise figures of these circuits (of the order of 1000). The high degree of noise present in these tubes is partly a result of their poor efficiency. Perhaps improvement in the efficiency of this tube will also improve its noise characteristics. Modifications of the klystron have been tried with advantage by substituting a non-resonant wave guide for the resonant cavities. This is the principle used by traveling wave tubes and experimental results indicate that considerable improvement is possible.

Traveling Wave Tube

At a number of points throughout this series of articles, and throughout many other articles covering microwave design, an equivalent phrase to "however development of the traveling wave tube may effect a decided improvement" has been used. So far most information available on traveling wave tubes is either in the experimental stage or is classified. However, in view of an increasing number of articles on this subject ([8, 9, 10, 11]) and since a commercial traveling wave tube has been made available (*Federal Telecommunication Laboratories, Inc.*), it seems likely that this tube will be used to a greater degree in the near future.

Fig. 5 shows schematically the important parts and their arrangement in a typical traveling wave tube. Briefly the operation of this tube is as follows: An electron beam is produced by means of the cathode and anode electrodes to the left of the tube. This beam is shot through the helix and a magnetic field is used to focus the "beam" so that a large percentage of electrons will hit the collector. Electrons are collected on the collector electrode at the right end of the tube. The helix itself is kept at a very high positive potential with respect to the cathode. The r.f. input is applied at the left hand end of the helix. This energy then travels down the tube around the helix with the velocity in the x direction approximately equal to the velocity of the electron beam. This sets up traveling waves up and down the tube. It can be shown that when the velocity of this wave is approximately equal to the electron beam the wave traveling in the forward direction (due to the interaction between the electron beam and the wave in such a manner that energy is fed from the beam to the wave) increases in amplitude exponentially (over a given range) as it travels. Thus the longer the tube, the greater the amplitude of the signal. A probe located at the right hand side of the helix couples this increased signal energy to an output load.

The traveling wave tube represents a very low impedance and can, if sufficiently long, provide a high degree of amplification. Since it is a low impedance device, extremely wide bandwidths can be obtained (600 megacycles and better at 3000 mc.). In fact the only real limitation of the bandwidth is the characteristics of the input and output coupling circuits.

The most important characteristic of this tube, for the purposes of this article, is that the noise figure is much better than any other previous tube for a given frequency in the microwave range. Noise figures as low as 12 have been reported[11] and it is possible to design receivers with noise factors as good as, if not better, than those using a crystal detector at virtually any microwave frequency. The low noise traveling wave amplifier now appears to be almost competitive with the crystal mixer on a noise figure basis and has some advantages, notably very great bandwidth, antenna isolation, and better mechanical characteristics. A typical traveling wave tube has the following characteristics: frequency—3000 mc.; bandwidth—600 mc.; gain (power)—20 db.; noise figure—11.5 db.

A very important application of this tube is in microwave repeaters. The function of such a repeater would be to pick up, amplify, and retransmit microwave signals. Heretofore, because of the disadvantages listed previously, the incoming signal could not be amplified directly to the power output desired. Instead, a receiver was used to detect the signal and provide an audio or video output. This signal was then used to modulate a microwave transmitter. Thus a complete receiver and transmitter was required at each repeater. Use of traveling wave tubes may permit amplification of r.f. signal directly to power desired without introduction of excessive noise, thereby simplifying repeater design to a considerable degree. Furthermore, because of the wide bandwidth available, this can be done without any distortion of the r.f. signal.

There are four primary disadvantages to the use of this tube at the present time; namely, availability, cost, requirements for well-regulated supplies (as in the case of klystrons[2]), and difficult magnetic field problems. As previously indicated, only one traveling wave tube is now available commercially and this has been placed on the market very recently. As de-classification permits, and demand increases, more tubes should become available at lower prices. There is no inherent reason why this tube should be more expensive than other tubes operating at these frequencies, once it can be produced in quantities. Further research and development should also make operation of these tubes less sensitive to d.c. voltage changes and simplify magnetic focusing.

In the next article in this series local oscillators and mixers will be considered.

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(*To be continued*)

Curve Generator

(*Continued from page 9*)

from the pulse former then operate a step counter to provide a fixed bias voltage for the grid of the tube under test, successively becoming more positive. Each time the plate voltage is driven negative the grid bias voltage rises to a new level. These stepwise increasing bias voltages are fed through a video divider which reduces their amplitude to the desired level. From the divider they go through a cathode follower to the test grid. A special control acting on a clipper circuit allows manual selection of a definite calibrated voltage for the highest positive grid step.

A special linearizing circuit provides for uniform increments in the step sequence of grid voltages, each oscillator pulse, through an inverse feedback arrangement, transferring a fixed charge into a large capacitor. The feedback can be controlled manually to provide any size grid voltage increment. The number of steps is controlled indirectly by the output of a step counter, arresting the entire process after a predetermined number of steps.

Two circuits have been included in the design of the characteristic curve generator which are not vitally necessary but which add to the convenience and reliability of the instrument. One is a "servo-sweep" circuit whose timing is controlled through the frame synchronizing switch. This circuit is especially useful for viewing the step-function signal at the grid of the tube under test. Another circuit, using four tubes, identifies the curves which have positive values of grid bias by means of a small marking "pip" superimposed on the positive grid lines. The curve generator, essentially as described here, will be available commercially in the near future.

New Products

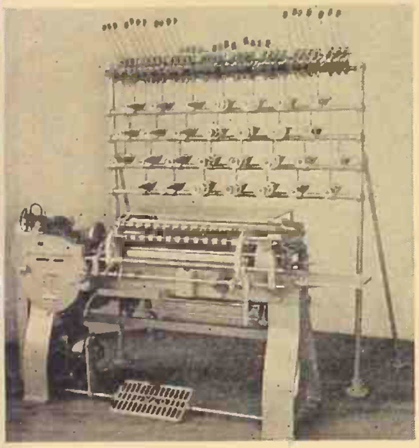
(*Continued from page* 23)

the measuring equipment to Type N systems.

The Type 874-LB Slotted Line has an over-all standing wave ratio of less than 1.02 at 1000 megacycles, and constancy of probe penetration is ±2½% or better. Also available are crystal rectifiers, bolometers, a bolometer bridge, stubs, fixed line elements, a line stretcher, a tee, an ell, terminations, attenuator filters, coupling elements and patch cords.

AUTOMATIC COIL WINDER

The high-speed automatic No. 107 winder for paper-insulated and acetate-



insulated coils is the third in a series of new coil winders introduced by *Universal Winding Company*, Box 1605, Providence 1, Rhode Island.

Automatic feeding of single or laminated insulating sheets achieves a rate of 25 inserts per minute. A new type of delivery shelf has been designed which handles either "Kraft" or glassine, from .0006 inches to .003 inches thickness and in widths of 24 inches up to 25 inches maximum. A static eliminator can be installed when acetate is to be handled.

Special attachments include an auxiliary "space-wind" traverse for spacing the first and last layers of high-tension coils, and a "mid-tap" attachment which permits shifting the wire guides at the end of a wire layer for "tap" location or to arrange for starting and finishing leads.

Editor's Note: The article entitled "Surface Wave Transmission Line" by Georg Goubau which appeared in the May issue, page 10, was essentially the text of a paper presented by Dr. Goubau at the 1950 I.R.E. National Convention in New York on March 8.

PHOTO CREDITS

3, 5 .... Federal Telecommunication Laboratories
6, 7, 8 .... Dalmo-Victor Co.
9 .... National Bureau of Standards
12 .... General Electric
15 .... Radio Corporation of America

ELECTRONIC POTENTIOMETER

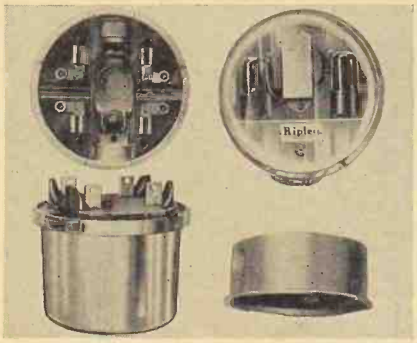
Southwestern Industrial Electronic Co., 2831 Post Oak Road, Houston 19, Texas now has on the market its Model P-2 Precision Electronic Potentiometer which is available for making precise potential measurements on high impedance electrochemical cells or electronic tubes and circuits.

The instrument is suitable for the measurement of potentials from zero to three volts in three ranges. Current flow in the measured circuit is less than 10^{-11} amperes. A built-in standard cell, combined with a 0.1% potentiometer and dual range dial, provides an accuracy of plus or minus (one millivolt plus 0.1%).

A brochure giving a complete description of this potentiometer is available upon request.

STREET LIGHT CONTROL

Ripley Company, Inc., of Middletown, Connecticut, has announced a Sunswitch mounted in a standard glass watt-hour meter case. Using the famous Sunswitch time-tested circuit, this street light control permits quick and easy



inspection of relay contacts and components during operation.

A time delay prevents intermittent operation as the result of lightning flashes, automobile headlights, etc. It uses only two tubes and the power relay carries a 3000-watt incandescent lamp load. A 500-watt size is also available.

FM TWO-WAY MOBILE UNIT

Motorola Incorporated, 4545 Augusta Blvd., Chicago 51, Illinois is now producing a completely new FM 2-way mobile radio unit designed specifically for true adjacent-channel systems. Designated as the "Uni-Channel Sensicon Dispatcher," the unit is described as an extremely compact and economical model.

The unit is available for operation in the 25-50 mc. or the 152-174 mc. land

mobile service bands. It has a rated r.f. power output of 12 watts in the low band and 10 watts in the high band. Models are available for operation from 6-volt d.c. or 117-volt a.c. primary power sources. The basic mobile package features a 3-unit type of chassis assembly drawer-fashion in a sturdy metal, welded, construction housing.

Two versions of the unit are offered. The front mount type allows complete permanent installation under any car or truck dashboard. The rear mount version is provided for mobile trunk-mounted installations or where space is not available in the front compartment.

POWER SUPPLY

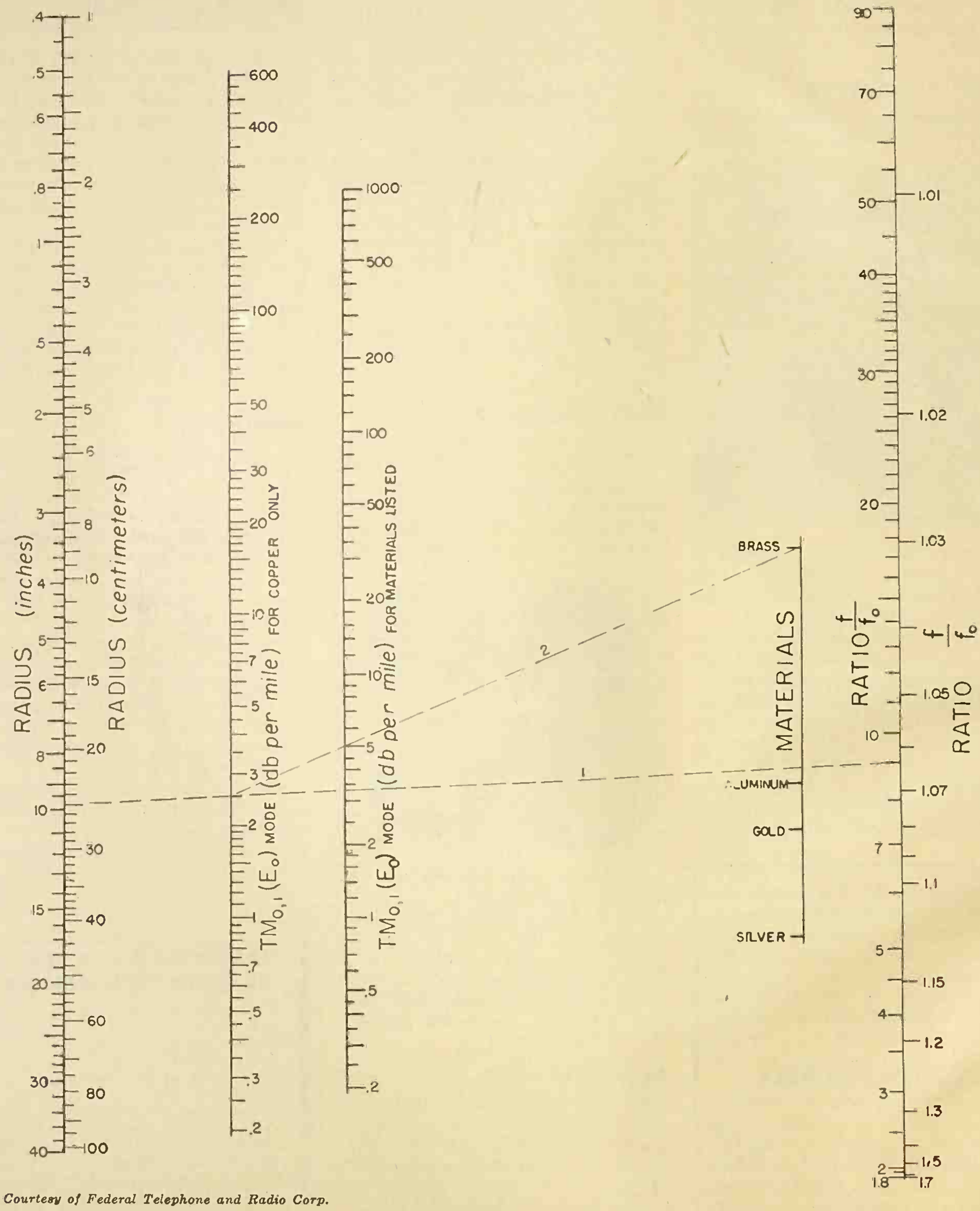
Electronic Associates, Inc., Long Branch, New Jersey, has announced its Model 107 regulated power supply which has a high voltage continuously variable from 100 to 400 volts by means of switch and variable control. Output current is 0 to 250 ma., with less than 1% variation for the regulated voltages from no load to full load.

Other available outputs include a fixed d.c. voltage of -150 volts at 15 ma., and unregulated output of 400, 520 and 660 volts at 250 ma. Output impedance is less than 0.5 ohm between 20 cycles and 20 kc., and less than 1 ohm between 20 and 200 kc.

Hum voltage is 5 millivolts or less at any voltage or load within the ratings. Line input voltage is 100 to 130 ± 5 volts a.c.; 60 cycles; power consumption 320 watts at full load, 120 watts at no load.

CIRCULAR WAVE GUIDE ATTENUATION

Nomograph for determining circular wave guide attenuation for the $TM_{0,1}$ (E_0) mode for wave guides constructed of various materials such as brass, aluminum, gold, silver, and copper.



Courtesy of Federal Telephone and Radio Corp.