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MAY 1944 Vol. 28, No. 5

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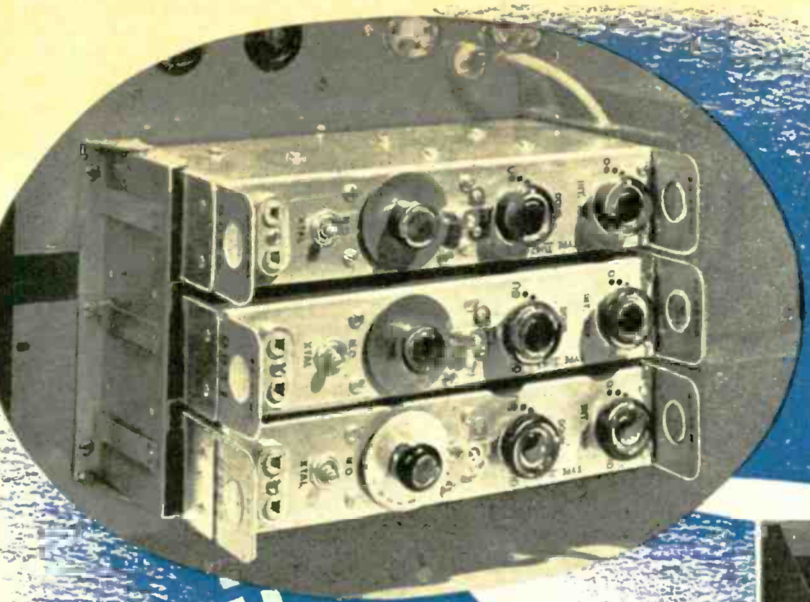

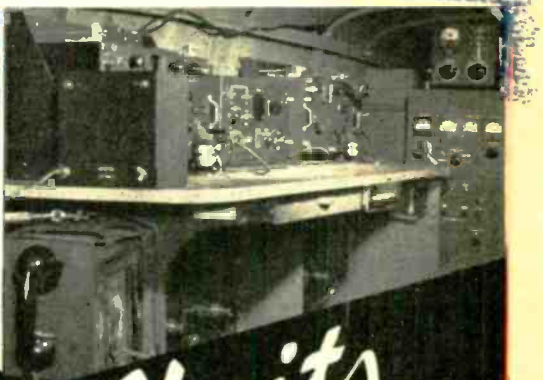

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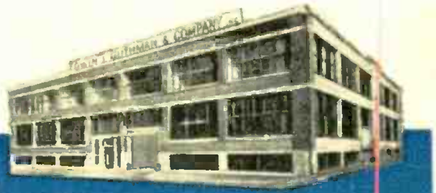

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Transients

ENGINEERS AND PHYSICISTS

★ In many large organizations employing physicists and engineers there is a degree of silent conflict between these two groups of workers. To some physicists an engineer is nothing more than a slightly over-educated mechanic, while some engineers think a physicist is simply an impractical visionary who can't drive a nail straight. While it is true that, occasionally, a physicist will get up and deliver a lecture which is largely incomprehensible to many engineers (and also, let it be said, to many physicists), it is likewise a fact that engineers could do a lot better in making a physicist's dream walk, talk, or sit up and bark, if they would only make a little more effort to understand what the other fellow is talking about.

This isn't too difficult. When a physicist sets up an equation, he employs units which are well established and consistent. He isn't likely to mix units of one system with those of another. Not so with some engineers. With thirteen or more systems of units to select from, many of which they haven't seen since they left school, they will occasionally dip daintily into this mathematical smörgasbord, picking from each unit system that which happens to please them most, often without telling anyone about it. Nor do they mind swapping units midstream in an equation.

To help clarify this muddle, we are publishing in this issue an article and table of units which the engineer is most likely to need. It will aid in making his scientific language more intelligible to others. It isn't complete; the author says that even among physicists there is no general agreement regarding the interpretation of some units. But it is a step toward bringing about a closer understanding between the two most important groups in radio and electronics research—engineers and physicists.

POCKET RADIOS

★ In planning for postwar radio receiver production it would seem that the need for smaller receivers has not received as much attention as it deserves. Granted that there will also be a considerable market for large console and table model receivers to replace those which have become out-moded, experience has shown the introduction of smaller sets has almost invariably met with a degree of public acceptance far greater than was expected when production schedules were set up. This was true when the original table-model receivers first appeared on the market and again, during the depression, when "cigar-box" midgets were first offered.

More recently, when the "personal" radio was first produced, the same situation developed. Although many engineers felt that any receiver which would cost about twenty dollars per kilowatt hour to operate from such small batteries would not be acceptable to the public, the initial demand was far in excess of the most optimistic estimates.

To produce still smaller receivers will, of course, require the co-operation of battery manufacturers, because the larger percentage of space must be provided for batteries. Much has been done in making electronic hearing-aid apparatus compact and light through careful battery design, but there is a definite need for smaller, lighter, and more efficient batteries. And special speakers and tubes, requiring lower battery power, will of course help.

INDUSTRIAL ELECTRONIC EQUIPMENT

★ One of the greatest drawbacks to the wider adoption of industrial electronic apparatus is the failure of some present-day equipment of this type to come up to the performance standards of heavy engineering equipment. When an electronic instrument is installed in an industrial plant it is expected to give the same reliable service as is obtained from motors and generators. If even a minor defect develops, such as a tube failure, the equipment is likely to be discarded as undependable. Although designers of such electronic units use the utmost care in specifying components of proven reliability, the tubes employed are usually types similar to those used in home receivers, where performance requirements are far less exacting.

Often these tubes are operated under conditions for which they were not designed, and which tend to shorten their useful life. But even under the best conditions it would seem well worth while to employ tubes capable of the same reliable performance as is obtained from those used in telephone communication systems. Naturally, such tubes will cost a great deal more than present types to manufacture. But the resulting increase in cost of the equipment is of little consequence in such applications, where a tube failure may hold up a production line.

J.H.P.

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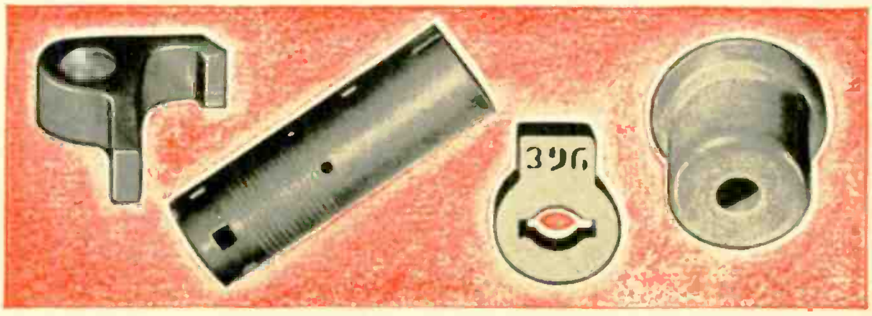

TECHNICANA

AUDIO-FREQUENCY MIXERS

★ The design of audio-frequency mixers is described in an article by M. F. Cooper in the *Wireless Engineer* for March, 1944. Mixing circuits as used in broadcast and recording studios are not as easily designed as commonly believed. A good mixer unit must not introduce any distortion, must have little effect on the devices coupled to it, must have a reasonably constant input and output impedance regardless of the setting of the controls, must correctly match the impedances of the incoming lines, the settings of the controls must have no effect on each other and the device must have minimum insertion loss.

It is explained in the article how the faders can be neglected at first when designing the mixer; later, they can be inserted merely as volume controls.

Like all other electrical devices, the incoming lines can be connected in parallel, in series or in series-parallel.

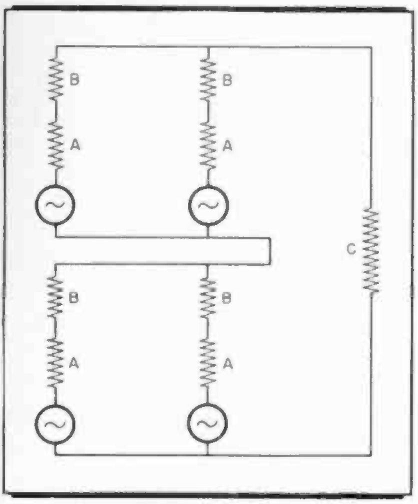

Figure 1

When they are connected in parallel as in *Fig. 1,* a compensating resistor B is needed. Here A represents the output impedance of the device feeding the mixer and C is the input impedance of the following amplifier or line. In accordance with the principles of impedance matching, the impedance of the mixer, as seen from any of the input lines should equal A and the impedance of the mixer when looking back from the output line must equal C. If there are n input circuits in

[*Continued on page 8*]

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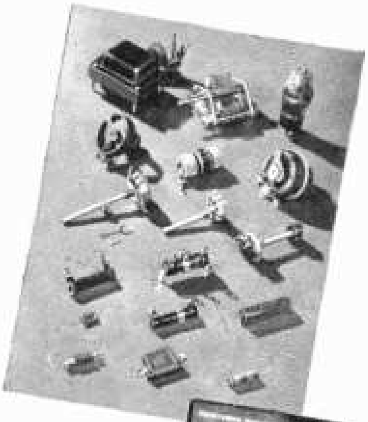

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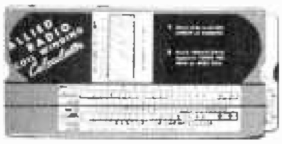

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TECHNICANA

[Continued from page 7]

parallel, the relations between *A, B* and *C* are:

$$A = \frac{n}{n-1} B$$

$$B = \frac{n(n-1)}{2n-1} C$$

$$A = \frac{n^2}{2n-1} C$$

If the mixers are connected in series, *Fig. 2,* the compensating resistors are in parallel with the incoming lines and the relations between *A, B* and *C* are:

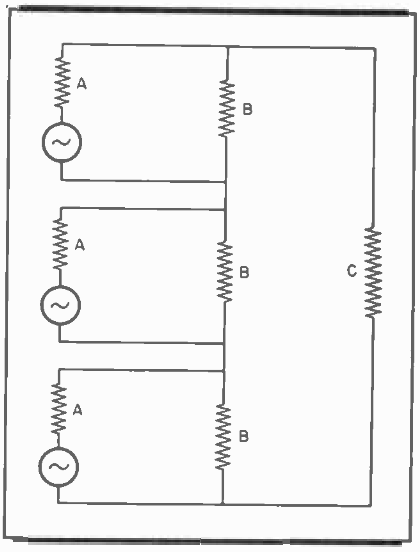

Figure 2

$$A = \frac{n-1}{n} B$$

$$A = \frac{2n-1}{n^2} C$$

$$C = \frac{n(n-1)}{2n-1} B$$

In a series-parallel type of mixer, *Fig. 3,* when *n* is the *total* number of input circuits,

$$A = \frac{n}{n-3} B$$

$$A = \frac{n^2}{4(2n-3)} C$$

$$C = \frac{4(2n-3)}{n(n-3)} B$$

When *A* and *n* are known, *B* and *C* are determined so that in no case can both *A* and *C* be chosen to suit conditions. Therefore, C may turn out to be an inconvenient value and

[Continued on page 10]

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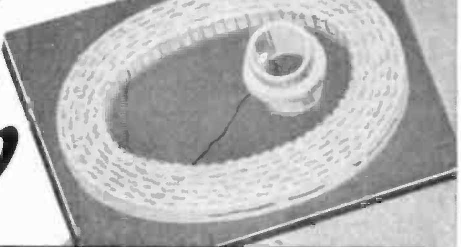

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TECHNICANA

[*Continued from page 8*]

tapered pads or matching transformers will then be needed.

If high-impedance lines are required to match a lower impedance line, the parallel connection should be used. If it is required to match several low-impedance lines to a higher impedance line, the series connections is most suitable. The series-parallel arrangement is best adapted to matching input and output lines, all of the same impedance.

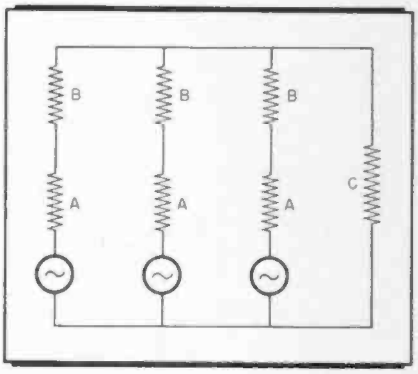

Figure 3

The article contains a table for each type of circuit in which either *A* or *C* is unity, so as to give the ratios between *A*, *B* and *C* for different values of *n*.

The insertion loss of the mixer, having *n* input circuits, is

$$10 \log_{10} (2n - 1) \text{ db}$$

UNDESIRED FM IN SIGNAL GENERATORS

★ The *Wireless Engineer* for March, 1944 contains a "Note on Frequency Modulation with Particular Reference to Standard Signal Generators" by F. M. Colebrook. This note deals with the undesired frequency modulation which may accompany amplitude modulation in ultra-high-frequency signal generators. The author first re-states some of the principles of FM and shows that in a frequency-modulated wave of large modulation index, the energy is spread out over a large part of the spectrum. The different side bands are separated by the value of the modulating frequency and their amplitudes vary. In *Fig. 4* only a few

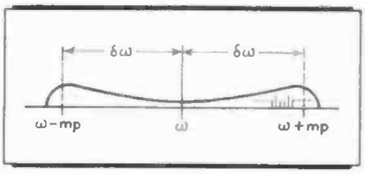

Figure 4

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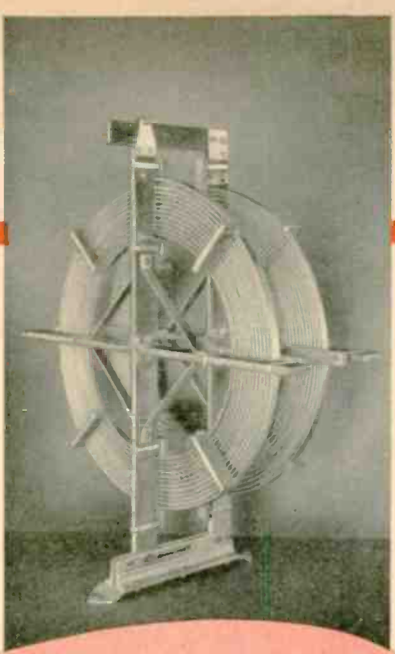

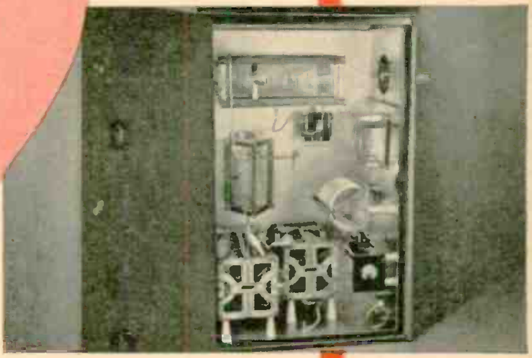

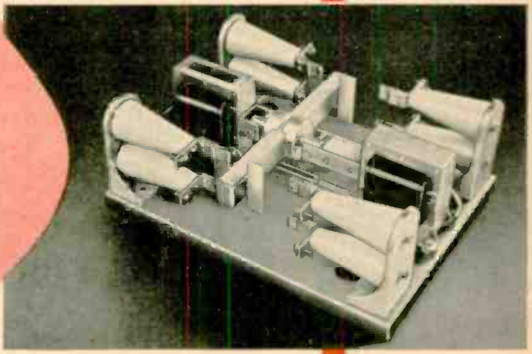

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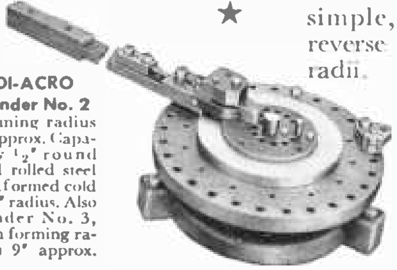

DI-ACRO Bender No. 2
Forming radius 6″ approx. Capacity ½″ round cold rolled steel bar, formed cold to 1″ radius. Also Bender No. 3, with forming radius 9″ approx.

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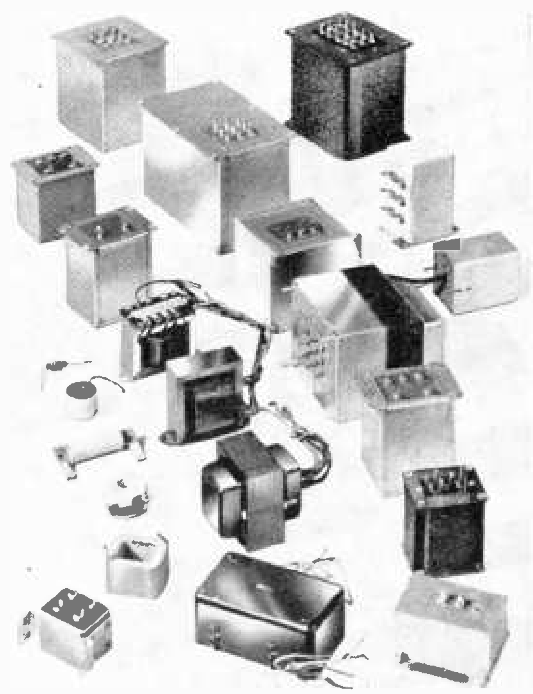

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TECHNICANA

[Continued from page 10]

of these sidebands are shown, the curve indicating their average amplitude over the spectrum. When amplitude modulation is present at the same time as frequency modulation, the distribution of energy curve then becomes nonsymmetrical as in *Fig. 5.*

In ultra-high-frequency oscillators the combination of FM and AM is likely to occur due to the change in inter-electrode capacitances of tubes with the electrode potentials. In such cases it can easily happen that the FM completely overshadows the AM effects. The FM can then not be regarded as an imperfection which can be allowed for; the FM must be eliminated. The author suggests M.O.P.A. circuits or a square-wave modulation caused by some form of audio-frequency "on-and-off" switching.

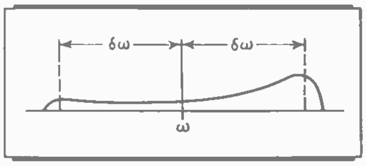


Figure 5

NEW OAK CATALOG

★ The Oak Manufacturing Co., 1260 Clybourn Ave., Chicago 10, Ill. has just announced a new catalog containing valuable engineering data sheets on switches, condensers, vibrators, mechanical tuners and relays. Engineers and manufacturers may obtain copies upon request to the manufacturer.

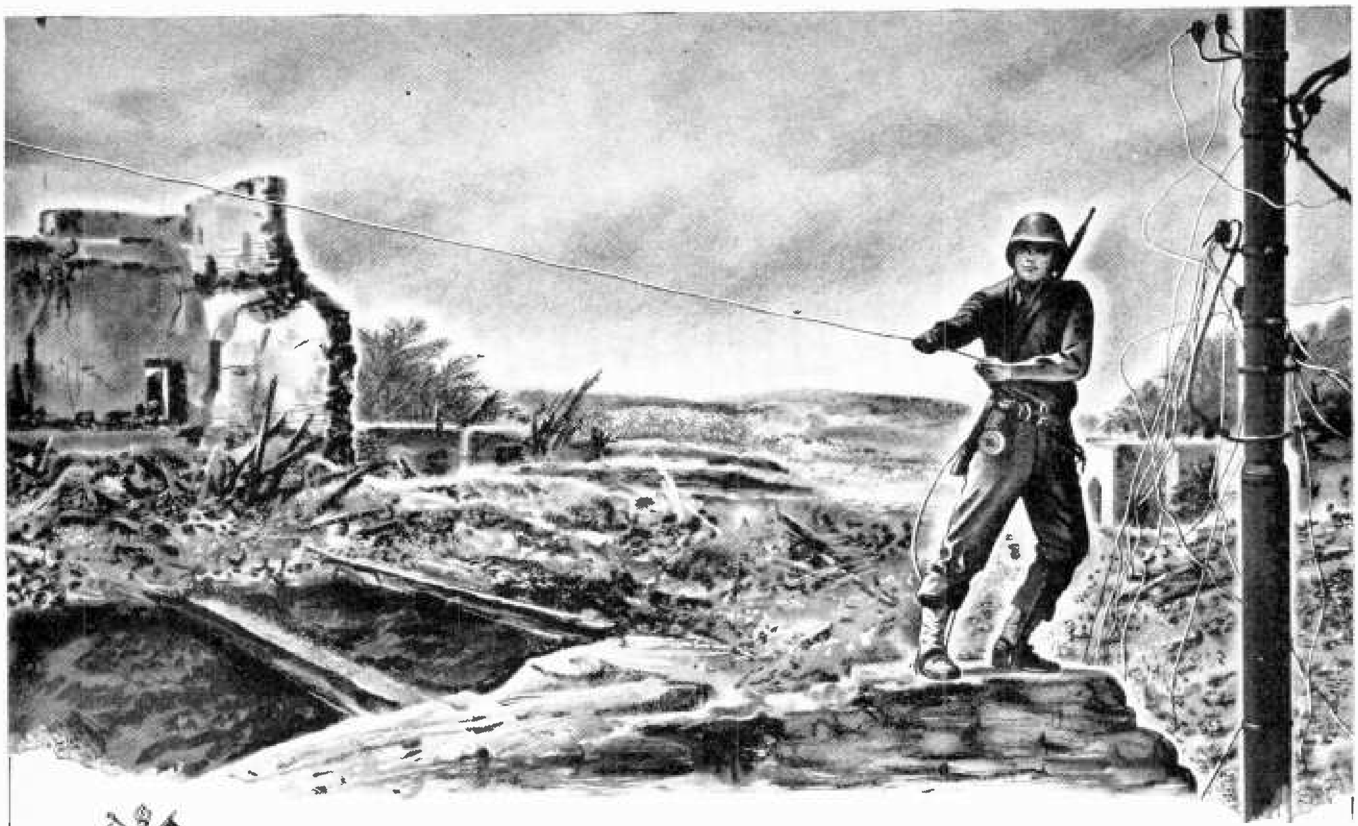
MICROPHONES AND RECEIVERS

★ *Electrical Communication*, Vol. 21, No. 4, 1944, contains an article by L. C. Pocock entitled "Microphones and Receivers with Special Reference to Speech Communication." It discusses the sensitivity, frequency characteristics and distortion of electro-acoustic transducers and should be of interest to engineers in the communication field.

For example, in speaking of the sensitivity ratings of microphones, the author says it is often asked how many volts output a given microphone will deliver and how many volts a reproducer will require. He then goes on to describe the difficulty involved, speech being of such a complex nature which constantly varies in frequency content and amplitude.

The average voltmeter connected in a speech circuit has little meaning. The volume indicator has its damping and period adjusted for speech measurement; its reading corresponds well

[Continued on page 16]



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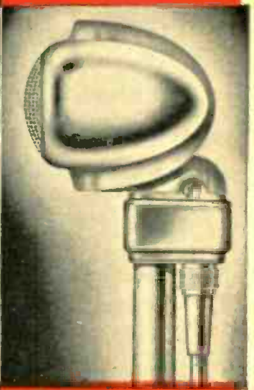

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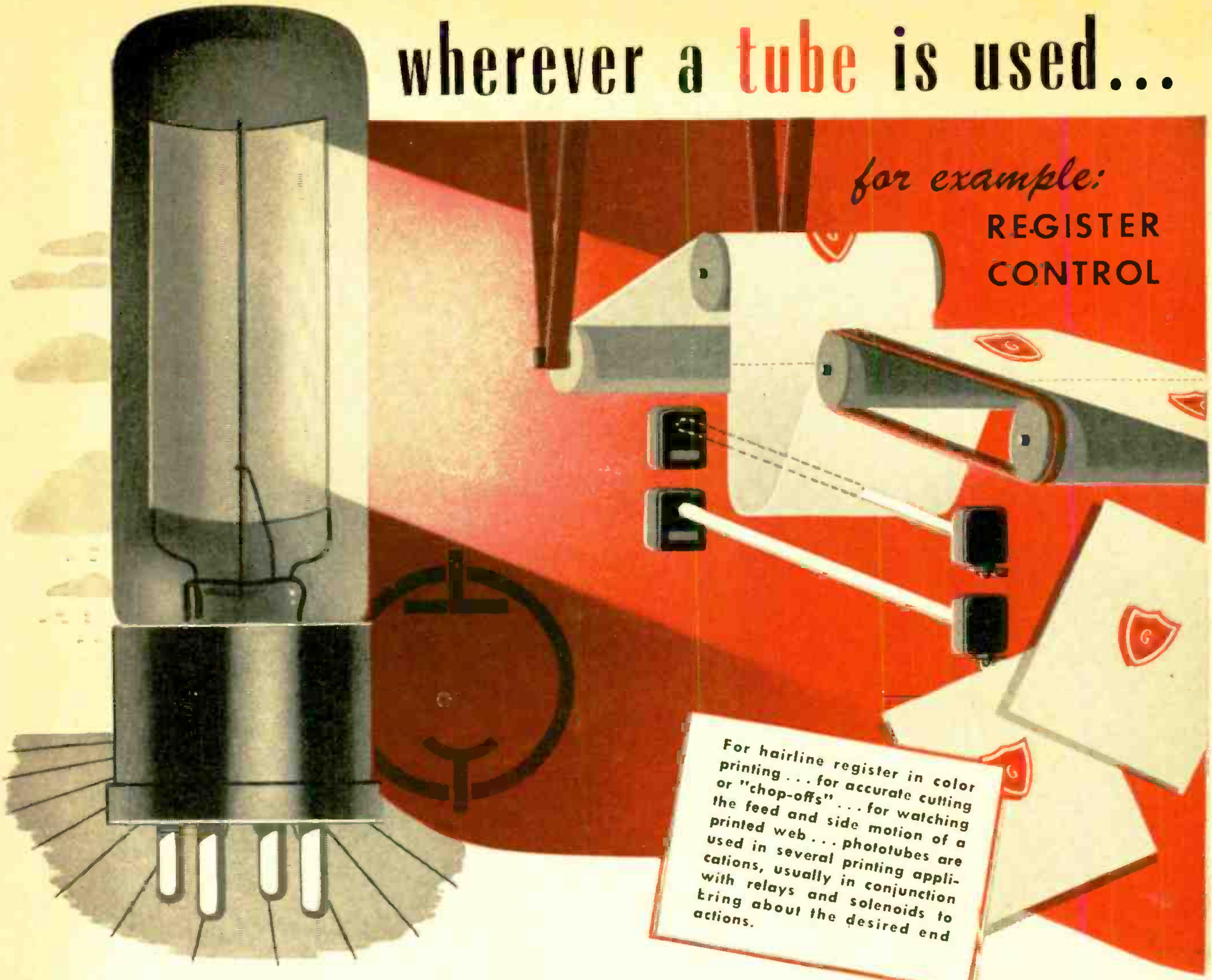

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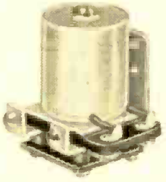

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[Continued from page 12]

with more elaborate measurements of the average speech power. Another instrument is the peak indicator; its damping has been adjusted so it can move up quickly but down slowly. An instrument to measure the total energy during a period of time is also described. It consists in using the electrical power delivered by the microphone to heat a cathode of a tube and to measure the plate current. This cathode has to be biased, or pre-heated, to bring it to the threshold of sensitivity.

The results are given for some microphones for normal conversational speech, which would give a reading of + 64 db on a noise-level meter at 50 inches. For instance, the electrical average speech power of one particular moving coil microphone at 2 inches was — 60.3 db (below 1 mw. in 600 ohms) as measured with the integrating meter. When speaking 12 inches from the microphone, the output was —75.3 db. The readings of the customary volume indicator for these two conditions were — 56.6 and — 73.0 db respectively.

The instantaneous peaks rise as much as 20 db above the average level. A table is given showing the percentage of the time that the instantaneous power exceeds different levels above the average speech power. If the permissible amplifier grid-swing is 20 db above the average speech power requirements, this percentage is zero. It is 18% when the permissible grid swing corresponds to the average speech power.

CATHODE FOLLOWER OUTPUT STAGE

★ The usefulness of the cathode follower is apparently inexhaustible; now it is proposed as an output stage in an article by C. J. Mitchell in the *Wireless World* for April 1944. The advantages claimed are: less distortion due to the negative feed back and improved loudspeaker damping due to the low output impedance.

In the cathode follower, used as output stage, the output transformer is connected in the cathode lead instead of in the plate lead. This will result in 100% negative feedback and the voltage gain of the stage will be slightly less than unity. *Fig. 6* shows the general arrangement and also illustrates the effect of the inter-electrode capacitances. For all practical pur-

[Continued on page 17]

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[Continued from page 16]

poses, the grid-plate capacitance is in parallel with the input circuit while the grid-cathode capacity is in parallel with but a small part of the input. The effect of the grid-cathode capacitance can usually be neglected.

The output impedance, the impedance looking back from the speaker, is approximately equal to the inverse of the transconductance in mhos. Thus a tube with a transconductance of 5000 micromhos would offer an output impedance of 200 ohms. The value of the load impedance of the tube has little effect on this output impedance.

As an example the author describes a circuit wherein he used a Mazda AC2 pentode connected as a triode. The input to the cathode follower is by means of an interstage transformer. This is necessary due to the fact that the input voltage must be larger than the output voltage, and is of the order of about 200 volts peak. Unless very high plate voltages are used this cannot be obtained from the usual resistance-capacity coupled amplifier. The grid return of the input transformer to the cathode follower is connected to a point on the voltage divider, making the grid positive with respect to chassis but negative with respect to the cathode by its customary amount. In some cases it may be possible to do away with this positive bias, and in some cases a small negative bias is needed. One should adjust for normal plate current of the tube.

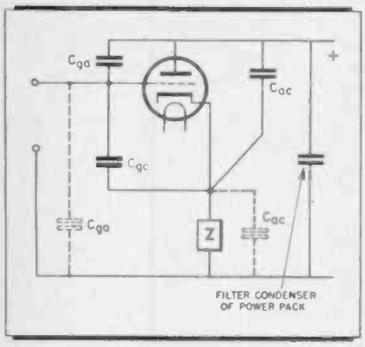

Figure 6

Contrary to expectations, the tube requires the same load impedance as it does under normal operating conditions. The tube characteristics are still the same and the tube still requires a load impedance of 5000 ohms in the example cited.

[Continued on page 56]

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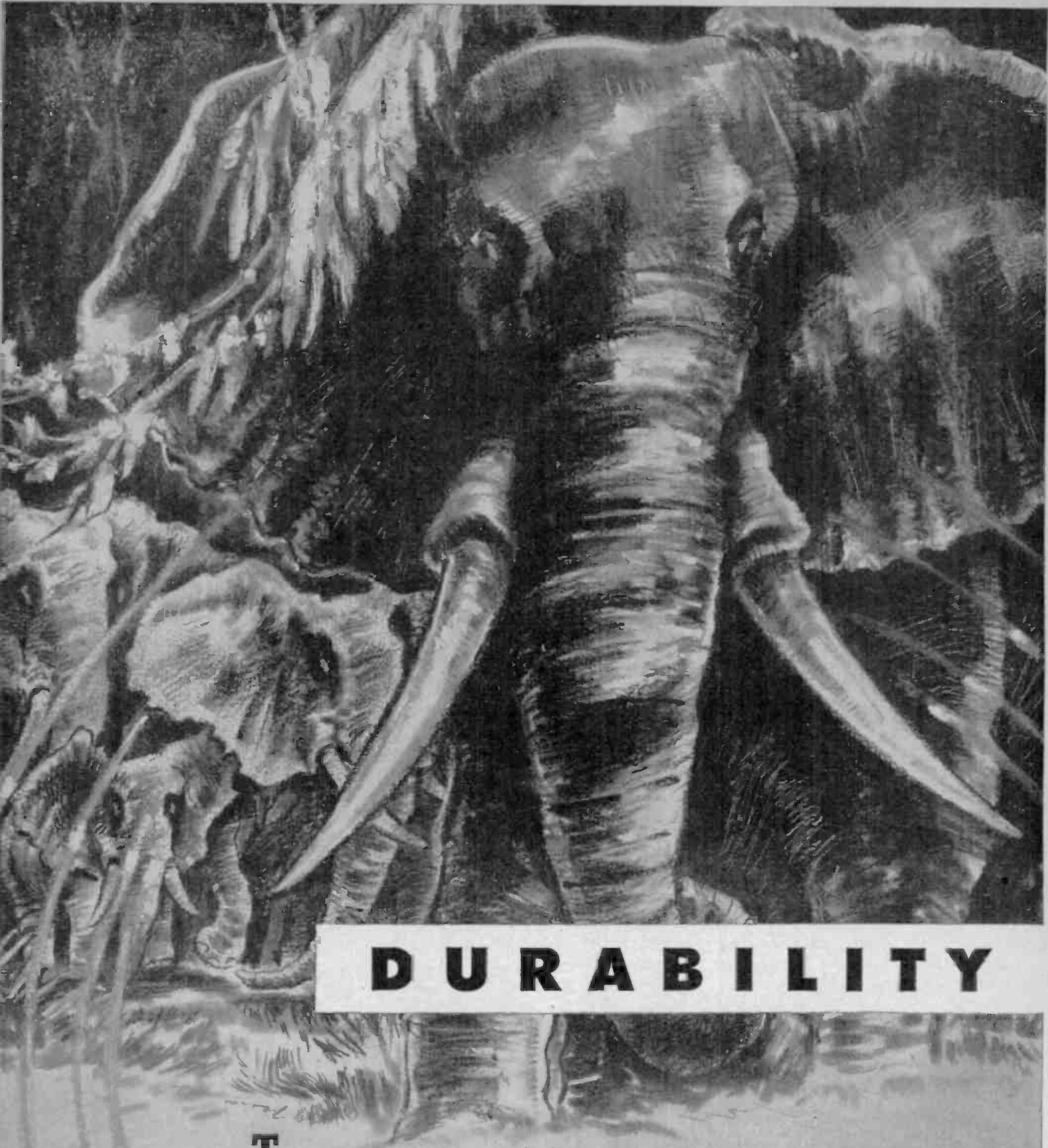

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WAVE GUIDE IMPEDANCE

V. J. YOUNG
Engineer,
Sperry Gyroscope Company

Factors involved in the determination of wave guide impedance, calculating impedance from field strength measurements, cut-off frequency, and other considerations are discussed

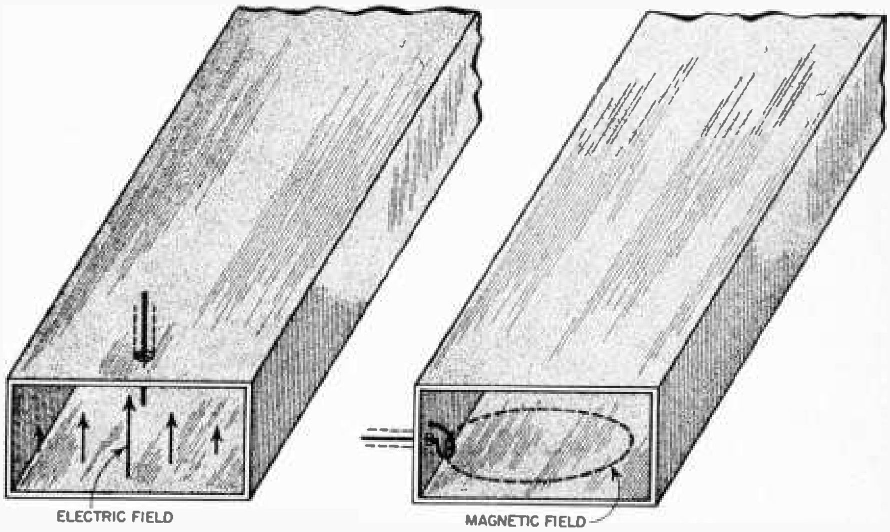

Fig. 1. Methods of measuring electric and magnetic fields for a rectangular wave guide operating in the $TE_{1,0}$ mode. The magnetic field links the loop while the electric field sets up a voltage along the length of a probe

When we desire to specify the operation of any electrical device such as a wave-guide assembly, we are confronted with making a choice among several procedures. For example, we might set out to describe the motion of charge in the system under all conditions of operation, or we might try to write expressions showing how the electric and magnetic fields will vary. Either of these, if done completely, would be an accurate specification and one which would cover all contingencies. The charge and current approach is the one usually used at audio frequencies or with direct currents. The discussion of electric and magnetic fields is apt to be more useful with microwaves.

Actually, we may always quote Maxwell's equations as telling us how any wave-guide apparatus will work since these expressions, themselves, are a very general way of stating all the requirements for any electrical apparatus. For a given set, however, this is hardly fair. Instead, it is necessary to put physical facts into the equations as boundary conditions and perform integrations so as to obtain algebraic relations connecting the electric and magnetic fields with physical properties of the wave guide. In general, this is not always practicable. Therefore, we usually try only to get values of quantities such as E/H, where E represents the electric field and H the magnetic field. In certain cases we may be able to compute E/H values directly by reasoning which starts from fundamentals; more often calculations which try to forecast the operation of a certain wave-guide assembly have to be based upon idealized conditions and are only expected to approximate actual results. Very frequently, too, the process of design is entirely empirical; charts and graphical constructions are made to show that a diaphragm or a slot with certain dimensions will cause a certain reactance when placed at certain positions, etc.

Limitations

A discussion of wave-guide impedance must start off with a warning that its calculation or measurement is not alone the whole story. It does not, for example, tell us anything about the dielectric breakdown strength which can limit the flow of power through the device, nor need it describe dissipative losses or radiation elsewhere in the circuit. It tells the ratio of the electric to the magnetic field at a certain point in the wave-guide, and nothing more. That we are able to make good use of the concept in making generalizations concerning the matching of elements and the procurement of the optimum operation of an over-all system is a matter for investigation quite apart from the definition. If the actual values of the electric and magnetic fields are known everywhere in a system at all times, the operation is entirely known; if only the impedance (i. e., the ratio of the field magnitudes) is known, considerably less information is at hand. But it happens that this ratio information is very useful and quite analogous to the concept of impedance as used in wired transmission lines as well as being, in general, much easier to compute or measure.

If the impedance of a certain wave guide terminated with a load (such as an antenna) is desired, the values of E and H at the entrance end might be

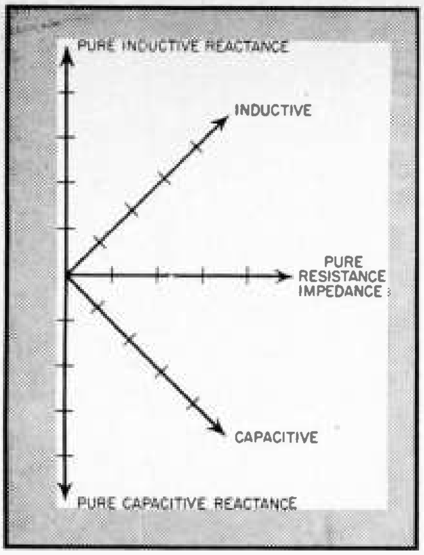

Fig. 2. Vector representation of impedance

measured as a function of time. Both would presumably be found to vary as approximately pure sine functions of time. If they did not, it would mean that more than one frequency was being fed into the assembly and that more than one mode of the guide was being excited. Separate calculations would then need to be made for each mode. Wave-guide impedance is no more independent of frequency than is impedance in the usual sense although, since a given design is usually intended for only a single frequency, or at least a fairly narrow band of frequencies, this does not usually concern us very much.

Just as in the case of ordinary wired circuits, wave-guide impedance usually implies more than just the ratio of two numbers representing the peak, average, or rms values of the sinusoidally varying fields. The impedance may, as a special case, be pure resistance or it may be reactive in a way corresponding either to capacitive or to inductive preponderance. What this means in terms of a wave guide may be strictly stated somewhat as follows:

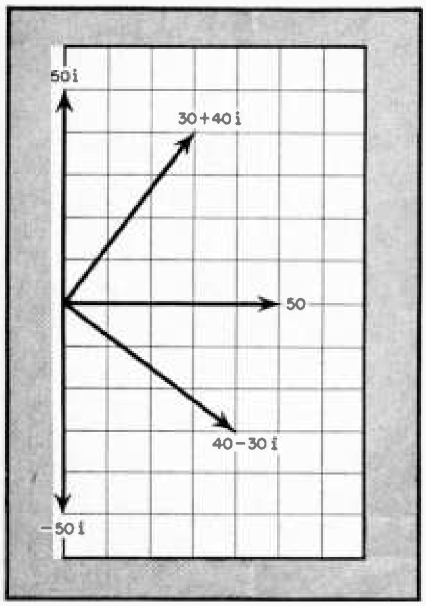

Fig. 3. Representation of impedance by use of complex numbers

Field-Strength Measurement

If at a particular point in a wave-guide a small loop is inserted so that a portion of the magnetic field in the guide links the loop but is only negligibly disturbed by its presence then, as the energy being transported by the wave guide flows past the loop the linkage varies and a current tends to flow in the loop *(Fig. 1)*. This current is a measure of the magnetic field and may be rectified to read the average strength of the field. If it were feasible to read the strength of the field directly without detection it would be found to vary with time as a sine function. That is, if time were marked along the x-axis of a Cartesian coordinate system and the values of the magnetic field at the loop were plotted along that axis but wtih y-coordinates determined by the field strength in accordance with a suitable scale on the ordinate, a sine curve would result. Positive values of the sine curve might correspond arbitrarily to magnetic flux passing in one direction through the loop and negative values to flux passing through in the other direction. Although it is not generally feasible to make measurements directly for such a plot, average value measurements can be made which indirectly confirm the result.[1]

Similarly, a small probe can be inserted into the wave guide at the same place along its length as the loop just referred to. This probe, which is insulated from the guide, can be introduced in such a fashion that its length extends along the electric field and its exterior end may continue as the center conductor of a coaxial line whose outer shield is attached to the wave guide *(Fig. 1)*. Even though the probe is small and extends only a short distance into the guide so as not to appreciably influence the operation of the guide, it will still be subject along its length to a varying electric gradient as electromagnetic waves carry energy past it along the guide. This will manifest itself as a very small flow of energy along the coaxial line in which the probe is terminated. With a proper arrangement this extracted energy may be measured and since it was induced into the test probe by the electric field, it is a measure of that field. Thus we may also think of plotting the electric field against time in Cartesian coordinates and, when that is done, a sine curve again results.

Nature of Wave-Guide Impedance

With these two sine curves in mind we are then ready to define explicitly the impedance of the wave-guide system at the point where our probe and loop were located. If, in proper units, the magnitude of the E field were 50 times greater than that of the H field, the impedance is 50 ohms. If the maxima of the two fields occur at the same instant of time, then that 50 ohms is pure resistive impedance. If the sine curve representing H is ahead of the E curve by an amount equal to a quarter period of the sine wave, the impedance is said to be pure capacitance; if H lags E by a quarter period, the impedance is pure inductance. All of this is very much like our concept of impedance as applied to ordinary circuits where only voltage and current are dealt with. Likewise, in a wave guide, pure resistance or reactance are limiting cases; actual measurements may show an intermediate phase shift between the two sine curves.

As in ordinary circuit theory, it is convenient to represent impedance as a vector. To do so some arbitrary direction such as horizontally and to the right is chosen to represent resistance; then a vector pointing vertically upward might be assigned the meaning of a pure inductance and one directed vertically downward that of a capacitance. Vectors drawn at intermediate angles represent a mixture of resistance and reactance. The length of the vector will, in all cases, represent the magnitude of the impedance. Thus, a 50-ohm impedance would be a vector drawn 50 units long according to some scale and would point to the right and somewhat upward or downward, depending upon the reactive components *(Fig. 2)*.

Again, as in ordinary circuit theory, a very compact and convenient way to specify impedance so as to show phase as well as magnitude is made available by the use of complex numbers. The scheme depends upon the fact that if we arbitrarily agree to always draw our impedance vectors in a Cartesian coordinate system with their tails at the origin, then a single point in that system may completely specify an impedance. In terms of complex notation such a point is written as $A + iB$, where A is the x-coordinate and B is the y-coordinate of the head of the desired impedance vector. In *Fig. 3* the impedances represented would, reading clockwise, be respectively denoted by

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[1] Reactive Phase in Wave Guides; RADIO, April, 1944.

complex members, as $50i$, $30 + 40i$, 50, $40 - 30i$, and $-50i$. All these vectors are 50 units long and, hence, represent impedances whose magnitudes are all 50 ohms.

Selecting a Unit System

As has been pointed out, if we desire to have impedance values as defined for E and H come out in ohms so as to correspond that much more closely to impedance in wired circuits, it is necessary that proper units be chosen for the measurement of each field. One proper set of units is automatically obtained if the MKS (meter, kilogram, second, or Giorgi system of units is used. In that system E is measured in volts per meter and H in amperes per meter. Thus:

$$\text{Impedance} = E/H = (\text{volts/meters})/(\text{amperes/meters}) = \text{volt meters/ampere meters} = \text{volts/amperes}$$

which we can see immediately from Ohm's Law to be the correct form to give impedance the dimension of ohms. Thus, the impedance of free space may be said to be 376.6 ohms. This means that out in space after electromagnetic energy has left the antenna, the electric field is always 376.6 times greater than the magnetic field if both are measured in Giorgi units.

Without carefully considering the properties of the medium, which are usually expressed by permeability and dielectric constant, we can nevertheless see that these are reasonable units for E and H and that they can measure what we want them to. Electric field is the sort of thing that occurs between the plates of a condenser. If the plates are 100 volts different in potential then, even though no material (i. e., a perfect vacuum) exists between the plates, we find it convenient to speak of the electric field there. This is so because if we insert a probe in that space, energy can be extracted under certain conditions. The electric field which we imagine to be present in the absence of all matter is just a measure of the way the 100-volt drop between the plates is divided up throughout the space. Volts per meter is a reasonable unit for measuring such a thing.

Similarly, if a charge is moving in free space or, according to Maxwell's equations, if the electric field is changing, a magnetic field is formed. Again we find it convenient to speak of the presence of this field even in a vacuum because whenever a magnet is inserted in the space it will usually be subject to a torque which will try to align it with the field. Presumably, the field in any region can always be simulated by allowing a given current to flow through a given length of wire properly located in that region. Hence it is reasonable to measure magnetic fields in terms of amperes per meter.

Orientation of Fields

The first problem in calculating the impedance of a geometric array of conductors which may form a waveguide is to decide how the electric and magnetic fields will be oriented in that array. In doing this we are really considering various modes of energy propagation. That is, depending upon the feed into the guide and the source frequency, it often turns out that a given wave-guide assembly will transport energy with the E and H fields oriented in accordance with two or more schemes (*Fig. 4*). We then say that propagation in two or more modes is possible. Certain rules[2] may be deduced from Maxwell's equations which can guide us in deciding what these modes are by telling us of certain necessary conditions which must obtain on the inner surfaces of the wave guide. We will first consider these rules in their most general form.

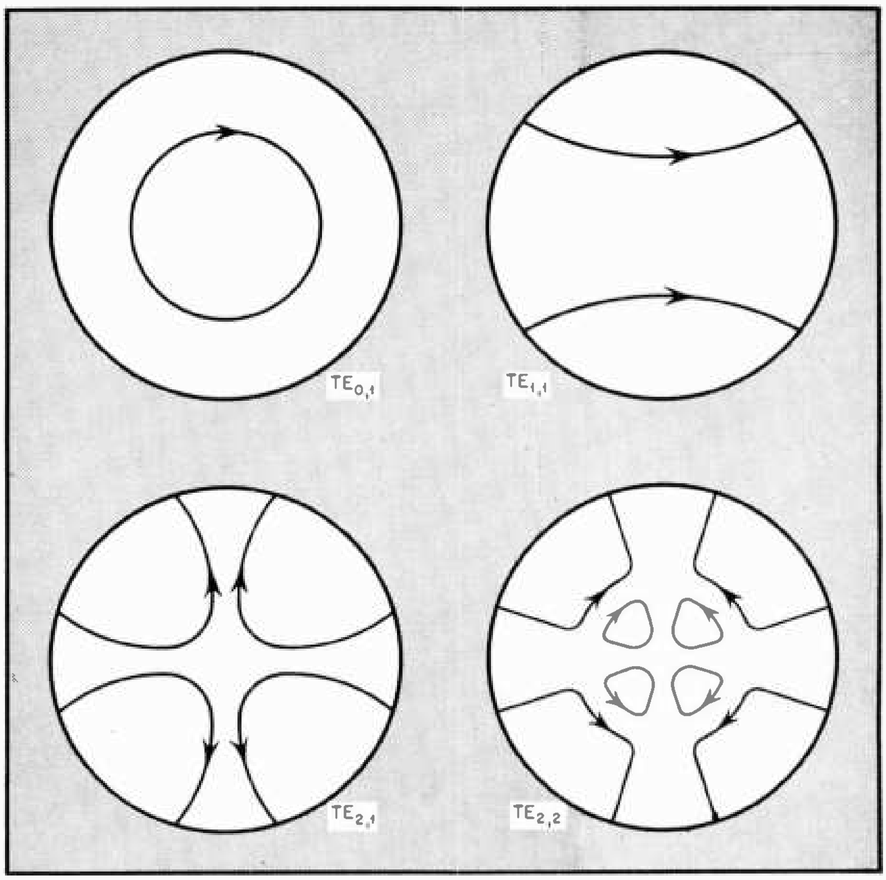

Fig. 4. End view of circular wave guide excited in certain modes. The force lines shown the direction of the electric field

The rules are valid at any surface of discontinuity of the medium such as at the surface of a conductor or at a plane which is the boundary between two kinds of dielectric. They are: (1) the tangential component of E is continuous; (2) the normal component of B is continuous, where B is defined as the product of H and the permeability of the material in which the measurement is made at the time of making the measurement; (3) the tangential component of H is discontinuous by an amount equal to the current per unit area flowing in the boundary surface; and (4) the normal component of D, which is defined as the product of E and the dielectric constant, is discontinuous by an amount equal to the charge per unit area on the surface of discontinuity. These rules, together with a sufficient knowledge of the geometry and properties of the materials plus a knowledge of the radiation properties of any holes in the assembly, are in principle enough to decide the validity of any propagation mode aside from the attenuation characteristic of its operation. But there is still in an actual wave guide the problem of constructing possible modes to be tested by the rules. This part of the job is an art, and only experiments with a given arrangement can prove whether or not unwanted modes will occur at given frequencies. Spurious modes

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[2] Maxwell's Equations in Electromagnetic Reflection; RADIO, Oct. 1943.

which are generated somewhere along a wave-guide transmission line can cause serious losses of power because elsewhere the line is not designed to pass them and they are attenuated out by causing excessive currents to flow and the power to go into heat through I^2R losses.

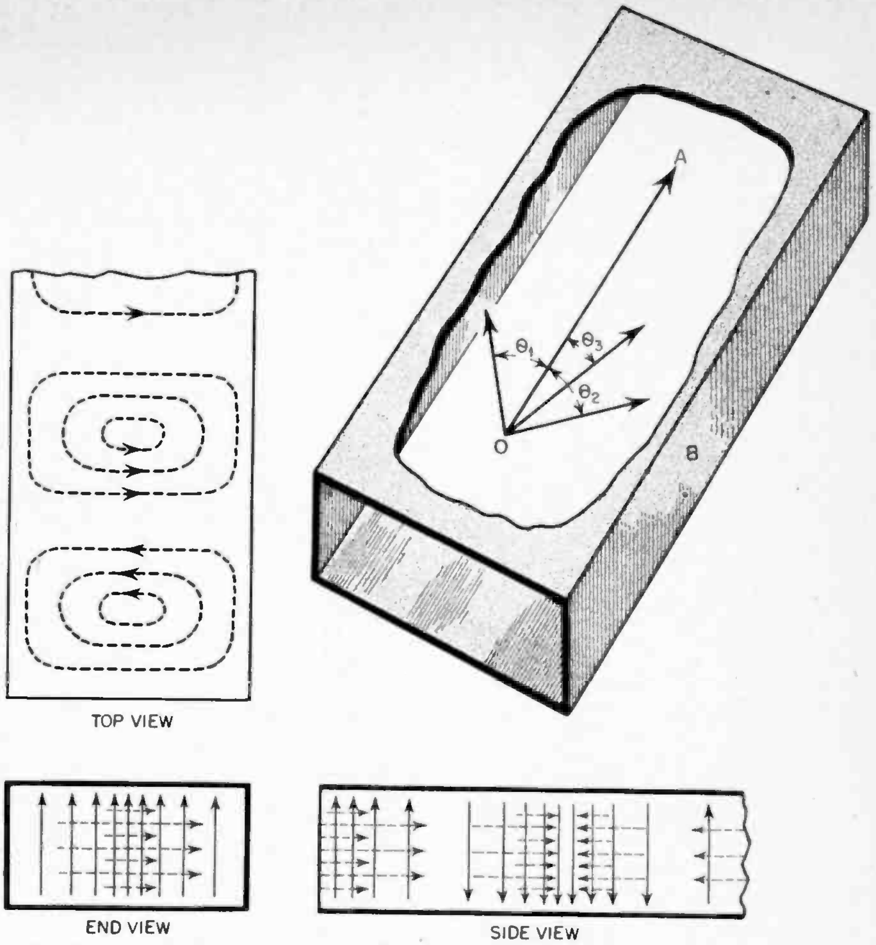

Fig. 5. Unity SWR transmission in a rectangular wave guide by the TE$_{1,0}$ mode. Solid curves show the electric field; broken ones plot the magnetic field

Field-Free Conditions

Very often wave guides are made only of highly conductive metals and use only air as a dielectric. In this case the only surface of discontinuity is that between air and the metal, which very closely approximates a surface between a vacuum and a perfectly conducting material. A vacuum has a dielectric constant and a permeability which are constant and well known. In the Giorgi system of units the permeability of a vacuum is $4\pi \times 10^{-7}$ henrys per meter, and the dielectric constant is 8.85×10^{-12} farads per meter. A perfectly conducting metal is a medium which can support no electric or changing magnetic fields except perhaps on its surface. That the interior of such a metal is field-free is clear from Lenz's law which states that whenever a magnetic field changes, currents are induced in neighboring conductors which oppose that change in the field. Since the metal is resistance-free, these currents completely cancel any change in the field. Steady magnetic fields, such as might arise from permanent magnets, are of no concern to us. Likewise, it is clear that no electric field can exist in a perfect conductor since, by Ohm's law, that would demand infinite current.

Thus, in special cases where only vacuum and perfect conductors are present, the boundary condition rules for constructing propagation modes may be specialized and written somewhat as follows: (1) the tangential component of E is zero; (2) the normal components of B and H are zero; (3) the tangential component of H is equal to the current per unit area flowing in the boundary surface; and (4) the normal component of E is equal to the charge per unit area on the surface of discontinuity divided by 8.85×10^{-12}. Taken together, these say qualitatively that E lines of force may start and end at the metal surfaces and are perpendicular to them. Likewise, magnetic lines of force do not start or stop on the surfaces and, in general, touch the surfaces only as tangents.

In *Fig. 5,* a section of a rectangular wave guide is represented as operating in an acceptable mode. In the end, top, and side views the electric and magnetic fields are shown by lines of force. These lines indicate the strength of the field by their spacing and, in accordance with the arrows, they show the field direction at every point through which they pass. The mode shown is one commonly used and is usually called the TE$_{1,0}$ mode. The letters TE refer to the fact that the electric field runs only transversely across the narrow dimension of the wave guide, while the magnetic field extends across the wider dimension and has a longitudinal component as well. The subscripts 1,0 indicate that in going across the wide dimension, one maximum in the electric field strength will be observed, while in moving across the guide in the narrow direction, the magnetic field is found to be constant and without maximums or minimums. It will be observed that this TE$_{1,0}$ mode qualitatively satisfies the boundary conditions which we have quoted. Namely; the H field lines curve so as to remain tangent to the wall at contact and the electric field intensity falls off to a zero value at the side walls so as to present no tangential components.

Desired Conditions

It is desired that the energy in the wave guide shown in *Fig. 5* flow along the guide in the direction OA. If any energy which flows crosswise of the guide, or even at an angle θ from the desired direction, is absorbed in the walls of the guide, then that energy is dissipated and the transmitted wave is attenuated. Since Poynting's vector showing the direction of energy flow is always mutually perpendicular to both the E and H fields, it is understandable that no energy will flow in a direction such as θ_3 toward the wider side of the guide. In order for it to do so, the E vectors would have to tilt to remain perpendicular to the new direction of propagation, and would thus presumably cause trouble with the boundary conditions. As for energy flowing to the other walls of the guide, the situation is different. No longitudinal components of E are needed; and H, except at the center of the guide, does have at least a small component along the guide.

In *Fig. 6,* another top view of a rectangular guide in the TE$_{1,0}$ mode is shown. The electric field is perpendicular to the paper. Vectors representing it are shown either as dots or small circles. The dots indicate a vector coming out of the plane of the paper and the circles show one going in. The strength of the field is indicated by the density with which these dots or circles are drawn. Thus, at the instant shown, the electric field has its maximum value at a point such as A. The intensity then falls off like a

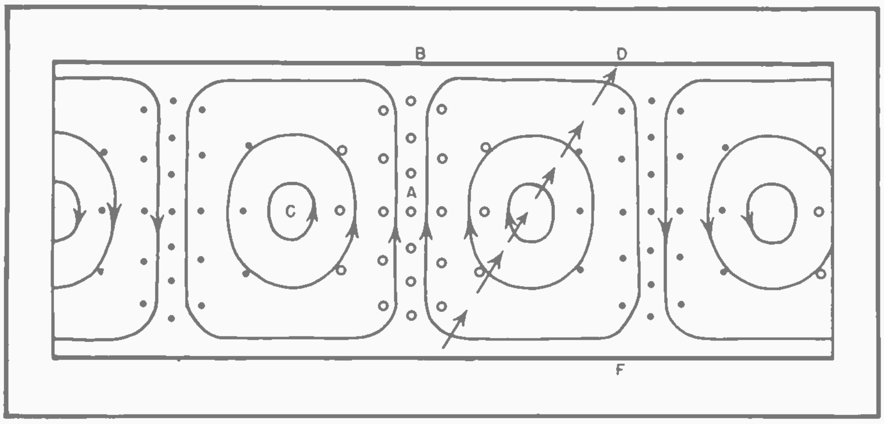

Fig. 6. Top view of rectangular wave guide operating in $TE_{1,0}$ mode with unity swr. Dots and circles represent the electric field and curves, the magnetic field

sine function, crosswise of the guide to zero at points like *B*, and lengthwise to zero at points like *C*.

This arrangement of the electric field, along with the magnetic field also shown, moves along the guide and in doing so carries energy with it. For a wave guide operating like the one shown in *Fig. 6*, this is strictly true for wave lengths which we say are short enough to be below cut off. The mathematics of showing this to be true is moderately complicated but it is, at least, apparent that such is possible. Remembering that the direction of Poynting's vector is obtained by thinking of the direction of motion of a right-hand screw turned so as to rotate the *E* vector into the *H* vector, it is clear that in *Fig. 6* a wave can be propagated to a point on the side wall in either of two manners. For example, several Poynting's vectors are shown in *Fig. 6* pointing toward *D* on one side wall. Those which are shown will not reach *D* simultaneously and, hence, are not the proper ones to indicate complete cancellation of energy flow to *D*, but at least they serve to show that Poynting's vectors propagated to *D* may be of the sort in which the *E* vector points out of the paper, or another sort in which the *E* vector heads into the paper but is compensated by a reversed magnetic field. Under proper conditions these may just cancel each other at points on the side walls and thus cause a zero tangential electric field there as required by the boundary conditions. When this is true, no energy is present at the wall surface and there is, consequently, no attenuation of the energy flow along the guide.

Cut-Off Frequency

As a matter of fact, in the $TE_{1,0}$ mode the cut-off frequency above which there is no attenuation may be determined very simply and to a certain extent can be intuitively verified. The shortest route by which a point such as *D* on the sidewall of the waveguide shown in *Fig. 6* can feel the effect of waves propagated from all points across the guide is along a transverse line like an imaginary one drawn from *D* to *F*. If the distance *DF* (the width of the guide) is equal to or greater than a half wave length, then the waves reaching *D* at a given instant from points along that line must have started at times up to ½ cycle sooner or more. Since the whole wave is moving along the guide, it is clear that in part this flow must correspond to *E* vectors coming out of the plane of the paper and in part to ones going in because a half cycle or half wave length along the guide is always sufficient to embrace both. The most interesting part is that this complete cancellation takes place even if the width of the wave guide is greater than a half-wave length because of the peculiar distribution and motion of the field strength values. But at wave lengths longer than twice the guide width, energy is carried to the side walls and, in attempting to violate the boundary conditions, it is dissipated. The cut-off frequency of a rectangular wave-guide in the $TE_{1,0}$ mode is specified by $\lambda_0 = 2b$, where λ_0 is the wave length in free space, and *b* is the wider dimension of the guide. At all longer wave lengths some attenuation is experienced; except for complications which may arise in order to avoid higher order modes when $\lambda_0 < b$, all other wave lengths are readily passed. A wave guide is analogous to a high-pass filter in this respect.

Specific Impedance

We are now ready to discuss the impedance of the $TE_{1,0}$ mode in a rectangular wave guide. To do so, we will first obtain a zero-order approximation by assuming that we may neglect the longitudinal components of the magnetic field and consider the propagation to move with a velocity like that in free space. In that case, if at some point on the boundary surface of the wider side of the guide the

[*Continued on page 70*]

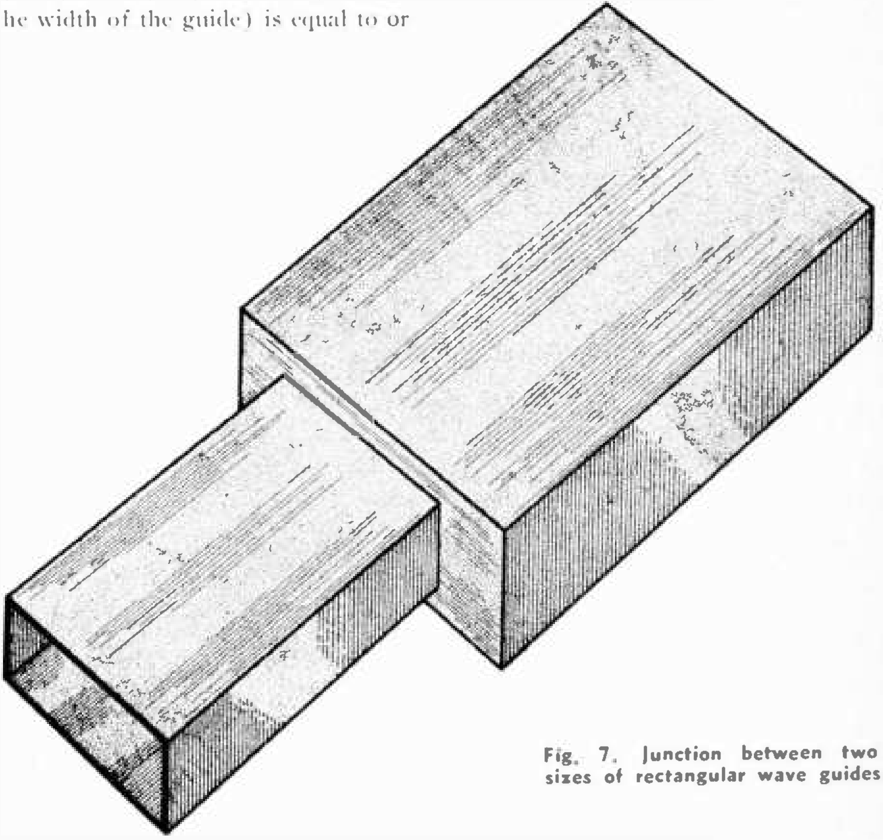

Fig. 7. Junction between two sizes of rectangular wave guides

UNIT SYSTEMS

And Their Relations

JOHN M. BORST

The existence of some thirteen or more systems of electric and magnetic units together with the habit of some writers to mix units of more than one system in a single equation has created confusion in the minds of many. It has become necessary to specify each unit used in an equation if one wishes to make certain that it can readily be used.

The unfamiliarity with the systems and the resulting confusion cannot be blamed on the engineers. It seems that most textbooks are very hazy on the subject, and when many sources are consulted one soon runs into contradictions. Much of the literature is devoted to a discussion of technicalities which may interest physicists but are of no use to the engineer. Further, many authors introduce modified systems of their own.

The aim of this article is to clarify the systems which the engineer is most likely to encounter, especially in the newer textbooks. Technicalities will be avoided so as not to confuse the reader. Also, the subject of dimensions will not be discussed.

The Unit

In order to measure the magnitude of a physical quantity, it must be compared with a standard amount, or unit, of this quantity. The magnitude is expressed by a ratio, a pure number, which denotes the number of times the unit quantity is contained in the measured quantity.

The size of the standard amount or unit can be arbitrarily chosen, but a satisfactory unit must have a convenient size so that the average quantity measured will not have to be expressed by means of cumbersome large or very small numbers.

One might say that a unit system is a collection of units for different quantities which are generally used together. The foot-pound-second system could be called such a system. Evidently the size of the unit of length, mass, and time were chosen independently for convenient size without regard to the relation between them.

Physical quantities are related to each other. These relations, when expressed mathematically in the most general way, will contain proportionality constants. For instance, the relation between volume and length can be expressed by the equation

$$V = k\,l\,w\,h$$

where l, w, h are the length, width and height, respectively, of a rectangular container and k is a proportionality constant depending on the units chosen. If l, w, and h are expressed in inches and V in cubic inches, then $k = 1$, but if V is in gallons, $k = 4.329 \times 10^{-3}$.

If any other equation in physics were written, a proportionality constant would have to be included, so long as the choice of units was still unknown.

In a *self-consistent* unit system the units are so chosen that all these proportionality constants, or as many of them as possible, will be unity. From this standpoint, the foot-pound-second system is not a self-consistent system.

In column 3 of the Unit Conversion Table included with this article are the equations which show the simple relations between the physical quantities, covering mechanics, electricity and magnetism. It should be clear that, if a unit system is to be selected, one cannot choose all units arbitrarily. In fact, it will be found that but a very few units can be so chosen; the others are then fixed by the equations. Thus, to cover the field of mechanics, three fundamental units can be selected. After this has been done, only one more is needed to cover the physics of heat and another for electricity and magnetism. Consequently, to cover the field of mechanics, electricity and magnetism, we can choose but four fundamental units and the other units are derived from these by means of the equations. These are called derived units.

The Cgs System

In the cgs system (for mechanics), the three fundamental units are the centimeter, the gram and the second. Even these three were not chosen entirely at random. The gram is supposed to be equal to the mass of a cubic centimeter of water at conditions of maximum density. From these three fundamental units of length, mass, and time, the other mechanical units are derived. Thus, for instance, the unit of velocity becomes one centimeter per second and the unit of acceleration becomes one centimeter per second per second. The unit of force, the dyne, is the force needed to give an acceleration of one centimeter per second per second to a mass of one gram.

By now the reader will probably want to know why one self-consistent system of units would not be sufficient and why there should have to be many.

[*Continued on page 244*]

RSION TABLE

AGAZINES, INC., New York, N. Y.

Compiled by
John M. Borst

PRACTICAL UNIT	1 e.s.u. = N Mks	1 e.m.u. = N Mks	1 practical unit = N Mks	UNRATIONALIZED MKS OR GIORGI UNIT	1 e.s.u. = N MKS (R)	1 e.m.u. = N MKS (R)	SUB-RATIONALIZED MKS OR GIORGI UNIT	1 MKS unit unrationalized = N MKS (R)	1 practical unit = N MKS (R)	Symbol	QUANTITY
	N ↓	N ↓	N ↓		N ↓	N ↓		N ↓	N ↓		
	UNRATIONALIZED MKS				MKS Subrationalized			MKS Subrationalized			
centimeter	10^{-2}	10^{-2}	10^{-2}	meter	10^{-2}	10^{-2}	meter	1	10^{-2}	l	Length
	10^{-3}	10^{-3}		kilogram	10^{-3}	10^{-3}	kilogram	1		m	Mass
second	1	1	1	second	1	1	second	1	1	t	Time
cm/sec.	10^{-2}	10^{-2}	10^{-2}	meter per second	10^{-2}	10^{-2}	meter per sec.	1	10^{-2}	v	Velocity
cm/sec²	10^{-2}	10^{-2}	10^{-2}	meter/sec²	10^{-2}	10^{-2}	meter/sec²	1	10^{-2}	a	Acceleration
	10^{-5}	10^{-5}		joule/meter = newton	10^{-5}	10^{-5}	joule/meter = newton	1		F	Force
joule	10^{-7}	10^{-7}	1	joule	10^{-7}	10^{-7}	joule	1	1	W	Work, Energy
watt	10^{-7}	10^{-7}	1	watt	10^{-7}	10^{-7}	watt	1	1	P	Power
x10^{11}) farad/cm				1/(9x10^{9}) farad/m			1/(36πx10^{9}) farad/m			ε_0	Permittivity of space
coulomb	10/c	10	1	coulomb	10/c	10	coulomb	1	1	q	Charge
oulomb/cm²	10^{5}/c	10^{5}	10^{4}	coulomb/m²	10^{5}/c	10^{5}	coulomb/m²	1	10^{4}	σ	Surface charge density
oulomb/cm³	10^{7}/c	10^{7}	10^{6}	coulomb/m³	10^{7}/c	10^{7}	coulomb/m³	1	10^{6}	ρ	Volume charge density
volt/cm	C/10^{6}	10^{-6}	10^{2}	volt/m	c/10^{6}	10^{-6}	volt/m	1	10^{2}	E	Electric field strength
	10^{5}/c	10^{5}		1/4π coulomb/m²	10^{5}/4π c	10^{5}/4π	coulomb/m²	1/4π		D	Electric flux density, Displacement density
	10/c	10		1/4π coulomb	10/4π c	10/4π	coulomb	1/4π		Ψ'	Electric flux displacement
farad	10^{9}/c²	10^{9}	1	farad	10^{9}/c²	10^{9}	farad	1	1	C	Capacitance
daraf	c²/10^{9}	10^{-9}	1	daraf	c²/10^{9}	10^{-9}	daraf	1	1	S	Elastance
	10^{5}/c	10^{5}		coulomb/m²	10^{5}/c	10^{5}	coulomb/m²	1		P	Polarization
volt	c/10^{8}	10^{-8}	1	volt	c/10^{8}	10^{-8}	volt	1	1	V	Potential, Potential difference
volt	c/10^{8}	10^{-8}	1	volt	c/10^{8}	10^{-8}	volt	1	1	e	E. m. f.
ampere	10/c	10	1	ampere	10/c	10	ampere	1	1	I	Current
ampere/cm²	10^{5}/c	10^{5}	10^{4}	ampere/m²	10^{5}/c	10^{5}	ampere/m²	1	10^{4}	ι	Current density
ohm	c²/10^{9}	10^{-9}	1	ohm	c²/10^{9}	10^{-9}	ohm	1	1	R	Resistance
ohm . cm	c²/10^{11}	10^{-11}	10^{2}	ohm . meter	c²/10^{11}	10^{-11}	ohm . meter	1	10^{2}	ρ	Resistivity
mho	10^{9}/c²	10^{9}	1	mho	10^{9}/c²	10^{9}	mho	1	1	G	Conductance
mho/cm	10^{11}/c²	10^{11}	10^{-2}	mho/meter	10^{11}/c²	10^{11}	mho . meter	1	10^{-2}	γ	Conductivity
0^{-9} henry/cm				10^{-7} henry/m			4πx10^{-7} henry/m			μ_0	Permeability of space
										ν	Reluctivity
	c/10^{8}	10^{-8}			4πc/10^{8}	4π/10^{8}	weber	4π		m	Pole strength
	c/10^{10}	10^{-10}			4πc/10^{10}	4π/10^{10}	weber . meter	4π			Magnetic moment
	c/10^{4}	10^{-4}			4πc/10^{4}	4π/10^{4}	weber/m²	4π		J	Intensity of magnetization
	10/c	10	1		10/4πc	10/4π		1/4π		U	Magnetic potential
4π ampere turn	10/c	10	1	1/4π ampere turn pra-gilbert	10/4πc	10/4π	ampere turn	1/4π	1/4π	M	Magnetic potential difference magnetomotive force
4π ampere turn	10^{3}/c	10^{3}	10^{3}	1/4π ampere turn pra-oersted	10^{3}/4πc	10^{3}/4π	amp. turn/m	1/4π	10^{2}/4π	H	Magnetizing force
weber/cm²	10^{4}/c	10^{4}	10^{4}	weber/m²	c/10^{4}	10^{-4}	weber/m²	1	10^{4}	B	Magnetic flux density, Magnetic induction
r or volt second	10^{8}/c	10^{8}	1	weber = volt sec.	c/10^{8}	10^{-8}	weber = volt-sec.	1	1	Φ	Magnetic flux
amp. turn)/weber	10^{9}/c²	10^{9}	1	(1/4π amp. turn)/weber	10^{9}/4πc²	10^{9}/4π	amp. turn/weber	1/4π	1/4π	ℛ	Reluctance
/(1/4π amp. turn)	c²/10^{9}	10^{-9}	1	weber/(1/4π amp. turn)	4πc²/10^{9}	4π/10^{9}	weber/amp. turn	4π		𝒫	Permeance
henry	c²/10^{9}	10^{-9}	1	henry	c²/10^{9}	10^{-9}	henry	1	1	L	Inductance

./number of e.s.u. = N.
e.s.u./magnitude of 1 e.m.u. = N.

To convert from e.m.u. to e.s.u. multiply by 1/N.

$c = 2.998 \times 10^{10}$
$1/c = 3.335 \times 10^{-11}$
$4\pi = 12.57$

$c^2 = 8.988 \times 10^{20}$
$1/c^2 = 1.112 \times 10^{-21}$
$1/4\pi = 0.7958$

A survey of various unit systems and their relationships to each other which should help to clarify this complex subject. The Unit Conversion Table, which accompanies this article, will be found useful in enabling a suitable choice of units for a given equation and in interpreting equations employed in modern textbooks

The difficulty here is to follow the rules of a self-consistent system and also to have all the units of reasonable size. To explain this further, let us imagine ourselves back in the time when a cgs system for mechanics was available and when this system had to be extended to include electricity and magnetism. In those days the relation between electricity and magnetism was not so well appreciated and the workers in electricity and those in magnetism proceeded independently.

First, take Coulomb's law for the force between two electric charges (as modified by Cavendish)

$$F = \frac{q_1 q_2}{k_e r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

In this equation, r, representing the distance between the two charges, is in cm and the force F is in dynes, these being the units of the cgs systems. k_e is a constant depending on the medium and was taken as unity for a vacuum. So, in order to maintain the equation in this form, without adding another proportionality constant, the unit of charge is determined. This unit is now known as a statcoulomb.

Having derived this unit of charge, the unit of potential difference, the statvolt, is easily found. If it requires one erg (unit of work) to move a charge of one statcoulomb from one location to another, the potential difference between these two points is one statvolt.

A statampere is one statcoulomb per second, etc., so all other units are easily derived.

Magnetomotive Force

Now consider those working in the field of magnetics and how they extended the cgs system. The first equation is again Coulomb's law

$$F = \frac{m_1 m_2}{k_m r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where k_m is a constant depending on the medium and which was chosen as unity for a vacuum; r is in cm, F in dynes as before. This equation determines the size of the unit pole.

The work done by carrying the unit magnetic pole once around a circuit is called the magnetomotive force (mmf). If this work amounts to one erg, the mmf is one gilbert; that defines the gilbert. A current flowing through a single turn which creates a magnetomotive force of 4π gilberts is one abampere.

Now this unit of current, the abampere, is not the same as the unit of current, the statampere, which was found before. In fact, it will be seen that all the units derived first, the electrostatic units, differ from the later electromagnetic units for the same quantities. Yet they were derived from the same fundamental mechanical units and using the same equations. Evidently there is something wrong.

If the electrostatic system is extended to include magnetic units, it will be found when reaching Coulomb's law for magnetic poles, that the two sides of the equation do not balance unless another factor is added to the equation. The same thing happens if the magnetic units are extended to include the electric quantities; then the same factor must be added to Coulomb's law for the force between two charges. This proportionality factor, usually written c^2, is numerically equal to the square of the velocity of light in cm per sec (3×10^{10} cm per sec.).

The accepted answer at present is that we have no right to assume that the dielectric constant of a vacuum is unity. Making that assumption amounts to choosing a fundamental unit. Similarly, we cannot assume that the permeability of a vacuum is unity; this also amounts to choosing a fundamental unit.

As explained above, only four fundamental units can be chosen and, having already three mechanical units, one cannot set both the dielectric constant and the permeability equal to unity and still have a self-consistent system. Therefore the two ways described above for obtaining a set of units must necessarily result in two different systems of units, since the fourth fundamental unit of each system is different. For purposes of convenience, it is now better to revise the symbols and a few of the equations.

The dielectric constant of a vacuum (permittivity of space) is to be denoted by the symbol ϵ_0 and the absolute dielectric constant of any medium by the symbol ϵ. The dielectric constant which we have been looking up in tables is the *relative* dielectric constant k_e, which is

$$k_e = \frac{\epsilon}{\epsilon_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The permeability of space or of a vacuum is denoted by the symbol μ_0, and the absolute permeability of any medium by the symbol μ. What we have been calling the permeability is the relative permeability of a medium

$$k_m = \frac{\mu}{\mu_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

So long as the defining equations of column 3 are used, there is a relation between ϵ_0 and μ_0 in any system. It is

$$\frac{1}{\sqrt{\epsilon_0 \mu_0}} = c \quad \ldots\ldots\ldots\ldots (5)$$

where c is numerically equal to the velocity of light expressed in units of the same system. For the cgs system that is 3×10^{10}.

The Laws of Coulomb must be rewritten to include these factors ϵ_0 and μ_0 and in other equations, wherever the *relative* dielectric constant and the relative permeability occurred, they should be replaced by the absolute quantities. For instance:

$$F = \frac{q_1 q_2}{\epsilon_0 k_e r^2} = \frac{q_1 q_2}{\epsilon r^2} \quad \ldots\ldots\ldots (6)$$

$$F = \frac{m_1 m_2}{\mu_0 k_m r^2} = \frac{m_1 m_2}{\mu r^2} \quad \ldots\ldots\ldots (7)$$

$$D = k_e \epsilon_0 E = \epsilon E \quad \ldots\ldots\ldots (8)$$

$$B = \mu_0 k_m H = \mu H \quad \ldots\ldots\ldots (9)$$

There are also some equations where the permeability or dielectric constant of vacuum alone came in and since this was unity in the system employed in some textbooks, it was left out. Such an equation was

$$B = H + 4\pi J \quad \ldots\ldots\ldots\ldots (10)$$

It should be written

$$B = \mu_0 H + 4\pi J \quad \ldots\ldots\ldots\ldots (11)$$

With the provision that the writing of the dielectric constant and the permeability be done in accordance with the above rules, any equation which is valid in the cgs electrostatic system is

[*Continued on page 24B*]

also truè in the cgs electromagnetic system and vice versa, without the addition of any constants. So long as all of the units are changed to the other system, no conversion factors need appear. A skeptical reader need but take any suitable equation and, changing to another system, include the necessary conversion factors for all units and he will see that the conversion factors cancel out.

In fact, we can go further and say that any equation which is valid in any self-consistent system of units derived from the line of equations shown in column 3 is also valid in any other self-consistent system of units derived from these same equations. But in all cases one must change all the units to the new system.

Now let us briefly review the unit systems. First there is the *cgs electrostatic system;* its four fundamental units are the centimeter, the gram, the second and the dielectric constant of space, which is unity. The names of the units are generally given the prefix stat-. In this system the permeability of free space (vacuum) is $1/c^2 = 1.113 \times 10^{-21}$ stathenry per cm.

The cgs electromagnetic system uses as its four fundamental units the centimeter, the gram, the second and the permeability of space equal to unity. In electromagnetic units the dielectric constant of free space is $1/c^2 = 1.113 \times 10^{-21}$ abfarad per cm. The names of the units in the cgs electromagnetic system are often prefixed ab-.

The ratio of the magnitude of a unit in the cgs electrostatic system to the magnitude of the corresponding unit in the cgs electromagnetic system is always some power of c. For the circuit parameters, such as resistance, inductance, capacitance, permeability and dielectric constant, it is c^2 or $1/c^2$ and for all other units it is either c or $1/c$. It appears that this was first discovered by Weber and this factor c is sometimes referred to as "Weber's constant".

Both of these are cgs systems and are sometimes called *absolute systems.* However, there seems to be no agreement on just what is an *absolute* system. According to some writers an absolute system is any system which has the units of length, mass and time as fundamental units. Another viewpoint seems to be that only cgs systems are absolute systems, and still another is that only the cgs electromagnetic system is an absolute system. When in a book or article the author states that he is using *the* absolute system, or *the* cgs system, he means the cgs electromagnetic system.

A practical system is any system which uses the ampere, volt, ohm, farad, henry, the joule and the watt, although some of the other units may differ in various practical systems.

The Gaussian System

The *symmetric system,* also known as the *Gaussian system,* will perhaps best be understood if we return to the point in this article where it was found necessary to introduce the factors ϵ_0 and μ_0. There is still another way out of this difficulty; in the Gaussian unit system both ϵ_0 and μ_0 are unity or rather there is no admission that there are such quantities. The discrepancy is then adjusted by changing some of the defining equations. Another way of saying it is that Gauss took the cgs electrostatic units for problems in electrostatics and the cgs electromagnetic units for problems in magnetics and in those equations where both electric and magnetic quantities occurred, he inserted the needed conversion factor. In the table, the Gaussian units above the dividing line are those taken from the cgs electrostatic system; those below the dividing line are from the cgs electromagnetic system. Therefore, if any unit above the dividing line is used in the same equation with a unit below the dividing line, the factor c must be added. For instance, the law for electromagnetic induction becomes:

$$e = -\frac{1}{c} N \frac{d\phi}{dt} \qquad \text{.............(12)}$$

And the relation between frequency, inductance and capacity becomes:

$$f = \frac{c}{2\pi\sqrt{LC}} \qquad \text{. .... (13)}$$

where f is in cycles per second, L in milli-microhenries (abhenries) and C in statfarads (1 statfarad is 1.11 $\mu\mu$f).

The insertion of these factors amounts to using another line of defining equations, or one might say that it is a mixture of two systems of units. Therefore, equations in the Gaussian systems will have to be changed when the units are converted to another system. In many cases this change consists only in the omission of that factor c or c^2.

Practical Systems

The unit systems so far described were used by physicists because of the simplicity of the equations when the cgs mechanical units were employed. However, because many of the units are either too small or too large for practical work the practical system was devised. Eight practical units were defined in terms of the cgs electromagnetic units; these were the ampere, the coulomb, the volt, the ohm, the henry, the farad, the weber, the joule and the watt. The ratios of the magnitudes of these units to the magnitudes of the corresponding cgs electromagnetic units are given in th table. All are integral powers of 10.

Once these eight units are chosen there are still several ways in which the other derived units can be determined. This appears to contradict our previous statement that but four fundamental units can be chosen arbitrarily but it does not. The eight practical units above are not all arbitrarily chosen. They bear certain relations to each other so as to maintain, for instance, Ohm's law without the addition of a coefficient of proportionality.

These units, being defined in terms of the cgs electromagnetic system and therefore in terms of length, mass and time, are often called the absolute practical units. Since it was too difficult to compare standards with the units of length, mass and time, a system which employed some fundamental electric units was desired. In this system, the International system, the ohm and the ampere are two of the fundamental units. They are defined in terms of a standard resistance, that of a column of mercury having a length of 106.3 cm and a mass of 14.4521 grams, and a standard unit of current which will deposit silver at the rate of .001118 gram per second. From these two units, and the centimeter and the second, all the others can be determined. The magnitudes of the international ohm and the international ampere were intended to be the same as the magnitudes of those units in the absolute practical system; however, they differ by a small fraction of a per cent. For all practical purposes they may be considered the same and this small difference was not taken in account in the conversion table of this article.

The difficulty is now, that this International practical system, which has been in use since 1908, is not complete. Although a comprehensive system can be built up from it, some of these units do not appear to have been in use. This does not mean that it could not have been completed.

If the centimeter is retained as the unit of length, the practical International system would have to have as a unit of mass the gram-seven (10^7 gram or 10 metric tons). Indeed, a unit system called the CGSS system was introduced by Bennett, having this unit of mass; it appears to have little use.

In this practical system, the value of

$$\epsilon_0 = \frac{1}{9} \times 10^{-11} \text{ farad per cm.}$$

and μ_0 equals 10^{-9} henry per cm.

These factors should be used in the

[*Continued on page 66*]

RADIO

MAY 1944

UNIT CONV

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			CGS	1 e.s.u. = N e.m.u.	CGS		1 e.m.u. = N practical units	1 e.s.u. = N practical units	
QUANTITY	Symbol	EQUATION	ELECTROSTATIC UNIT	N ↓	ELECTROMAGNETIC UNIT	SYMMETRIC OR GAUSSIAN UNIT	N ↓	N ↓	
Length	l		centimeter	1	centimeter	centimeter	1	1	
Mass	m		gram	1	gram	gram			
Time	t		second	1	second	second	1	1	
Velocity	v	$v = l/t$	cm/sec.	1	cm/sec.	cm/sec.	1	1	
Acceleration	a	$a = v/t$	cm/sec.^{2}	1	cm/sec^2	cm/sec.^{2}	1	1	
Force	F	$F = ma$	dyne	1	dyne	dyne			
Work, Energy	W	$W = Fl.$	erg	1	erg	erg	10^{-7}	10^{-7}	
Power	P	$P = W/t$	erg/sec.	1	erg/sec.	erg/sec.	10^{-7}	10^{-7}	
Permittivity of space	ε_0	$k_e = \varepsilon/\varepsilon_0$	1 statfarad/cm	1	1/C^2 abfarad/cm	1 statfarad/cm			1/(S
Charge	q	$F = q_1 q_2/\varepsilon r^2$	statcoulomb	$1/c$	abcoulomb	statcoulomb	$10/c$	10	
Surface charge density	σ	$\sigma = q/A$	statcoulomb/cm^2	$1/c$	abcoulomb/cm^2	abcoulomb/cm^2	$10/c$	10	
Volume charge density	ρ	$\rho = q/v$	statcoulomb/cm^3	$1/c$	abcoulomb/cm^3	statcoulomb/cm^3	$10/c$	10	
Electric field strength	E	$E = -\text{grad } V$	statvolt/cm	c	abvolt/cm	statvolt/cm	$c/10^8$	10^{-8}	
Electric flux density, Displacement density	D	$D = \varepsilon E$	$1/4\pi$ statcoulomb/cm^2	$1/c$	$1/4\pi$ abcoulomb/cm^2	$1/4\pi$ statcoulomb/cm^2	$10/c$		
Electric flux displacement	Ψ	$\Psi = DA$	line = $1/\pi$ statcoulomb	$1/c$	$1/4\pi$ abcoulomb	line = $1/4\pi$ statcoulomb	$10/c$		
Capacitance	C	$C = q/V$	statfarad = cm	$1/c^2$	abfarad	statfarad or cm	$10^9/c^2$	10^9	
Elastance	S	$S = 1/C$	statdaraf	c^2	abdaraf	statdaraf	$c^2/10^9$	10^{-9}	
Polarization	P		statcoulomb/cm^2	$1/c$	abcoulomb/cm^2	statcoulomb/cm^2	$10/c$		
Potential, Potential difference	V	$V = Fs = W/q$	statvolt	c	abvolt	statvolt	$c/10^8$	10^{-8}	
E. m. f.	e	$e = -d\Phi/dt$	statvolt	c	abvolt	statvolt	$c/10^8$	10^{-8}	
Current	I	$I = dq/dt$	statampere	$1/c$	abampere	statampere	$10/c$	10	
Current density	ι	$\iota = I/A$	statampere/cm^2	$1/c$	abampere/cm^2	statampere/cm^2	$10/c$	10	
Resistance	R	$R = e/I = V/I$	statohm	c^2	abohm	statohm	$c^2/10^9$	10^{-9}	
Resistivity	ρ		statohm-cm	c^2	abohm . cm	statohm . cm	$c^2/10^9$	10^{-9}	
Conductance	G	$G = 1/R$	statmho	$1/c^2$	abmho	statmho	$10^9/c^2$	10^{-9}	
Conductivity	γ	$\gamma = 1/\rho$	statmho/cm	$1/c^2$	abmho/cm	statmho/cm	$10^9/c^2$	10^{-9}	
Permeability of space	μ_0	$k_m = \mu/\mu_0$	$1/c^2$ = stathenry/cm		1 abhenry/cm	1 abhenry/cm			1
Reluctivity	ν	$\nu = 1/\mu$							
Pole strength	m	$F = m_1 m_2/\mu r^2$	statunit	c	unit pole	unit pole			
Magnetic moment		$= ml$	statpole . cm	c	pole . cm	pole . cm			
Intensity of magnetization	J				pole/cm^2	pole/cm^2			
Magnetic potential	U			$1/c$					
Magnetic potential difference, magnetomotive force	M	$M = 4\pi NI$		$1/c$	gilbert	gilbert	$10/c$	10	1/
Magnetizing force	H	$H = M/l$		$1/c$	oersted	oersted	$10/c$	10	1/
Magnetic flux density, Magnetic induction	B	$B = \mu H$	statweber/cm^2	c	gauss	gauss	$c/10^8$	10^{-8}	
Magnetic flux	Φ	$\Phi = BA$	statweber	c	maxwell or line or abvolt-sec.	maxwelll or line or abvolt-sec	$c/10^8$	10^{-8}	web
Reluctance	$\mathcal{R}$	$\mathcal{R} = M/\Phi$		$1/c^3$	gilbert/maxwell	gilbert/maxwell	$10^9/c^3$	10^9	(1/4
Permeance	$\mathcal{P}$	$\mathcal{P} = 1/R$		c^3	maxwell/gilbert	maxwell/gilbert			weber
Inductance	L	$L = e/(dI/dt)$	stathenry	c^3	abhenry or cm	abhenry or cm	$c^2/10^9$	10^{-9}	

NOTES MKS (R) = subrationalized MKS unit.

1 e.s.u. = N e.m.u. The conversion factor N is in the column below this heading. This can also be read: multiply number of e.s.u. by N to obtain e.m.u.

Also, number of e.m.
or, the magnitude of

Characteristics of RADIO WIRE AND CABLE

J. M. CALLER
Engineer, Sperry Gyroscope Company

A comprehensive survey of the various types of wire and cable used in radio equipment, with analyses and sound, practical information regarding their selection to meet specified service conditions

PART I

THE most basic component of any electrically energized equipment and all too often the one given least attention in design is the electric conductor. At first glance, wires and cables seem to be relatively simple items which should cause no trouble in operation provided they are not overloaded. Such a concept might be nearly true if bare conductors could be used. With but few exceptions, however, some form of insulation is necessary and thereby the conductor is transformed into a specialty product requiring engineering skill of the highest order to manufacture and utilize successfully.

Many engineers will undoubtedly say that the foregoing statement is grossly exaggerated. That it is true, nevertheless, should be apparent when one considers the manifold insulation requirements which enter regularly into electric wire and cable design. These requirements listed below are just as important as the more obvious limitations of electric current capacity and voltage drop with respect to satisfactory and reliable operation.

Dielectric Properties
- Dielectric strength
- Insulation resistance
- Surface leakage resistance
- Power factor
- Dielectric constant

Physical Properties
- Operating temperature range
- Softening and brittle points
- Moisture resistance
- Flame resistance
- Life expectancy

Mechanical Properties
- Flexibility and endurance
- Abrasion resistance
- Crushing resistance
- Vibration and shock resistance

Chemical Properties
- Imperviousness to oils, acids, etc.
- Non-corrosiveness
- Color stability
- Fungus and vermin resistance

It should also be appreciated that these insulation properties are not separate and distinct but interdependent in a rather complicated manner. For example, the wire insulation may be flexible at room temperature but may soften under heat or stiffen under cold, with adverse effect upon one or more of the dielectric properties. Likewise, the entrance of moisture, oil, or chemicals may completely change or even destroy the original characteristics of the insulation. Add to these requirements the primary necessity for minimum diameter and weight in aircraft applications and the picture is substantially complete but certainly not simple.

Terminology

Unfortunately, wire and cable terms are employed somewhat differently in the power and electronic fields. In power engineering, the terminology is fully standardized[1] and rigidly employed according to definitions. A wire is defined as "a slender rod or filament of drawn metal" and therefore applies only to solid conductors such as magnet wires. All other types are classified as cables since a cable is defined as "either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple-conductor cable)". In radio engineering, there are no written standard definitions and the terms "wire" and "cable" are applied more loosely. A wire is understood to be a single conductor of small diameter, either solid or stranded, which thus extends the scope of the term beyond magnet wires to include Litz, lead, and ordinary hook-up wires. The larger single conductors, coaxial or concentric lines, and sheathed multiple conductors (except flexible cords) are known as cables. Flexible cords, twisted pair, and parallel pair are familiar terms meaning the same in both fields and need no explanation. It would be best, however, to mention the "harness" as a term commonly used in radio to denote an assembly of single conductors (wires) tied or bound together and usually equipped with terminals.

In the following discussion, the terminology employed will be that which is conventional to radio and electronic parlance. All references to wire and cable furthermore will be understood to mean insulated types unless qualified by the term "bare". There should be no confusion provided these and the foregoing concepts are kept firmly in mind.

Conductors

Materials:—Copper is without question the metal of the electrical industry. More than one-half of the entire amount produced in the United States is consumed by that industry and the major part of that portion is utilized in the form of electric conductors. There are several reasons for this demand. Of first importance, copper has the lowest electrical resistivity of all metals except silver, and a low temperature coefficient of resistivity.* In addition, it is highly ductile, strong, resistant to fatigue and corrosion, uniform, and low in cost.

Largely because of the present emergency, much effort has been and is still

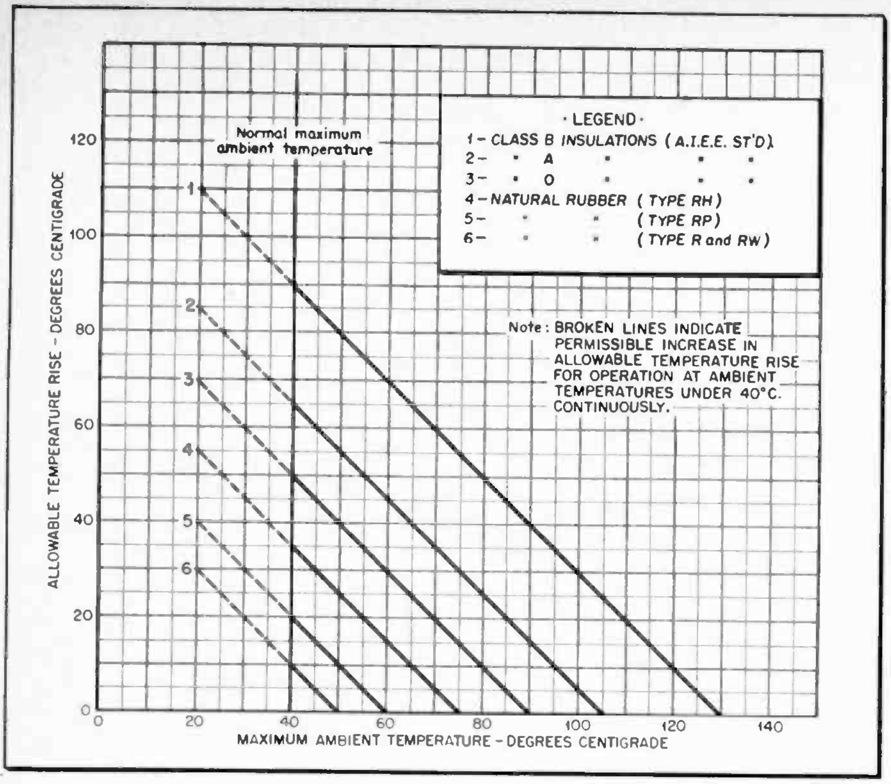

Fig. 1. Allowable temperature for various insulations

being directed toward the development of suitable substitute materials. Pure aluminum and zinc, as well as alloys thereof, have been tried with varying degrees of success but all are in one respect or another considerably inferior to copper. The most promising substitute to date is "copper-clad" in which a layer of copper is applied over a steel core to obtain a high-conductivity sheath but even this has received little acceptance. The latter type of construction should not be confused with silver-clad copper conductors which are often employed in ultra-high frequency circuits as a means of reducing losses due to the "skin effect."

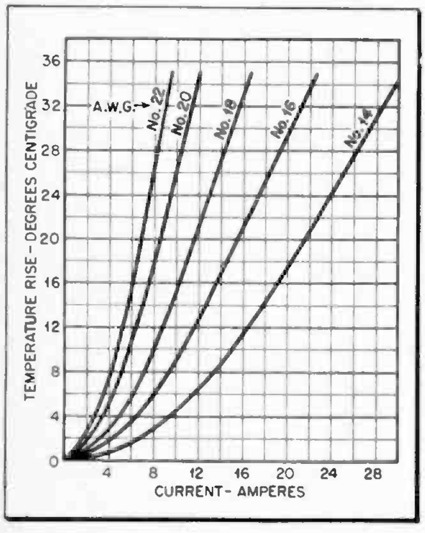

Fig. 2. Temperature rise

Sizes:—Conductor sizes are popularly specified in terms of wire gauge numbers. Many different wire gauges have been devised and become established but the only one of importance to the electrical industry in this country today is the American Wire Gauge—commonly abbreviated to A.W.G. This gauge is also known as the Brown and Sharpe (B&S) gauge since it was originated by J. R. Brown, one of the founders of the Brown and Sharpe Mfg. Co. It has gained precedence over all of the others probably because of its inherent advantages from an engineering standpoint in that a simple mathematical relationship between successive sizes is maintained constant throughout.

An excellent treatise on the subject of wire gauges is available from the Bureau of Standards[2], covering the historical and theoretical considerations involved. Space limitations here prohibit any such discussion but it will be advantageous to include some facts about the American Wire Gauge that may be committed to memory. The nominal range of this gauge is from No. 0000 (4/0) to No. 36[†] with the diameters of these limiting sizes defined as 0.4600 inch and 0.0050 inch respectively. Since there are 38 sizes between these two diameters, the ratio of any diameter to the next smaller is equal to

$$\sqrt[39]{\frac{.4600}{.0050}} = \sqrt[39]{92} = 1.123$$

(approximately). The square of this ratio is 1.261 which is therefore equal to the ratio between any two successive areas in circular mils (C.M.). It is also useful to remember the following approximate resistance relationship:

A.W.G. No.	*Ohms/1000 Ft.*
10	1
13	2
16	4
19	8
20	10

This relationship is maintained over each succeeding ten sizes throughout the entire gauge.

Coatings:—Tin coating, commonly called "tinning", of the copper conductor has been so widely employed for so many years that it might be classified as a standard practice of the wire and cable industry. It was probably employed originally on large cables in lieu of a paper or textile separator to protect the copper from corrosion by active ingredients in the rubber compounds commonly used as electrical insulation. At any rate, the advent of high-production methods in radio manufacturing later made the use of such tinning on hook-up wires essential. With untinned wire, the soldering time at each joint would be increased perhaps ten times and there are usually not less than fifty joints in the smallest type of radio receiver.

Since tin became one of the critical materials, lead and lead-tin alloy have been employed to a large extent. These substitute coatings, admittedly inferior to pure tin with respect to solderability, were made mandatory upon the manufacturers for several months through a WPB Limitation Order. This order at first limited the tin content to 20 per cent (by weight) but was later amended to permit up to 40 per cent for military radio and radar use, and was finally waived entirely in the latter applications for solid conductors up to A.W.G. #20. Since very few flexible hook-up wires contain strands of larger diameter, it can be said that pure tin coatings are again available for all electronic equipments being manufactured for the Armed Forces.

Strandings:—Flexible conductors are usually designed so that the aggregate area of the strands will approximate

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[*] The electrical resistivity of pure copper, as defined by the International Annealed Copper Standard, is 0.15328 ohm (meter, gram) at 20° C. and the temperature coefficient of resistivity, referred to 20° C., is 0.00393 per degree C. Commercial grade, soft-drawn copper is ordinarily of 98 percent conductivity (or better) with a temperature coefficient of 0.00385 per degree C. Hard-drawn copper of commercial grade is about 2.7 percent higher in resistance per given length than soft-annealed.

[†] Extensions of this gauge down to No. 46 have been made and are being used regularly.

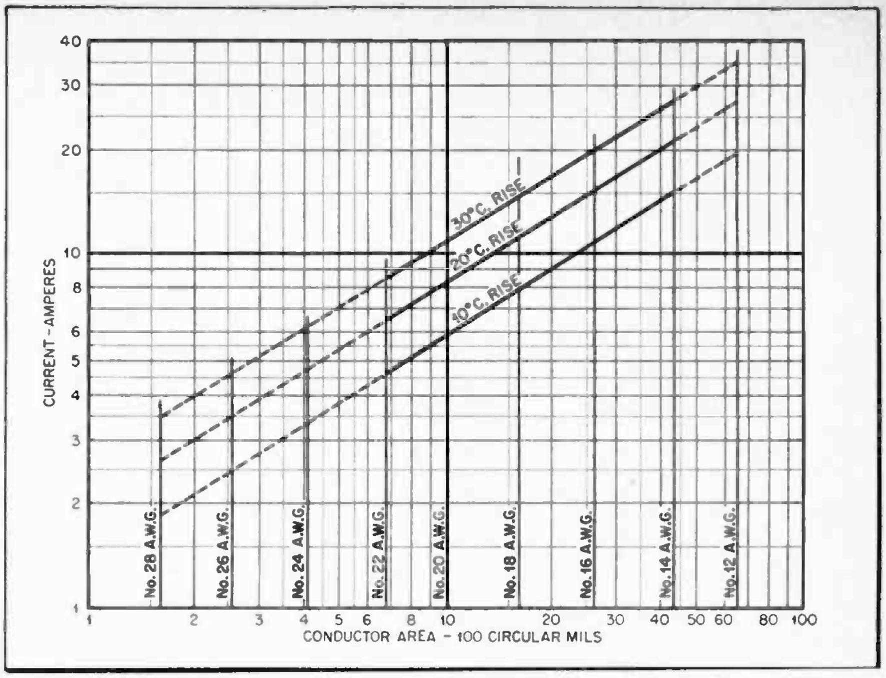

Fig. 3. Current-carrying capacity

the desired gauge size. An addition of not less than two per cent should be made for subsequent reduction of area through broken strands. Splices in the individual strands during manufacture are permissible but there should be no splicing of the conductor as a whole.

There are three types of stranding commonly employed — bunch, concentric, and rope lay. In bunch stranding, the individual wires are simply twisted together as a group and the number of wires comprising the bunch may be selected at will. Concentric stranding on the other hand follows a fixed pattern using one straight wire as a core around which are twisted layers of wires in consecutive multiples of six. Thus the number of wires in concentric stranding is fixed by the series 7, 19, 37, 61, 91, etc. Such stranding is much to be preferred over the bunch method since the conductor is perfectly circular in cross-section, insuring uniform wall thickness when extruded insulation is applied, and will not separate easily when the insulation is stripped. Rope-lay stranding is simply an extension of concentric stranding wherein several stranded conductors are twisted together in concentric fashion to form a large conductor with good flexibility.

It is misleading to speak of conductor flexibility without properly qualifying that term. True flexibility, or pliancy, is a function of the fineness of stranding; that is, for a given conductor size, the greater the number of strands and the smaller the strand diameter, the better the flexibility. On the other hand, flexing endurance which is often referred to as flexibility appears to bear little or no relationship to the fineness of stranding but is more dependent upon the quality of the copper and varies widely, for a given material, with the amplitude of flexure. Either or both of these criteria of flexibility may be important to the equipment designer depending upon the specific conditions under which the wire is to be used.

Temperature Limitations: — The most important consideration for any insulated electric conductor is the maximum permissible operating temperature. Since this is a fixed limit, the allowable temperature rise due to the flow of electric current will depend upon the ambient temperature. The higher the ambient temperature, the lower will be the allowable temperature rise, and the reverse is likewise true.

It is interesting to note that the maximum permissible operating temperature is determined not by the conductor proper but by the type of insulation thereon. Insulations utilized for electric wires and cables are classified under A.I.E.E. Standards[3] with respect to the nature of the material and the impregnation thereof as follows:

Class O insulation consists of cotton, silk, paper, and similar organic materials when neither impregnated nor immersed in a liquid dielectric.

Class A insulation consists of: (1) Cotton, silk, paper, and similar organic materials when either impregnated or immersed in a liquid dielectric; (2) films and sheets of cellulose acetate the other cellulose derivatives of similar properties; and, (3) varnishes (enamel) as applied to conductors.

Class B insulation consists of mica, asbestos, fiber glass, and similar inorganic materials in built-up form with organic binding substances.

Limiting values of operating temperature and temperature rise, based upon a reference ambient temperature of 40° C., for these three classes of insulation are shown in the following table:

Class of Insulation	*Maximum Operating Temperature*	*Allowable Temperature Rise Above 40° Ambient*
O	90° C.	50° C.
A	105° C.	65° C.
B	130° C.	90° C.

The reference ambient temperature of 40° C. was selected, for the purpose of establishing limiting values of temperature rise to be used in design, on the basis of the duration time over which elevated ambient temperatures may be encountered within the continental United States. It is a well-known fact that the rate of deterioration of insulation increases exponentially as the temperature increases. The duration and extent of the higher ambient temperatures to which electrical apparatus may be subjected in operation is therefore a very important consideration. Weather Bureau data recorded over periods ranging from 15 to 75 years at numerous stations located throughout the entire country indicate that the following outdoor temperature durations are but seldom exceeded.

Outdoor Temperature	*Duration Time (Maximum)*
30° C.	12%
35° C.	3%
40° C.	0.5%
45° C.	0%

From the foregoing, the choice of 40° C. as a reference maximum ambient temperature is immediately apparent. It should be recognized, however, that this value should be relied upon in design only for equipment used within the United States and under conditions where indoor temperatures do not exceed those outdoors. Much higher ambient temperatures will be found inside of an airplane or an automobile, in the engine room of a ship, and in the tropics. Such are the conditions, however, under which most of the radio and other electrical equipment being produced for today's military needs must function. The designer therefore should in each individual case obtain the best possible knowledge of the climatic conditions to be encountered in service. For ambient temperatures which at times exceed 40° C., the temperature rise should

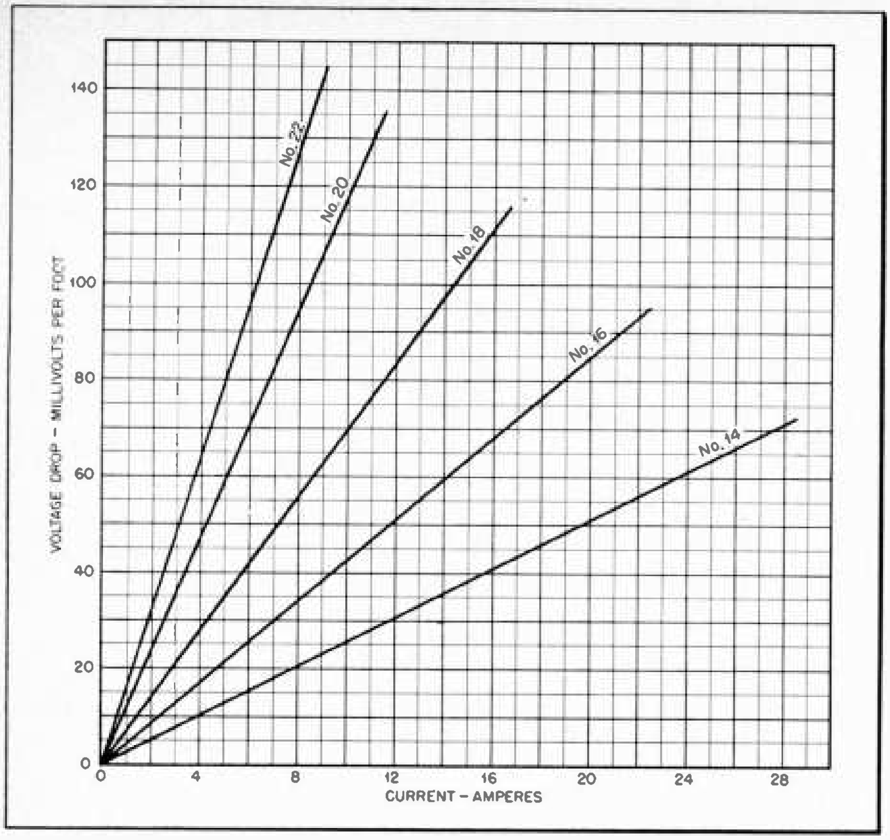

Fig. 4. Voltage drop in millivolts per foot

be reduced by an equal amount so that the maximum operating temperature for the type of insulation employed will never be exceeded. The curves shown in *Fig. 1* illustrate the allowable temperature rise with respect to maximum ambient temperature for various types of insulating materials used on electric conductors. In addition to the three (A.I.E.E.) standard classes of insulation, which are important principally to magnet wires, there are included here corresponding curves for natural rubber and the more popular types of synthetic rubber and plastic elastomers utilized on radio hook-up wires and cables.

Current-Carrying Capacity: Knowing the allowable temperature rise, the next consideration will be the choice of a conductor size sufficiently large to meet that requirement when carrying the circuit current. This is particularly important with respect to hook-up wires for filament and primary supply circuits but there is unfortunately a dearth of authoritative information in the literature on this subject for the sizes commonly employed; viz., A.W.G. #14 to #22 and smaller. The small amount of data available on current-carrying capacity in this size range is either unreliable or ultra-conservative.

Theoretical considerations indicate that the current required to produce a specified temperature rise in an insulated conductor is given by the equation:

$$I = \sqrt{\frac{T}{R_c R_{th}}}$$

where

I = current in amperes
T = temperature rise in degrees C.
R_c = conductor resistance at operating temperature in ohms/foot
R_{th} = thermal resistance of insulation in thermal ohms/foot

Determination of the thermal resistance (R_{th}) is somewhat complicated, involving the geometry of the insulated conductor and the thermal volume and surface resistivities of the insulation as follows:

$$R_{th} = 0.00522\rho v \log \frac{D}{d} + \frac{0.00411\rho s}{D}$$

where

R_{th} = thermal resistance of insulation in thermal ohms/foot
ρv = thermal volume resistivity in degrees C./watt/cm.^{3}
ρs = thermal surface resistivity in degrees C./watt/cm.^{2}
d = diameter of conductor in inches
D = diameter of insulated conductor in inches

The preceding formula for thermal resistance (R_{th}) is a simplified version of the one given in a report by NEMA[4] covering an analysis of current ratings for rubber-insulated building wires and cables, A.W.G. #14 and larger, in conduit. Resistivity values specified therein are $\rho v = 500$ for rubber insulation and $\rho s = 314D + 650$. Assuming that these factors may be applied equally well to smaller sizes (A.W.G. #14 to #22) with average insulation thickness of .020 to .025 inch, the relationship between current and temperature rise should be approximately as shown in Table I.

Since this tabulated data applies to natural rubber and is accurate only to the extent of the assumptions necessarily made, its limitations are obvious. Natural rubber, as will be discussed later, is no longer generally available for insulation purposes; synthetic rubbers and plastic elastomers are now the rule. In view of this situation, additional test information is definitely required to establish current ratings for the smaller sizes with present day types of insulation.

Such tests have been performed by the Sperry Gyroscope Co. on conductors ranging from A.W.G. #14 to #22 inclusive insulated with an extruded (.025) wall of synthetic resinous compound of the vinyl copolymer type known commercially as Vinylite V. The method employed was chosen to simulate operating conditions of semi-restricted ventilation, the conductor being supported on dowels in a one-foot square configuration and enclosed within a box allowing one inch of free space on each side. Values of temperature rise plotted against current for the respective conductor sizes are shown in *Fig. 2*.

A rearrangement of these curves for more convenient usage is given in *Fig. 3*. In this case, the current is plotted against conductor area for three 10° C. increments of temperature rise and the curves are extrapolated to indicate the limitations of sizes smaller than A.W.G. #22. On this basis, the various conductor sizes would appear to

[*Continued on page 72*]

TABLE I

Temperature Rise	A.W.G. #14	A.W.G. #16	A.W.G. #18	A.W.G. #20	A.W.G. #22
10° C.	11.5	8.5	6.5	4.5	3.5
20° C.	16.0	12.0	9.0	6.5	5.0
30° C.	20.0	15.0	11.5	8.0	6.5

Factors Involved In CHOOSING TUBE TYPES

A. C. MATTHEWS

PART I

Practical considerations in the selection of proper vacuum-tube types for various applications are discussed

The employment of vacuum tubes in communication equipment is dependent upon several factors inherent in their design. These shortcomings or limitations should be carefully considered in choosing a specific tube from the more than 500 types available.

One of the main items to be borne in mind is that individual tubes of the same type are likely to vary as much as plus or minus 30% from their published characteristics. This wide tolerance seldom occurs in a particular production run, but is often encountered when replacements are obtained at a later date or from another source of supply. It is therefore desirable to check all designs with "high" and "low" limit tubes over the full range of operation.

The use of "special" tubes either as to type or characteristic is unsound from a design standpoint, since the replacement of such tubes is very often difficult, particularly when the equipment is likely to be used in a location far distant from a good source of supply.

Much valuable work has been done by various groups and organizations in attempting to standardize a list of "Preferred Tube Types." Such a list can only be of value so long as the equipment designer makes a conscientious effort to specify these tube types. Obviously the list will be revised from time to time as the radio art advances due to technical developments. It is therefore the duty of every design engineer to keep himself informed as to the status of this standardization program. In doing so he not only helps himself by selecting tube types which are currently available, and in all probability more uniform as to characteristics, but he helps the industry as a whole by making it possible for the tube manufacturers to concentrate their production on a few types, thereby increasing efficiency and production.

A discussion of the more important limitations which affect the choice of a proper tube type follows.

Types of Emitters

The type of filament or emitter plays a very important part in the operation of a vacuum tube. These may be divided into three main groups: (1) clean metal, (2) contaminated metal and (3) oxide coated emitters.

In the clean metal emitter group we have tungsten as representing the only practical pure metal emitter commonly used. (Pure metals, in general, have relatively low emission.) Tungsten filaments are fairly critical to applied voltages as far as useful life is concerned. When the emission requirements are not heavy it is advisable to operate the filament at 5% below normal voltage. This will result in nearly doubling the tube life and is to be recommended. A 10% reduction in filament voltage will result in approximately five times normal life. Obviously at such reduced voltages the emission capabilities will be impaired.

Tungsten filaments are employed in practically all high-power transmitting tubes because of the difficulty in obtaining a high vacuum with the oxide coated type, and the fact that positive-ion bombardment when high plate voltages are employed is likely to harm the emitter.

The most popular of the contaminated metal emitters is the thoriated-tungsten type. This consists of about 2% of thorium oxide (ThO_2) in the tungsten. By a special process the thorium is brought to the surface of the tungsten. The filament is then usually given a hydrocarbon treatment which forms tungsten carbide (W_2C) on the outer surface. This tends to decrease the rate of thorium evaporation and greatly increases the life of the tube.

The operation of thoriated type emitters at reduced filament voltages is not recommended since this would slow down the diffusion of thorium to the surface, with the result that the tube would lose its emission. The activity of a thoriated filament may sometimes be restored by removing the plate, screen and grid voltages and subjecting the filament to from 200 to 250% normal voltage for approximately one minute, after which the tube should be allowed to age at 150% normal filament voltage for approximately ten minutes.

The thoriated-tungsten filament is seldom used for transmitter tubes because high plate voltages tend to remove the thorium from the surface faster than it can be replaced by normal action.

Caesium, potassium and sodium may also be absorbed on the surface of tungsten to improve the emission although these metals have not been used extensively in present day tubes.

The third type of emitter, known as the oxide-coated type, usually has a longer life than the other two. It is capable of copious emission at relatively low temperatures and therefore is ideally suited as a source of emission for vacuum tubes. The usual coating consists of barium and strontium oxide. This is obtained by passing the filament or cathode through an aqueous suspension of barium and strontium carbonates, after which the filament is heated while being evacuated, thereby converting the carbonates to oxides.

The oxide-coated filament or cathode cannot be reactivated once the emission has decreased, so it is important to maintain filament voltages at their design center to obtain a long useful life.

Heat Dissipation

When the electron stream from the cathode strikes the plate element it gives up its kinetic energy in the form of heat which must be dissipated. For this reason there is a definite limit to the amount of current that may be passed through a tube, depending upon the rate at which the heat generated may be dissipated. Small tubes require only normal air circulation around them, while larger types necessitate the use of forced air cooling. Still larger power tubes often require circulating water for cooling purposes.

The maximum safe operating temperature of a tube is usually limited by the ability of the electrodes to dissipate the heat. In an attempt to increase the heat radiation small power tubes often use blackened plates, while in the larger tubes graphite or carbon plates are employed. But the limiting factor is the glass-to-metal seal, which is likely to fail at temperatures in excess of 200° C.

Although a tube may be rated at 25 watts plate dissipation this does not necessarily mean that only 25 watts input can be employed unless all of the power is dissipated in the plate electrode. This, fortunately, is very seldom the case as it more often happens that inputs of twice the plate dissipation are employed wherein the extra power is absorbed in the output circuit.

In addition to the plate dissipation large power tubes have a specified grid dissipation. This rating should be adhered to rigidly since exceeding it may cause the grid to emit "primary" electrons which would obviously affect normal operation. This applies to both control and screen grids. Overheating the grid element may also cause it to liberate occluded or adsorbed gases, thus destroying the usefulness of the tube. In fact it is entirely possible to actually melt or burn out the grid wires due to improper operation.

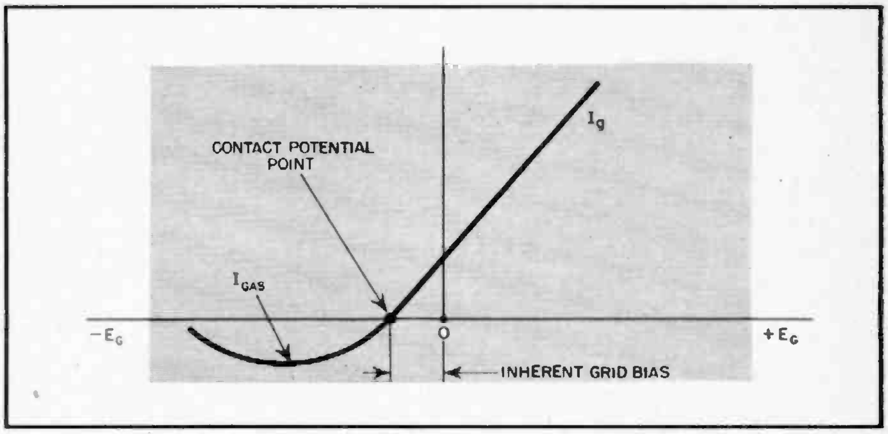

Fig. 1. Inherent grid bias due to contact potential

Insulation Breakdown

Another consideration in the choice of a tube is voltage breakdown. Unfortunately, designs in which the length of the glass is long, thus giving a high breakdown voltage, usually have long leads and cannot be successfully used at very high frequencies. A compromise must therefore be made wherein these two factors are balanced to the satisfaction of the particular application. It should also be remembered that the voltage arc-over distance in air is much shorter than in a vacuum. This, of course, is only of importance where the electrode connections are all brought out at a single end, in which case the tube base may arc over before any breakdown appears within the tube envelope.

The use of high-grade insulation is rather obvious, but since it is so important a few comments are not out of order. First, insulating materials used in the construction of a tube must be of as high a quality as is consistent with good mechanical strength. Spacers and separators should show no signs of distortion under the high temperatures encountered. Since the losses increase with both temperature and frequency the insulation should be carefully chosen with these points in mind. It is surprising how much loss can be attributed to the ordinary bakelite tube base at frequencies as low as 30 megacycles.

Secondary Emission

Secondary emission is the result of high-velocity electrons emitted from the cathode striking another element with sufficient force to dislodge electrons from its surface. This type of emission, except in a few applications[1], is useless and should be made ineffective, if possible. Secondary emission is present at the plate of all tubes, however, unless another element is present which has a higher positive potential, the electrons will be attracted back to the plate and therefore have little effect on the operation of the tube. This effect is not confined to the screen or plate since it can occur at the control grid under certain conditions, particularly when the temperature is high; this is noticeable when the grid is driven highly positive so that grid current flows. The velocity of the electrons emitted from the cathode is then likely to become great enough to dislodge secondary electrons from the grid, and with high plate potentials this effect may be sufficient to cause the grid current to actually reverse thereby affecting tube operation.

Contact Potential

The fact that electrons are emitted from the cathode in the absence of an accelerating potential with sufficient velocity to carry them to the grid, accounts for the grid current observed on most tubes with zero bias applied. An illustration of this is shown in *Fig. 1*, where grid current is plotted against grid potential. This inherent grid bias is commonly referred to as contact potential, and is largely a matter of emission. Obviously an increase in cathode temperature will increase the emission and also the velocity of the electrons and thus the inherent grid bias. As the end of the tube life is approached (emission becomes weak)

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[1] Dynatron oscillator and electron-multiplier tubes.

the inherent grid bias will decrease.

With grid current present the input circuit will be loaded and normal operation will be affected. Voltages of the order of ½ to 1½ volts are likely to be encountered in normal tubes in high-resistance circuits and it is therefore advisable to operate all tubes with sufficient grid bias to accommodate the highest anticipated input voltage, plus the contact potential. Exceptions are special circuits utilizing this effect.

Tube Noise

The fact that electrons are emitted from the cathode in a random manner rather than in a continuous stream gives rise to what is known as "shot effect." It is seen that this random flow can account for a fluctuation current being superimposed on the main plate current. When this is passed through the external plate load an a-c voltage is produced which is amplified along with the signal voltage. The magnitude of the random noise voltage is ordinarily less than one part in a million as compared to the plate current; except where an oxide-coated cathode is used. In the case of an oxide-coated cathode additional noise will be present due to the irregularity of the emitting surface. The additional noise being known as the "flicker effect."

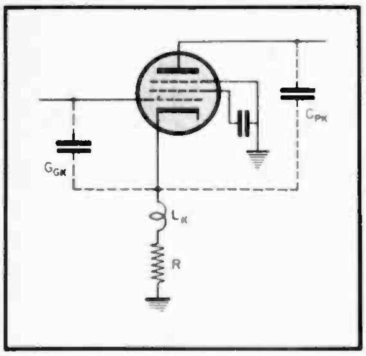


Fig. 2. Feedback path through C_{gk}-C_{pk} when cathode is ungrounded

A factor in the magnitude of the shot noise is the effect of space charge around the cathode. It is well known that when a tube is operated so that space charge exists the total available emission current does not reach the plate, in which case it can be seen that the random electron flow is appreciably reduced. It is evident then that full rated voltage should be applied to the filament to produce an abundance of electrons in order that the proportion of steady plate current to noise current is favorable. Conversely, when the emission is limited by low filament temperatures more of the electrons reach the plate and the noise current is a more substantial part of the total. When filaments are operated at 60% of the normal rating the current is limited by the emission, and space charge commences to disappear, making the noise due to shot effect increase tremendously. Incidentally, this happens in practice when the tube approaches the end of its life. Here the noise vs. filament voltage or temperature curve shifts so that the effect then occurs at normal operating voltages.

Another source of noise present in multi-element tubes is the result of random variation in the division of currents between screen and plate. When the screen current is small compared to the plate current, noise is found to be proportional to the screen current. The alignment of the screen grid with other grids helps in this respect.

Noise resulting from gas ordinarily is not a serious factor, this is the result of positive ions being attracted by the grid causing a current to flow which is opposite in direction to the usual grid current caused by signal rectification. If the grid gas current (reverse grid current) is less than a few hundredths of a microampere no trouble will be experienced.

The total electrical noise due to a tube when used as an amplifier is the algebraic sum of the separate noise voltages.

Other Causes of Noise

In addition to tube noise due to shot effect, etc., electrical or mechanical defects may set up disturbances which in many cases are serious from the noise standpoint. The physical construction of a tube requires that insulating spacers be employed to properly support the elements. If, because of distillation of metal or other conducting material during exhaust, a film is deposited on the insulating spacers which separate the elements, then a noise will be developed when any fluctuation in the resistance of the film occurs. It is not necessary that the film be continuous between elements, since the presence of a "spot" of conductive film in microphonic contact with one of the elements can create quite a disturbing noise voltage. This source of trouble can be minimized by scoring the insulator, when mica is used; or by applying a coating of some finely divided ceramic to roughen the surface, thus breaking up the resistance path.

Another source of noise is due to sliding contacts between metal parts even though they carry no current. Ordinarily all such contacts are securely welded, but unless the weld has been properly made it may become loosened during shipment and result in a noisy tube. Such tubes can be easily detected in an equipment by tapping the envelope gently and noting whether noise is produced. The noise produced will be "scratchy" and should not be confused with microphonic noise sometimes present.

Microphonic noise is definitely periodic in nature and is the result of mechanical vibration of the elements with respect to one another. Low current filament-type tubes are usually the worst offenders in this respect, although recent advances in design have considerably improved this situation by the use of additional supports for the filament and the reduction of clearances between element supports and insulating spacers. Isolation of the tube to prevent mechanical vibration from setting up disturbances is commonly used in practice. Isolation is preferably obtained by the use of suitable shock mounts on the tube socket, rather than on the entire equipment, although in many cases both are required.

Input Resistance

The input resistance of a tube is determined by two factors, one present with the cathode taking no current, the other only when cathode current is flowing. Since it is more convenient to consider the input loading in terms of conductance we will refer to the first as the "cold input inductance" and the latter as the "hot input conductance."

The cold inductance is chiefly due to the dielectric loss in the glass envelope, insulating supports and the tube base. As would be expected, it is practically the same for all tubes of similar construction, being of the order of 0.3 micromhos per megacycle in the case of ordinary receiving tubes.

The hot conductance is somewhat more complex and of dual origin. Its magnitude depends upon the physical construction and the electrode voltages. One component is due to electron transit time and the other, cathode lead inductance. At low frequencies the hot conductance is negligible (infinite resistance) but as the frequency is increased it becomes of increasing importance since it is a function of the square of the frequency. In the vicinity of 100 megacycles, with ordinary receiving tubes, the input conductance equals the normal transconductance (internal loss equals the power output) and the tube is practically useless since it will no longer amplify.

The conductance due to electron transit time is not particularly troublesome at frequencies below 10 megacycles, since in this region there is no serious loading effect on a reasonably good tuned circuit. However, as mentioned above, as the frequency is increased the effect becomes quite objectionable. The reason for this is quite apparent if one considers the time

[*Continued on page 60*]

SUPERSONIC WAVES

ARTHUR QUIRK
Engineering Dept., Harvey Radio Laboratories, Inc.

Methods of producing supersonic waves, their properties, and practical considerations in the design and characteristics of supersonic oscillator circuits are presented

★ The past quarter century has seen a fairly rapid development in the field of high-frequency sound waves, i. e., waves having frequencies above the limit of audibility of the human ear. This field has been referred to as supersonics by some investigators and as ultrasonics by others, with the majority vote probably going to the former term. It is the purpose of this article to discuss, in a broad way, the methods of producing supersonic waves, their properties and uses.

In a general way, the properties of these waves are similar to those of ordinary sound waves, with the exception that certain phenomena are observed with the high-frequency variety which do not occur with the audible type or are not observed because of limitations of apparatus. When it is realized that supersonic waves have been generated which have wave lengths of the order of magnitude of light waves, it is easy to see that the physical size of equipment for work in this field is small, and that, therefore, the effects of the waves can be determined with small samples.

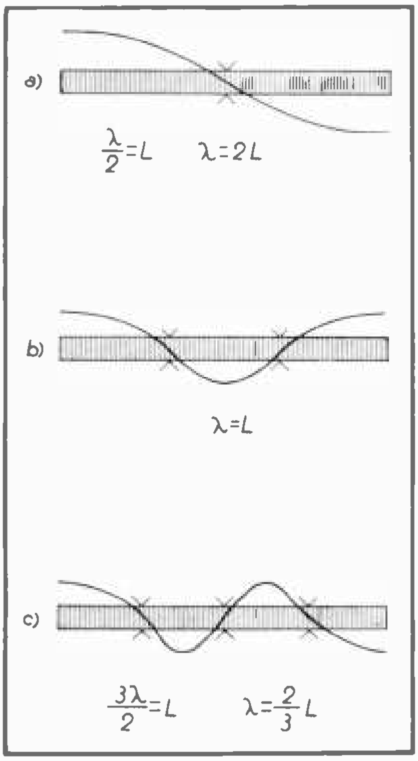


Fig. 1. By clamping the rod of a magnetostriction oscillator at various points, it may be made to produce waves of varying length, as indicated above

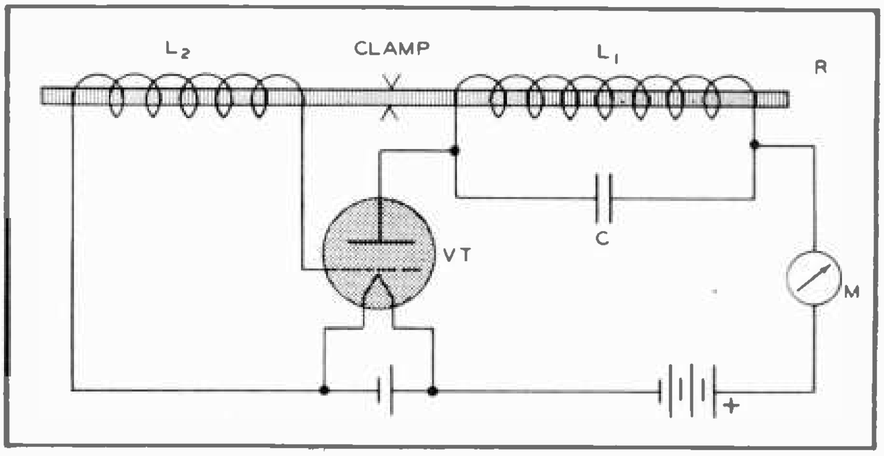


Fig. 2. Pierce magnetostriction vibrator. The rod R is clamped at its midpoint and inserted in the coils, which are large enough to permit the rod to vibrate freely

Producing Supersonic Waves

Although several investigators have produced supersonic waves by means of such devices as the electric arc and spark, specially designed whistles similar to that of Galton, the methods in use today are confined primarily to two, the magnetostriction oscillator and piezo-electric crystal oscillator. Each of these is used in a certain frequency range, and will be described in some detail.

Magnetostriction oscillators are based on an effect observed by Joule in 1847, namely, that when an iron rod is magnetized it suffers a change in length. This work was extended by others, who found that the increase in length continued until a certain critical value of the magnetizing field was reached, after which the rod began to decrease, finally to become shorter than when unmagnetized. The effect is extremely small, of the order of one part in a million. Of more interest is the behavior of nickel and its alloys such as monel and invar, which always show a decrease in length with increasing magnetic field strength.

If such a rod, previously unmagnetized, is brought into an alternating magnetic field, it will shorten twice in each cycle of the field, and therefore will vibrate with a frequency equal to twice that of the field. If the rod is premagnetized, it will vibrate with the same frequency as the field. And if resonance between the field and the natural elastic period of the rod is established, the amplitude of oscillation of the rod is a maximum and consequently, the energy radiated from the ends of the rod is also a maximum. The natural frequency of a rod vibrating in its fundamental mode is given by Newton's equation

$$f = \frac{1}{2L}\sqrt{\frac{E}{d}}$$

where L is the length of the rod, d is its density, and E is the elasticity. Rods may be clamped at various points and so vibrate at harmonics of the value obtained by use of the above equation.

In *Fig. 1a* is a rod clamped at the middle, making this point a node. Hence the two ends will be antinodes, and wave-length $\lambda = 2L$. If the rod is clamped as in *Fig. 1b,* then obviously $\lambda = L$. Clamping the rods at three points gives $\lambda = 2/3L$, and so on for higher order harmonics. As would be expected, the energy radiated from the ends of the rod is greatly reduced when operation takes place at the harmonic frequencies.

In *Fig. 2* is shown the Pierce magnetostriction vibrator. The rod R, clamped at its midpoint is inserted in the coils L_1 and L_2, both of which are large enough so that the rod may vibrate freely. The coil L_1 with condenser C_2 forms the oscillating circuit. Here is a case of magnetic feedback to maintain the oscillation for as the rod vibrates due to the changing field of coil L_1, a voltage is induced in coil L_2, which in proper phase is supplied to the grid of the vacuum tube. Here the steady plate current of the tube contributes to the premagnetization of the rod.

The Hartley Oscillator

Oscillation may be maintained in a more familiar manner as shown in *Fig. 3.* Here is the conventional parallel-feed Hartley oscillator. One end of the rod lies within the tank coil L_1. Coil L_2 is used to provide for premagnetization of the rod, and is fed from a separate battery. The clamps shown divide the rod in thirds so that vibration is in the second harmonic as in *Fig. 1b.* These are two simple means by which supersonic waves can be produced, and many alternate methods will suggest themselves.

In such vibrators which are to produce a large amount of supersonic energy, eddy current losses become serious. These may be reduced by using the rod in the form of a tube, and by cutting longitudinal slots in the tube. Success is also obtained by using nonferromagnetic materials plated with nickel. Eddy current losses are reduced to a very low value by making the rods of thin laminations of insulating material coated with nickel.

Magnetostriction oscillators have the advantages of being relatively inexpensive, simple, and of producing a large energy output, especially at the lower supersonic frequencies. A principal disadvantage is the upper frequency limit which can be conveniently reached. About 60 kc is the maximum with reasonable power output. Nevertheless magnetostriction vibrators have been designed to give a very short *effective* length to the rod so that frequencies of the order of 300 kc may be produced. A second serious defect is the fact that the elasticity of the rod is affected by the degree of magnetization of the sample. This has the effect of broadening the resonance curve. Finally, the frequency of a given sample varies with temperature.

In these rod vibrators, the supersonic energy is radiated from the ends of the rod. Emission of energy in all directions in a plane is obtained by using a circular ring which is set into vibration so that any section of the ring vibrates back and forth along a radius, so projecting the sonic energy in all directions in the plane of the ring.

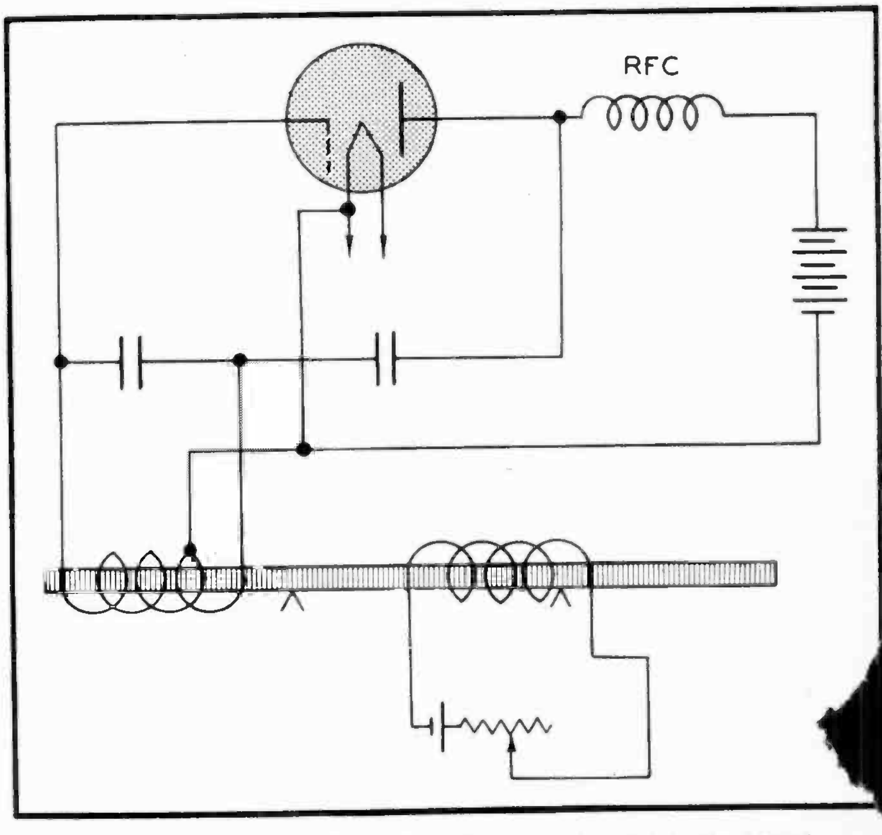


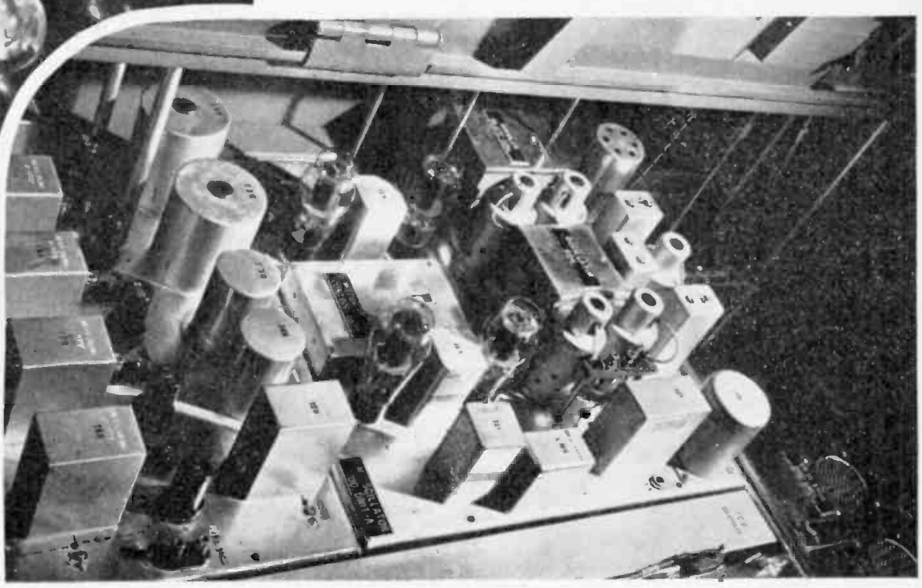
Fig. 3. Hartley oscillator. One end of the rod is inserted in the tapped tank coil; the other coil and battery are utilized to premagnetize the rod

WBAM's F-M TRANSMITTER

Oscillator modulator unit of WBAM's FM transmitter, New York City. The transmitter was developed by Bell Telephone Laboratories and manufactured by the Western Electric Company.

WBAM, affiliate of WOR, is New York's first commercial FM station.

A selection of tubes important to the operation of WBAM's 10kw FM transmitter. Group includes jacketed 389AA and 357A vacuum tubes, and six 315A rectifiers.



NEW ASA STANDARDS

★ With the aim of increasing production of radio components vitally needed by the military, the American Standards Association recently announced completion of two new American War Standards in the radio field —Power-Type Wire-Wound Rheostats and Variable Wire-Wound Resistors. Both types of resistor are used as electronic controls in power, range-finding, and aircraft equipment.

The two standards, complete with outline drawings, cover the performance requirements, test methods, standard dimensions, and standard resistance values of the quality required by the Armed Forces. Both standards include applicable specifications and drawings; classification; materials and workmanship; general and detailed requirements; methods of sampling, in-
pection and tests; and packaging,
king and marking for shipment.

main difference between these
standards is that the power-type
und rheostat can dissipate greater power in a given physical size because of a higher operating temperature. The variable wire-wound resistor, having a low-operating temperature, is chiefly employed in radio and electronic devices.

The two standards were set up by a combined committee of representatives of the radio industry and the Armed Forces, and have already been adopted by the U. S. Navy Department, Bureau of Ships, and the Signal Corps Standards Agency of the U. S. Army. It is expected that they will be used in the design of new equipment and in the preparation of new manufacturing facilities, as well as for procurement purposes.

MEG-O-MAX RESISTORS

Sprague Meg-O-Max Resistors are a new development meeting the need for high resistance value units capable of operating at high voltages and ambient temperatures, and also capable of dissipating power.

The new resistors are said to possess a degree of resistance stability and mechanical ruggedness unavailable in any other type exclusive of the costly and hard-to-get wire wound meter multipliers.

Meg-O-Max Resistors are formed of a series of pressed and sintered ring-shaped segments electrically joined in such a way as to cause the units to be non-inductive. Finished units are encased in an hermetically sealed, rugged glass envelope provided with ferrule terminals. The result is a rugged construction capable of withstanding aircraft vibration tests, salt-water immersion tests, and mechanical shocks produced by rapid acceleration.

Sprague Meg-O-Max Resistors are employed as high voltage bleeders, and as coarse accuracy meter multipliers for voltage indicators. Other present applications include use in high-voltage networks, measuring equipment, rectifier systems, high-voltage voltage dividers, and as broad accuracy meter multipliers.

Data sheet is available from the Sprague Specialties Company, Resistor Division, North Adams, Mass.

CORRECTIONS

In the schematic diagram of the "Multi-Range V-T Voltmeter," shown on page 25 of the February 1944 issue, the transformer secondary center-tap should connect to the bottom end of the 40,000-ohm resistor, instead of ground.

In Fig. *6*, page 30, of the March 1944 issue, the curve designated as a parabola should have been termed a hyperbola.

RADIO DESIGN WORKSHEET

NO. 25—USE OF SQUARE WAVES

USE OF SQUARE WAVES

The square wave is coming into wide use in the testing of both passive and active networks. Such a wave, shown in *Fig. 1,* can be represented by an infinite series of sinusoidal terms. The approximate representation of a square wave with a finite number of terms was discussed in Radio Design Worksheet, No. 15 (RADIO, July 1943, page 29). An equation representing the wave of *Fig. 1* can be written:

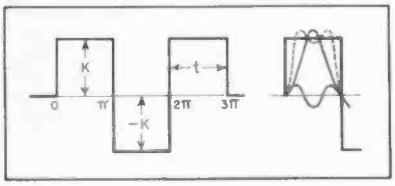


Figure 1

$$e = \frac{4E}{\pi} \sin \omega t + \frac{4E}{3\pi} \sin 3\,\omega t + \frac{4E}{5\pi} \sin 5\,\omega t + \ldots \frac{4E}{N\pi} \sin N\,\omega t$$

The ideal square wave *(Fig. 1)* rises instantly to a positive maximum, K, and then remains at constant amplitude for one-half cycle. Likewise it falls instantly to zero and beyond to —K at the end of the first half-cycle, after which the voltage amplitude remains constant at —K until the completion of the first cycle.

It has been shown that the behavior of a network to sinusoidal waves can be completely determined by a knowledge of its transient response to an abruptly steep wave front or square wave.* The wave forms of speech and television signals are complicated and contain many transients. Such a situation develops when a sudden transition from black to white takes place in scanning a television image.

It is customary to use square waves of at least two different frequencies in testing networks. One frequency should be sufficiently high to eliminate the effects of poor low-frequency response and the other of sufficiently low frequency to be substantially unaffected by high-frequency response or phase shift. The time required for a wave to reach its maximum value depends on the frequency range of the network under test. A rapid rise indicates little high frequency attenuation. The damping of the network at high frequencies is indicated by the shape of the top of the output wave. Thus, in *Fig. 2,* the output wave from one network has a flat top indicating a highly damped circuit while the other shows a wave with an irregular oscillation at the top, indicating less damping. The damping of a circuit is given by its decrement, generally expressed as

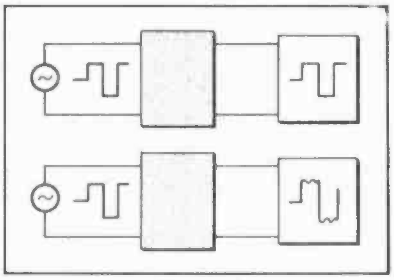


Figure 2

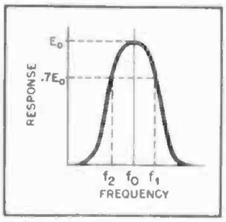


Figure 3

$$\delta = R/2\pi fL = \pi\Delta f/f_o = \pi R\ \sqrt{L/C}$$

$\Delta f = f_1 - f_2$

f_o = geometric mean frequency (*See Fig. 3*) of pass band.

Multiplying the frequency of the square wave used in the test by the number of oscillations which occur in one cycle of this output wave yields the approximate value of the natural period of oscillation of the network under test.

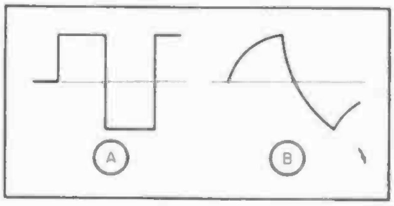


Figure 4

Thus, shift or circuit delay at high frequencies is indicated by rounding of the corners of the output square wave. Constant delay (or phase shift which is proportional to frequency) is indicated by square corners. In *Fig. 4A,* the rounded edges of the corners at the end of the voltage rise or fall indicate excessive phase shift or delay at high frequencies. This tendency may be likened to the charge and discharge of a capacitor through a resistance, which was discussed in Radio Design Worksheet, No. 18 (RADIO, October 1943, page 42). In this case the current rise was shown to be represented by the relation:

$$I = \frac{E}{R}\,\epsilon - \frac{t}{RC}$$

An output wave form for high attenuation at high frequencies and e cess delay is shown in *Fig. 4B* output wave having a train of tions at the top res having sharp

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* Transient Response of Multi-Stage Video-Frequency Amplifiers—A. V. Bedford and G. H. Fridendahl—*Proc. IRE,* Vol. 25, No. 4, April 1939.

and delay characteristics. The amplitude and duration of the wave train is a measure of the cutoff frequency.

When it is desired to investigate the low-frequency characteristics of a network, a low-frequency square wave is used. The frequency of the square wave in this case should be low enough to be noticeably affected by low-frequency cutoff. In the investigation of the low-freqency characteristics of a network a somewhat different interpretation of the shape of the output wave is required. Thus a sagging of what would normally be the maximum portion (flat top) of the output wave indicates low-frequency attenuation and excess or insufficient delay is indicated by a falling or rising tendency in the output square wave. Consequently, the output wave shown in *Fig. 5A* indicates excessive low frequency delay. The reverse of this condition shown in *Fig. 5B* indicates insufficient delay at low frequencies. The sagging characteristics of the output wave shown in *Fig. 5C* indicates low-frequency attenuation whereas the tendency of what would normally be a horizontal top to droop indicates insufficient delay at low frequencies.

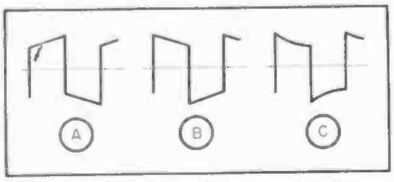


Figure 5

It is possible to relate the output wave characteristics and the frequency of the square wave to measure quantitatively the characteristics of the network under investigation. Space limitations prevent a presentation here of methods of accomplishing this but such a description will be given in a future worksheet.

Perhaps the chief use of square waves is in making adjustments to a circuit and observing their effect on the circuit characteristics. This is chiefly a function of the design engineer. However, as indicated above, square waves can be used to advantage in detecting maladjustment if the desired characteristics of the circuit re known. As a result, their use to equipment is becoming more im-
t.

CIRCUITS

of the series
g. 6 is

$$X = 2\pi fL - \frac{1}{2\pi fc}$$

and the effective impedance is

$$Z = \sqrt{R^2 + X^2}$$

At resonance, the inductive and capacitive reactances are equal in magnitude and opposite in phase so the reactance vanishes, leaving

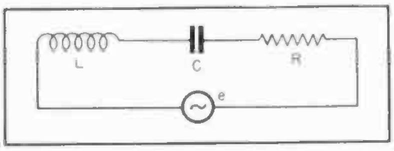


Figure 6

$$Z = \sqrt{R^2} = R$$

Thus, at resonance

$$I_R = \frac{e}{R}$$

At these frequencies

$$I = \frac{e}{\sqrt{R^2 + X^2}}$$

Let

$$A = \frac{I}{I_R} = \frac{R}{\sqrt{R^2 + X^2}} = \frac{1}{\sqrt{1 + \tan^2\theta}}$$

Where θ is the phase angle between I and I_R.
Then:

$$\theta = I \tan^{-1} \frac{\sqrt{1 - A^2}}{A}$$

Frequency Modulation

A sinusoidal wave may be modulated by operating on any one of the three parameters of the generalized wave $A \cos(\omega t + \theta)$, namely, amplitude, phase, and frequency. The common expression for a frequency-modulated wave is

$$\begin{aligned} I = A\, [J_o\, M \sin \omega t + J_1\, M] \\ \{\sin (\omega + p)t - \sin (\omega - p)t\} + \\ J_2\, M\, \{\sin (\omega - 2p)t - \\ \sin (\omega + 2p)t\} + \ldots\ldots \end{aligned}$$

where A is the amplitude of the original carrier wave and p is 2 times the frequency of the modulating signal. The J's are Bessel functions of the first kind and of the order indicated by the subscript. The quantity M represents the variation of frequency of the carrier from the unmodulated mean value, divided by the modulating signal frequency. Thus

$$M = \frac{\Delta f}{F}$$

where

$$f = \frac{\omega}{2\pi} \text{ and } F = \frac{p}{2\pi}$$

The quantity M is frequently called the modulation index, and may be compared in certain respects to percentage modulation of an amplitude-modulated wave. The modulation index may frequently exceed unity, whereas percentage modulation cannot exceed unity without serious distortion. From the equation above, it is obvious that a frequency-modulated wave may contain an infinite number of symmetrical pairs of side frequencies.

If the modulation index is less than unity, the amplitude of the first pair of side frequencies will be approximately proportional to M, while the amplitude of the higher order side frequencies will be very small. When the modulation index exceeds unity, the higher order side frequencies become of more importance because they will carry more energy, while the amplitude of the carrier will decrease.

In a frequency-modulated wave, the extent of the frequency deviation is proportional to the amplitude of the modulating signal. Consequently, two modulating signals of 500 and 5000 cycles frequency but identical amplitude, acting individually, would produce identical frequency deviations. Contrast this with a phase-modulated wave in which the 5000-cycle signal would produce 10 times the phase change of the 500-cycle signal.

The relative phase of the carrier in a frequency-modulated wave is in quadrature with the carrier of an amplitude-modulated wave; phase in both cases being relative to side frequencies. Consequently, interfering amplitude-modulated signals are much attenuated in FM systems. This is one of the outstanding advantages of frequency modulation over amplitude modulation.

There are three important fundamental differences between amplitude- and frequency-modulated waves. For example, for a single modulating signal frequency there are but two side frequencies in an amplitude-modulated wave in comparison with a number of energy-bearing side frequencies in a frequency-modulated wave. The energy in the side frequencies adjacent to the carrier of a frequency-modulated wave may be negligible compared to higher order side frequencies. Again, the amplitude of the side frequencies in an amplitude-modulated wave can never be greater than half the carrier amplitude without serious distortion resulting, whereas in FM the amplitude of side frequencies can materially exceed that of the carrier.

New Products

"SALAD-BOWL" SPEAKER

A new speaker has been designed by Bell Telephone Laboratories and is now being produced by the Western Electric Company. This high powered unit, sometimes called the "salad bowl" because of its shape, has passed the rigid Navy tests to insure reliable operation.

Designed for speech reproduction, this speaker has an outside diameter of 12½ inches and weighs approximately 25 pounds. The unit is composed of three principal sections: the base, which provides space for a transformer, and a terminal strip, and provisions for the lead-in cable; the horn, which is of the folded exponential type; and the magnetic unit which is fitted with a two-piece permanent magnet, and diaphragm. The loudspeaker is constructed principally from formed sheet steel and moulded plastic.

The voice coil impedance of the unit is approximately 7.5 ohms. The speaker develops the high sound pressure of 50 dynes per square centimeter when operated at the rated electrical input and measured at 10 feet from the speaker on the sound axis in open air.

NEW MEGOHM METER

Essentially a direct-reading ohmmeter but incorporating a vacuum-tube voltmeter in order to cover relatively high resistance values, Model L-2 Megohm Meter announced by Industrial Instruments, Inc., 156 Culver Ave., Jersey City, N. J., offers several new features for this type of instrument. In addition to laboratory usage, especially for checking leakage resistance of cables and insulating materials, locating defective insulation in equipment, and measuring carbon resistors, it is readily adaptable to production testing, particularly of radio condensers.

Entirely self-contained, it operates on 110-volt 60 cycle a.c. Arrangements are provided for the rapid charging of condensers under test. An external battery voltage supply may be used where voltages other than the self-contained 200-volt supply, are desired. The instrument may be satisfactorily operated with external voltages up to 1000.

Internal resistance standards enable the operator to check calibration and make compensating adjustments when necessary. Full length of scale is 3¾" with less crowding at high-resistance end than is usual in such an instrument. Using the internal 200-volt supply, maximum range extends from 1 megohm to 100,000 megohms in four overlapping ranges but can be extended to 500,000 megohms with an external 1000-volt supply. Maximum resistance in series with condenser or insulation under test is only 1 megohm. This assures practically constant voltage across

[Continued on next page]

NEW ELECTRON MICROSCOPE

One of a small quantity of General Electric simplified electron microscopes is shown. These will soon be shipped on high priority orders to industrial laboratories and colleges to obtain experience on the use of the simplified units in various fields.

Component parts of the microscope are the same as those announced when General Electric demonstrated a "war model" of the microscope at the National Chemical Exposition in Chicago more than a year ago. The new instruments, however, are now "housed" in a desk design for convenience of operation.

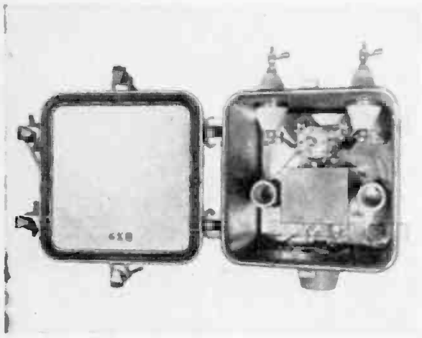
These G.E. microscopes operate on ordinary house current, are capable of producing images 10,000 times the size of the specimen and are approximately ten times more powerful than the best light microscope.

New Products

test terminals and minimizes the effect of tube ground current. Stability is assured by balanced tube circuit and voltage regulators in the internal power supply. The Model L-2 Megohm Meter measures 10" h. x 8" w. x 15" deep, and weighs 10 lbs.

NEW ANTENNA TRANSFORMER

The Andrew Company, of 363 East 75th St., Chicago, announces a new antenna transformer unit to couple an unbalanced 70-ohm co-axial cable transmission line to the 700-ohm terminals of a rhombic receiving antenna (or to any antenna terminal stub of 700-ohm impedance). The efficiency of the equipment holds losses down to less than 1 decibel over a frequency range of from 4 to 22 megacycles.



The transformer unit is designed for out-of-doors installation as close to the antenna terminals as possible; and it is housed entirely within a weather-proof cabinet with a water-tight cover.

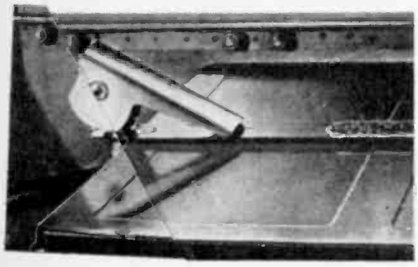
Circuit design of the transformer unit provides for simple d-c continuity checking throughout the whole length of the antenna from the coaxial cable input terminal position, thereby facilitating antenna inspection and maintenance. The unusually broad frequency response is achieved by close coupling and by powdered-iron transformer cores of high permeability.

Further information for interested engineers is available from the manufacturer.

BATTERY HOLD-DOWN CLAMP

This new patented Battery Hold-Down Clamp has been developed by The Paul Henry Company, 2037 South La Cienega Boulevard, Los Angeles 34, California.

The new clamp was designed to alleviate e difficulties encountered in removing or changing batteries under extreme climatic conditions, or where the element of time saving is important.



The clamp replaces the two wing nuts, and by the use of the clamp, in which is incorporated a cam action, all safety wiring is eliminated. The positive locking action is obtained from the pressure exerted on the cam. Distinctive features of the clamp are that it is obtainable with various nut sizes and screws into present battery boxes. The cam lever is easily released manually.

Approval for the installation of this equipment has been granted by the Army Air Force, Materiel Command, Wright Field.

PORTABLE D-C POWER SUPPLY

This portable d-c power supply, manufactured by P. R. Mallory & Co., Inc., Indianapolis, Indiana, is designed for use on assembly lines, in laboratories and maintenance departments.

It provides a source of portable d-c power for manufacturing, testing and operating all electrical and electronic equipment in aircraft and other units employing 12 or 24 volt systems. The power supply can also be used to taper charge batteries or battery carts of similar voltages.

The unit is designed to operate from 3-phase a-c lines of 208 and 230 volts. Three models are offered: No. VA1500, with d-c output of 10 to 16 volts at 100 amperes or 20 to 32 volts at 50 amperes; No. VA3000, with d-c output of 10 to 16 volts at 200 amperes or 20 to 32 volts at 100 amperes; No. VA4500, with d-c output of 10 to 16 volts at 300 amperes or 20 to 32 volts at 150 amperes. Models with similar d-c output but for operation on 460 volts a-c, are also available.

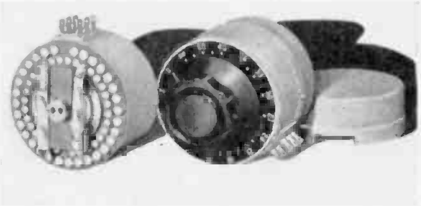
Rectification is provided by Mallory Magnesium-Copper Sulphide Dry Disc Rectifiers.

NEW ATTENUATOR

An improved line of attenuators, featuring a new detent gear, new materials and new type steel cover, has just been announced by The Daven Company, 191 Central Avenue, Newark 4, New Jersey.

The new Daven detent gear provides more positive action, greater degree of accuracy, more uniformity in operation, longer life and a stronger stop mechanism.

Contacts and switches of these attenuators are made of tarnish-proof silver alloy, giving uniform and definite electrical contact. It should be of interest to note that the cleaning and lubricating of the contact points are now completely eliminated.



The new type steel cover provides improved magnetic shielding. The body of the cover forms an integral part of the attenuator assembly, protecting the resistors. A snap-on cap gives ready access to switch blades and contacts.

KELVIN-WHEATSTONE BRIDGE

Combining both Kelvin and Wheatstone bridges, the Shallcross Type 638-2 Bridge provides a resistance measurement instrument having range of from 0,0001 ohms to 11.11 megohms in a single, portable unit. The convenience of being able to make practically all resistance measurements with one instrument makes this bridge useful for laboratory and school use, maintenance work, many forms of production line testing, and field investigations.

When used as a Wheatstone bridge for measurements between 1 ohm and 1 meg-

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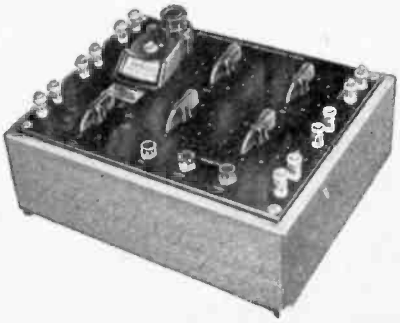

ECHOPHONE MODEL EC-1

(Illustrated) a compact communications receiver with every necessary feature for good reception. Covers from 550 kc. to 30 mc. on 3 bands. Electrical bandspread on all bands. Six tubes. Self-contained speaker 115-125 volts AC or DC.

ECHOPHONE RADIO CO., 540 N. MICHIGAN AVE., CHICAGO 11, ILLINOIS

This Month

CROSS-BOW DRAWS QUARTZ

The cross-bow is being used by Westinghouse research engineers as a helpmate to the electron microscope.

Fashioned from tough, flexible steel and mounted on a wooden stock, the cross-bow shoots an arrow that draws out quartz filaments 1/30,000th of an inch in diameter which are used to calibrate the magnifying power of the electron microscope.

To make such a very delicate thread, according to Dr. Alois Langer of the Westinghouse Research Laboratories, requires a high initial burst of speed that "spins out" the quartz while it is in a hot, fluid state and before it has a chance to cool and harden. The cross-bow is about the simplest and most efficient instrument for doing this.

Some of the filaments drawn by the bow are so delicate that they are invisible to the naked eye when viewed under direct light, the engineer reported. In order to be seen they must be held at eye-level against a strong light. The light glances off the shiny filament, scattering its rays in different directions and making the filament appear much larger than it actually is.

When the Westinghouse engineer wants to replenish his supply of filaments, he places the cross-bow in firing position and attaches a small, cylindrical piece of quartz to the end of the arrow. Using a very hot flame from an oxy-hydrogen torch, he heats the quartz until it is just about to melt.

Then he pulls the trigger. The arrow darts from the bow at high speed, trailing behind it gossamer-like threads of quartz. Unbroken pieces up to 20 feet in length are not unusual, but more often the filaments are dispersed in smaller sections throughout the route the arrow takes. They are extremely flexible and can be wound round the finger like thread.

To measure the actual thickness of the filament, it is first put under the electron microscope and gauged by other methods of comparison. Once its diameter has been fixed accurately, it becomes a "measuring stick" for determining the magnifying power of the electron microscope.

FRANK R. DEAKINS NAMED HEAD OF RCA-VICTOR CANADA

Frank R. Deakins has been named President of RCA Victor Company, Ltd., of Canada, a wholly owned subsidiary of the Radio Corporation of America.

Mr. Deakins rejoins the Canadian company in which he held the position of executive vice president from 1932 to 1934. He will direct the activities of more than 3,300 employees employed in the manufacture of radio and electronic equipment for the wartime needs of the Canadian government.

Mr. Deakins first became associated with the radio industry when he was with the General Electric Company. He rose to become the sales manager of the radio department. He joined RCA in 1930 as assistant to the president when RCA began to manufacture its own radio and electronic equipment.

Frank R. Deakins

He was made manager of RCA's Engineering Products Division in 1931 and the next year joined RCA Victor Limited of Canada as executive vice president. He returned to RCA Victor, Camden, in 1934 to become manager of the special apparatus division. Since the entry of the United States into the World War, Mr. Deakins has been executive assistant to the general manager.

SPRAGUE SPECIALTIES COMPANY CHANGES NAME

Without changing ownership or management Sprague Electric Company is now the official name of the Sprague Specialties Company of North Adams, Mass., nationally known designers and manufacturers of Sprague Condensers, Koolohm Resistors, Power Factor Control Equipment and other important electrical components.

Believing that for some time past the word "Specialties" has not adequately indicated the nature of its business, the company has made this change and sent formal notification to suppliers, customers and others.

[*Continued on page 42*]

REA

MAGNET WIRE HEADQUARTERS

BARE AND ALL INSULATIONS

SILK COTTON
PAPER FORMVAR
ENAMELED

REA MAGNET WIRE COMPANY
FORT WAYNE, INDIANA

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This Month

RMA CONFERENCE

The second War Production Conference of RMA, in connection with the Association's twentieth annual membership meeting, has been planned for June 6-7, at the Stevens Hotel, Chicago. War production will be the keynote of the industry meeting, including all RMA Divisions and committees, but streamlined to meet war conditions. There will be no exhibits or meetings for jobbers or dealers, and no banquet or other social features.

President Paul V. Galvin of RMA will preside at the Association membership luncheon on June 7, under the program arranged by Chairman A. S. Wells of the Convention Committee. A prominent government official is being invited as the guest speaker.

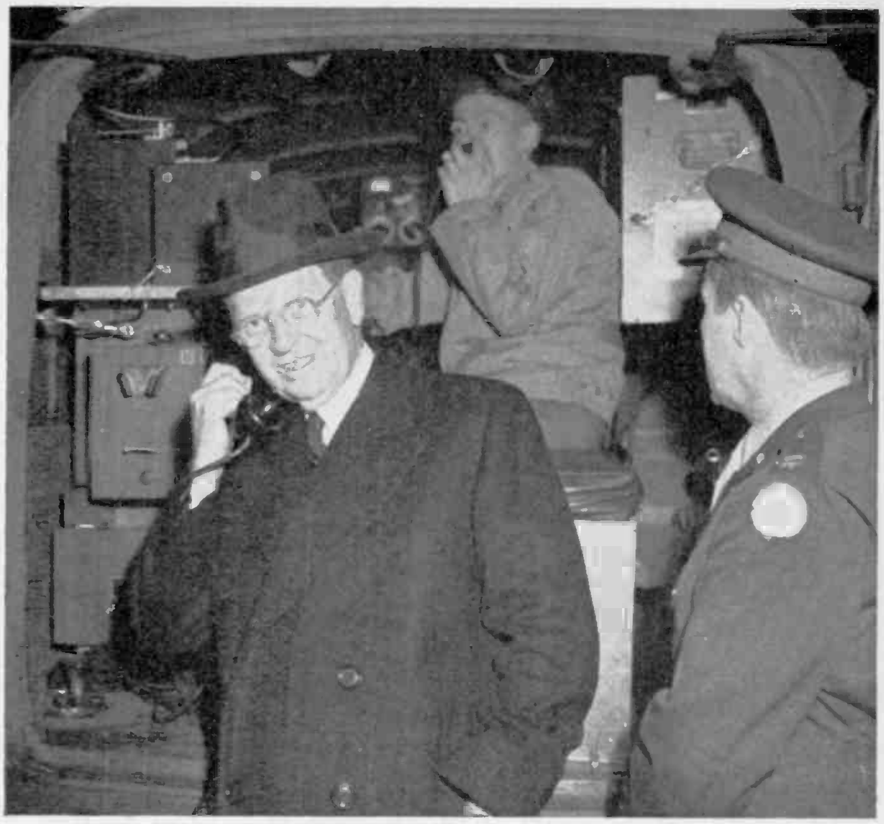
New officers and directors of RMA will be elected at meetings of the Association's Board of Directors and its Set, Tube, Transmitter, Parts, Amplifier and Sound Equipment Divisions. Committee meetings will be held on the first day of the conference, with an informal luncheon for committee members in attendance, with the annual industry luncheon being held the following day, June 7.

NEW MALLORY V-P

John M. Smith, General Manager of Manufacturing for the RCA-Victor Division of Radio Corporation of America, has resigned to join P. R. Mallory & Co., Inc., Indianapolis, Ind. as Vice-President in Charge of Manufacturing.

John M. Smith

Mr. Smith has been associated with the Radio Corporation of America for the past fourteen years. Prior to that time he was engaged for sixteen years in manufacturing activities with the Incandescent Lamp Divison of the General Electric Co., Nela Park, Cleveland.



Mayor Edward J. Kelly of Chicago inspects the Hallicrafters Company's famed SCR-299 unit.

LEAR APPOINTS RADIO HEAD

William P. Lear, president of Lear Avia Inc., manufacturers of radio and aircraft equipment, of Piqua, Ohio and Grand Rapids, Michigan, has announced the appointment of Elmer R. Crane of Washington, D. C. as general manager of the Radio Division of the company. Mr. Crane will make his headquarters in Grand Rapids, where radio production by Lear Avia is being centralized.

Elmer C. Crane

Elmer R. Crane is well known among radio engineers. After eighteen years with Western Electric, he spent two years in Washington, with the Radio and Radar Division of the War Production Board, from which he retired to join Lear Avia. As head of the Products and Facilities Branch of WPB, he handled problems dealing with the production of radio and radar prime equipment and components for the military services.

The appointment of Mr. Crane by Lear Avia marks the start of expanded radio production under the personal guidance of Mr. Lear. Radio production will be centered at Grand Rapids; radio research and development will remain in Lear Avia's New York laboratories.

UNIVERSAL NOTES

The Universal Microphone Company, Inglewood, Cal., has issued a bulletin to sub-contractors discontinuing three of its wartime catalogue items, viz., jacks, plugs and switches.

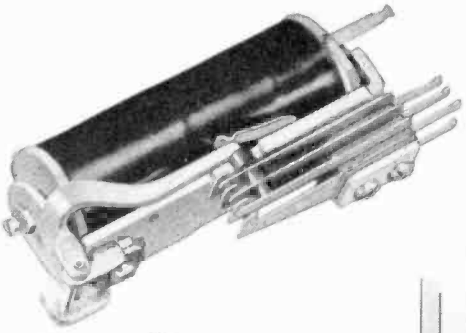
Small quantities, however, will continue to be available to jobbers on priorities until the present stock is depleted.

The discontinuance of these items was necessary because current prime contracts for microphones have absorbed the manufacturing facilities of jacks, plugs and switches into 1945.

The first jobbers' edition of *Micro Topics*, an eight page issue, contains articles on past and present production of microphones as well as general trade information. It will be issued at frequent

[*Continued on page 52*]

Breakdown Tests Give New slants on Insulation



IN special test rooms like this, Automatic Electric relays undergo insulation breakdown tests under extremely high voltage. From long study of such tests, Automatic Electric engineers have developed effective safeguards against high potentials in actual service.

* * *

When war uses of electrical control equipment focused attention on the need for improved insulation, Automatic Electric engineers were well prepared. For insulation technique is a factor in relay design to which they had already given long study. Today, improved methods to meet wartime needs have not only improved the performance of war equipment, but also will add to dependability of peacetime designs.

Similar studies are constantly being made of spring design, contact materials and pressures, magnetic circuits, finishes and coil designs. The resulting experience is one basic reason why Automatic Electric relays perform so dependably under tough conditions.

You can take advantage of this background by calling in the Automatic Electric field engineer. A specialist in electrical control, he works daily with designers of war products, and will be glad to work with *you* in selecting the apparatus best suited to your needs.

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[*Continued on page 46*]

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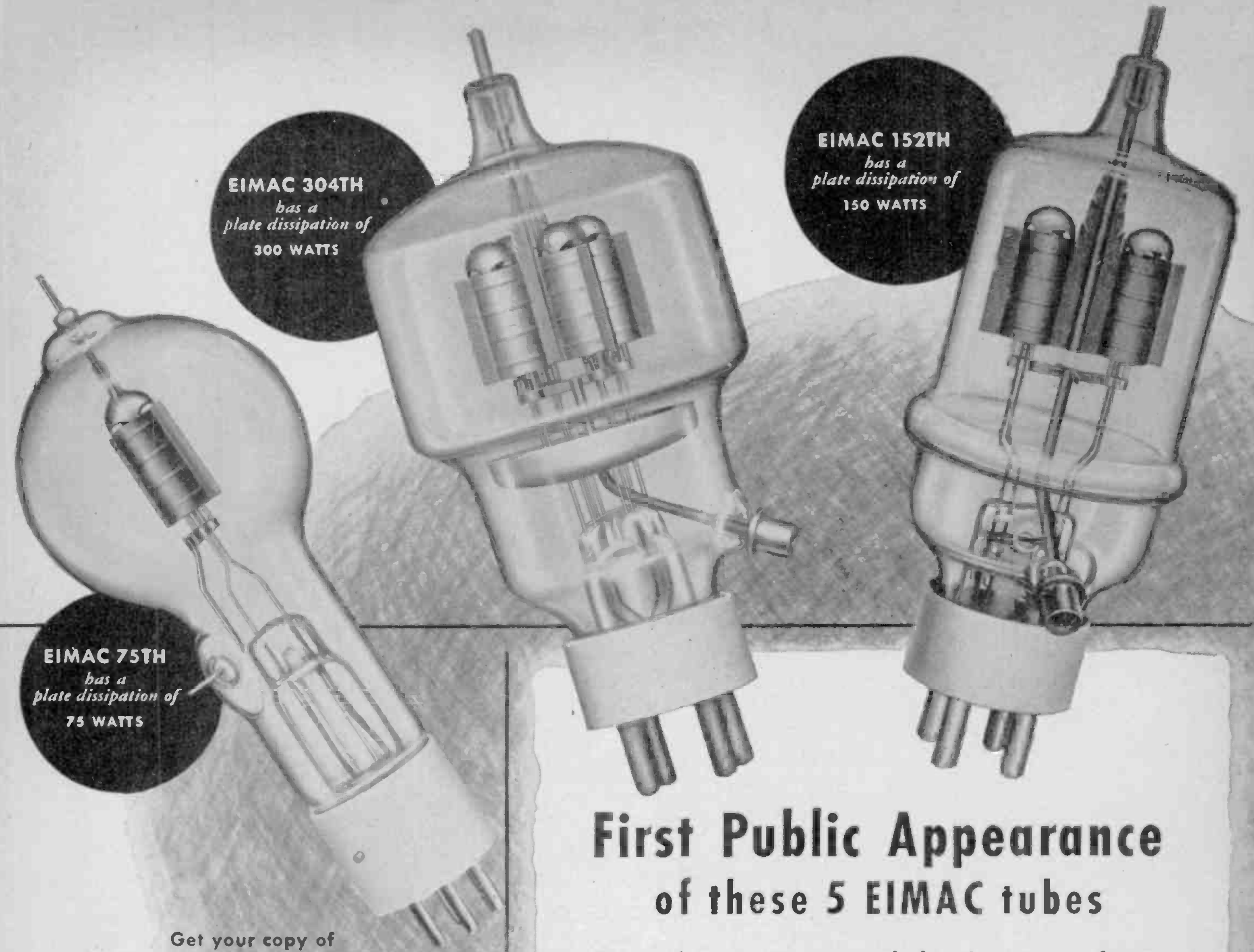

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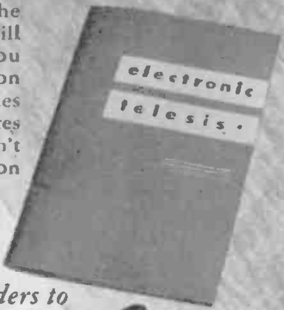

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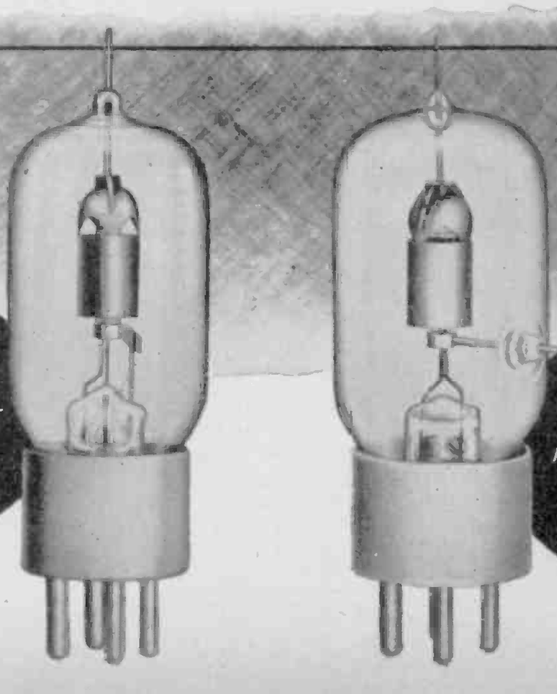

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[*Continued on page 50*]

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[*Conclusion*]

"MANPOWER, MUSIC AND MORALE"

A plan for helping personnel relations achieve more effective personal relations in war production activities is outlined in a booklet just published by the RCA Industrial and Sound Department.

A well planned blending of manpower, music and morale is discussed in a pictorial round-the-clock exposition. It shows how an internal broadcasting system is a direct communication line to each employee, and how plant broadcasting helps build and maintain good morale, saves valuable time, simplifies plant administration, improves productive efficiency and creates good will.

The booklet, titled "Manpower, Music and Morale," describes, among other things, a new type of pre-installation service—a scientific sound survey by expert RCA engineers. Among features which are carefully explained are RCA's industrial music library service, a proposed training program available for plant broadcasting system directors, and details of planned psychological surveys to study employee reaction to music in industry.

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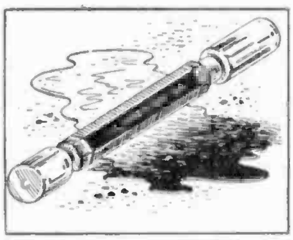

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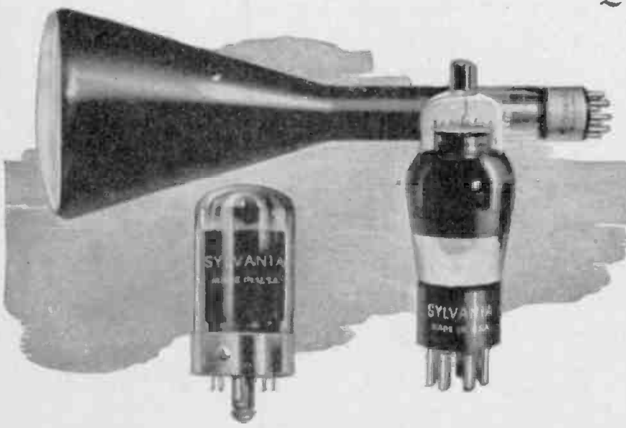

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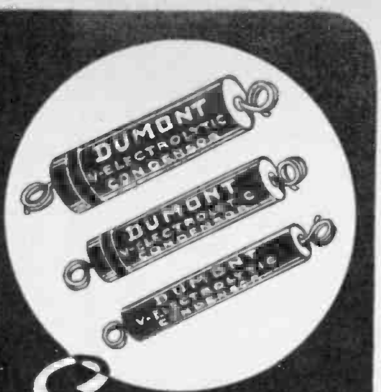

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[*Continued from page 42*]

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Micro Topics is now on its second year of publication as a bi-weekly employees' journal. The jobbers' edition will be separate and distinct from the house organ.

Editorial supervision will be under Dr. Ralph L. Power, Los Angeles radio counsellor. Mailing will be to jobbers and to others in the electronics field who request the edition.

SKILLIN MADE V.P.

Mr. Harold W. Harwell, President of Great American Industries, Inc., Meriden, Connecticut, announces the appointment of *Mr. Walter F. Skillin* as vice-president of the corporation. Mr. Skillin, formerly chief engineer for Chandler-Evans Division of Niles-Bement-Pond Company, South Meriden, Connecticut, assumed his new post February 1, and will be located at the general offices of the corporation in Meriden, Connecticut.

FACTS ABOUT PLASTICS

A new, twenty-four page, non-technical booklet covering all types of plastics, their uses, and general information on the plastics industry has just been released by The Richardson Company, Melrose Park, Illinois.

This illustrated book explains the host of properties which fit Insurok and other plastics to the wide range of present and postwar uses. The limitations of plastics are also covered.

The two main groupings of plastics, thermosetting and thermoplastic, are described and illustrated in layman's language. Special sections are devoted to the forms of plastics, laminated and molded. The manufacturing and production processes of each are well illustrated.

The book is designed primarily for the non-technical man who may be serving on his company's postwar product committee and is desirous of obtaining a general knowledge of plastics and their applications. Copies are available only to those who write for them on their company letterhead to: The Richardson Company, Department 100, Melrose Park, Illinois.

G.E. APPOINTS WILLIAMS

E. E. Williams has been appointed Sales Manager of the Laboratory and Measuring Equipment Section of the General Electric Specialty Division, which is a part of the company's Electronics Department. Mr. Williams will have his headquarters at Schenectady.

In his new capacity, Mr. Williams will be responsible for the sale of laboratory, electronic measuring and test equipment, and will continue in charge of certain military radio subcontracts.

TUTTLE TRANSFERRED

James Tuttle, former manager of RCA Victor Distributing Corporation of Chicago, has transferred to the general purchasing department of the RCA Victor Division. According to Fred Wilson, General Purchasing Director, Mr. Tuttle becomes a field procurement specialist operating out of Chicago headquarters.

WILLIAMS TO WAR WORK

J. M. Williams, RCA Victor's Record Advertising Director, has transferred to an important war work assignment with the Company. He will resume his direction of the Company's record advertising when the new assignment is completed. In the meantime, *J. L. Hallstrom* will direct RCA Victor's record advertising and sales promotional activities, in addition to retaining his duties as record Merchandise Manager.

G. E. NAMES BENNETT

Howard W. Bennett has been made Manager of the Specialty Division of the General Electric Company's Electronics Department, according to an announcement by Dr. W. R. G. Baker, Vice President in charge of the department. In this capacity, Mr. Bennett will be responsible for the engineering, manufacturing, and sales operations of that division.

Howard W. Bennett

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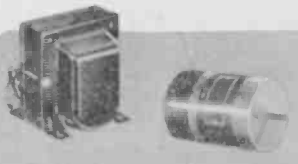

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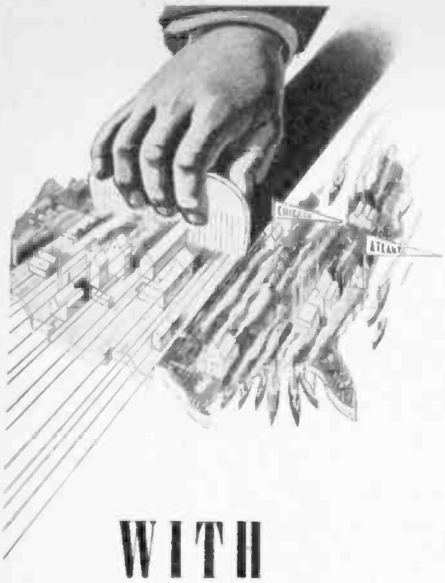


WITH A FINE COMB

Ever vigilant, Lafayette Radio Corporation's tracers fine-comb the field for radio and electronic components and equipment. We deal only with top-flight manufacturers, so quality and performance are assured. And the accent throughout is on Service. Wherever possible, same-day deliveries are maintained. If technical and priority problems perplex you—we've got 25 years of experience behind us to help pull you through. Call, write, wire, or teletype—either to Chicago or Atlanta. Orders, in any quantities, filled from both cities. Note: we build equipment to specifications.

Write or wire Dept. F-5 for our new 8 page circular listing merchandise available for immediate delivery. All of this material is subject to prior sale.

If you live in or near one of the 35 blood bank center cities, call the Red Cross today for an appointment . . . . your blood is needed.

Lafayette Radio Corp.

901 W. Jackson Blvd.
CHICAGO 7, ILLINOIS

265 Peachtree Street
ATLANTA 3, GEORGIA

New Products

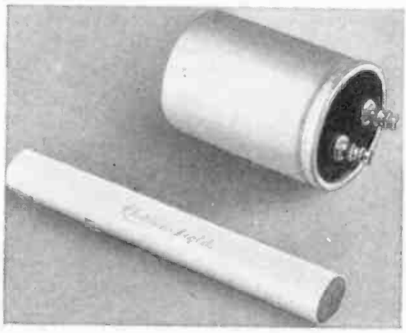
[*Continued from page 38*]

ohm, normal accuracy is 0.3% or better. Low-resistance measurements using the Kelvin range utilize current and potential terminals to eliminate lead and contact resistance. The accuracy of Kelvin measurements at ranges lower than 0.1 ohm is on the order of 3%. The rheostat is variable in steps of 1 ohm for Wheatstone bridge measurements, and 1 micro-ohm for Kelvin bridge measurements. Separate keys are provided for the battery and galvanometer circuit. Accuracy of component resistors is 0.1% except the 1 ohm resistors which have an accuracy of 0.25%. Built-in galvanometer has a sensitivity of 0.25 microamperes from millimeter deflection.

Full details will be sent on request to the Shallcross Manufacturing Company, Jackson & Pusey Avenues, Collingsdale, Pa.

MIDGET TRANSFORMER

A transformer that compares in size with an ordinary cigarette has just been announced by the Acme Electric & Manufacturing Co. of Cuba, New York, for certain electronic applications. This transformer in an aluminum case is only one inch in diameter and 1-7/16" in height overall. The weight is approximately 2 ounces. Rated at 1.4 henries at 0.25 amperes direct current, with a resistance value of 100 ohms.



V-T VOLT OHMMEGGOR

Radio City Products Model 665 provides insulation testing at 500 volts up to 10,000,000,000 ohms (10,000 megohms) with two other unique features—a comprehensive electronic multitester, and a capacity meter measuring from 0.0000025 to 2,000 mf.

The V.T. Volt Ohmmeggor Insulation Tester Model 665 includes a VR-105-30 voltage regulator tube and its associated circuits, 13 a.c. and d.c. voltage scales, measuring from a fraction of a volt to 6,000 volts, with 29 ranges.

The instrument is direct reading—complete, ready to operate—with high voltage test leads, r.f. lead; signal-tracing probe. Vacuum tube voltmeter on all ranges—input resistance 16 megohms maximum. V.T. Ohmmeter—7 ranges to 1,000 megohms.

Model 665 is described in further detail in the new RCP Catalog No. 128, available on request to Radio City Products Company, Inc., 127 West 26th St., New York 1, N. Y.

CE-29 PHOTOTUBE

Continental Electric Company, Geneva, Illinois, announce the production of a new improved type of blue sensitive phototube using an octal five-pin base, interchangeable with similar tubes produced by other manufacturers. This tube is dimensionally similar to the CE-30 which was introduced a few months ago and which has become very popular in industry. With these two tubes, it is, therefore, possible to convert an equipment from being red-sensitive to blue-sensitive and vice versa by simply interchanging the phototube.

The CE-29 is of short, sturdy, construction and is particularly sensitive to blue and violet light near the short wave-length limit of visibility. It is, therefore, particularly useful with light sources rich in violet, blue, and green light. In many ap-

[*Continued on page 56*]

COAXIAL CABLES

ANDREW Coaxial Cables for the famous HALLICRAFTERS SCR-299

ANDREW Coaxial Cables are standard equipment on the Hallicrafters-built SCR-299: the mobile communications unit that is doing such an outstanding job on the fighting fronts. It is highly significant that ANDREW Coaxial Cables were chosen as a component of this superb communications unit.

The Andrew Company is a pioneer manufacturer of coaxial cables and accessories. The facilities of the Engineering Department are available to users of radio transmission equipment.

ANDREW
ANDREW CO.

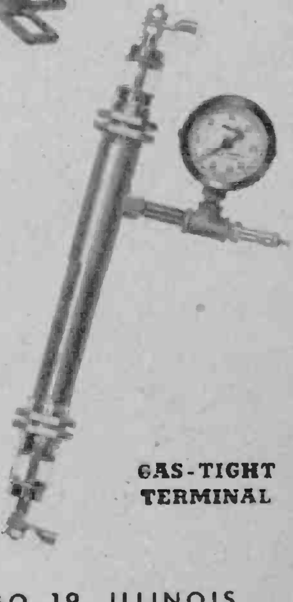
DRY AIR PUMP

COAXIAL CABLES. The Andrew Company is now able to supply standard 70 ohm 7/8" soft temper coaxial cable in lengths up to 4,000 feet! The cable is electrically identical to rigid cables of equal size, but has these extra advantages: the cable may be uncoiled and bent by hand, thus greatly simplifying installation; no connectors, junction boxes or expansion fittings need be installed in the field; thus a big saving is made in installation time and labor.

DRY AIR PUMP. This hand-operated pump quickly, efficiently and economically dehydrates the air inside coaxial cables, in addition to having a multitude of other applications. It dries about 170 cubic ft. of free air, reducing humidity from 60% to 10%.

GAS-TIGHT TERMINAL. The new Andrew glass insulated terminal is an outstanding development that provides a 100% air-tight, gas-tight system for gas filled coaxial cables. A special design that minimizes shunt capacity makes this terminal ideally suited to high frequency operation.

COAXIAL ANTENNA. Suitable for fixed station use and pretuned at the factory to the desired operating frequency, the Andrew type 899 vertical coaxial antenna provides an efficient, easy-to-install, and inexpensive half-wave radiator in the frequency range from 30 to 200 MC. Careful engineering has utilized to the utmost the well known advantages of the coaxial antenna over other types of vertical half-wave antennas.



GAS-TIGHT TERMINAL

CATALOG DESCRIBING COAXIAL CABLES AND ACCESSORIES FREE ON REQUEST.
WRITE FOR INFORMATION ON ANTENNAS AND TUNING AND PHASING EQUIPMENT.

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KEY TO
Laboratory Standards

Standard Signal Generators
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Square Wave Generators
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U. H. F. Noisemeters
•
Pulse Generators
•
Moisture Meters
•

MEASUREMENTS CORPORATION
BOONTON, NEW JERSEY

New Products

[*Continued from page 54*]

plications this tube will possess advantages even with light sources which produce considerable red and infra-red light. Though the CE-29 is not sensitive to red and infra-red light, its basic sensitivity on an energy basis is at least ten times that of conventional red-sensitive phototubes. RMA spectral sensitivity designation is S-4. Several other types with different dimensions will be available in the near future.

Complete technical data is given in Bulletin #PC15 which will be sent on request.

MULTI-SOCKET WRENCH

Having the same approximate dimensions as a single socket wrench and with very little additional weight, the new Tesco Multi-Socket Wrench automatically accommodates #10 standard, #12 standard, ¼" standard and light, and 5/16" light hexagon nuts. Merely by pressing the wrench over any of the three sizes of nuts automatically selects the proper nested hexagonal tube suited to that particular nut.

By no means a "gadget," the Tesco Socket Wrench is specifically designed for heavy duty service. Its design is such that any stress incident to turning a nut is transferred to the outer hardened-steel casing. It is also designed to provide a clearance through the barrel for studs up to 5½" length, thus making it adaptable to turning nuts on long studs. Both handle and barrel have moulded insulation capable of withstanding a dielectric test for one minute at 5,000 volts rms.

The wrench is practically unbreakable, the handle being a die cast aluminum member pressure-moulded to the hexagon steel barrel.

Descriptive literature will gladly be sent on request to the manufacturer, The Eastern Specialty Company, 3617-19 North 8th St., Philadelphia, Pa.

FACTS ABOUT PLASTICS

A new, twenty-four page, non-technical booklet covering all types of plastics, their uses, and general information on the plastics industry has just been released by The Richardson Company, Melrose Park, Illinois.

This illustrated book explains the host of properties which fit Insurok and other plastics to the wide range of present and postwar uses. The limitations of plastics are also covered.

The two main groupings of plastics, thermosetting and thermoplastic, are described and illustrated in layman's language. Special sections are devoted to the forms of plastics, laminated and molded. The manufacturing and production processes of each are well illustrated.

The book is designed primarily for the non-technical man who may be serving on his company's post-war product committee and is desirous of obtaining a general knowledge of plastics and their applications. Copies are available only to those who write for them on their company letterhead to: The Richardson Company, Department 100, Melrose Park, Illinois.

Orrin E. Dunlap, Jr., recently appointed director of advertising and publicity for the Radio Corporation of America

Horton H. Heath, who has been named assistant to the vice-president and general manager of the Nat'l B'casting Co.

TECHNICANA

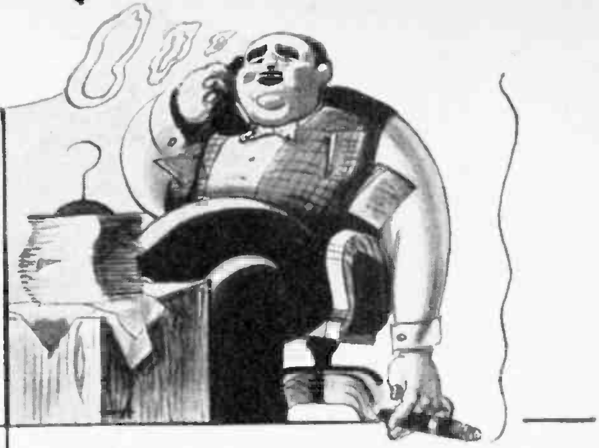
[*Continued from page 17*]

In the curves shown there is practically no frequency discrimination except at the very low frequencies where the curve rises; this is due to phase shift in the feedback circuit. It is stated that a very large output can still be obtained if the tube is overbiased, the feedback reducing the resultant distortion.

The filament winding of the output stage should be disconnected from the

[*Continued on page 64*]

Three attitudes that hamper the War Effort

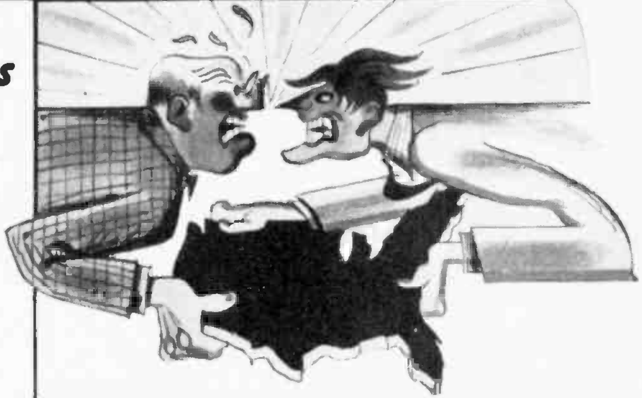


IGNORING NATIONAL DESTINY

Many men are solving the problems of war as they would ordinary business difficulties. Having solved them, they ignore the most important phase. Their attitude toward the war's meaning and its effect on national destiny is apathetic and disinterested.

USING VITAL ISSUES TO PERSONAL ADVANTAGE

To further their own selfish aims, many men seize upon vital issues to confuse and confound the average citizen. When the times call for statesmanship, America is treated to a sorry spectacle of demagoguery, greed, blocs, distortion, shrewd manipulation of emotions.



PULLING IN DIFFERENT DIRECTIONS

While commands in various war theatres are being consolidated and strengthened, here at home there are men who have forgotten the unity after Pearl Harbor. Each is off on his own particular project, seldom remembering that thousands of other men will die before the conflict is over.

THERE IS NO PLACE IN THE COUNTRY FOR SUCH MEN

We of ECA are working not only to produce the materials of war but, like all good citizens, to help attain the objectives of the war. We know that we must be vigilant . . . especially so now. Men of evil intent have come out of hiding. In smoke-filled rooms attractive bargains are being arranged — with the "little people" included out. Energy which should be devoted to the support of the Commander-in-Chief, and those under him, is being used to stir up distrust and dissension. What appears to be overlooked is that the ultimate aim of victory is a decent world . . . where men of good will live and work together with a full understanding of each other's needs and hopes and aspirations. We have already learned, the hard way, what isolationism and selfishness and disunity can mean. Must history again repeat itself?

eca

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SHAPPE-WILKES INC.

TABLE II

CURRENT CARRYING CAPACITY (Amperes)

Temperature Rise	A.W.G. #14	A.W.G. #16	A.W.G. #18	A.W.G. #20	A.W.G. #22	A.W.G. #24	A.W.G. #26	A.W.G. #28
10° C.	15.0	11.0	8.0	6.0	4.5	3.3	2.5	1.8
20° C.	21.0	15.5	11.5	8.5	6.5	4.8	3.5	2.6
30° C.	27.5	20.0	15.0	11.0	8.5	6.3	4.5	3.4

RADIO WIRE & CABLE

[*Continued from page 28*]

have safe current-carrying capacities approximately as shown in Table II.

It is not intended that this information be utilized to full advantage as other factors such as different insulation materials, reduced radiation when cabled in harnesses, restricted ventilation in conduits, etc. will influence the results. Liberal safety factors, insofar as possible, should always be applied in design.

Voltage Drop: — Another criterion which may influence the selection of conductor size is the voltage drop under operating conditions. In low-voltage, high-current circuits containing long wiring runs such as often found in aircraft cable installations, this factor may be more important than current-carrying capacity. Voltage drop when excessive can of course be reduced to a practicable value by resorting to a conductor one or two sizes larger than necessary to carry the circuit current.

Exact calculation of voltage drop is somewhat more complicated than at first realized. Cognizance must be taken of the increase in resistance with operating temperature according to the fundamental relation:

$$R_t = R_{t1}\,(1 + \alpha_{t0}\,[t - t_1])$$

where: R_t = resistance at operating temperature t° C.
R_{t0} = resistance at initial or reference temperature t_1° C.
α_{t0} = temperature coefficient of resistance at initial or reference temperature (as selected).

The value of α_{t0} will depend upon the conductivity of the copper as well as upon the temperature t_0 but may be obtained from the equation:

$$\alpha_{t0} = \frac{1}{\dfrac{1}{n(0.00393)} + (t_1 - 20)}$$

where n = per cent conductivity expressed decimally (viz., 99% = 0.99).

Using these formulas, it will be found that the resistance of copper will be over 20 per cent higher at 75°C. than at 20° C. Obviously, therefore, an appreciable error would be incurred if the voltage drop were calculated on the basis of constant resistance. *Fig. 4* illustrates the relationship between current and voltage drop for conductors of sizes A.W.G. #14 to #22, as obtained by simple computation from measurements of current and resistance in the test described under "Current-Carrying Capacity" above.

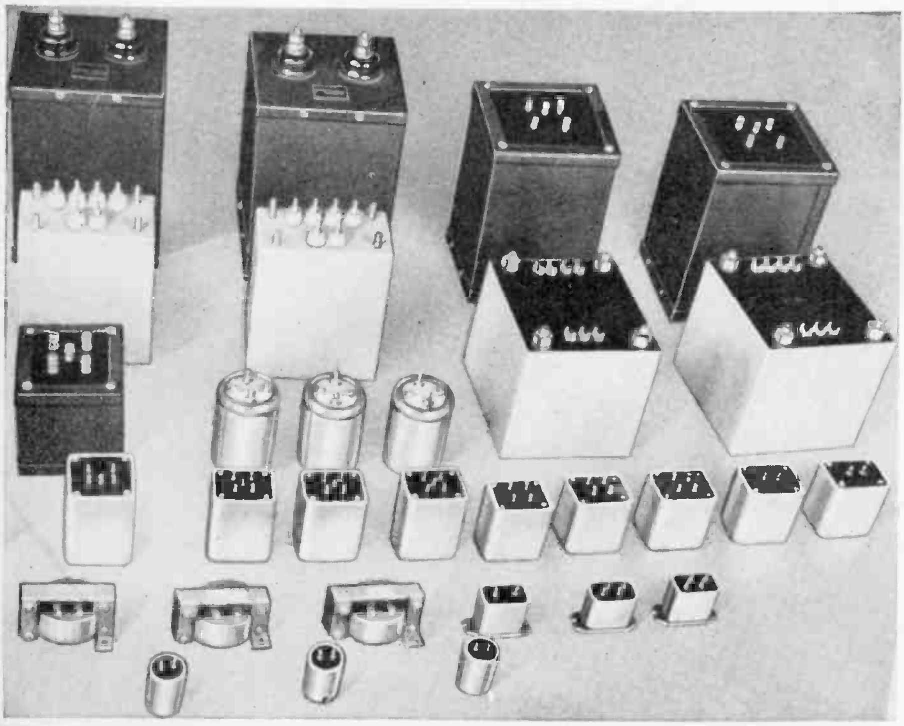
References

1. "American Standard Definitions of Electrical Terms." A.S.A. C42-1941. Published by American Institute of Electrical Engineers.
2. "Copper Wire Tables." Circular No. 31. Bureau of Standards, Department of Commerce, Washington, D. C.
3. "Introduction to A.I.E.E. Standards." *Journal of A.I.E.E.*, No. 1 (June 1940). Published by American Institute of Electrical Engineers.
4. "Determination of Maximum Permissible Current-Carrying Capacity of Code-Insulated Wires and Cables for Building Purposes." NEMA Report, June 27, 1938. Published by National Electrical Manufacturers Association, Washington, D. C.

HYTRON ADDS BEVERLY PLANT

The oldest exclusive manufacturer of radio receiving tubes, and the first radio tube manufacturer to go into all-out War production, Hytron Corporation of Salem, Massachusetts, has increased its output more than five times since June, 1942. Over and over again it has been necessary to expand manufacturing facilities to meet the demands of the armed services. In addition to its large new plant at Newburyport, Massachusetts, Hytron recently acquired a feeder plant at Beverly, Massachusetts.

The new plant at Beverly will employ several hundred persons concentrating upon the production of electronic tube "mounts" (completed assemblies of internal parts). This plant will serve as a "feeder" for the Salem factory. The Beverly location was chosen because of its proximity to both Salem and Newburyport; and to tap a new source of labor supply.



Performance Engineered Electronic Transformers
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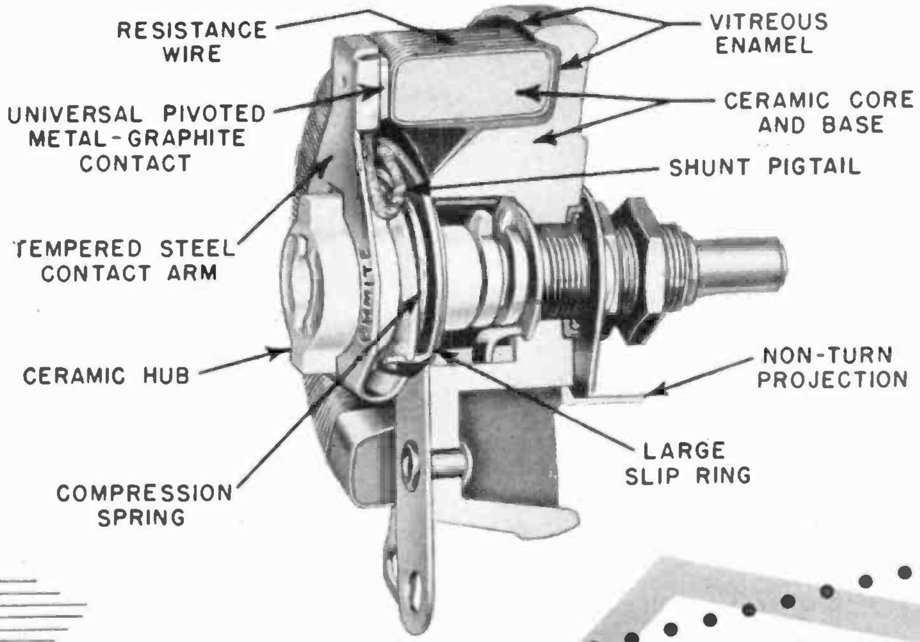
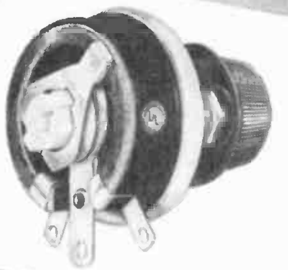
The Inside Story of OHMITE *Rheostats*





OHMITE Design Makes the Difference in Smooth, Close Control

Everywhere . . . on every battle front . . . and in the tools of Industry . . . you find Ohmite Rheostats doing critical control jobs.

Permanently smooth, close control is built-in . . . to withstand shock, vibration, heat and humidity. Construction is compact . . . all ceramic and metal. There is nothing to shrink, shift or deteriorate.

Illustrated in the cutaway above are many of the features which contribute to the consistent dependability of Ohmite Rheostats.

Widest range of sizes—ten models from 25 to 1000 watts, from 1$\frac{9}{16}$" to 12" diameter—in straight or tapered winding, in single or tandem assemblies—to meet every control need in the most advanced electronic devices.

Write on company letterhead for complete, helpful 96-page guide in the selection and application of Rheostats, Resistors, Tap Switches, Chokes and Attenuators.

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Be Right With **OHMITE** **Rheostats • Resistors • Tap Switches**

● Eight selected capacitance values make up the Aerovox Victory Line of paper tubulars. Used individually or in combination, these values take care of upwards of 90% of usual paper capacitor replacements. Otherwise, these units are just the tried and proven Aerovox Type '84 paper tubulars. Non-inductive paper section Extra-wax-sealed. Colorful label jacket. Bare pigtail terminals that won't work lose.

VICTORY LINE
PAPER TUBULARS

D.C.W.V.	CAPACITY
600	.001 mfd.
600	.002 mfd.
600	.005 mfd.
600	.01 mfd.
600	.02 mfd.
600	.05 mfd.
600	.1 mfd.
600	.25 mfd.

● **Ask Our Jobber . .**

Ask for these Aerovox Victory paper tubulars. It will pay you always to have an assortment on hand. Ask for the latest Aerovox catalog—or write us direct.

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CHOOSING TUBE TYPES

[*Continued from page 31*]

required for an electron to travel from cathode to grid or plate. So long as the transit time remains a negligible fraction of one complete cycle of the signal voltage no bad effects are noticed. But as the transit time becomes an approachable part of one cycle a phase shift between the signal voltage and the charging current induced in the grid takes place. suppose the electrons travelled from the cathode to the grid in zero time. Then the charge induced on the grid by the electron stream would be in phase with the signal voltage impressed on the grid. Actually, it takes a definite time[2] for the electrons to reach the grid from the cathode, and the charge induced on the grid by the electron stream reaches its maximum at a later time than the maximum of the signal voltage. A phase difference therefore exists between the signal voltage and the capacitive charging current due to the electron stream. Energy is thus dissipated which must be supplied from the input circuit. The result is an increase in grid conductance or decrease in input resistance.

The other component of the hot input conductance is due to cathode-lead inductance. See *Fig. 2*. This lead represents an impedance at high radio frequencies and since in most applications the grid and plate circuits are both returned to the cathode it is apparent that an appreciable impedance is undesirable. Since the voltage drop due to the cathode current across this impedance lags the signal voltage by 90° any current fed through the grid-cathode impedance will be in-phase with the signal voltage, because current through the grid-cathode impedance will lead the cathode by 90°. With both the signal voltage and the in-phase current variable, the input impedance will likewise be variable.

It is possible by the use of an unbypassed cathode resistor to neutralize the in-phase current fed back to the grid. The voltage across the resistor is 90° out of phase with that across the cathode-lead and therefore 180° out-of-phase with the signal. When using an unby-passed cathode resistor it is important that the screen and suppressor circuits be by-passed or connected back to ground instead of to cathode since this element is no longer at ground potential. It should also be noted that the grid-cathode and grid-plate capacities now form a grid-plate feedback path since the cathode is above ground and obviously should be as small as possible. From the above the importance of making all cathode return connections as close to the cathode pin as possible is clearly shown.

The preceding discussion covers the most important limitations with respect to radio frequencies below approximately 50 megacycles. Special considerations for operation at ultra-high frequencies will be discussed in more detail later.

Tube Ratings

The equipment designer should be guided by the published ratings of the tube manufacturer when specifying operating conditions for a new design. It is therefore important that the designer know under what conditions these ratings were established. First, it should be determined whether the published data are based on "absolute maximum" or "design-center maximum" ratings. The absolute maximum ratings, as its name indicates, is the maximum voltage or current recommended under any possible condition of power supply input. Obviously this is only important when operating with the highest power line or battery supply voltage likely to be encountered in service. Under this rating some tubes have a factor of safety and a slight increase is permissible, however, many tubes do not have a comfortable margin so it is good engineering practice never to exceed the maximum under any condition.

The "design-center maximum" ratings are based on average or normal supply conditions. For a-c operated equipment in the United States this is 117 volts. Variations of plus or minus 10% are to be expected with ordinary commercial power lines and can be tolerated without affecting tube life.

Equipment powered by automobile storage batteries should use 6.6 volts input as the design-center. In this type of service it is found that variations are likely to exceed plus or minus 10% so a conservative design would limit the plate and screen voltages to 90% of design maximum.

With the low current drain 1.4 volt tubes, the design should be based on 1.35 volts for the filament or heater when operated in series from a 117-volt power line. Under no circumstances should the filament be subjected to over 1.6 volts. In a series filament arrangement precautions must be taken to "by-pass" the space current, since this automatically adds to the filament current in series type of operation. This may readily be accomplished by the use of bleeder resistors across the filaments so

[*Continued on page 62*]

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[2] About 10^{-9} seconds for ordinary receiving tubes under normal operating conditions.

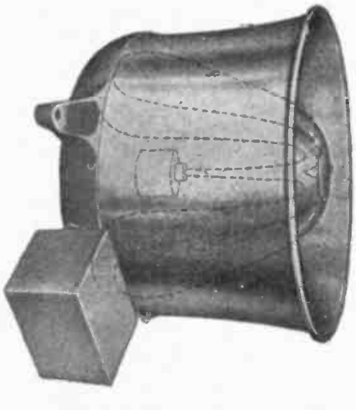
THE ANSWER TO TODAY'S PROBLEM-

RACON's...*the leading speaker line...for all types of sound installation!*

Most of the best industrial p. a. installations in use are RACON speaker equipped. They are the finest speakers made and there is a type for every conceivable application.

For Marine p. a. installations, too, RACON leads. Approved by the U. S. Coast Guard, RACON speakers are used aboard Army and Navy vessels. Only RACON can supply, when needed, patented Weatherproof, Stormproof Acoustic Material which is impervious to any weather condition and prevents resonant effects.

WPB will now accept applications for industrial war plant sound installations. Use WPB Form 617. Specify RACON's.



Left: **MARINE HORN** Speaker, approved by the U. S. Coast Guard. Several sizes available, Stormproofed, of the re-entrant type, suitable for indoor or outdoor use—may be used as both speaker and microphone. *Right:* **RE-ENTRANT TRUMPET**; available in 3½', 4½' and 6' sizes. Compact. Delivers highly concentrated sound with great efficiency over long distances.

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NEW IMPROVED "T"-PAD ATTENUATORS BY TECH LAB

- Stainless Silver Alloy contacts and wiper arms.
- Rotor hub pinned to shaft prevents unauthorized tampering and keeps wiper arms in perfect adjustment.
- Can be furnished in any practical impedance and db. loss per step upon request.
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CHOOSING TUBE TYPES

[Continued from page 60]

affected. With battery operation of the the filaments in parallel, the circuit constants should be chosen to give acceptable performance when the voltage per cell has decreased to 1.1 volts. This voltage is considered the end of life of the cell. Plate and screen battery voltages should never exceed 10% over normal published values.

After the ratings have been determined as being design-center or absolute, the next step is to decide on whether the design will be for continuous or intermittent service. Tubes for transmitter service in particular, because of the high power involved, are given two ratings. These are known as CCS (continuous commercial service) and ICAS (intermittent commercial and amateur service). Communication equipment is usually designed around CCS ratings since they have been chosen for reliability of performance under continuous operation and are more nearly representative for this type of service. The ICAS rating assumes intermittent operation of approximately 5 minutes on and 5 minutes off, with a maximum of power output for a minimum physical size being of more importance than long life.

Ratings of tubes for rectifier service are based on fundamental limitations in the tubes themselves. In general these include factors such as the maximum peak inverse voltage, maximum peak current and the maximum d-c output current. In some cases it is permissible to increase the d-c output voltage over the rated value providing the output current is reduced in proportion. The tube manufacturer should be consulted however, unless the proposed increase is small.

A list of references will appear at the end of Part 2.

WESTINGHOUSE APPLIES FOR TELEVISION LICENSES

Application for licenses for three television broadcasting stations, to be built at Philadelphia, at Boston, and at Pittsburgh as soon as critical materials are available, have been filed with the Federal Communications Commission by Westinghouse Radio Stations, Inc., Lee B. Wailes, general manager, has announced.

Establishment of television stations in these cities, he said, will entail construction of new studios, transmitters, and other facilities as additions to three of the company's "standard" broadcast outlets—KYW in Philadelphia, KDKA at Pittsburgh, the nation's first radio station broadcasting scheduled programs, and WBZ at Boston. Two floors of television studios built in 1938 at station KYW await only the release of critical materials for completion.

Mr. Wailes suggested that future televised programs, in addition to those originating as "live" shows in local studies, would include motion pictures and "pick-ups" of outside events, such as football games, parades, and other public gatherings. He based his conclusions on a study of television techniques and program sources.

SYLVANIA EXPANDS

A two-story brick addition, now under construction, will add 18,000 square feet of floor space to the Mechanical Design and Equipment Development Section of Sylvania Electric Products' radio division home plant in Emporium, Pa., it was announced recently.

Completion of the addition is scheduled for late spring, under the contract let to Hughes Foulkrod Company of Philadelphia. Construction will be supervised by Sylvania. The addition will be paid for by the United States Navy.

TELEVISION IN INDUSTRY

Disclosure of potentialities of television as a new and effective aid to industry after the war Ralph R. Beal, Assistant to the Vice President in Charge of RCA Laboratories, told members of the Engineering Society of Detroit of the imminent expansion of this promising art and science.

Mr. Beal envisaged television as the "means of coordinating activities in giant manufacturing plants and also of peering into places and situations that might be inaccessible or extremely hazardous to man."

"We know now," the research engineer said, "how it can be used to extend the eyesight of the plant manager to critical operations that ordinarily would require much time and effort to reach for personal inspection or which might even be inaccessible—how television can aid immeasurably in plant control.

"Television cameras at strategic points can be connected by wire to receivers where production experts, foremen and supervisors can follow the flow of fabricated or raw materials and watch the progress of the work. Such setups will be particularly valuable in mass production assembly lines, and they may be extended to include loading platforms and shipping rooms."

According to Mr. Beal, television cameras may be used in connection with chemical reaction chambers, making visible to the operator without personal risk the chain of events occurring in complicated chemical production units, and thus enable him to control the process with optimum results. He said specially-built cameras may be used in furnaces to observe steps in the formation of alloys, and others may solve vital problems of analysis in important industrial processes.

"In addition," Mr. Beal stated, "television equipment may facilitate port movements of ships. The cameras located fore and aft, and on port and starboard sides of vessels, could lessen the hazards of docking and insure safety in crowded shipping lanes.

"We likewise foresee the use of television in metropolitan traffic control and along congested motor routes. Cameras may be installed permanently at busy intersections to flash to traffic headquarters running, up-to-the-minute picture accounts that should greatly aid traffic experts in easing congestion."

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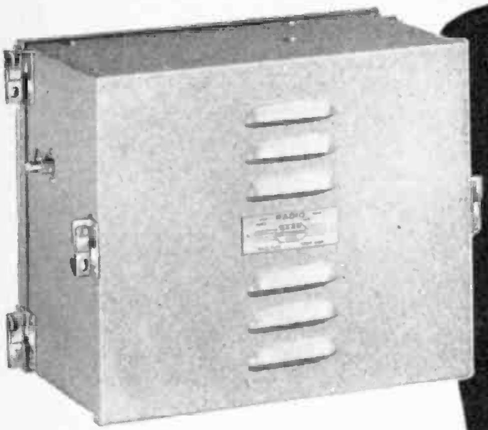
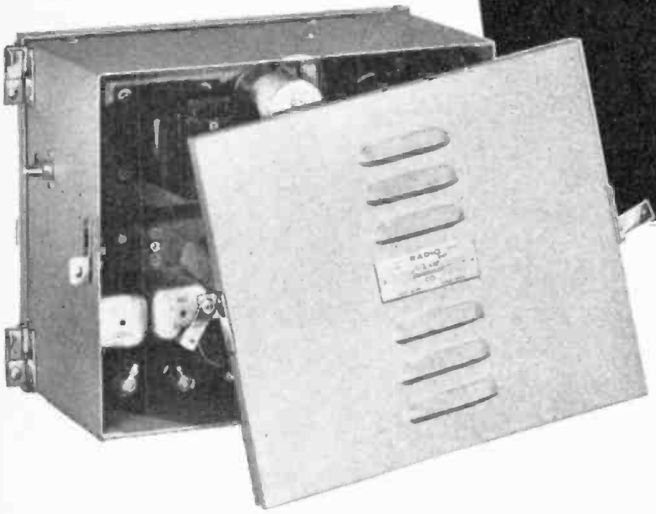
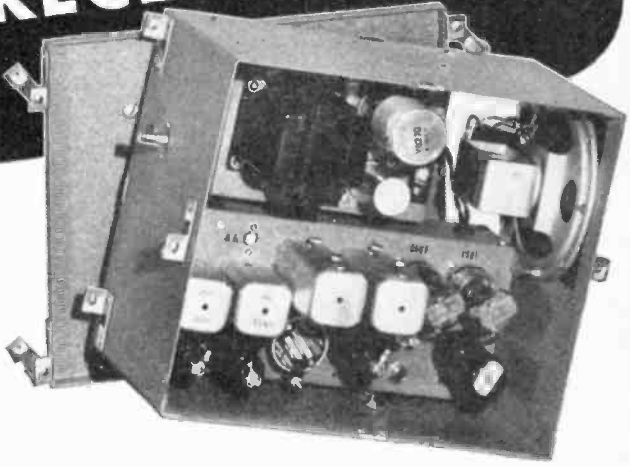


1 The Kaar 11-X receiver is installed beneath the dash, and held securely by bolts through firewall.



2 For simple servicing, such as the replacement of tubes, the dust cover is removed by releasing two convenient snap catches. Takes but a moment.



3 For complete servicing, the entire chassis can be removed from the vehicle by releasing four snap catches. All wiring is instantly accessible.

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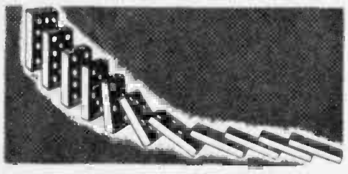

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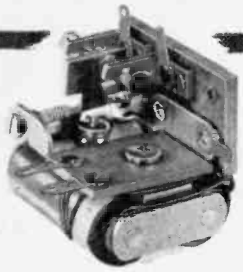

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TECHNICANA

[*Continued from page 56*]

filament circuits of the other tubes because the large voltage fluctuation of the cathode might otherwise damage the insulation between the filament and cathode. Evidently any tube, pentode or triode, can be used, the main requirement being a high transconductance.

FREQUENCIES FOR TELEVISION

★ With the preparation for post-war television service, the choice of the best carrier frequencies to be used is again a problem of the day. The *Wireless World* for April, 1944 contributes an unsigned article discussing this problem.

First we must make up our minds, says the author, whether we want a long-distance or a local service. Since a long-distance service would require the use of the ionosphere as a transmission medium, and since the ionosphere is subject to variations which would distort the picture, the service will have to be "local".

In this local service it will be necessary not to interfere with others at a distance, meaning that we must choose frequencies which are higher than any which would be returned to earth by the ionosphere at any time of the day or night, or at any season or at any period of the sun-spot cycle. To find the lowest frequency which is just high enough that it will not be returned to earth under any of these conditions there are considerable data to guide us.

The television signals of Great Britain were received at Riverhead, L. I. during the winters of 1936-1937, 1937-1938 and 1938-1939, the most active time of the sun-spot cycle. The wave was probably reflected twice by the *F2* layer. Examining the report of these transatlantic receptions, it is shown that the reception was only during the winter time and that the sound channel, 41.5 mc was received over a much longer season than the video channel at 45 mc. Also, it was shown how the reception became less frequent when the sun-spot activity began to decrease. This appears to indicate that 45 mc is near the maximum frequency which could thus be reflected by the ionosphere.

The records made at Washington for the maximum useful frequencies *(MUF)* at different times are another source of information. In November and December, 1937, the critical frequencies were higher than at any other time. The average over a month of critical frequencies for the *F2* layer, for a distance of 3500 km was 43 mc. Allowing a maximum variation of 15% about this figure gives us a maximum frequency of 49.4 mc. Therefore, 50 mc seems to be the lowest safe frequency to use if reflection from the ionosphere is to be avoided.

There still are sporadic reflections from the *E* layer to be considered. Past evidence indicates that such reflections become rarer at higher frequencies and that in any case it would be unlikely for a 50 mc signal to be reflected twice which it would have to do to bridge the Atlantic.

The article further points out that the working radius of a television station is not restricted to the optical range. The increased range is due to the refraction of the space wave in the

[*Continued on page 72*]

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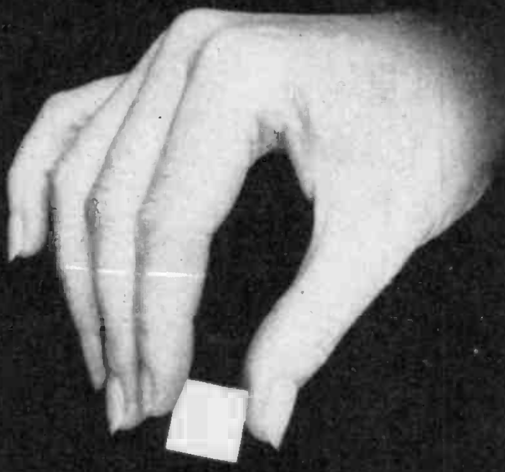

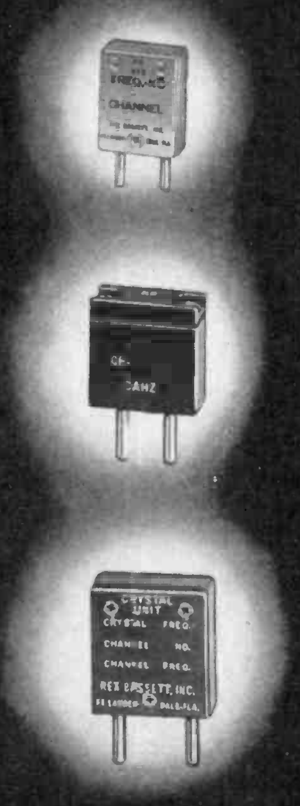

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UNIT SYSTEMS

[Continued from page 24B]

equations where they are required. If this system is completed to include units for all quantities, it will be a self-consistent system derived from the same defining equations as the cgs electromagnetic system. Therefore, an equation would not need to be changed when practical units are substituted for electromagnetic units, so long as *all* units are changed to the practical system. For instance, in the equation for induced e.m.f.

$$e = -N \frac{d\phi}{dt} \quad \text{..............(14)}$$

is usually given in the practical system as

$$e = -N \frac{d\phi}{dt} \times 10^{8} \quad \text{........(15)}$$

The added factor here is due to the fact that the unit of flux in equation 15 is still the maxwell or line which does not belong to the practical system. If the *weber* is used instead, *all* the units are from the practical system and the equation is the same as equation 14.

In the table, the column headed "practical units" refers to this International practical system. Some of the units were left out since no confirmation of their use could be found.

MKS Units

It was shown by Ascoli that the practical units could be extended to form a complete or comprehensive system in many ways, depending on the choice of the units of length and mass. The most promising of these, as pointed out by Giorgi, was the MKS system which uses the meter, kilogram and second as fundamental units. Here at last would be a system that could be used by physicist and engineer alike, a single system to be used universally henceforth and which would do away with all conversion factors.

The MKS system or Giorgi system was adopted by the International Electrotechnical Committee at Scheveningen and Brussels in 1935. At that time the fourth fundamental unit had not yet been determined. In 1938, at Torquay, the fourth unit was agreed upon; it defined the permeability of space as 10^{-7} henry per meter. The question of rationalization was left undetermined. The system was to go into general use on January 1, 1940. Due to present conditions no further agreement was reached.

Meanwhile, the system has been used in several books in this country. A student of waves and the newer applications of radio should know it in order to understand this literature.

In the MKS system (the unrationalized system), the fundamental units are length, mass and time; therefore, it is called an absolute system. It is also a practical system, since it contains the eight practical units. Most units are no different from the so-called practical units of the recent past, except that one must watch these quantities which used to be "per cm or per cm²". These are now "per meter and per meter²".

Since the MKS system is self-consistent and derived from the same defining equations as the cgs electromagnetic system, any equation remains the same in either system. Thus, any equation in any of the four systems: cgs electro-static, cgs electromagnetic, practical, and MKS unrationalized, can be transferred to any of the other of these four systems and thereby does not gain a proportionality or conversion factor. Of course, this applies only if *all* of the units are expressed in the same system and when the quantities ϵ_0 and μ_0 are inserted where they belong.

Rationalization

It will be seen on looking through the equations of column 3, that there are some constants in them. There is a 4π here and there; this factor arises out of certain geometrical problems in space and can hardly be avoided. In equations which have to do with fields and waves this factor occurs again and again, so that it would simplify matters if it could be eliminated.

Rationalization is the process of removing the factor 4π from much used equations by changing the size of certain units. However, the factor 4π will then occur in some other, less used, equations.

In a system to be rationalized we can start out with the following requirements:

Unrationalized system	Rationalized system
$\Psi = 4\pi q$	$\Psi = q$ .....(16)
$M = 4\pi NI$	$M = NI$ ...(17)

Thus making the units of electric flux and magnetomotive force of a different size will fulfill our purpose. However, now one must go through all the equations, making adjustments in the magnitudes of the units. This can be done in two ways; there are two ways of rationalization. In the first method, the factor 4π is kept out of ϵ_0 and μ_0 and then comes into nearly every other unit. In such a system the size of many units is changed by the factor

$$\sqrt{4\pi}$$

[Continued on page 68]

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UNIT SYSTEMS

[*Continued from page 66*]

The other method is called *sub-rationalization.* In a sub-rationalized system ϵ_0 is multiplied by $1/4\pi$ and μ_0 by 4π. Then there are but a few units which are changed by the rationalization process. These are easily recognized in the table where the conversion factor is shown next to the MKS sub-rationalized units.

By this definition, the MKS system is used in a sub-rationalized form. It is popularly spoken of as *MKS-rationalized,* since many people do not make the distinction between rationalized and sub-rationalized systems.

The cgs electromagnetic system is sometimes used in the rationalized form and is then called the Heaviside system. The symmetric system has also been rationalized and was then called the Lorentz system.

In the MKS subrationalized system, some equations incorporate a 4π factor which did not previously contain one. For instance, Coulomb's laws become

$$F = \frac{q_1 q_2}{4\pi \epsilon r^2} \quad \dots\dots\dots\dots\dots\dots (18)$$

$$F = \frac{m_1 m_2}{4\pi \mu r^2} \quad \dots\dots\dots\dots\dots\dots (19)$$

where

$$\epsilon = \epsilon_o k_e \text{ and } \epsilon_o = \frac{1}{36\pi} \times 10^{-9} \text{ farad per meter}$$

$$\mu = \mu_o k_m \text{ and } \mu_o = 4\pi \times 10^{-7} \text{ henry per meter}$$

Below are a few equations written in the different ways in which they occur when systems are changed. It is obviously beyond the scope of this article to show every equation that could possibly be affected by sub-rationalization. The reader is referred to the bibliography below for such information.

Cgs ELECTROSTATIC Cgs ELECTROMAGNETIC PRACTICAL MKS UNRATIONALIZED	GAUSSIAN SYSTEM	MKS SUB-RATIONALIZED
$\nabla \cdot H = 4\pi\gamma E + \frac{\delta D}{\delta t}$	$\nabla \times H = \frac{1}{C}\left(4\pi\gamma E + \frac{\delta D}{\delta t}\right)$	$\nabla \times H = \gamma E + \frac{\delta D}{\delta t}$
$\nabla \times E = -\frac{\delta B}{\delta t}$	$\nabla \cdot E = -\frac{1}{C}\frac{\delta B}{\delta t}$	$\nabla \times E = -\frac{\delta B}{\delta t}$
$\nabla \cdot B = 0$	$\nabla \cdot B = 0$	$\nabla \cdot B = 0$
$\nabla \cdot D = 4\pi\rho$	$\nabla \cdot D = 4\pi\rho$	$\nabla \cdot D = \rho$
$P = \frac{1}{4\pi}(E \times H)$	$P = \frac{C}{4\pi}(E \times H)$	$P = E \times H$
$M = 4\pi NI$	$M = \frac{4\pi}{C} NI$	$M = NI$
$e = -N\frac{d\phi}{dt}$	$e = -\frac{N}{C}\frac{d\phi}{dt}$	$e = -N\frac{d\phi}{dt}$
$e = -L\frac{dI}{dt}$	$e = -\frac{L}{C^2}\frac{dI}{dt}$	$e = -L\frac{dI}{dt}$

A Universal Way of Writing Equations

There has been some attempt to write equations so that they would be independent of any system. The same equation would hold in whatever system, including Gaussian or rationalized. An example of this is Coulomb's law.

$$F = \frac{\alpha}{4\pi} \frac{q_1 q_2}{\epsilon r^2} \quad \dots\dots\dots\dots\dots (20)$$

where the factor α is a constant which varies with the system. For the MKS subrationalized system this factor would be unity but for all other systems of our table it would be equal to 4π. A similar factor β is used for the magnetic equation and still another factor λ in some others. However, the method does not seem standardized; many authors introducing this own systems.

Use of the Table

This table was prepared for the purpose of giving the name and defining equation for each unit in six systems and to supply the conversion factor for all units from one system into any other. In order to save space, each conversion factor has been given but once. In other words, where it is shown in the conversion column that 1 statvolt = c abvolts, it is not necessary to show the conversion factor in the other direction. To change from abvolts to statvolts one must, of course,

[*Continued on page 70*]

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UNIT SYSTEMS

[*Continued from page 68*]

invert the factor, so 1 abvolt $= 1/c$ statvolt.

As to the manner of giving the conversion factor, there is again a possibility for confusion. The column is headed

1 e.s.u. unit $= N$ e.m.u. unit

and the factor N is then in the column below. It is believed that such a statement offers no ambiguity. It can also be read, "To convert from e.s.u. units to e.m.u. units, multiply by *N*."

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WAVE GUIDE IMPEDANCE

[*Continued from page 23*]

in accordance with our boundary condition number 4, a charge must be present on that surface with a density equal to $\epsilon E_1 = 8.85 \times 10^{-12} E_1$. The charge, in accordance with our present approximation, then moves along the guide with the velocity of light given by $C = 8 \times 10^{10}$ and, hence, corresponds to a current density of $8 \times 8.85 \times 10^{-12} \times 10^{10} E_1 = C_\epsilon E_1$. By the boundary condition of rule 3, it follows that the magnetic field at that point must be $H_1 = C_\epsilon E_1$ and the impedance given by $E_1/H_1 = 1/\epsilon C$. Because it is well known that

$$C = \frac{1}{\sqrt{\epsilon\mu}}$$

it may be stated equally well that the impedance of free space is given by

$$\sqrt{\mu/\epsilon}$$

In the actual case of the $TE_{1,0}$ mode in a rectangular wave guide, the H field is somewhat larger. The correction factor, as we wish to say it, due to a stronger magnetic field to account for the longitudinal component or to a lower velocity of propagation, is

$$\frac{1}{\sqrt{1-(\lambda_0/2b)^2}}$$

Thus the specific impedance is

$$\frac{\sqrt{\mu/\epsilon}}{\sqrt{1-(\lambda_0/2b)^2}}$$

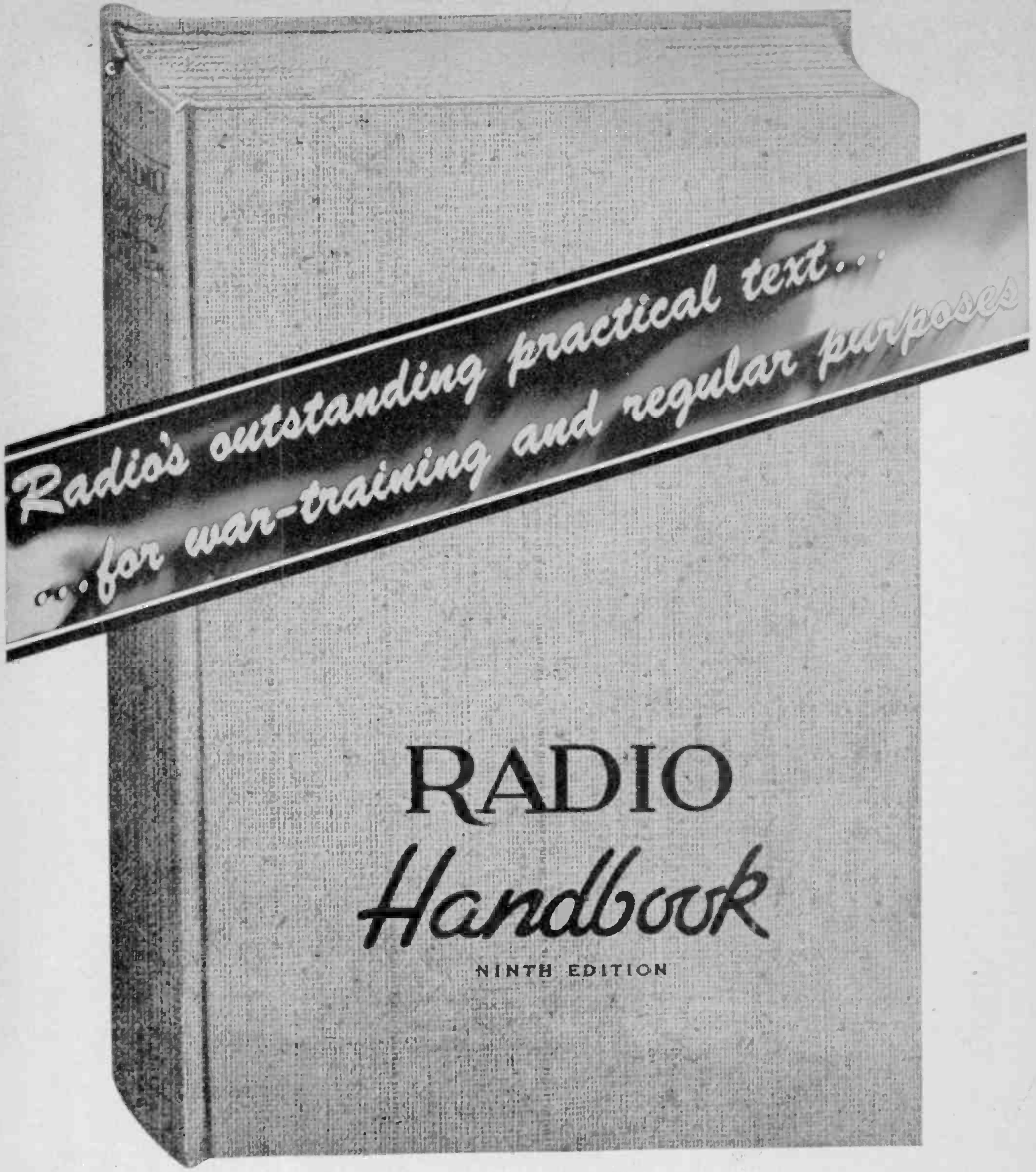
It is interesting to note that this expression is independent of the narrow dimension of the wave guide. This corresponds to the fact that no energy flows crosswise of the pipe in that direction as we have pointed out. In the other dimension of the guide there is a crosswise energy flow (which may cancel out at the surfaces) so the impedance is affected.

This impedance is said to be a specific impedance, analogous to a notation used in acoustics, because still another condition must be added before an overall impedance applicable to the joining of two wave guide sections of different size can be written down. The condition is that when flow takes place from a guide of one size to that of another, as shown in *Fig. 7,* it is a sort of total amount of electric and magnetic flux which must join at the junction if there is to be no reflection with an attendant standing wave to indicate a mismatch. Another way of saying this is that the charge and current on the wider wall of the guide must join smoothly at the junction. Now, E alone does not tell about the amount of charge present, since a given E may be obtained by a little charge on closely spaced plates or by more charge on plates further apart. The quantity in which we are really interested is aE, where a is the narrow dimension of the guide. Likewise, it is bH that requires the currents to be continuous at the junction. Thus, finally, the impedance of a rectangular wave guide in the $TE_{1,0}$ mode may be given as

$$aE/bH = (a/b)\,(\mu/\epsilon)/\sqrt{1-(\lambda_0/2b)^2}$$

This impedance is often called the current impedance since it is the specification necessary to cause the current flowing in the wide side of the guide to be continuous.

««« »»»



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TECHNICANA

[*Continued from page 64*]

troposphere. Refraction takes place because the dielectric constant of the air varies with altitude along with pressure, temperature and vapor content. Thus the rays which travel from the transmitting station at angles slightly above the horizontal can be bent and returned to earth beyond the horizon. At frequencies near 50 mc the working range is thereby extended beyond the optical range 1½ times.

Discontinuities in the atmosphere, due to boundaries between air masses of different temperature cause reflections and may cause fading as well as accidental reception at greater distances.

In conclusion, it is felt that the best frequencies are above 50 mc and that very much higher frequencies may introduce difficulties due to the reflections from buildings and hills.

NEW OSCILLOGRAPH

To facilitate the investigation of transient as well as recurrent phenomena over a wide frequency range, Allen B. du Mont Laboratories, Inc., Passaic, N. J., announce their new Type 247 Oscillograph.

This instrument utilizes the new Type 5CP1 cathode-ray tube with intensifier electrode, operated at an overall accelerating potential of 3000 v. High-intensity patterns are obtained on the 5" diameter screen. The medium-persistence green screen is standard. If a permanent record of transient phenomena is required, the instrument may be supplied with short-persistence blue screen for high-speed photographic recording, or with the long-persistence green screen for visual observation of low-speed phenomena.

The sweep frequency range has been extended down to one-half cycle per second providing a wider range of sweep operation. Thus it may be used for observations on low-speed machinery and for other low-frequency functions. The time-base provides recurrent, single or repetitive sweep operation. An unusual beam control circuit is used with single sweep operation, to darken the screen except during the actual sweep cycle, providing a reduction of background illumination and resulting in photographs of greater contrast. Exceptionally uniform response over a very wide frequency range for both the vertical and horizontal axes; a distortionless, continuously-variable low-impedance attenuator or gain control; a Z amplifier channel for applying external timing signal to the grid of the modulating electrode; and other features and refinements, mark this instrument. Dimensions: 14" w., 19" h., 26" d. Weight 130 lbs.

ADVERTISING INDEX

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In this "radio" war, the "ham," along with the professional, became the backbone around which the Services and war plants built the myriad, complex communications systems of war, and the secret electronic weapons. He has trained and inspired the new recruits—the tens of thousands of potential "hams."

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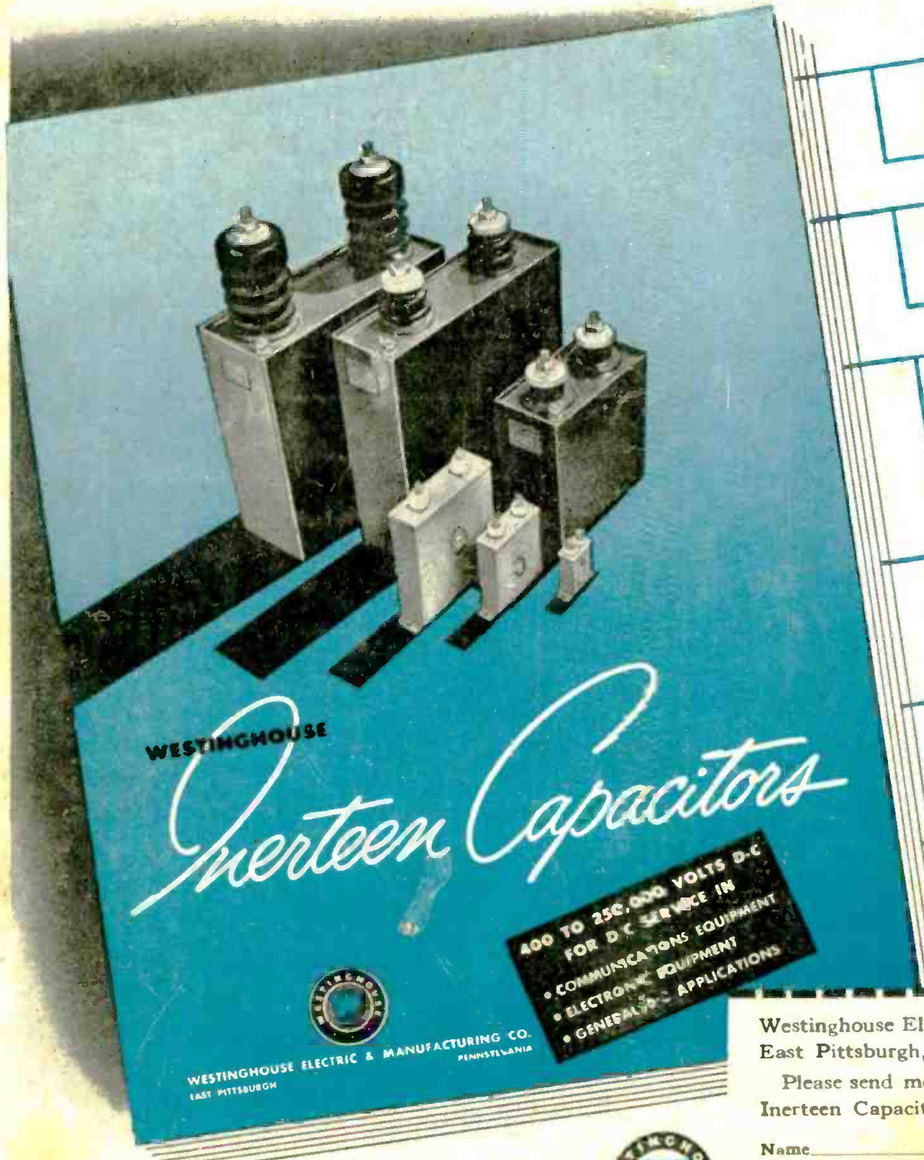

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