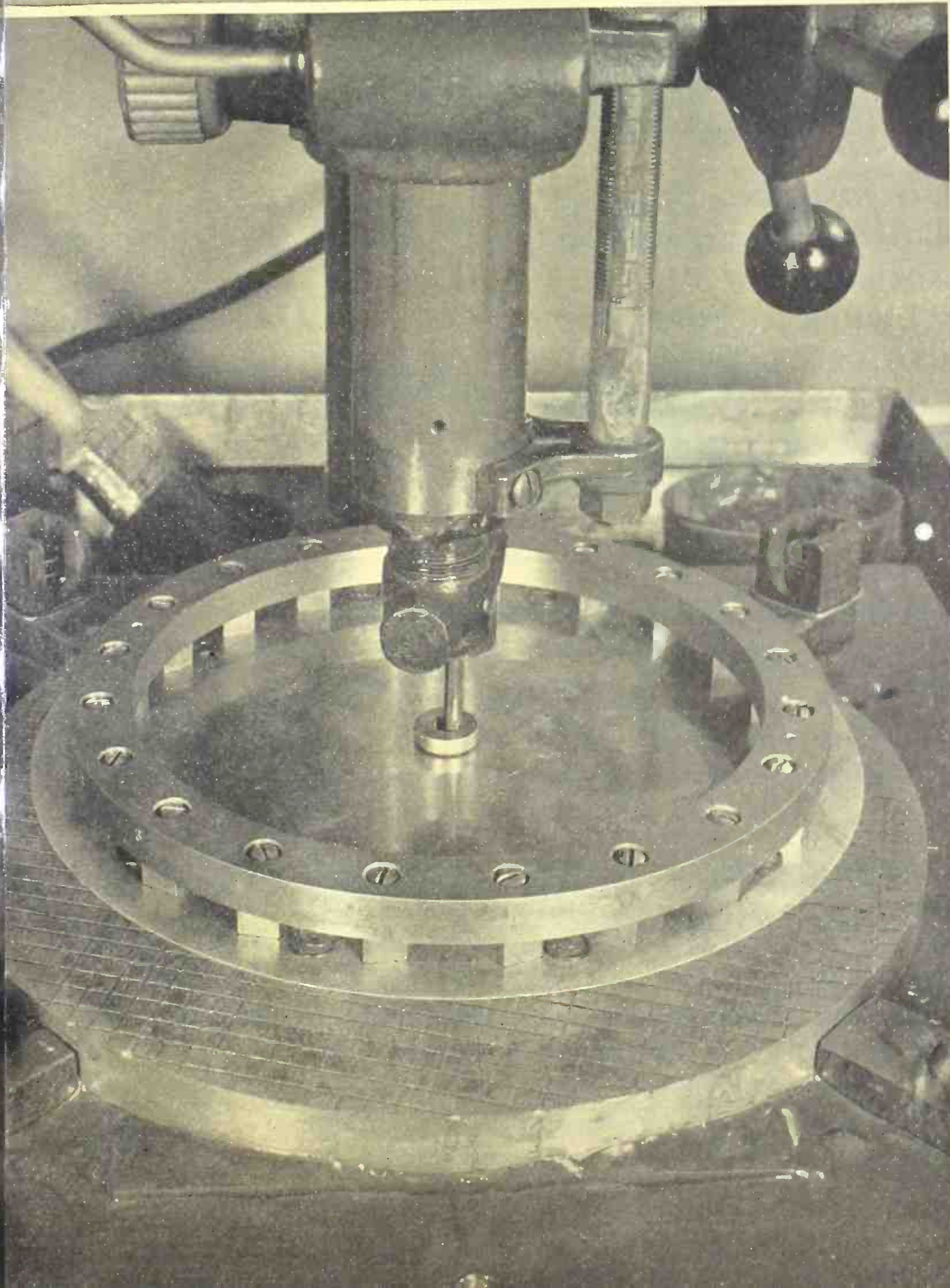
JANUARY, 1950

RADIO & TELEVISION NEWS

RADIO-ELECTRONIC Engineering



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DEPARTMENTS

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VOLUME 14, NUMBER 1,

COVER PHOTO—Courtesy of National Bureau of Standards

Pentagonal block apparatus developed at NBS for producing quartz oscillator plates thin enough for high frequency use. Twenty pentagonal blocks, rigidly attached to a steel ring, are shown resting on crystals (not visible) in corresponding nest openings.

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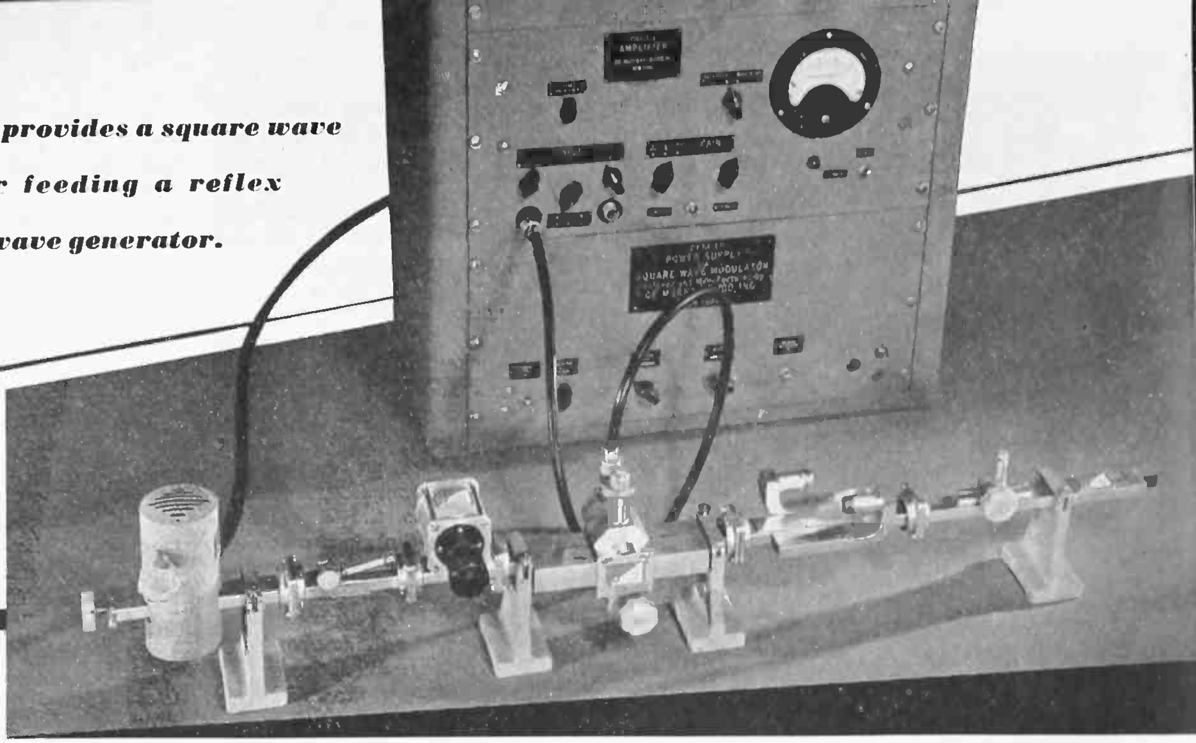

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Klystron Power Supply And

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b. Two closely separated grids connect to a resonant cavity which is kept

to the r.f. gap and its associated cavity.

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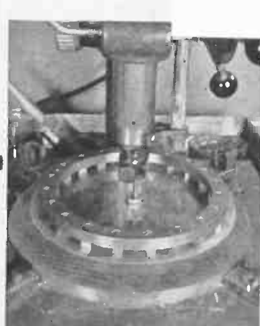

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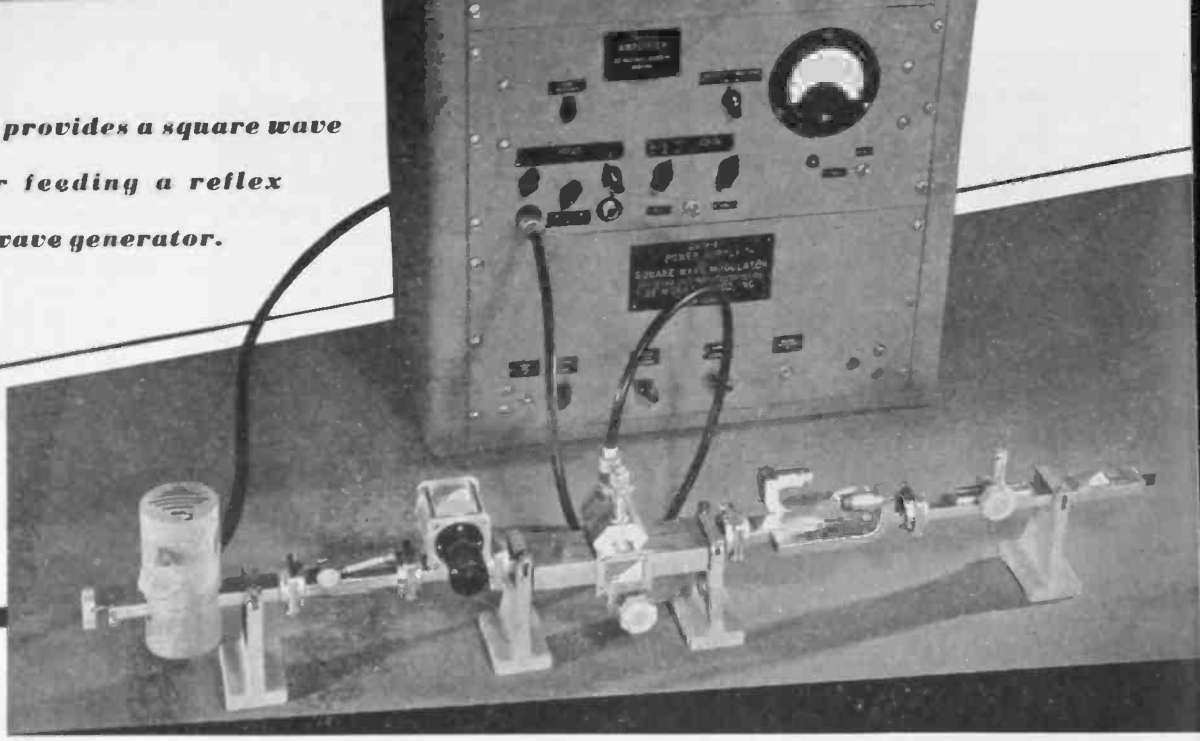


Fig. 1. Bench test setup including the power supply and square wave modulator along with various microwave equipments.

Klystron Power Supply And Square Wave Modulator

By SAMUEL FREEDMAN

New Developments Engr., DeMornay Budd, Inc.

MICROWAVE test and evaluating setups including the field of microwave spectroscopy commonly depend on tubes employing velocity modulated electron beams with repeller electrodes known as reflex klystrons for microwave power source. Such tubes are employed instead of conventional types because of the effect of the inductance in connections and the fact that the transit time is comparable with or in excess of the period of oscillation for the latter.

Any velocity-modulated tube or so-called "klystron" derives a radio frequency intensity-modulated current for operating an output circuit. Instead of dependence upon the number of electrons, the power is dependent on the changes in the velocity of the electrons with respect to each other. In what would be the cathode-grid region of a conventional triode, the following is provided:

a. The cathode emits electrons when subjected to sufficiently high temperature just as in the case of a conventional tube.

b. Two closely separated grids connect to a resonant cavity which is kept highly positive. Their separation forms an r.f. gap. The region between the cathode and this r.f. gap may be called a cathode-anode region in which the electrons emitted by the cathode receive their d.c. acceleration.

c. The r.f. gap subjects these electrons to an oscillating or r.f. field. This field alternately slows down or speeds up the electrons to produce velocity modulation.

d. A drift space beyond the r.f. gap permits the electrons to continue travel until they come under the influence of a "repeller" or "reflector" which is biased negative with respect to the cathode and much more so with respect to the r.f. gap and its associated cavity.

The acceleration or deceleration of the electrons in traversing the r.f. gap causes each electron to have a different speed beyond that point. This results in the bunching or grouping of the electrons. The more an electron is accelerated in traversing the r.f. gap, the further it can travel in the direction of the negatively charged repeller electrode before being reflected back in the direction of the r.f. gap. On the initial trip through the r.f. gap, as many electrons speed up and gain energy from the r.f. field as are slowed down and give up energy to the same r.f. field. They balance to zero. However, when the electrons are repelled back by the repeller, they are bunched. In returning to the r.f. gap, with the proper phase relations based on correct values of beam and repeller voltages, they can be made to give up energy. The amount of useful power between zero and maximum for a stated tube depends entirely on the correct phase relations of the oscillation which in turn depend on the availability of the proper potentials derived from a power supply.

If the tube transit time conditions are met and there is sufficient d.c. beam current to compensate for load losses and circuit power dissipation, the tube will oscillate and deliver power. The transit time depends upon the reflector voltage and the beam voltage. This results in oscillation and useful power for certain values of voltage and none for others. Each set of voltages resulting in power conditions is known as a *mode.* A dominant or more efficient mode will always exist for a particular tube at a particular frequency. The availability and utilization of this mode is dependent on the power supply voltages necessary to energize the tube being readily available.

In microwave test setups the amount

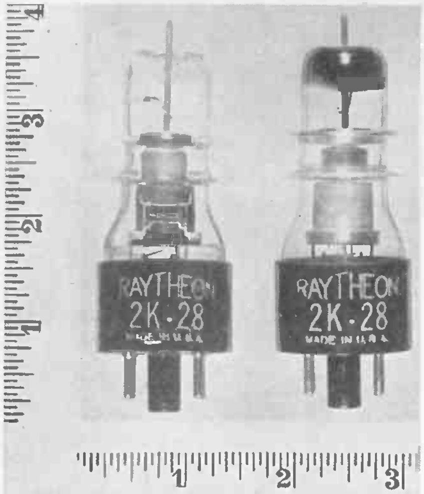


Fig. 2. Two views of the type 2K28 reflex klystron.

of power required is sufficiently low to permit operations even with low tube efficiency, such as operation at one of the less efficient modes of the reflex klystron. A few milliwatts are normally sufficient in most cases. In many setups, an attenuator capable of providing attenuation of 10 to 30 db. is placed between the signal source and point of measurement to assure stability of measurement. As little as 10 to 25 milliwatts may be used. In some cases, systems have been tested with a few hundred microwatts, or even less.

The reflex klystron type of tube normally used in this work differs from other types of klystrons in that it is a single-resonator instead of a multi-resonator type. The electron beam passes once through the resonating cavity and then encounters a negative electrode which causes the electron to return through the cavity on a second transit at which time useful power is developed. The reflex type of tube may have its resonant cavity within the enclosed vacuum envelope or it may employ an externally attached cavity for the type of tube illustrated in Fig. 2. In the latter case, as for the Type 2K28, a cavity encompasses and electrically connects to the copper fins extending through the glass seals.

Most of the conventional reflex klystron tubes operate at a beam voltage of 300 volts and a beam current averaging about 22 milliamperes. The repeller voltage is applied to an electrode which normally draws only a few microamperes of current. Modes of oscillation where any reflex tube does and does not function occur in the range of reflector voltage from zero to over 300 volts negative with respect to the cathode. In the case of the 2K25 tube, at least four or five modes can be developed depending on the range of voltage available from the power supply and the construction of a particular tube. In other cases such as the 726 or 2K29, less modes can be developed. In the case of the 2K50 tube which has been produced in limited number but for which a demand exists for resumption of production, despite the much higher frequency (1 centimeter region), fine tungsten grids for the cavity gap permit larger beam and shorter transit distance through the gap. This tube requires more critical adjustment of potentials and a power supply must have special or additional provisions to meet this requirement. Optimum reflector voltage varies from tube to tube of the same type as much as plus or minus 30 volts.

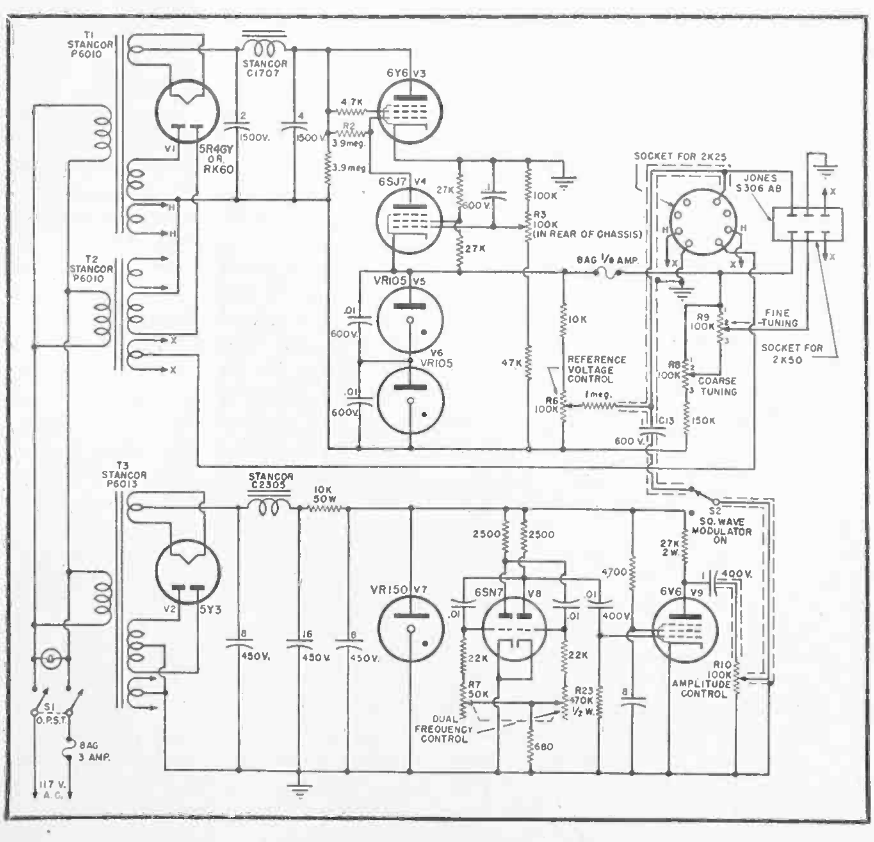
Two tubes of considerable interest because of their availability in quantity at low cost in the postwar surplus market are the types 2K28 and 2K25 for the 10 and 3 centimeter bands respectively. The following data is based on the *Raytheon* Velocity Variation Oscillator (their name for the reflex klystron). Fig. 4 describes various electrical characteristics for the type 2K25 tube versus changes of negative repeller voltage. Fig. 7 describes additional data versus frequency and changes in resonator potential. The power output changes about 1½% per volt change in resonator potential.

Heater requirements are 6.3 volts a.c. or d.c. at .44 amperes. The maximum ratings are 330 volts d.c. for resonator or shell voltage, 0 to —400 volts d.c. for repeller voltage range, 32 milliamperes d.c. for cathode current, 45 volts d.c. for heater-cathode potential difference and a frequency range of 8702 to 9548 mc. Power output varies from 20 to 33 milliwatts.

Fig. 6 shows graphs for the 2K28 comparing repeller voltage range versus change in wavelength. The frequency of this tube is determined by its resonator geometry. The complete resonator consists of two gold-plated copper discs and an external cavity which makes contact to them. The cavity used with the tube should have a dimension of .4 inch and should grasp an outer annular ring of 1/16". Maintaining proper cavity dimensions is important in that the cavity is usually made of brass and has a relatively large expansion coefficient compared to the glass between the two discs. By contacting the outer edges of the discs most of the movement caused by expansion will be taken up by the flexing of the copper discs without placing undue strain on the copper-to-glass seals.

Heater requirements for the 2K28 call for 6.3 volts a.c. or d.c. at .65 amperes. The maximum ratings are 300 volts d.c. for the grids, 45 milliamperes d.c. for cathode current, 0 to —300 volts d.c. for repeller voltage, 45 volts d.c. for heater-cathode potential difference and 1200-3750 megacycles for the frequency range with suitable

Fig. 3. Circuit diagram of the power supply and square wave modulator.



cavity. The tube is rated at 115 milliwatts output in the frequency range 3400-3600 megacycles with 250 volts d.c. on the grids, 20 milliamperes d.c. cathode current and —170 to —300 volts d.c. repeller voltage when operated on the 4th mode. When operated with 300 volts on the grid, this changes to 30 milliamperes d.c. cathode current, —155 to —290 volts d.c. repeller voltage on the 4th mode, 140 milliwatts power and frequency range still 3400-3600 megacycles.

In addition to special power supply requirements for these tubes, there must be modulating provisions of the microwave signal source in order to permit demodulation later by means of a crystal detector. Amplitude rather than frequency modulation is necessary. There are two methods normally used for AM. These are the sawtooth and the square wave. The square wave form of modulation is normally used because the sawtooth type has a marked FM component in the output of a klystron. Square waves will have a much lower FM component and it will not distort the readings. FM particularly cannot be tolerated if the energy is to be detected on a standing wave detector since the maximas and minimas will not fit the frequency and will create confusion. Reflex tubes are modulated by applying the square-wave signal to the oscillator repeller. FM is minimized by using a square wave with sufficient amplitude so that the oscillator drops out of oscillation for alternate half cycles, provided this be done below a limit where the tube is not driven into the next lower mode of oscillation.

Fig. 5 is the front panel view of a power supply and square wave modulator developed to meet the requirements of properly energizing and modulating the reflex klystron type of tubes. It is widely used in the microwave art by schools and laboratories for the so-called low voltage type of reflex oscillators described here. It is similar to the TVN-7BL unit used by the MIT Radiation Laboratory during World War II but is now known as the Type DB-407 from commercial sources. Fig. 3 is the complete circuit diagram including part values. Fig. 1 shows the unit mounted in a rack with a companion amplifier to furnish energy indications. In a typical application, working with a microwave bench test setup of fabricated wave guide components, a power cable leading from the back of the power supply and modulator unit energizes and modulates a tube such as the 2K25 located within a shielded and ventilated tube housing. In the Fig. 1 setup, the output is fed through the following components when viewed from left to right:

a. Tube mount for the Type 2K25 tube. The tube supply and modulator voltages are fed into the tube mount via an octal socket. The tube's antenna extremity protrudes into a wave guide forming part of the over-all assembly. A tunable back plunger is provided for terminating the wave guide with an adjustable short. A knob on the ventilated tube shield is used to vary the physical dimension of the klystron for tuning purposes. It controls the tuning screw on the tube to change position of tuning bows which are part of the tube's physical construction.

b. Flap attenuator for padding purposes. A hinged attenuator strip is made of carbon coated bakelite. The position of this flap can be varied, thereby permitting the strip to be inserted any desired depth into the wave guide. The attenuation will increase with increasing depth of penetration. The unit illustrated is designed for a maximum of 10 db. attenuation.

c. Frequency meter of the absorption cavity type. The cavity size is varied by a movable plate to resonate at any frequency throughout its operating range. It is moved by a micrometer with engraved calibrations on the micrometer barrel. These calibrations can be converted to frequency or wavelength by referring to the calibration charts furnished by the manufacturer.

d. Standing wave detector for measuring amplitude and phase conditions within the wave guide system. A silicon crystal detector or a bolometer (which may be a 1/200 ampere *Littelfuse*) connects from the moving probe traveling in the wave guide slot. A coaxial cable connects from the detector to a tuned amplifier to furnish an indication on the meter.

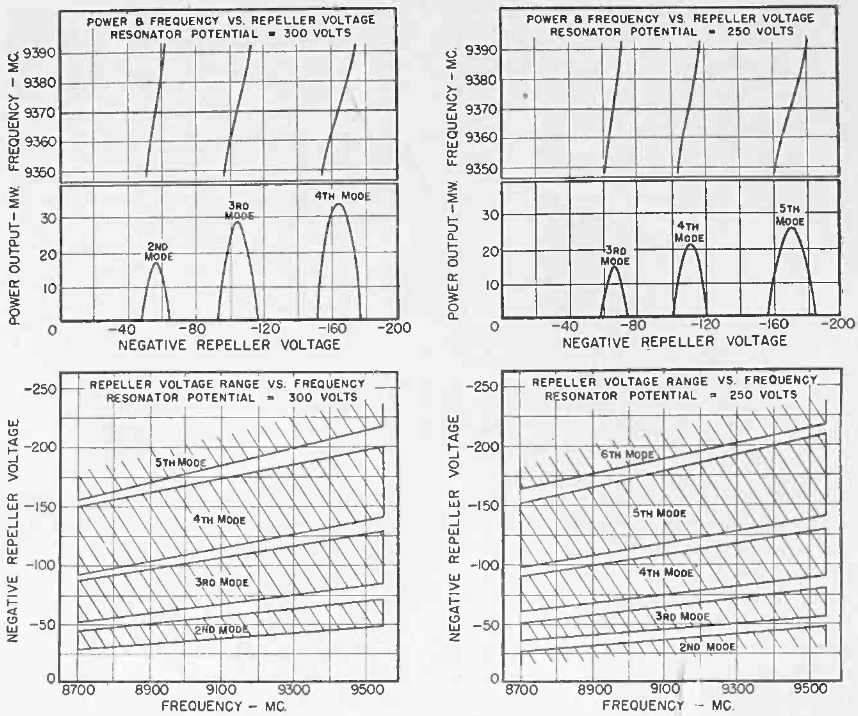
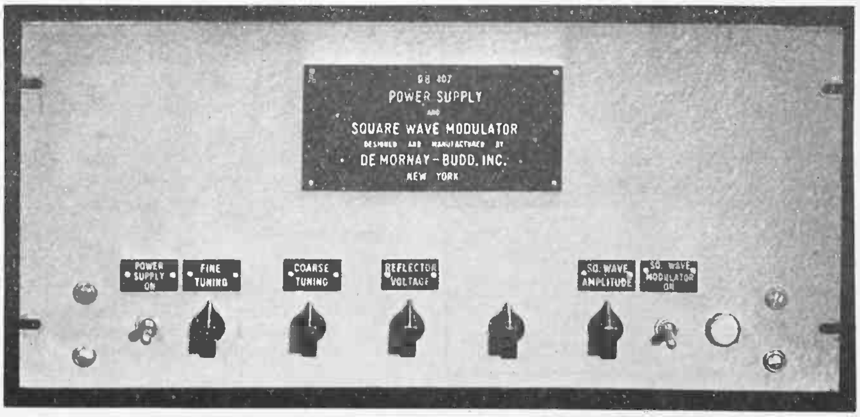


Fig. 4. Electrical characteristics of the type 2K25/723A/723B klystron oscillator.

Fig. 5. Front panel view of the square wave modulator.



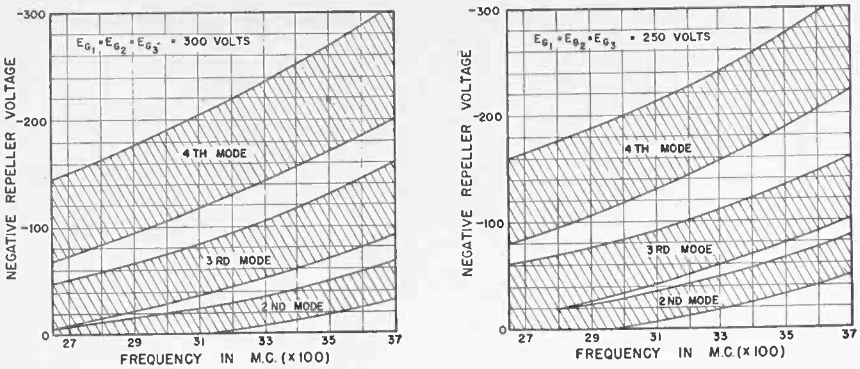


Fig. 6. Repeller voltage range vs. wavelength for type 2K28 tube. The exact value of repeller voltage producing maximum output at a certain frequency will vary somewhat from tube to tube, but the voltage for all tubes will fall within the shaded area indicated for each mode.

e. An optional bi-directional coupler in which samples of energy traveling in both directions in the wave guide are taken from the primary or main wave guide line by two auxiliary wave guides. It provides a means for measuring actual wave-guide power propagating in either or both directions at low power levels without disturbing the main transmission line. These may be taken off at the coaxial connections leading from the auxiliary guides.

f. Power termination and variable stub tuner. The power termination terminates a wave guide in its characteristic impedance and dissipates all of the microwave energy incident to it. It is a dummy load to provide practically reflectionless impedance match. The variable stub tuner further serves to vary the impedance in phase and magnitude to the optimum value.

The DB-407 power supply and modulator described in this article draws 80 watts from 115 volts, 60 cycle, single phase source. It delivers 6.3 volts at 2 amperes for heater and —300 volts for cathode as well as —300 to —450 volts d.c. for repeller requirements. When used with the 6-prong socket in the case of the 2K50 tube, there is also provided control triode voltage of —300 to —350 volts. The square wave modulator has a frequency range of 500 to 2000 c.p.s. The amplitude of the square wave is 0 to 100 volts peak to peak.

Referring to Fig. 3, the main power supply functions from the two transformers T_1 and T_2 and a full-wave rectifier V_1. It is separate from the square-wave modulator power supply, which functions from the transformer T_4 and the full-wave rectifier V_2.

Control of the output voltage of the main supply is accomplished by tubes V_3 and V_4. V_3 acts as a current-regulator tube, its grid voltage being determined by the plate current of the 6SJ7 (V_4) flowing through the bias resistor of that tube. The resultant increase of the drop in R_2 changes the grid voltage of the 6Y6 (V_3) negatively. For a given current delivered to the klystron cathode, this change in grid voltage must be balanced by an increase in the drop across the 6Y6. With proper circuit adjustment, this restores the output voltage to its original value.

The voltage which appears at the grid of the 6SJ7 is the difference between a positive voltage, taken from a voltage divider across the output voltage, and the fixed negative bias provided by tubes V_5 and V_6 voltage regulators. The constant bias provided by these regulator tubes, including especially the independence of this bias on the 6SJ7 plate current, is essential to the operation of this system. Adjustment of the bias, by means of the variable resistor R_3, provides the means of adjustment of cathode voltage for the klystron. This resistor is set and locked at —300 volts. The regulated reflector voltage is obtained by tapping off from a voltage divider R_6 placed across the two voltage regulator tubes.

The voltage supply for the square wave modulator is regulated by tube V_7 (VR150). Tube V_8 (6SN7) and its associated circuit form a conventional multivibrator consisting of a two-stage resistance-capacitance coupled amplifier with the output leads of the second stage connected to the input leads of the first. The dual adjusting control of the grid returns R_7 adjusts the frequency of operation. In order to prevent the load from affecting the multivibrator frequency, the output voltage is taken from a buffer amplifier tube V_9 which is excited by the multivibrator.

Sequence of operation is as follows:

1. With chassis grounded, connect the unit to klystron tube with the appropriate cable.
2. Turn square wave modulator switch to "ON" position.
3. Adjust all panel controls to central position.
4. Turn power supply switch "ON."
5. After 5 minute warm up, tune reflector voltage for maximum output of the tube as indicated on the meter.
6. Adjust square wave amplitude for maximum output.
7. Tune square wave frequency for maximum response. The setup is then ready for operation.

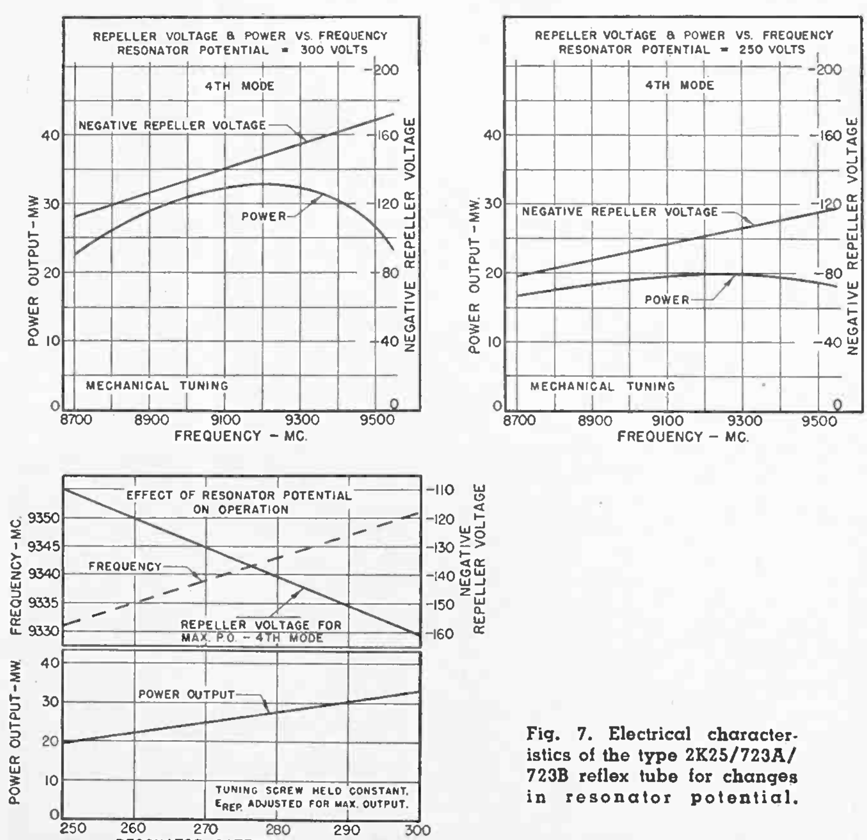


Fig. 7. Electrical characteristics of the type 2K25/723A/723B reflex tube for changes in resonator potential.

HIGH IMPEDANCE D. C. VOLTMETERS

By

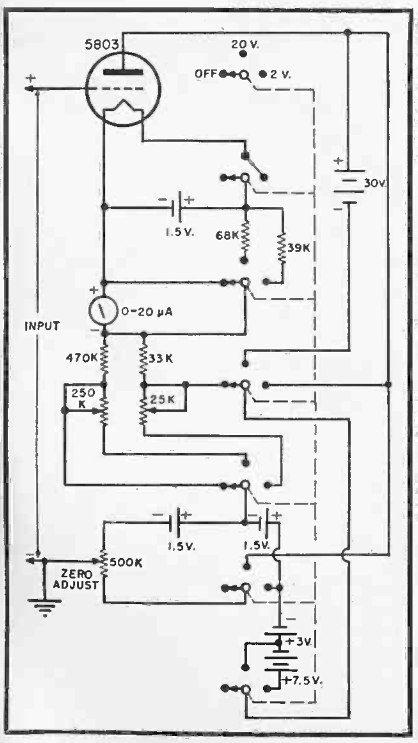
EDWIN N. KAUFMAN

(Left to right) A "Fusite" octal header, a hermetic glass bead, a type 5803 tube, and interior and exterior views of a probe such as that shown in Fig. 2. Next is a 50,000 megohm resistor, a type 5803 electrometer tube and a very small probe.

Input impedances of the order of 10^{12} ohms are possible with electrometer tubes now available.

FOR many applications a direct current voltmeter with very high input impedance would be desirable. The average 'high' impedance voltmeter boasts of 10, 20, or possibly 100 megohms input resistance. These same meters are incapable of being used to indicate potentials on the order of ten millivolts. It has been possible for some time to construct d.c. voltmeters with almost inconceivably high input resistances. With comparatively little trouble voltmeters with an input value of 1,000,000 megohms (1,000,000,000,000 ohms) can be constructed. Resistance values of this magnitude are generally referred to as log. functions, the above being 1.0×10^{12}. This advance has been assisted greatly by the advent of the electrometer tube pioneered and perfected by the *Victoreen Instrument Company* of Cleveland, Ohio. Electrometer tubes are so designed and constructed that minute grid current is drawn. This is necessary, because it can easily be seen that a very small amount of grid current thru a grid resistor of the above magnitude would place a varying and objectionable grid bias on the tube. The electrometer tubes VX32/5803 and VX41/5800 have grid currents on the order of 10^{-14} ampere when properly operated. Converting 10^{-14} into decimal figure we arrive at .000,000,000,000,01 amperes. Due to the liberation of photoelectrons when in light these tubes must be enclosed so that no light falls upon them. Careful shielding is also required to prevent 60 cycle hum pickup which in any strength will cause the tube to become paralyzed. Without shielding it is possible to detect a 60 watt electric light bulb twenty feet away due to its alternating magnetic field, if this sort of application is desired. Due to the very high leakage resistance of the electrometer tube base and grid resistor they should not be touched with the fingers or contamination will occur. Should contamination occur by some accident it is possible to restore the original surface resistance by washing the tube base with alcohol and distilled water and baking in an oven for about an hour at 100°C.

Fig. 1. Typical electrovolter using the 5803 electrometer triode. Note that the leakage resistance of the tube is used as the grid resistor.

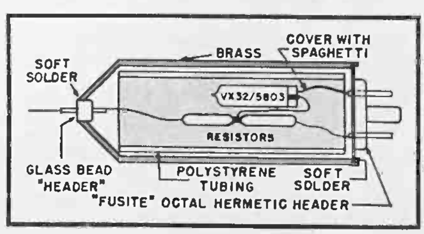


Resistors can be obtained from 10^{8} to 10^{14} ohms to be used with the above tubes. The temperature and voltage coefficient of these resistors are very small, in the order of 0.1 per-cent combined per degree Centigrade. Normal operating range is from −40°C. to 120°C.; relative humidity up to 98, and a voltage range of 100 microvolts to 1,000 volts. Resistors cost $5.50 up to 100,000 megohms, while electrometer tubes list at $12.50 each. For the average use the VX32/5803 electrometer tube is recommended.

It must be realized that substances normally thought of as insulators are in reality resistances which if allowed in contact with the grid of the electrometer tube will shunt the effective grid resistance to a lower value. It is strongly recommended that the grid probe support be a hermetic glass bead feed thru insulator; such as manufactured by *Electrical Industries, Inc.*, 42 Sum-

(*Continued on page* 30)

Fig. 2. Probe for use with Fig. 3.



V.H.F. TANK DESIGN

This flat type quarter-wave tank combines the desirable characteristics of coaxial and balanced two wire circuits.

By
B. E. PARKER

AT V.H.F. the design of the grid and plate tank circuits becomes of increasing primary importance. Many factors often completely disregarded at lower frequencies must be carefully evaluated in the design. Some of these practical considerations are shown for the three most commonly used forms of quarter-wave sections of transmission line. Each of these three types, coaxial, balanced two wire, and flat element, may be represented by the equivalent low frequency lumped form shown in Fig. 3. In transmission lines the inductance and capacity are in actuality distributed throughout the entire length.

The effective values of L and C are determined by the surge impedance of the line. It is apparent from this that the design of the tank circuit is largely dependent on this characteristic surge impedance.

Each of the three types of transmission lines when used for tank circuits has its distinctive advantages.

The coaxial type tank lends itself readily to single-ended construction where only one tube is used. The radiation losses are extremely low since the conducting surfaces are effectively shielded by the outer conductor. Short tube connections are realizable as the tube can be placed often right into the end of the coaxial tank. Numerous coaxial tube types are available on the market and are designed specifically for this application. The characteristic surge impedance of the tank can be made quite low to permit tank lengths sufficiently long for good efficiency. The relationship of the surge impedance to the effective electrical and physical length of the tank will be shown later.

The balanced two wire line lends itself quite readily to push-pull operation. With push-pull operation the tube input and output interelectrode capacities are in effect connected in series which decreases considerably the shortening effect of the tube capacities on the physical length of the tank. In other words, the use of a tube type having 10 $\mu\mu$fd. input capacity in a push-pull circuit would result in only 5 $\mu\mu$fd. appearing across the end of the tank. Even order harmonics are largely eliminated by the push-pull operation. This is often advantageous where second harmonic radiation must be suppressed to a high degree.

The flat type quarter-wave tank is essentially an outgrowth of the balanced two wire line, in which the wires or round elements have been replaced with flat elements. Fig. 2 is a representative tank circuit of this type. It has most of the desirable characteristics of both the coaxial and balanced two wire line circuits, as it can be made to have low characteristic surge impedance and fairly low radiation loss. It is easy to fabricate in even the most modestly equipped workshop which makes it ideal for experimental work. The flat type tank is adaptable to either push-pull or single ended operation. Fig. 5 shows a commercial application of such construction for push-pull operation. Fig. 1 shows an experimental laboratory unit using single-ended construction with a type 2E26 tube operating at approximately 170 mc. The commercial evolution of flat tank circuits is quite new, in fact, the writer knows of only one prominent FM manufacturer and two television manufacturers who have utilized this type of construction in new models.

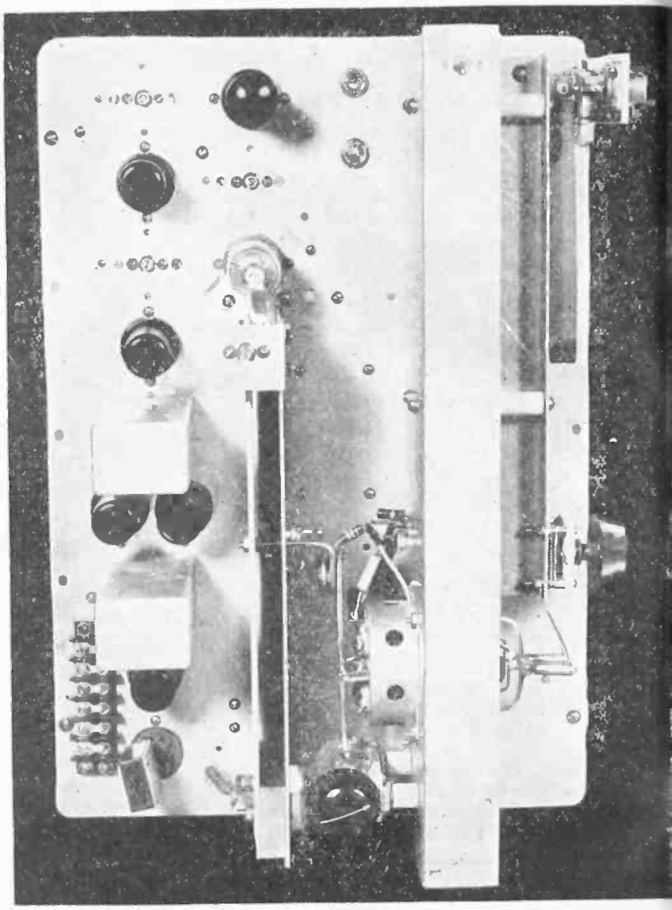


Fig. 1. Experimental laboratory unit using single-ended construction operating at approximately 170 megacycles.

Physical Lengths of Tanks

The physical lengths of all three types are dependent on characteristic surge impedance, tube interelectrode capacity, effective tube lead length, and shielding or proximity effects.

The characteristic surge impedance may be calculated for a coaxial tank by:

$$Z_0 = 138 \log_{10} b/a \quad (1)$$

where Z_0 = characteristic surge impedance
b = radius of outer conductor
a = radius of inner conductor

For balanced two wire line:

$$Z_0 = 276 \log_{10} D/a \quad (2)$$

where D = center to center spacing
a = radii of conductors

For flat element type:

$$Z_0 \cong 377\ s/w \quad (3)$$

where w = width of line
s = spacing between surfaces $(w \gg s)$

With the characteristic surge impedance and effective tube interelectrode capacity known, the physical length of the tank for any of the above types may be figured for a given frequency. Since for resonance the inductive reactance must equal the capacitive reactance ($X_L = X_C$) it will be necessary to find the reactance of the effective tube interelectrode capacity. The value of this capacity in $\mu\mu$fd. may be found in the tube handbook or manufacturer's literature. The line in order to be resonant must present an inductive reactance equal to this capacitive reactance. By the following, the length of the line may be calculated:

$$\tan \theta = jZ_0/Z_{in} \qquad (4)$$

where θ = length of line in degrees
Z_{in} = input impedance in ohms
Z_o = characteristic surge impedance

Taking a typical example for a flat element tank with the following parameters:

Tank spacing between elements	1"
Width of tank elements	2.5"
Effective shunt capacity due to tubes	16.5 $\mu\mu$fd.
Frequency	88 mc.

The capacitive reactance of this shunt capacity is 110 ohms.

To find the characteristic surge impedance, substitute in Eqt. (3). This gives Z_o = 151 ohms. Now to arrive at the electrical length in degrees and the actual physical length in inches, merely substitute in Eqt. (4). This gives a value of θ of 36.1°.

Since the wavelength is expressed in degrees (36.1°), this must be converted to inches. 36.1° corresponds to approximately one tenth (.1) of a wavelength. A wavelength at 88 mc. is 134 inches, making the tank length 13.4 inches.

Consideration must be given to two other factors which affect the final over-all length in practice, namely, tube electrode lead lengths and proximity effects of shielding. The length of tube leads will serve to make the tank effectively longer electrically. The presence of shielding due to the enclosure and the chassis will serve to lower the actual characteristic surge impedance of the tank. This has the effect of shortening the electrical length of the tank. These effects may be considerably lessened by careful layout and mechanical design.

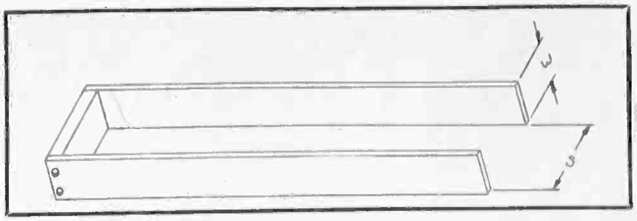


Fig. 2. Representative flat type of quarter-wave tank.

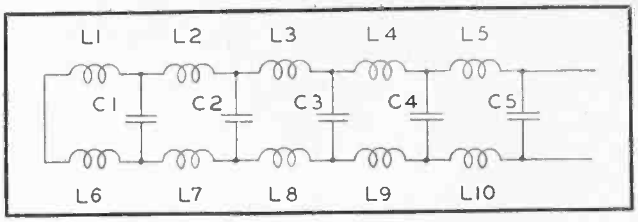


Fig. 3. Equivalent low frequency circuit of quarter-wave tank.

Tuning Methods

Tuning is usually accomplished by one or more of the following methods:

1. A variable capacitor placed across the high impedance end has been the most popular method. This works quite

(*Continued on page 27*)

Fig. 4. Power amplifier of a Gates 3 kw. FM transmitter, tuned by varying surge impedance of tank.

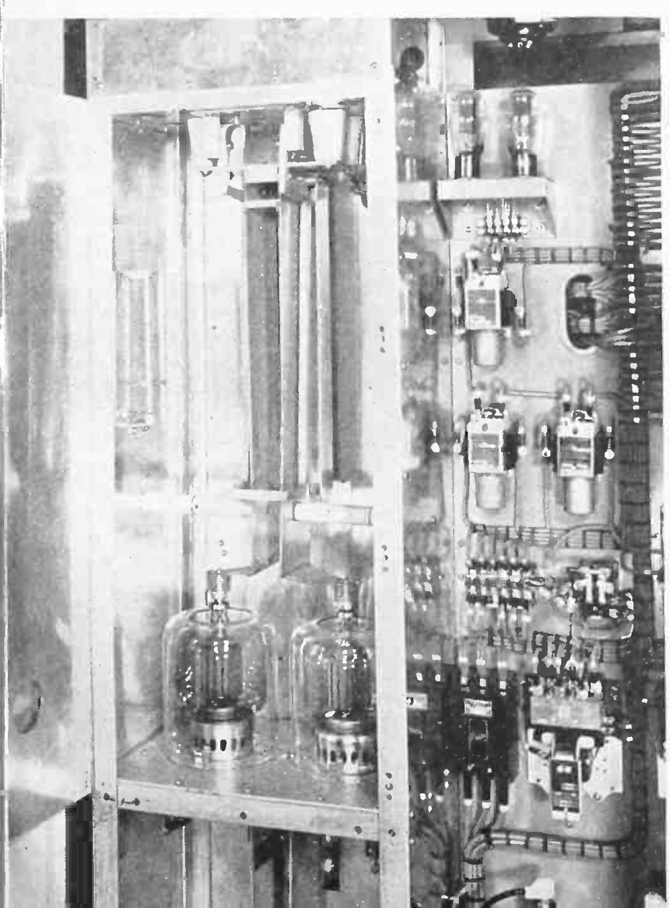
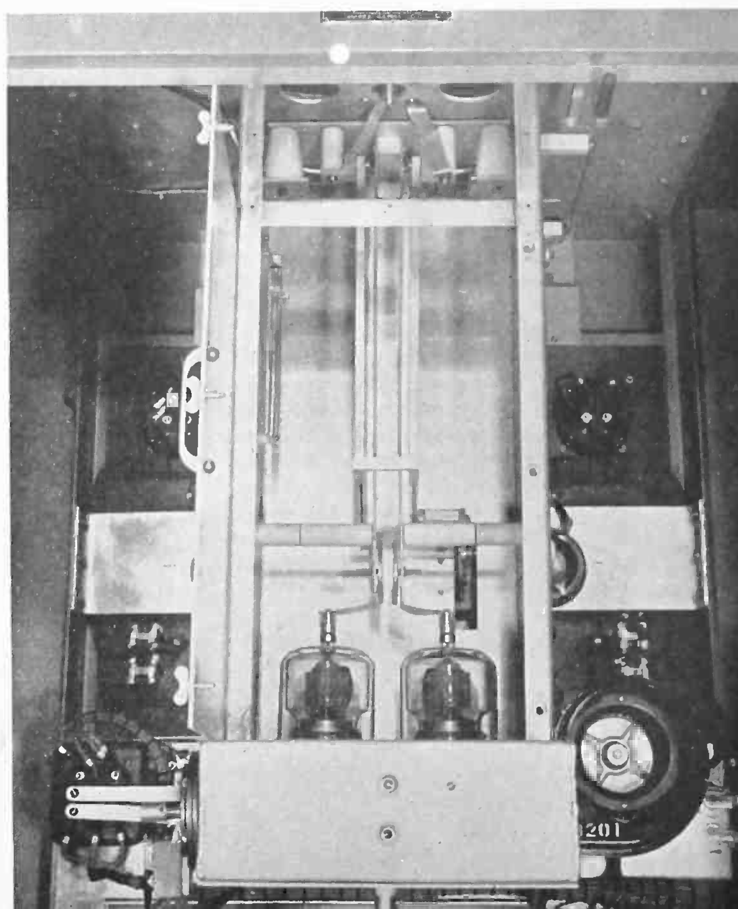
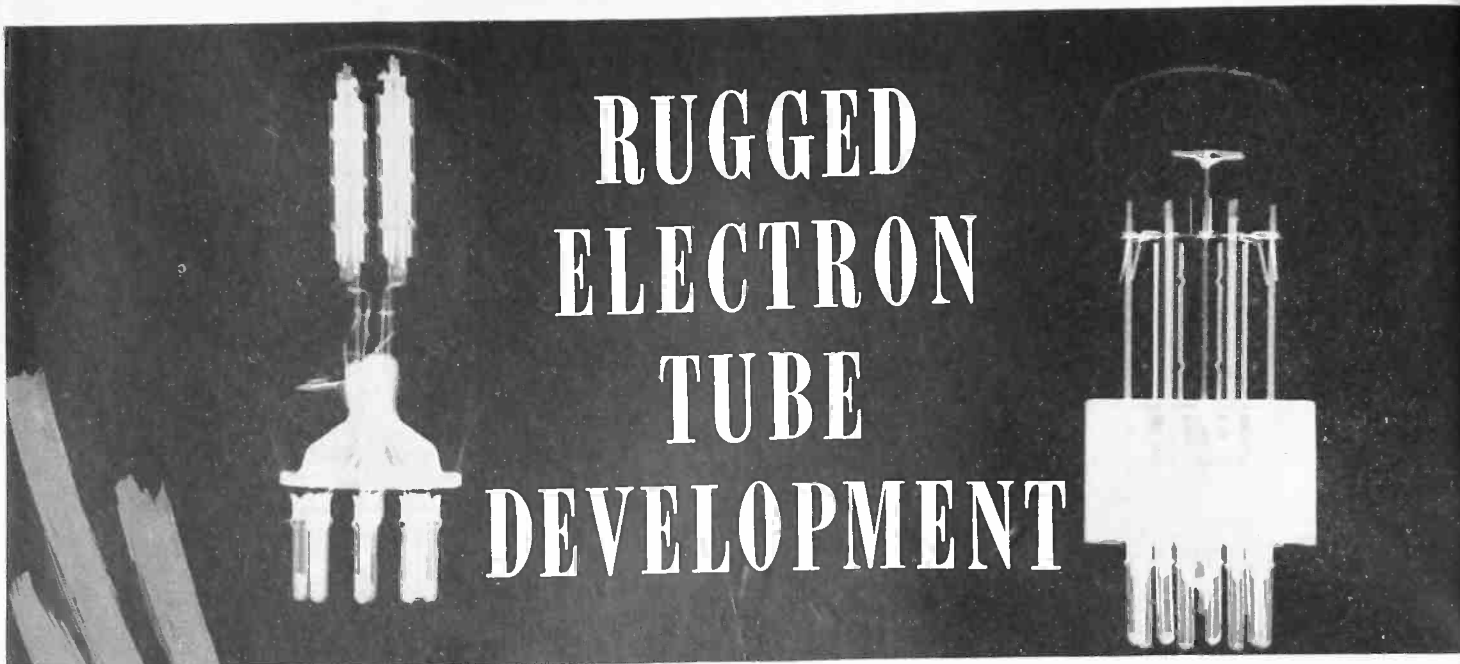


Fig. 5. Commercial application of the flat type of quarter-wave construction for push-pull operation.





RUGGED ELECTRON TUBE DEVELOPMENT

Mechanical vibration and resonance, high impact shock and centrifugal acceleration tests at NBS show up tube weaknesses and assist in evaluating more rugged designs.

Radiograph of two 6SN7GT tubes. Left, normal construction. Right, ruggedized version. Below, interior view of motor-driven centrifuge.

RUGGED electron tubes are indispensable wherever electronic equipment is used under severe conditions of vibration, shock, or acceleration. Important in the development of such tubes are methods of testing for sturdiness and durability. These methods are now being studied and developed at the National Bureau of Standards as part of a comprehensive tube ruggedization program under the direction of I. L. Cherrick of the Bureau's Electron Tube Laboratory. One phase of the project consists of a survey of the actual operating conditions for electron tubes in various kinds of commercial, industrial, and military applications. This study provides a practical basis for the design of test equipment to simulate hazards of actual use.

In addition to working out adequate test methods, the Bureau is developing new kinds of rugged tubes. The design of these tubes is based on an analysis of the ways in which ordinary tubes fail under test or in service. A detailed knowledge of operating conditions and tube failures is thus a useful guide to the design of tubes that will be strong enough to operate properly under severe mechanical abuse. Some tubes may have to withstand great extremes of temperature as well, but in any case the mechanical design of a rugged tube is strictly governed by the required electrical properties.

The Bureau's facilities for testing the ruggedness of electron tubes now include vibration apparatus, mechanical resonance testers, high-impact shock machines, and high-speed centrifuges. Some tests are conducted with typical electrical potentials applied to the tube elements so that noise modulation, short circuits, and other effects can easily be studied. Destructive field conditions can be reproduced through the proper choice of vibration, resonance, impact, and acceleration tests.

After receiving various ruggedness tests, tubes are examined for structural failures. X-rays are sometimes used to reveal the extent of structural changes without opening the tube envelope. Materials for certain tube elements are examined spectroscopically to determine their exact composition and to find impurities that might weaken the tube structure. This determination of the real causes of tube failure is an important part of the rugged tube program. Out of these studies will come recommended specifications for materials best suited to particular ruggedization problems. In some cases new materials and new methods of fabrication must be developed to meet the unusual requirements of ruggedization.

Vibrations produce the most common mechanical stress encountered by electron tubes under service conditions. Continuous and intermittent vibrations are present in vehicles, in aircraft, on shipboard, and in industrial applications. A survey of the actual vibrations in each type of service shows that there are definite, characteristic vibration frequencies—a noise spectrum—associated with each application. In motor vehicles the vibrations are usually of rather low frequency, but in aircraft they may range up to 10,000 c.p.s.

The Electron Tube Laboratory's mechanical vibration machines employ electric-motor drive arranged so that motor speed can be adjusted to vibrate the driven element at any selected frequency between 7 and 60 c.p.s. Vibration equipment of this type can, of course, be designed to produce higher frequencies, but this is not usually done because of the lack of precision in frequency control, excessive wear on moving parts, and the appearance of unwanted harmonics. In some cases it may be useful to construct a vibration machine to work at a particular fixed frequency up to several thousand cycles per second, although it would be necessary to limit the amplitude of vibration to prevent self-destruction of the machine.

Several different types of low-frequency vibration apparatus are in use at the Bureau. One vibrator employs an unbalanced fly-wheel suspended on leaf springs; the frequency of vibration depends on the speed of rotation, and the amplitude depends on the stiffness of the springs. Also in use is a vibrator in which the circular motion of a flywheel is converted to linear vibration of a test table through a simple mechanical linkage. The amplitude of vibration is approximately 0.2 inch peak to peak.

Electron tubes are often tested by continuous vibration for periods of several days to produce fatigue failures at the points of weakness. These tests are usually conducted at a fixed frequency that is representative of field conditions. In shorter runs the vibration frequency is usually varied cyclically in order to study the effect of a range of frequencies on the performance of the tube under test.

Mechanical vibrations have many different effects on the operation and life of electron tubes. Fatigue failures due to vibration are very common in ordinary tubes. They are especially likely to occur in tube elements made of crystalline materials, such as filaments and cathode coatings. Improperly welded joints are another frequent source of trouble. When the tube is operated under vibratory conditions, flashovers between electrodes may occur, and mica contacts will often chip or split if they are placed against a glass envelope. The grid wires and the plate of an electron tube, however, seldom exhibit fatigue failures. High-amplitude resonance vibrations in the tube structure may occur at particular frequencies, and the vibration of tube elements may affect the operation of the tube by introducing microphonics. Noise modulation results from the vibration of tube elements and the consequent variation in interelectrode spacing.

Mechanical Resonance Tests

The most severe effects are encountered in cases where the vibration applied to the tube contains components of a particular frequency which corresponds to the natural frequency of vibration of some tube element or structure. The electrical noise in the output of the tube will then have a sharp peak at this resonant frequency which may be large enough to completely override the desired signal. Microphonic effects are a major problem in applications where the normal mechanical vibration occurs over such a broad frequency spectrum that the natural resonant frequency of a particular tube element is excited by some component of the incident vibrational energy.

Mechanical resonance apparatus differs from vibration equipment principally with regard to size—resonance testers are smaller and involve lower energies. The mechanical resonance testers in use at the Bureau are in the form of loudspeaker-type vibrators. The vibrator is excited by means of an audio oscillator and amplifier which produce an audio-frequency signal that can be varied from low frequencies up to more than 20,000 cycles per second. This vibration is monitored by means of a magnetic-type moving-coil vibration pickup attached to the tube mounting. The proper electrode potentials are furnished by a battery power supply to minimize extraneous noise effects. In testing for microphonism a special mounting is used to transmit the vibrational energy directly to the tube, and a cathode-ray oscilloscope is connected to the plate circuit of the tube so that noise modulation corresponding to a given mechanical vibration frequency will appear as a deflection on the oscilloscope screen.

At certain critical frequencies noticeable resonances may occur in any tube. The vibration of the plate itself may be sufficient to produce an objectionable noise effect. In some cases the mechanical resonance vibration may be sufficient to cause fatigue failure of tube elements. For example, oxide coatings of cathodes will often flake off as a result of resonance vibrations. The best preventive for resonance conditions is to design the tube so that the natural resonant frequencies of the various tube elements are higher than the vibration frequencies met in practice. It is important to use stiff materials for structural parts, to shorten the tube structure, and to design the cross sections of elements for greatest rigidity.

In general, mechanical resonance can be reduced by isolating the tubes from sources of low and high frequency vibration by means of rubber mountings of suitable design and by making

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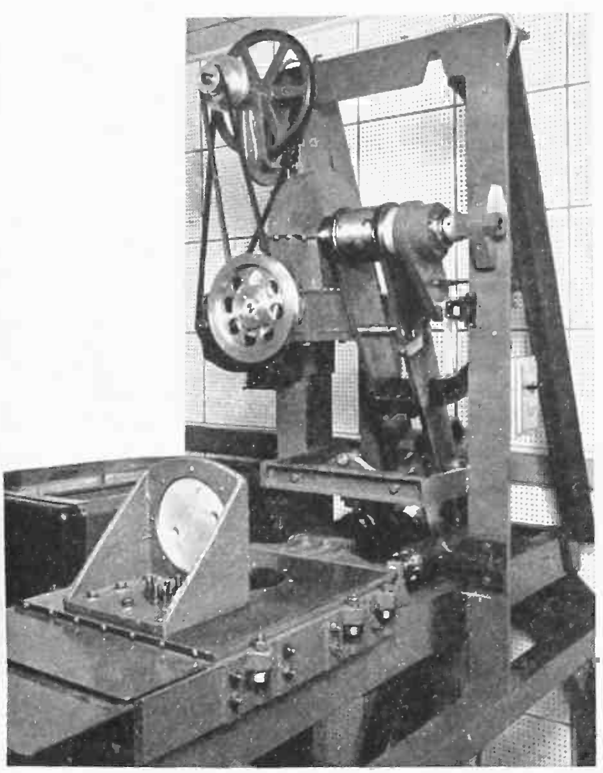
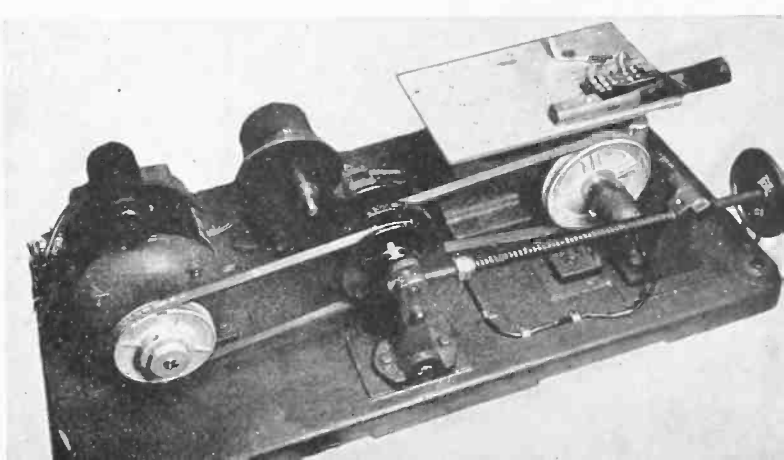


High-impact machine used at NBS to administer severe mechanical shocks to electron tubes. These tests determine the ability of tubes to withstand rough handling and dropping.



Mechanical vibration machines are used to test the ability of tubes to withstand low-frequency vibrations. This machine employs a cardioid cam to vary vibration frequency through a continuous cycle.

BRIDGE-BALANCED D.C. AMPLIFIER

By
G. A. and T. M. KORN
Curtiss-Wright Corp.

This amplifier overcomes drawbacks of earlier d.c. amplifiers and also offers some important advantages.

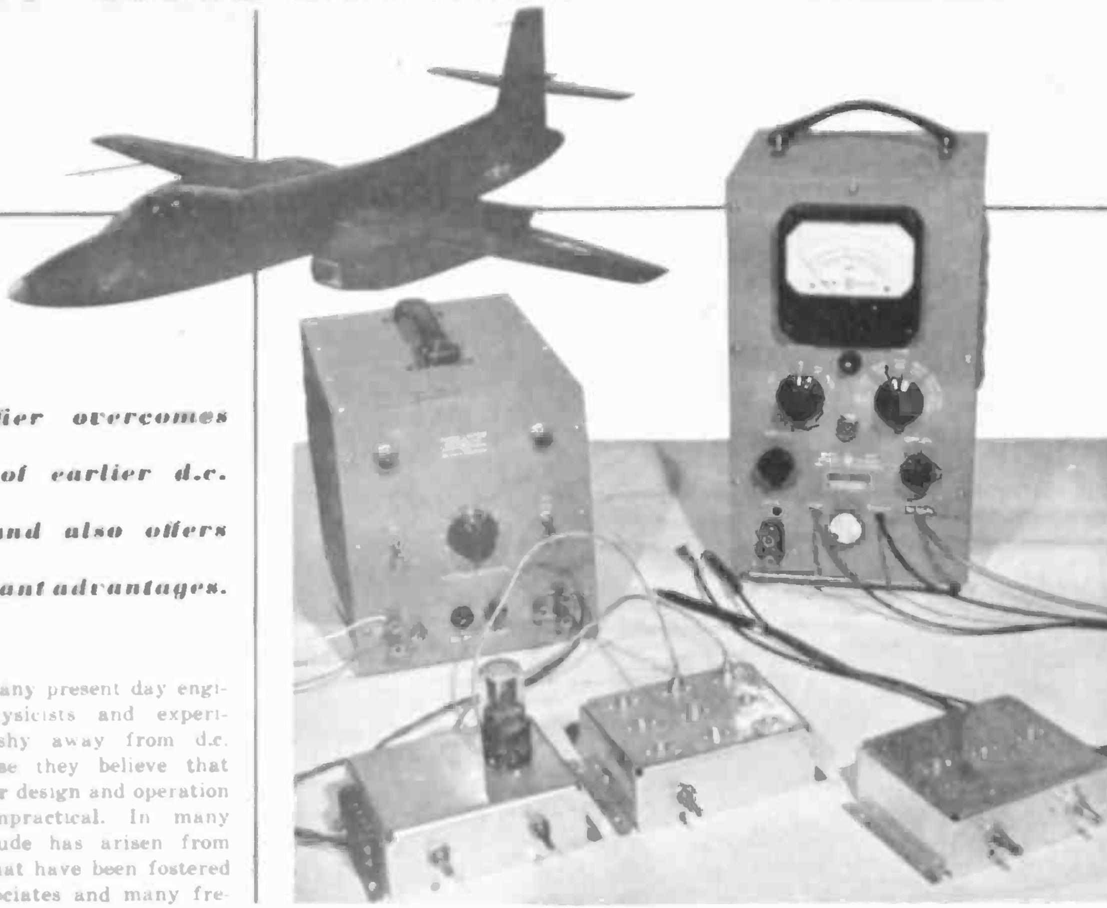


Fig. 1. D.c. amplifiers, a simple power supply, and some capacitive networks form a small electronic computer. Raggazini[6] has shown that such devices can simulate flight conditions of a new type airplane long before the first model is built. The aircraft shown is a Curtiss XF-8T.

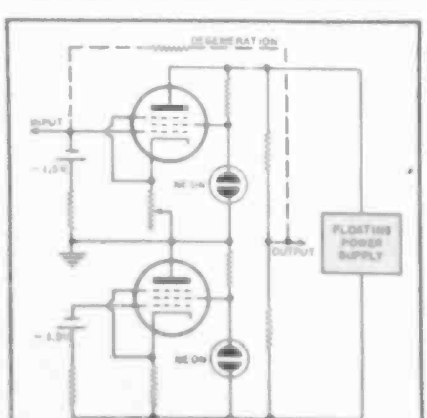
ALL TOO many present day engineers, physicists and experimenters shy away from d.c. amplifiers because they believe that difficulties in their design and operation render them impractical. In many cases, this attitude has arisen from misconceptions that have been fostered by teachers, associates and many frequently used electronics textbooks.

Modern circuits and techniques have overcome many of these difficulties. The new type of bridge-balanced d.c. amplifier described in this article not only overcomes earlier drawbacks of d.c. amplifiers but also offers several important advantages in ease of operation and low-cost construction. Furthermore, this new amplifier is particularly well suited to portable battery operation, making it valuable not only to engineers, physicists and experimenters but also for certain applications in physiology and photography.

A d.c. amplifier might be defined as one which has a finite gain at zero frequency, but perhaps a more meaningful definition may be obtained by comparing a d.c. amplifier with an ordinary a.c. amplifier. In the a.c. amplifier, the output voltage is not affected by d.c. voltage changes at the input since the output and input are isolated by capacitors. A change in the input level of a d.c. amplifier, however, results in an amplified change of the output d.c. level.

This property of d.c. amplifiers permits them to amplify voltages which vary quite slowly, such as those obtained from pressure gauges, thermocouples and certain other measuring devices. High quality d.c. amplifiers have long been applied in physiological research work to measure nerve currents. More recently, they have acquired a new and striking usefulness in their application to servomechanisms and analog computers. They serve as electronic voltmeters and also provide low-frequency amplifiers for photocells, oscilloscope deflection plates, etc.

Fig. 2. Loss in gain due to unbypassed cathode resistors may be avoided through the use of bias cells.



The ideal d.c. amplifier for all these applications would be one having high stable gain, good frequency response and freedom from drift. Drift in d.c. amplifiers may be caused by changes in plate and filament voltages as well as changes in contact potential, tube characteristics, and circuit component values. It would also be highly desirable to obtain the output at the same d.c. level as the input using a minimum number of power supplies. This latter characteristic would permit convenient cascading of similar stages and application of feedback circuits. The ideal d.c. amplifier should also provide ease of operation, ruggedness, and easy balancing while requiring only readily available, low-cost circuit components.

Several means for achieving these desirable characteristics are already available. In addition to the familiar parallel or Miller compensator,[1] series compensation,[2] as shown in Fig. 4, has been used to eliminate the effects of changes in filament emission and contact potential in d.c. amplifiers. Emission and contact potential changes similar to those in the amplifier tube V_1 occur in the compensator tube V_2 and tend to balance out the resulting drift at the output terminal B. If the output is taken between B and C, changes in the plate supply voltage also tend to be balanced out and little or no regulation is necessary in the plate supply. In this series compensating circuit, the signal is applied to the grid of tube V_1 with the output being taken from the plate. For zero signal input, the quiescent output voltage varies from slightly above to slightly below 100 volts. This tends to make cascading and application of feedback from the output to the input difficult since the following grid would have to operate at a high positive potential. If, however, output is desired at zero d.c. level, a negative power supply is needed as indicated in dotted lines, and both supplies must be regulated.[3]

The new type of bridge-balanced d.c. amplifier to be described has all the advantages of series compensation and at the same time directly provides output at zero d.c. level and permits both the output and input voltages to be conveniently referred to a common ground reference.

In the simplest form of the new amplifier, shown in Fig. 6A, the amplifier tube V_1 and the compensator tube V_2 constitute two arms of a bridge in such a way that both input and output voltages appear at zero d.c. level. The power supply may or may not be left floating with respect to d.c. ground, thereby presenting several possibilities. It should be noted that only a single power supply is needed, although one positive and one negative supply may be used in series if desired.

The output voltage is balanced to the zero d.c. reference level at zero input by means of the variable cathode resistors indicated in Figs. 2, 3, 4, 6A, and 7.

The power supply may be center-tapped, as shown by the dotted lines in Fig. 6A. This scheme is used if several stages are to be cascaded, as in Fig. 3, and must be operated from the same power supply. An inspection of the circuit in Fig. 6A shows that the stage gain of the new amplifier is exactly one-half of the gain of the conventional stage shown in Fig. 6B. Comparison of the corresponding circuit elements in Figs. 6A and 6B enables one to design the new amplifiers by means of *standard resistance-coupled amplifier tables*, if allowance is made for the degeneration due to the unbypassed cathode resistors. The loss in gain may be avoided through the use of bias cells as shown in Fig. 2.

If only a single stage of amplification is involved, the power supply may also be floating with respect to ground (except for high audio frequencies at which the distributed capacitances C effectively bypass both sides of the supply

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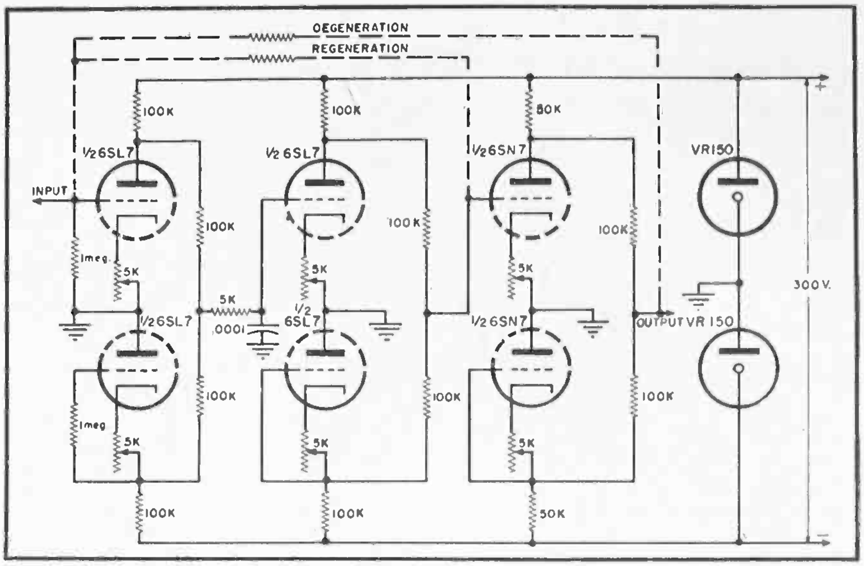


Fig. 3. Center-tapped power supply used when several stages are cascaded.

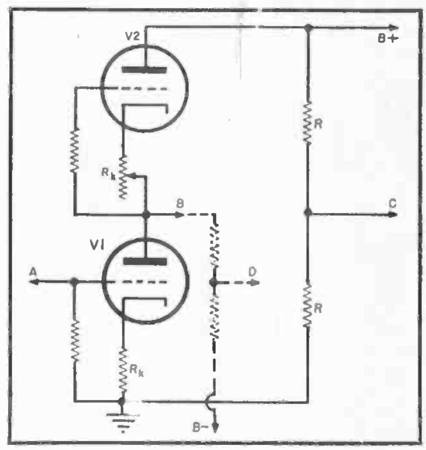


Fig. 4. Series compensation has been used to eliminate the effects of changes in filament emission and contact potential in d.c. amplifiers.

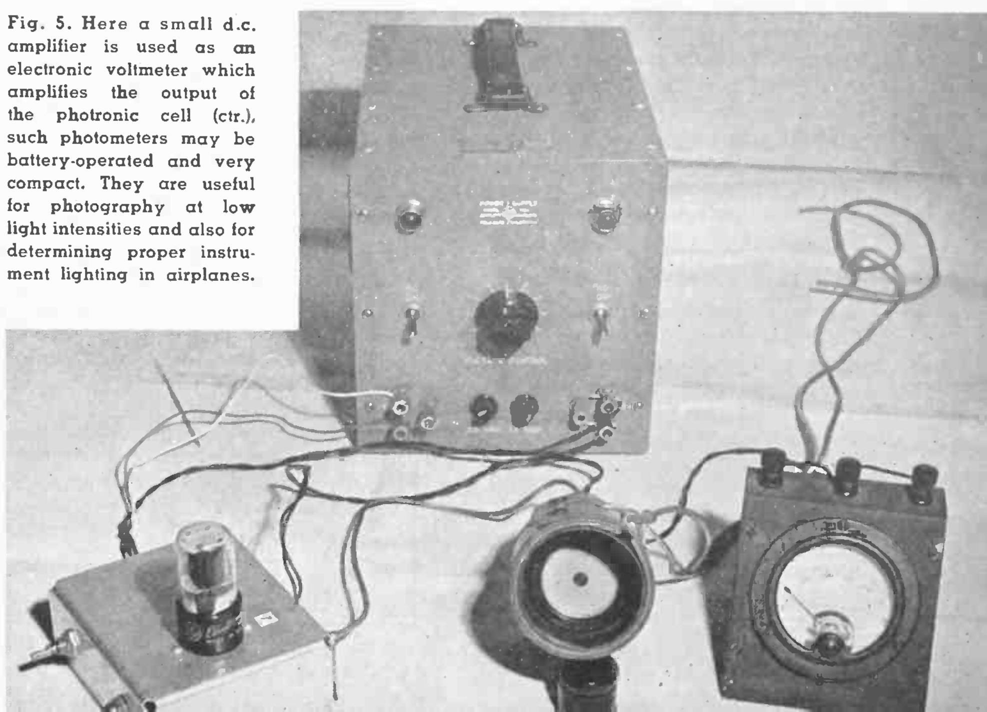


Fig. 5. Here a small d.c. amplifier is used as an electronic voltmeter which amplifies the output of the photronic cell (ctr.), such photometers may be battery-operated and very compact. They are useful for photography at low light intensities and also for determining proper instrument lighting in airplanes.

By
HARRY L. GERWIN

High sensitivity and rapid response make this recorder suitable for checking a wide variety of antennas.

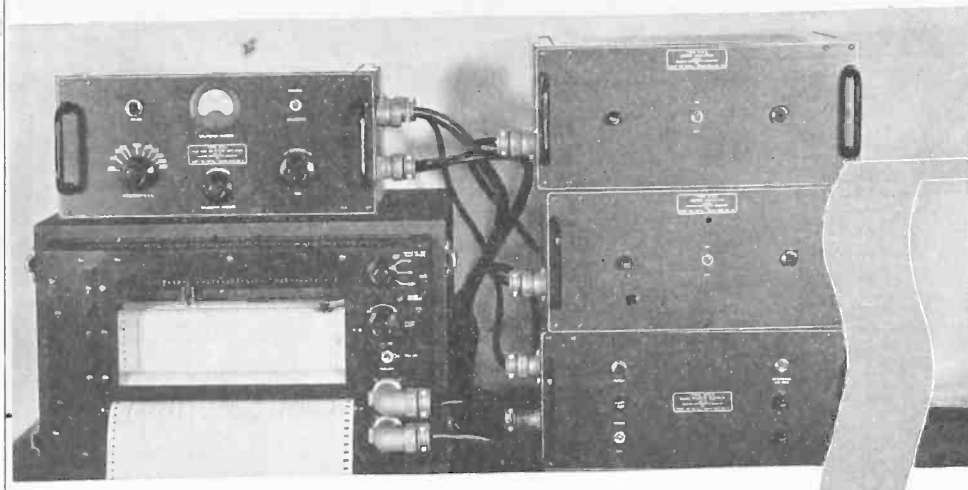


Fig. 1. The complete automatic recorder ready for operation.

AUTOMATIC ANTENNA Pattern Recorder

THE LARGE number of field strength pattern measurements required to adjust properly and/or evaluate an antenna inevitably lead to the use of automatic recording equipment. An automatic recorder has been devised which is capable of recording accurately and quickly a complete field strength pattern. The principal objective in the design of this device was high-speed response of the writing pen drive system without loss of accuracy. This feature is necessary, since the system is required to record patterns of rotatable antenna systems in which the mount is sometimes limited in how slowly it can rotate and still rotate smoothly. This minimum rotational rate determines the pen-writing response required, because the faster the antenna is rotated the faster the pen must travel to trace out the pattern.

Characteristics of Recorder

It is generally desirable to measure the relative radiation power of an antenna pattern in decibels. The recorder must then produce a linear writing pen displacement proportional to the logarithm of the r.f. power derived at the antenna. The linear decibel output is particularly advantageous because it produces a recording of the power variations encountered in measuring a field strength pattern of an antenna that has the same degree of accuracy at any point on the scale. The measuring range of this recorder is 40 db. plotted on a 10-inch scale.

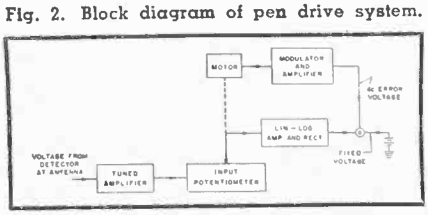
An indication of the response characteristics of the pen servo is shown in Fig. 4, which is the output curve plotted by the pen servo system for a 19.6 db. amplitude square wave input. It is seen that the pen servo will correct for an approximate 20 db. step function in 0.185 seconds. Over-all accuracy of the system is dependent primarily on an input potentiometer made up of inherently stable resistive elements.

Since the chart displacement must be linear it is made proportional to the angle of rotation of the antenna. As the recorder was designed for measuring narrow beam antennas, the patterns are plotted in cartesian coordinates. The paper can be driven at any one of three speeds: 20¼" per 10°, 20¼" per 60°, or 20¼" per 360°.

Pen Drive System

A block diagram of the pen drive servo system is shown in Fig. 2. To facilitate the measurement of r.f. power, the power source is amplitude-modulated at a convenient frequency, generally between 500 and 2000 c.p.s. The voltage derived from the detector (usually a bolometer) affixed to the antenna under test is fed to a tuned amplifier which has a bandpass of approximately 10 per-cent of the modulating frequency. The tuned amplifier is used to reject unwanted signal frequencies, thereby obtaining higher sensitivity. This characteristic is necessary because the recorder must be extremely sensitive to measure the side lobes and minima of an antenna pattern when the power output of the r.f. source is limited and the gain of the antenna under test is low.

Fig. 2. Block diagram of pen drive system.



The output of the tuned amplifier, which is linear over an amplitude range of 100 db., feeds an input potentiometer in which the output voltage of the sliding contact varies in a negative exponential fashion with a linear movement of the contact. This output voltage provides the control signal for the servo motor which repositions the sliding contact and the writing pen attached to it. Servo systems are designed on a linear basis; therefore it is necessary to modify the voltage from the sliding contact so that it varies linearly with a linear movement of the contact. This function is performed by the lin-log amplifier, whose output varies as the logarithm of the input function.

Up to this point in the system the original modulating voltage has been used. The output of the lin-log amplifier is rectified to produce a d.c. voltage which is compared with an arbitrary fixed voltage, and the difference or error voltage is fed to a modulator. The modulator converts the d.c. error voltage to a 60-cycle a.c. error voltage which drives one phase of a 2-phase motor. The motor then positions the sliding contact on the potentiometer, thus reducing the error voltage to a minimum. The sliding contact and writing pen seek a position which is proportional to the logarithm of the voltage fed to the input potentiometer. In this way the linear decibel type of pen writing is obtained.

The fast response time with a critically damped system was made possible by the unique pen drive system. The pen carriage (which also holds the movable tap of the input potentiometer) is driven by a cable from a drum fastened to the motor shaft. This type of drive system (shown in Fig. 5) provides low inertia, no backlash, low friction, and a mechanical resonant frequency above the passband characteristics required. Local feedback is applied in the usual manner to extend the frequency characteristics of the two-phase induction motor, to reduce its nonlinearity and to improve the servo output stiffness, thus improving static accuracy.

The input or negative-exponential potentiometer mentioned above is approximated by cascading a number of symmetrical π sections made up of resistive elements. It is constructed by starting with a slide-wire potentiometer to which shunt resistors have been added at equally spaced intervals to form the π sections (see Fig. 3). The potentiometer is an approximation to the desired function since the function is correct only at the tap points; at all other points the voltage at the sliding contact is a linear interpolation of the voltage between taps. By the use of a suitable number of elements the maximum error can be reduced below the operating accuracy expected of the entire system.

The antenna pattern recorder has a voltage range of 80 db. Using a bolometer as a detecting element (square-law detection) a total range of 40 db. variation of r.f. energy can be recorded on the chart.

Chart Drive

The chart drive performs the function of maintaining a chart displacement that is directly proportional to the angle of rotation of the antenna. A block diagram of the basic system is shown in Fig. 5. It consists of a synchro generator, a synchro control transformer, a servo motor amplifier and a two-phase induction motor.

The synchro generator, driven mechanically from the antenna mount, initiates 60-cycle voltages which are transmitted to the synchro control transformer at the recorder. A difference in the relative angular position of the synchro generator at the antenna mount and the synchro control transformer at the recorder generates an electrical error signal which is applied to the input of a servo motor amplifier. The amplifier output operates the two-phase chart motor which drives, through appropriate gearing, the synchro control transformer in such a direction that the error signal is reduced to a minimum. The angular position of the control transformer is thereby kept aligned with the synchro generator at the antenna mount. The recording chart drum is geared directly to the control transformer, and thus, the paper displacement will always indicate the antenna position. Actually, two synchro control transformers are appropriately geared to the chart paper drum and the chart drive motor. When the antenna system is provided with two synchro output speeds geared 36 to 1, and 1 to 1, the three chart speeds are available by switching electrical connections without the necessity for shifting gears at any time.

Local feedback is also applied in the chart drive system to obtain improved operation. This insures precision tracking between the chart paper and the antenna mount.

Systems Operation

Fig. 1 is a photograph of the complete recorder system, which is built as five individual units in order to make it portable. Most antenna work is done at fixed installations and the equipment lends itself to rack mounting, but in many cases it is desirable to measure antenna patterns of radar or radio equipment on location. Such patterns are easily obtainable. The radar transmitter can usually be used as the power source and the only additional equipment needed is a bolometer holder matched to the frequency being measured, an r.f. pickup element such as a dipole, horn, or parabola, synchro inter-connecting wiring and a suitable location for the pickup element. The precautions taken in setting up a permanent installation must also be

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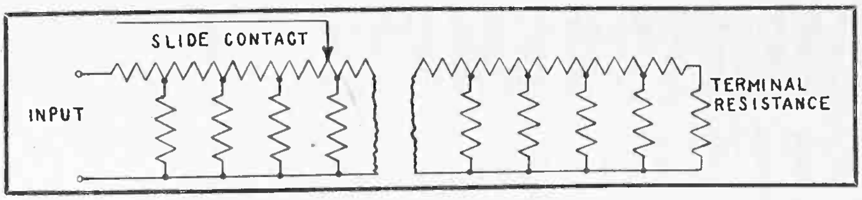


Fig. 3. Schematic diagram of negative-exponential potentiometer.

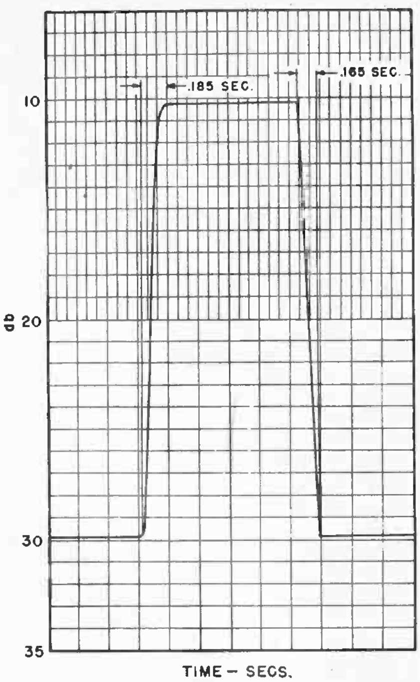


Fig. 4. Output curve plotted by pen servo system for a 19.6 db. square-wave input.

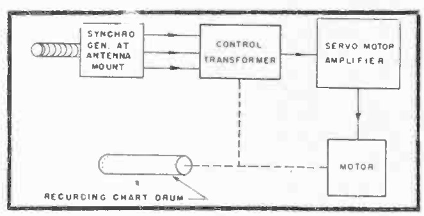


Fig. 5. Block diagram of the basic chart drive system.

Fig. 6. A view of the pen drive system.

MEASUREMENT of STUDIO and ROOM ACOUSTICS

by

DAVID FIDELMAN

The General Radio type 759-B Sound Level meter.

Part I of a 2-part article discussing such factors as reverberation, sound diffusion, and noise level.

THE FIELD of sound reproduction has at the present time reached the stage of development where it is possible to reproduce sounds from a loudspeaker, after numerous stages of recording and transmission, which will sound almost indistinguishable from the original sounds which entered the microphone. In addition, present electronic and electromechanical techniques are constantly being used to improve sound reproduction equipment toward the ultimate purpose of making the reproduced sound identical with the original.

However, no matter how well the output sound reproduces the input, the entire character of the reproduction can be drastically altered by faulty acoustic design either in the room where the sound originates, or in the room where it is reproduced. Bad acoustic design can result in loss of intelligibility and "presence," increased noise level and reduction of dynamic range, resonances and spatial distribution defects, and generally make good program material unpleasant to the ear. This factor has long been recognized, and considerable work has been done in the design of studios, rooms and auditoriums to determine how to attain the best acoustic qualities. The problem is a complex and difficult one, and has still not been solved to complete satisfaction, although considerable progress has been made toward its solution.

Even under ideal conditions, the design of any room, studio or auditorium is difficult because of the limitations imposed by architectural factors. Therefore compromises usually must be made in designing for optimum acoustic performance. Then, once the room has been completed it is tested to see how well it meets the performance requirements. Methods of testing form an extremely important part of any type of design procedure, and in acoustics this is especially true. The ideal test gives a measure of the performance, indicates what may be wrong and by how much, and gives some indications of what steps may be taken to correct any defects which may exist.

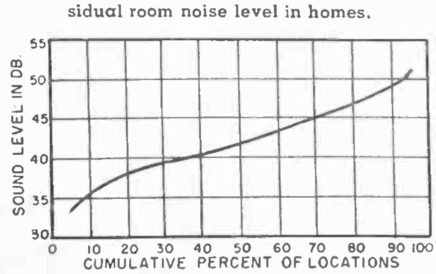
Such tests have only recently been developed for acoustic measurement, and have considerably increased our knowledge about what factors are important in determining the acoustic quality of a room, and what their effects are. The purpose of this article is to describe these measurement techniques, and to show how they aid in the improvement of acoustic designs.

In order to understand the methods and equipment used for the measurement of studio and room acoustic properties, it is first necessary to understand what factors are involved and their effects upon any sounds which are present in the room.

Specific Factors Which Determine Acoustic Properties of Rooms

When sound is listened to in a room or an auditorium, the room has two important effects: (a) it reverberates and reflects the sound from the walls, ceiling and floor; otherwise, if there were no reverberation, the sound would appear as if it were being heard in a completely open space; (b) it excludes external noises. Therefore measurements of the acoustic properties of rooms must concern themselves primarily with various types of reverberation and noise measurements.

Fig. 1. Graph showing the residual room noise level in homes.



Reflections from the boundary surfaces of the room, which basically determine its acoustic character, can have several different effects depending upon the nature of the sound which is heard. These different effects require different measurement techniques.

In general, a number of measurements must be performed before it can be determined whether the acoustic properties of a room will be acceptable. Usually the factors which should be known include the following:

(1) Reverberation and reverberation time, including
  (a) fluctuation during decay
  (b) echo and flutter echo
(2) Sound diffusion (and sound concentrations)
(3) Transient characteristics
(4) Noise level

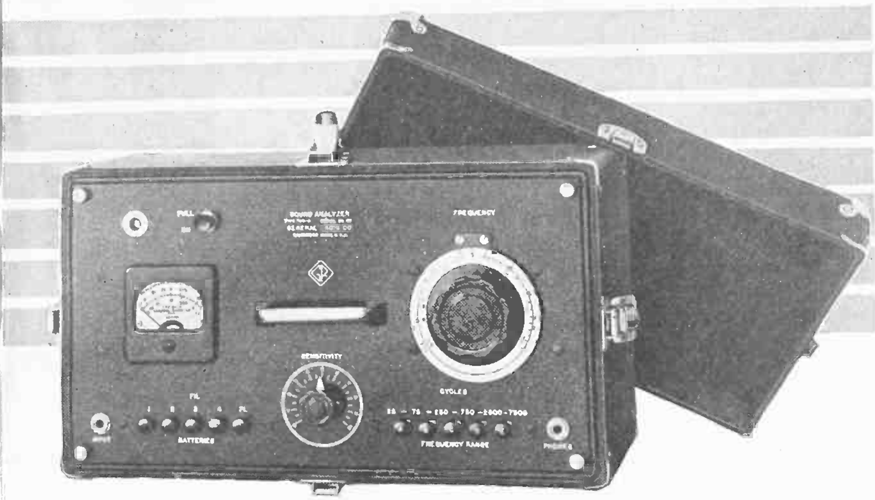
and when the room is the one in which the sound is being reproduced, it is also desirable to know the relationship between the reproducing system and the room acoustics, as given by:

(5) Power output of the reproducing system

(6) Frequency résponse of reproduced sound

Some of these factors have been studied extensively, and standards determined which correlate the measured value with the acoustic performance. In the case of a few of the above factors, standards have not yet been determined, but practical experience has

sound intensity than at other points in the room, and creating the impression that the sound originates at the concave surface. If standing-wave patterns are possible at certain frequencies, these frequencies will tend to be overaccentuated at positions where the standing-wave patterns are set up. For best acoustic properties, the sound pattern in the room should be as *diffuse* as possible at all frequencies, with no standing-wave patterns and no points



The General Radio Type 760-A Sound Analyzer.

shown what should be the requirements for acceptability.

When a sound is started in a room the intensity does not immediately reach its maximum, because it takes an appreciable time for some of the sound to reach the walls and undergo one or more reflections before it reaches the listening point. The intensity reaches its maximum when the steady-state condition is attained. After the sound source stops, it also takes an appreciable time before the various reflections are no longer heard, having been completely absorbed. This persistence of sound is called *reverberation*, and is different from an echo in that it consists of a large number of reflections which blend evenly with one another and with the original sound. The *reverberation time* has been defined as the time required for the sound intensity to decrease 60 db. after the source has been stopped.

When there are large flat surfaces, these may give rise to distinct reflections which are heard as *echoes* if the path difference is too great. When parallel walls are located opposite one another, there may be heard a succession of distinct reflections between them—this effect is known as *flutter echo*.

The presence of concave surfaces tends to focus sounds towards their center of curvature, giving a greater

of excessive sound concentration. Under these conditions, the decay of sound (reverberation) when the source stops will be smooth, marked only by small fluctuations.

The reverberation time and the sound diffusion characteristics of a room are essentially steady-state characteristics, since the sound is allowed to reach equilibrium conditions before these factors are measured. However, all natural sounds are essentially transient in nature, therefore the behavior of the room for transient sounds is of great importance. It is therefore necessary also to know whether the steady-state reverberation time and sound diffusion are accurate for transient sounds, and what differences may exist. In many cases the transient characteristics are much more important than the steady-state, and sometimes give much more information about the characteristics of the room.

The ease with which the reproduced sound may be heard and understood, and the dynamic range which is possible, depend upon the residual noise level in the room. The tolerable noise level in the studio and in the reproducing system depends upon the noise level in the listening room. The average noise level in empty theaters is 25 db. (reference level is 10^{-16} watts per square centimeter); with an audience the average will generally be about 42 db. The noise

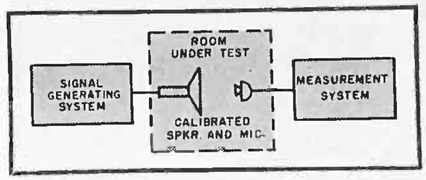


Fig. 2. Basic test setup for performing acoustic measurements in rooms.

level of most residences is given in Fig. 1, which shows that there is a wide variation in noise from one location to another.

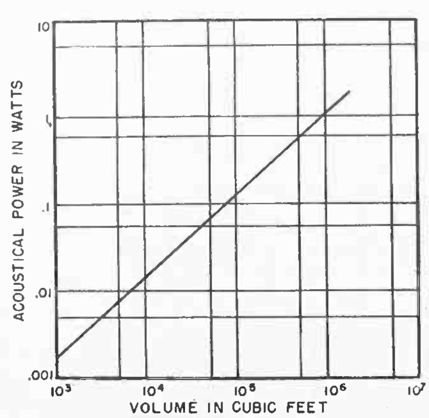
In any audio reproduction, it is important also to know the relationship between the reproducing system and the acoustics of the listening room. The power output from the loudspeaker should be capable of producing a minimum sound intensity of 80 db., and for best performance should be capable of producing a level up to 100 db. without distortion. Fig. 3 shows the acoustical power required, as a function of the room volume, to produce a sound level of 80 db.

The sound output from the loudspeaker should have a flat frequency response characteristic. The function of the reproducing system is to reproduce at the ear of the listener a duplication of the sound which is present at the microphone, and to affect the tonal qualities as little as possible. In certain cases it is necessary to restrict the reproduced frequency range because of acoustic or reproduction difficulties, but in such cases the restriction is a compromise rather than a desirable situation.

General Technique of Acoustic Measurements

Acoustic measurements consist essentially of generating a known sound signal in the room which is under test, and determining the resulting sound distribution. The basic setup for performing measurements of this type is shown in Fig. 2. A signal generator of the proper type supplies the desired

Fig. 3. Acoustic power required to produce an intensity level of 80 db. as a function of the room volume.



The General Radio type 759-B sound level meter being used to perform acoustic measurements in a motion picture theater.

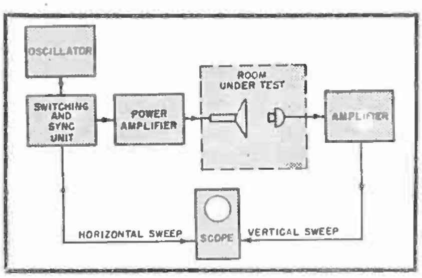


Fig. 4. Setup for performing transient acoustic measurements.

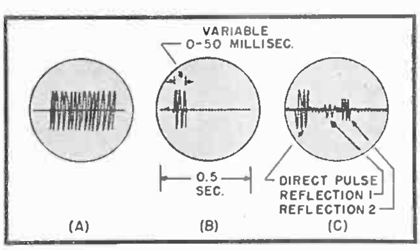


Fig. 5. Typical oscillograph pictures of wave shapes in various parts of a test setup. (A) audio oscillator output, (B) sound output of loudspeakers, (C) sound received at microphone.

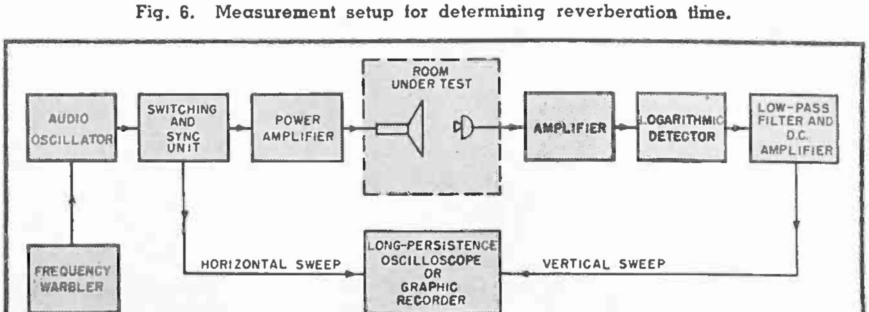
signal which is applied to the calibrated loudspeaker. (The signal generator here is taken to include not only the generator of the low-level signal, but also any auxiliary amplifiers which may be necessary to increase the electrical signal level before applying it to the loudspeaker so that the necessary amount of sound energy may be supplied for testing.) When testing a room in which sound is to be reproduced, it is often preferable to use the amplifier and loudspeaker system which is already installed; then the electrical test signal is applied directly to the amplifier input. The sound in the room is picked up by a microphone of known characteristics, whose output is amplified and applied to the measuring device. The specific type of signal which is generated, and the type of measurement system, will be determined by the particular acoustic characteristic under test.

Generally, a calibrated loudspeaker will not be available, whereas standard calibrated microphones are readily available. It is not necessary that both the loudspeaker and the microphone have known characteristics, since if the characteristics of one are known it can be used to calibrate the other. Therefore only a standard microphone is necessary to obtain completely accurate and reliable acoustic measurements. A calibrated microphone which has been widely used for this type of service is the condenser microphone. These microphones are calibrated against a primary standard sound source, and may therefore be used as secondary measurement standards. Because of its small physical dimensions this type of microphone is effectively a "point pickup" which does not appreciably disturb the sound field, and it has good frequency response characteristics up to approximately fifteen thousand cycles per second.

The characteristics of the loudspeaker may be calibrated in terms of the microphone characteristics. However, such a calibration must be done in such a manner that the acoustics of the measuring room do not affect the results. The measurement must be performed in what is known as a "field-free" room. The requirement of such a room is that all reflected sound and the noise level be so low that they can be neglected in the measurement. The simplest and most direct method of obtaining these conditions would be to perform the calibration out of doors at a great distance from reflecting objects, if favorable weather and noise conditions can be obtained. Field-free conditions are also achieved in special rooms which are carefully designed to have extremely small reflections from the boundary surfaces. In practice the best measuring room available will be a small deadened or partially deadened room. In such cases, the most satisfactory results are obtained by placing the microphone close to the loudspeaker so that the level of the direct sound striking the microphone is at least 20 db. or more above the reflected sound.

In most acoustic room measurements the effects of standing waves are undesirable and should therefore be minimized. This can most readily be done by frequency-modulating the test signal (usually called "warbling") by about ± 10% of the mean frequency, at a rate of several times per second. When this method is used there will be continuous small changes in the standing-wave pattern, but resonances will not have a chance to build up.

Fig. 6. Measurement setup for determining reverberation time.



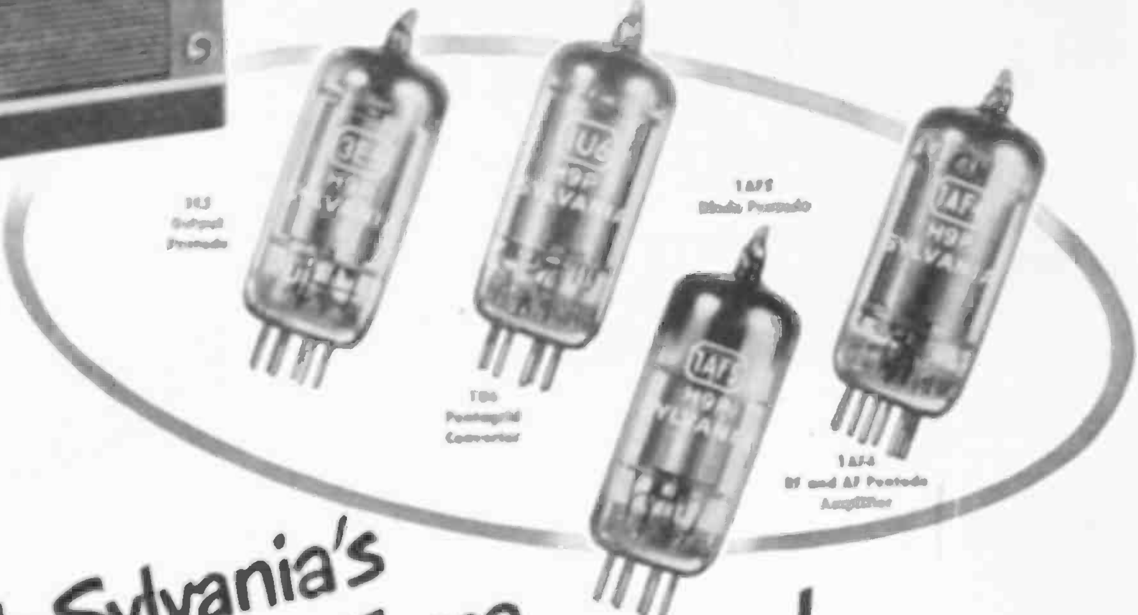
Measurement of Specific Acoustic Characteristics

The basic setup of Fig. 2 is used for measurement of all the various factors that represent the acoustic properties of studios and rooms. Different types of signal generators and measuring devices are used, according to the specific factor being measured.

The method of measuring reverberation time is indicated schematically in Fig. 6. The signal is generated by an audio oscillator set to the desired frequency and warbled. The output of the oscillator is applied to the switching and synchronizing unit, which controls the sequence of measurement operations. The signal is then amplified by a power amplifier which drives the loudspeaker that generates the sound signal. The sound in the room is picked up by the microphone and amplified, then detected by a logarithmic detector to give a d.c. reading on a (decibel) scale, and fed to a low-pass filter. The output of the filter is then amplified by a d.c. amplifier. The amplified output, which gives the reverberation decay characteristics of the room, may be observed either by means of a graphic pen-and-ink level recorder or upon the screen of a long-persistence oscilloscope.

The switching and synchronizing unit turns on the sound source for a time long enough for steady-state conditions to be reached, then switches off the signal and permits the sound in the room to decay. The microphone picks up the sound intensity in the room at all

TRIPLE "A" BATTERY LIFE OF YOUR 1950 PORTABLES



with Sylvania's new line of 25 ma battery miniatures!

A complete tube complement for longer-service portables

Sylvania—and only Sylvania—brings set manufacturers this group of low-drain battery-type tubes that consume only half as much heater current as previously available types. Requiring only 25 ma filament current, they will triple life of present "A" batteries!

These new tubes also offer opportunities for the design of *smaller* "A" batteries, which will permit manufacture of more compact portables without sacrifice of performance.

The four types include a pentode amplifier, a converter, a diode pentode and an output pentode—forming a complete tube complement for portables. They offer comparable power output and sensitivity to previous types . . . and give excellent performance with a plate supply of only 45 volts.

Remember . . . these new tubes come to you from the same company that first made the 1.4 volt battery tube available!

Typical Operating Conditions

Characteristic	1AF4	1AF5	1U6	3E5
Filament Voltage (volts)	1.4	1.4	1.4	2.8
Filament Current (ma)	25	25	25	25
Plate Voltage (volts)	90	90	90	90
Transconductance (µmhos)	950	600	275*	1100
Plate Resistance (megohms)	1.0	2.0	0.6	0.12
Power Output (mw)	—	—	—	175

*Conversion Transconductance

MAIL COUPON FOR SPECIFICATION SHEETS

Sylvania Electric Products Inc.
Radio Tube Division, Advertising Dept. B-2301
Emporium, Pa.

Gentlemen: Please send me complete specifications on Sylvania low-drain tubes 1AF4, 1AF5, 1U6 and 3E5.

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Company ______
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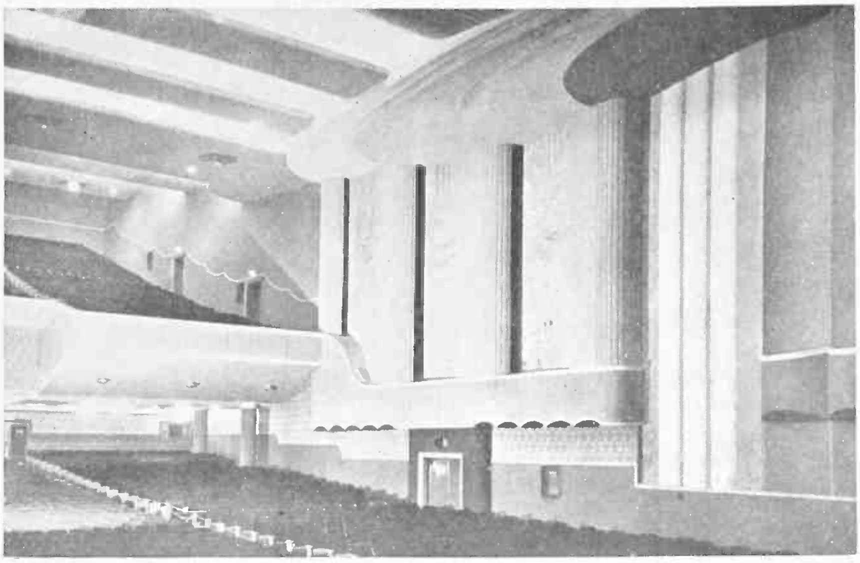
SYLVANIA ELECTRIC



Photograph of the interior of the Cine Orfeon, Mexico City. Note sound-diffusive construction of walls and ceilings; undesirable resonances and reflections are further minimized by use of sound-absorbing material on back and side walls above wainscoting, and on front of balcony.

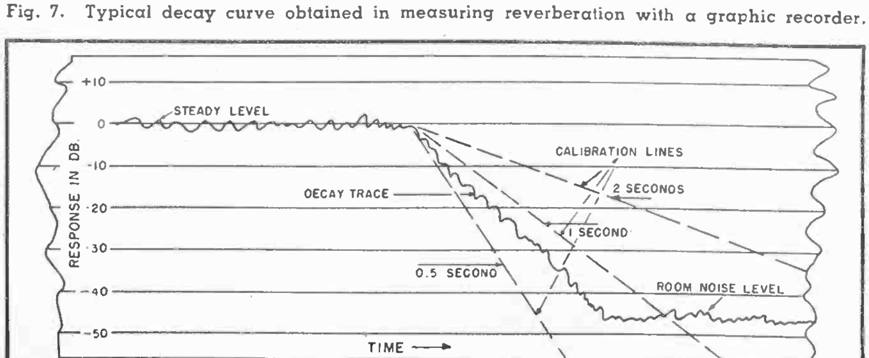
The H. H. Scott Type 410-A Sound Level Meter.

times, and the sound intensity at the microphone is plotted upon the oscilloscope screen or by the graphic recorder. The decay of sound from the moment the source is switched off is observed, and the slope of the decay curve is measured to give the reverberation time for 60 db. decay. There may be fluctuations during decay of the order of 10 or 20 db., but the average slope is the one which is used. In estimating the decay time it is preferable to use the initial slope, since this is the most important to the ear and the remaining portion of the decay is normally masked by subsequent sounds. The presence of large-scale fluctuations and changes in the average slope of the decay curve indicates that the room does not have a completely diffuse sound pattern, and that best acoustic performance has not been achieved.

When the sound decay curve is being measured by a graphic recorder, the measurement setup shown in Fig. 5 may be used without the synchronizing and switching unit. In this case, the sound source is turned on and kept on long enough for steady-state conditions to be reached, then the paper is allowed to run in the recorder and the sound source switched off. The sound decay pattern will then be recorded.

Because of the cyclically changing standing-wave pattern due to the frequency-modulated signal, when the graphic recorder type of measurement is used the recorded decay curve will be different depending upon the exact time at which the signal is cut off. With the oscilloscope method of measurement these fluctuations tend to average out, due to the superposition of a number of different decay curves which in general start at different times in the warble cycle. The effects of standing-wave patterns and interference effects can be further smoothed out by the use of multiple loudspeakers and microphones. In practice, it is desirable to reduce these errors by taking several measurements for each of several locations of loudspeaker and microphone, differing in position by about one yard. If three readings for each of four different positions are taken, accuracy in reverberation time to about 0.1 sec. can be obtained.

Fig. 7. Typical decay curve obtained in measuring reverberation with a graphic recorder.



The degree of sound diffusion is measured mainly by observing the standing-wave pattern in the room when sound is present. Some indications can be obtained from the reverberation characteristic, but such observations are not too good because in measuring reverberation steps are taken to eliminate the effects of standing waves. The simplest and most direct method of determining the standing-wave characteristics of a room is to produce a steady sound in the room and survey the room with the microphone to determine the intensity pattern. (In this type of measurement an omnidirectional microphone should be used, and the directional pattern of the loudspeaker radiation taken into account.) With complete diffusion the sound intensity will be uniform throughout the room for all frequencies, or will vary gradually with position according to the directional characteristic of the loudspeaker and the absorption by air of the higher frequencies. The relative intensity of maximum and minimum points will be a measure of the diffusive character of the room, and any sound concentrations will also be detected. Another method of performing this measurement is to keep the microphone fixed and slowly sweep the signal frequency over the entire audio range. Assuming the frequency characteristics of the loudspeaker and the microphone to be reasonably flat, variations in response will indicate standing waves in the room. However, this latter method does not indicate whether there may be any concentrations of sound at various points in the room.

The transient characteristics are measured by applying a test signal which has transient properties similar to those of natural sounds, and observing the resulting sound at the loudspeaker. This method has the advantage that the results can be expected to correspond closely to the actual conditions under which the room will most often be used. The complete test setup for this type of measurement is shown in Fig. 4. For a permanent record, the oscilloscope screen may be photographed. Otherwise, a graphic recorder may be used with a low-pass filter and d.c. amplifier as used in the reverberation-time measurement system shown in Fig. 6. In addition to the transient acoustic characteristics of the room, this system also gives considerable information concerning echoes and the location of the various reflecting surfaces which give rise to echoes and large-scale reflections.

The signal wave shapes are shown in more detail in Fig. 5, to give a better indication of the type of data obtained with this method of measurement. The output of the audio oscillator is a continuous sine wave which may be set to any frequency at which the acoustic characteristics are desired. The switching and synchronizing circuit contains a gating mechanism (either a motor-driven cam-operated switch or an electronic gating circuit) which permits the signal through in pulses as shown in Fig. 5B. The signal pulse length is adjustable from 0 to 50 milliseconds duration and is repeated at intervals of about 1 second, so that the reflected sound decays to a negligible value before the next impulse. The horizontal time scale on the oscilloscope screen can be set for a sweep time of 0.5 sec. across the face of the screen. (If a graphic recorder is used, the switching and synchronizing circuit will be set for just one signal pulse, and the recorded response will be the response to this one pulse.) The type of signal received by the microphone consists of the direct sound pulse plus whatever reflections there may be from any parts of the room, as shown in Fig. 5C. By measuring the time taken for any reflections to arrive at the microphone after the direct pulse, and by actually laying out and plotting the various possible sound paths between the loudspeaker and the microphone in the room under test, the location of the various reflecting surfaces can readily be determined.

In practice, each measurement should be taken at three different positions at each location in the room, and at several different frequencies over the entire audio-frequency spectrum. A total of at least 10 to 15 different pulse reflection measurements should be averaged for each location. This type of averaging will tend to cancel out any spurious spatial or frequency effects.

Part 2 of this article will include a discussion of such items as noise level, sound power output, frequency response, and room acoustics.

(To be continued)

NEW PRODUCTS

MERCURY ARC LAMP

Huggins Laboratories, 738 Hamilton Ave., Menlo Park, Calif., has announced the Ames Type-A mercury arc lamp

for light source in interferometers, Schlieren optical systems, shadowgraphs, monochronometers, and in high-speed photography. Light intensities of 90,000 candles per square centimeter can be reached at maximum brilliance with these units.

Arc dimensions are 2.85 cm. (1.125 in.) by 1 mm. (0.039 in.). Cooling is accomplished with ordinary tap water requiring 2½ gallons per minute, and average life at rated maximum brilliance is five hours.

Shown are the lampholder with lamp extracted, and in the background, the fully-controllable a.c. power supply. Light output is 65 lumens per watt; power input is 2 kw.; 1.2. amp. at 1750 volts.

TEMPERATURE TEST CHAMBER

A compact, economical, and convenient temperature-controlled chamber for the rapid performance of ambient temperature tests is now being produced by *Statham Laboratories, Inc.*, 9328 Santa Monica Blvd., Beverly Hills, California.

The Model TC-1 Temperature Test Chamber is completely portable and self-contained and is especially de-

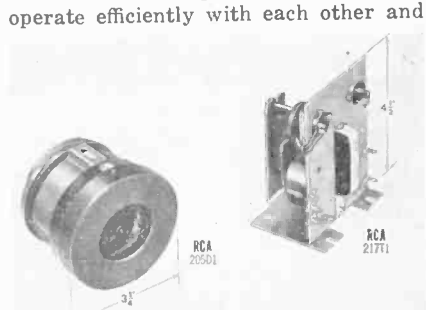
signed for the convenience of individual research workers and the small laboratory unit as well as for the production line tests of all types of small products.

The unit is fully insulated and consists of a completely sealed inner chamber and outer cabinet of welded dural construction.

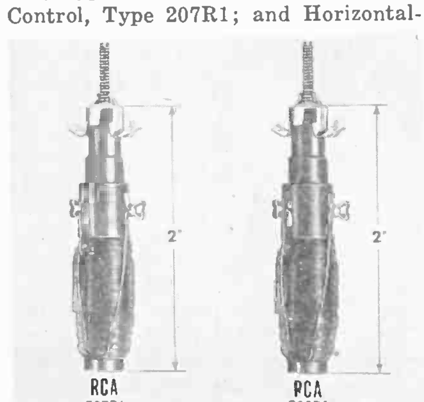
COMPONENTS FOR DEFLECTION SYSTEMS

Four new components for use in 10-inch and 12-inch television receivers having deflection systems designed to use the horizontal-deflection amplifier tube 6AU5-GT and the high-voltage rectifier tube 1V2, are now being offered to equipment manufacturers by *RCA*'s Tube Department, Harrison, N. J.

These new components, designed to operate efficiently with each other and



with the 6AU5-GT and 1V2, are Deflecting Yoke, Type 205D1; Width Control, Type 206R1, Horizontal Linearity Control, Type 207R1; and Horizontal-

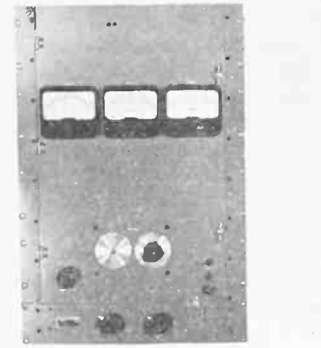


Deflection-Output and High-Voltage Transformer, Type 217T1.

The 205D1 magnetic deflecting yoke is intended for use with picture tubes having a deflection angle up to about 60° and operating at an anode potential up to 12 kilovolts. The 217T1 is designed for use with a single 6AU5-GT driver tube and with two 1V2 rectifier tubes in a voltage-doubler arrangement to supply a d.c. output voltage up to 12 kilovolts.

R.F. PHASE MONITOR

Model 109 high-precision phase monitor for measuring phase relations at radio frequencies was recently an-



nounced by *Clarke Instrument Corporation*, 910 King St., Silver Spring, Md.

According to reports, the instrument has an absolute accuracy of ±1 degree and resolution and repeatability of ±0.1 degree. Phase is read directly from two dials calibrated in 0.1-degree increments. The instrument continuously and automatically indicates the phase difference and requires no manipulation on the part of the operator.

Model 109 Phase Monitor requires 28 inches of panel space and is supplied with finishes to match those used by the various manufacturers of transmitting and associated equipment.

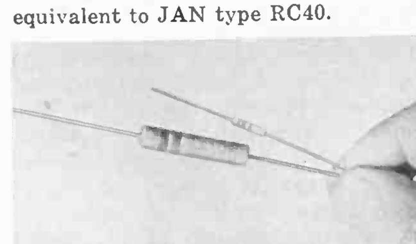
PULSE TRANSFORMERS

Raytheon Manufacturing Company, Waltham, 54, Massachusetts, is offering a complete line of pulse transformers suitable for use in driver circuits as blocking oscillator or interstage units.

A chart giving complete data on many of *Raytheon's* pulse transformer designs is available upon request. Write for DL-K-315, and address request to Department 6460-NR2.

MINIATURE RESISTORS

International Resistance Co., 401 N. Broad St., Philadelphia 8, Penna., has added to its line of BT Insulated Resistors two new miniature units. Type BTR at ⅓ watt meets JAN-RC10 specification and type BTB at 2 watts is equivalent to JAN type RC40.



Like all Advanced Type BT's, these resistors are protected against moisture by a phenolic resin housing molded at high pressure and copper leads are securely anchored inside insulation and heavily tinned for easy soldering.

Full data in catalog form is available by writing the company.

UHF OSCILLATOR

The Model 112 u.h.f. oscillator announced by *Measurements Corporation*, 116 Monroe St., Boonton, N. J., covers the frequency range of 300 mc. to 1000 mc. The frequency calibration is accurate to ±0.5%.

Model 112 has a maximum output voltage, varying with frequency, between 0.3 volt and 2 volts, and provides

a tunable signal source between 300 mc. and 1000 mc. for measurements and testing such as tracking and alignment of u.h.f. receivers; standing wave measurements, transmission line measurements, antenna pattern measurements, impedance measurements and other applications.

ONE HALF OCTAVE FILTER

The Applied Acoustics Model SA-2 one-half octave filter is now available from *Gertsch Products, Inc.*, 11846 Mississippi Ave., Los Angeles 25, California.

Each filter is comprised of separate high and low pass filters each having seventeen different cutoff frequencies ranging from 37.5 cycles per second to 13,600 cycles per second in one-half octave steps. Selection of each cutoff frequency is made by push-button switches providing 203 useful positions.

The unit is available either in rack panel or carrying case and weighs 87 pounds.

COLOR SENSITIVE INSTRUMENT

A color-sensitive device which breaks up a light beam from any source into its spectrum, measures the relative spectral energy at each wavelength, and makes a permanent record of the measurements in the form of a graph has been announced by *General Electric's* Special Products Division.

Designated a "recording spectroradiometer," the instrument consists of a grating monochromator, photometer recorder, and power supply. The spectroradiometer measures 25 x 27 in. x 23 in., weighs 150 lbs., and can scan the complete spectrum from 230 to 650 millimicrons at speeds varying from 1 to 10 minutes, depending upon the nature of the spectrum.

Additional information on this device is contained in publication GEC-604 which is available to readers from *General Electric Co.*, Schenectady 5, N. Y.

TRANSFORMER CORE MATERIAL

Ferroxcube is the new transformer core material introduced by *North American Philips Company, Inc.*, 100 E. 42nd St., New York 17, N. Y. It is a ferromagnetic ferrite which reduces electrical losses in components such as horizontal output transformers of the type used in television receivers; in intermediate frequency transformers such as are used in superheterodyne circuits and in amplifier transformers for long distance wire communication circuits. It is applicable also in other circuits requiring low-loss inductors, coupling transformers and intermediate frequency transformers.

Ferroxcube is said to be extremely adaptable in molding and lends itself readily to the production of unusual or difficult shapes and is now available from *Philips* in a number of standard shapes or in custom shapes to meet manufacturers' requirements.

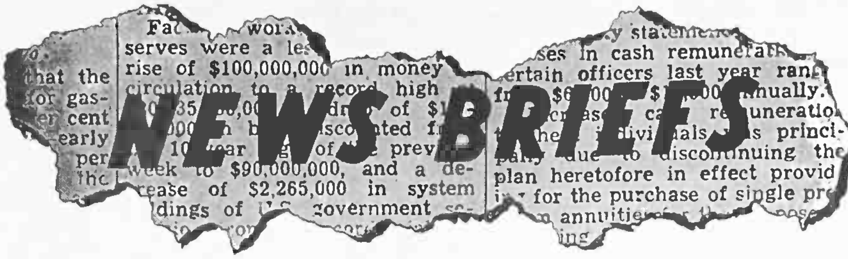
D. C. CHOPPER

In response to a demand for a Chopper which will operate from d.c., *Stevens-Arnold, Inc.*, 22 Elkins St.,

South Boston, Mass., has announced the availability of their line of Self-Excited Choppers.

These Choppers offer modulation/de-

(*Continued on page* 30)



PHYSICAL SCIENCE INTERNSHIPS

An integrated work-study program, beginning at the college-sophomore level, has been established by the National Bureau of Standards which offers vacation-time employment and graduate

fellowships to outstanding students in science and engineering to broaden their undergraduate or graduate training.

Dr. L. L. Marton is shown demonstrating the operation of the electron microscope to a group of Science Aids in the Bureau's electron physics laboratory.

This program permits the student to alternate periods of full-time study with actual experience in his chosen field, supplemented by on-the-job training and orientation courses at the Bureau.

Information regarding qualifications for appointment may be obtained from the Personnel Division, National Bureau of Standards, Washington 25, D. C.

ELECTRO HAS NEW PLANT

Electro Products Laboratories, pioneer manufacturers of Electro battery eliminators for radios, has a new location at 4501 North Ravenswood Ave.,

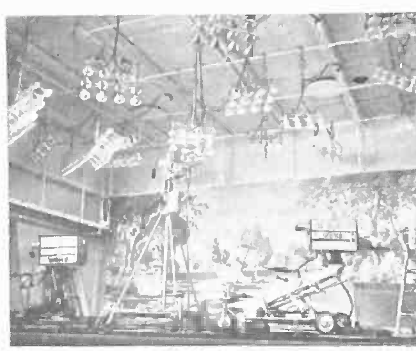
Chicago, Illinois, where both manufacturing and servicing facilities will be improved. Expanded production facilities are also expected to improve delivery on the Pressuregraph and Syncromarker.

Spacious display rooms are designed for displaying and demonstrating electronic instruments, and a staff of factory trained technicians is ready to offer a systematized, highly efficient service for quickly repairing electronic instruments.

PACKAGED TV STUDIO LIGHTING

The newest improvement to the modern television studio is *RCA's* packaged studio lighting system designed for use with television studio cameras. Among the items featured are high-intensity fluorescent banks, high-intensity spots, and incandescent banks to meet all studio lighting requirements.

All lights can be rotated 360° horizontally and 170 degrees vertically.



They are designed for pyramid-mounting on studio ceilings, and all are mechanically controlled through silent-operating fairleads that terminate in a central control board.

Shown is a typical studio layout using the packaged studio lighting system which is available through the Broadcast and Television Studio Equipment Section of the *RCA* Engineering Products Department, Camden, N. J.

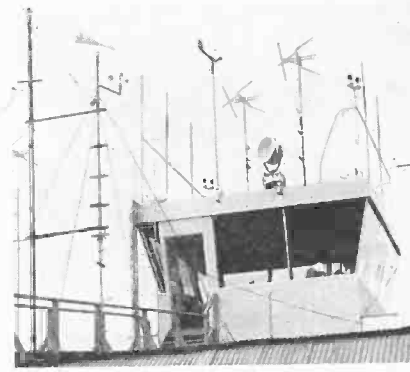
TV MONITOR REGISTERED

Television Utilities Corporation's TV monitor has been registered under the trade-mark "Private Eye." The first 30 units have been undergoing tests for many weeks at broadcasting stations, the company reports, with good results.

According to the manufacturer, these monitors will match the performance of units costing three times as much and will stand any test required by engineers. Some of the equipment incorporated into this low priced unit is a foolproof synchronizing system, a video frequency response out to 4.5 mc. plus or minus 1 db. or better, and is equipped to operate on a wide range of input voltages.

CONTROL TOWER INSTALLATION

A compact, modern control tower which aeronautical engineers expect will set the pattern for future installa-



tions has been installed at the Reno, Nevada airport. Constructed by *United Air Lines* and operated by the CAA, the tower features polarized angled windows to eliminate glare, v.h.f. receivers and transmitters on all frequencies for contact with private, military and commercial aircraft, and a counter device to keep daily totals of all planes using the field.

Seen in the photograph are the two "spider web" type antennas for v.h.f. transmission, obstruction lights, anemometer, beacon light, and a flashing light gun to direct aircraft with no radio receivers.

MARITIME STUDENTS STUDY RADAR

A *Westinghouse* three-centimeter radar set has been installed at the Alameda, California, Training Station of the U. S. Maritime Service to give

students a thorough training in the theory and operation of radar, as well as scope interpretation and radar navigational techniques. Students receive first hand experience under simulated marine conditions and are given approximately eight hours of practical instructions using the radar set.

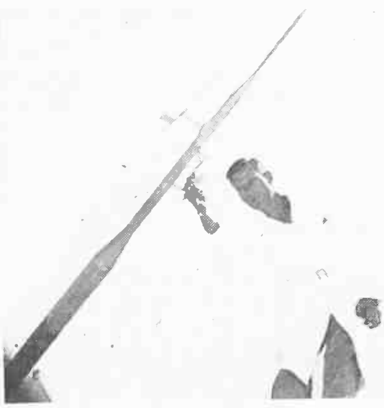
Left, Lt. Commander Jack Halpern, instructor in charge of radar and loran classes, is showing a student how to adjust the brightness of the range markers.

The *Westinghouse* radar set, consisting of two parts, has a 50 kw. nominal peak power output. The antenna, on the top of the "deck house," is of the enclosed radome type.

MAST FOR PROBING OF TRANSONIC SPEEDS

G. M. Giannini & Co., Pasadena manufacturer of flight test instruments for supersonic aircraft, has designed a new instrument mast for *Northrop Aircraft, Inc.* which delivers its information by radio telemetering to ground recorders.

Housing self-contained temperature, speed, pitch and yaw instruments, it is expected to reduce lag errors seen in



conventional cockpit dial instruments operated by air pressure lines carried in a probing mast. Telemetered reactions of instruments in the *Giannini* mast are flashed to recorders at the speed of light.

ELECTRONIC DISPATCHER FOR ELEVATORS

Engineers of the *Westinghouse Elevator Division*, Jersey City, N. J. have developed sensitive vacuum tube devices to accelerate the automatic dispatching of high speed elevators.

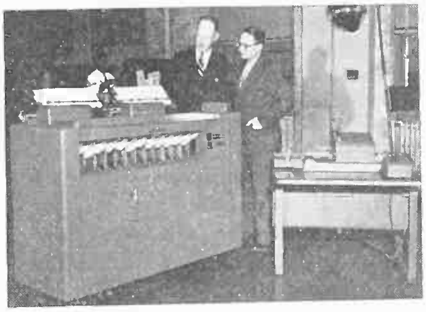
These electronic circuits, which transmit thousands of split-second impulses every hour, have been incorporated into the *Westinghouse* Selectomatic elevator control system to integrate cars, floors and push-button calls into a smooth flow of service to all floors.

First installations of the system will be made in the Merchants Exchange, Memphis, Tenn., and the projected 39-story Mellon-U. S. Steel skyscraper at Pittsburgh, Pa.

Two of the new developments include an electronic timer which serves as the core of the dispatching system, and an electronic counter which insures adequate service on the lower floors when regular low-zone cars have been speeded up to aid service on upper floors.

CENSUS MACHINE DEMONSTRATED

A machine which combines in one operation the simultaneous functions of classifying, counting, accumulating,



and editing and then prints the statistical data resulting from groupings of information was recently demonstrated at the Washington headquarters of the Bureau of the Census.

The Electronic Statistical Machine, which was developed by *International Business Machines Corporation*, has a capacity up to 10,000 units in each of 60 different classifications while simultaneously sorting the cards into predetermined groups at the rate of 450 cards a minute.

Mr. Louis H. LaMotte, *IBM* Vice-President, is shown making the presentation to Dr. Philip M. Hauser, right, Acting Director of the Bureau of the Census.

U. OF MASS. ENGINEERING LAB

The School of Engineering at the University of Massachusetts recently dedicated its newest addition, The Gunness Engineering Laboratory, named for Christian I. Gunness, late head of engineering at the university.

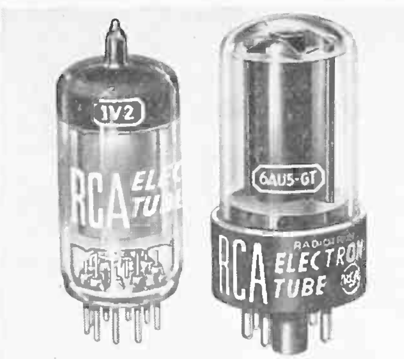
The building contains classrooms and laboratories for the departments of civil, mechanical and electrical engineering, servicing the needs of about 500 students majoring in these fields.

At a cost of $475,000, the building contains a double classroom seating 100 students, five staff offices, a main office and quarters for the maintenance staff.

NEW TUBES

RCA TV TUBES

Two new tubes which will, according to reports, provide high efficiency operation of horizontal deflection systems



for ten-inch and 12-inch picture tubes are now available from the Tube Department, *Radio Corporation of America*, Harrison, N. J.

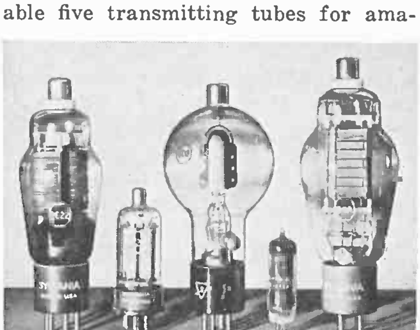
The 6AU5-GT is a high-perveance, beam power amplifier of the single-ended type. Its features include low mu-factor, high plate current at low plate voltage, and a high operating ratio of plate current to grid-No. 2 current. A power supply of 250 volts, or less, is all that is required for a receiver utilizing such a deflection circuit and the 6AU5-GT.

The 1V2 is a high-voltage, half-wave rectifier tube of the single-ended, 9-pin miniature type. When used in a doubler circuit which is transformer coupled to a horizontal-deflection circuit employing the 6AU5-GT, the 1V2 is especially suited for rectifying the high-voltage pulses provided by the transformer.

SYLVANIA TUBES

Transmitting Tubes

Sylvania Electric Products Inc., 500 Fifth Ave., New York 18 now has available five transmitting tubes for ama-



teur, mobile and portable applications. Tubes in this group include two power triodes, a v.h.f. beam power amplifier, a pentode power amplifier oscillator and a miniature beam pentode.

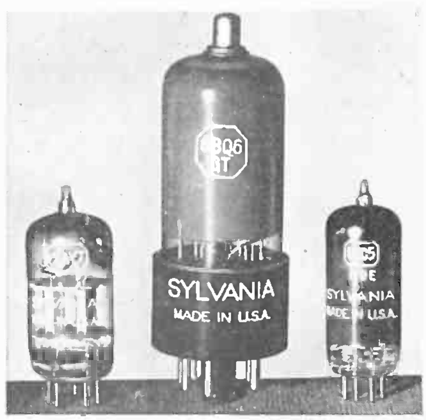
Types 811A and 808 power triodes are suitable as a class B a.f. power amplifier and modulator; for plate modulated r.f. power amplification in class C telephony; as a self rectifying amplifier; and as a class C amplifier.

The v.h.f. beam power amplifier, type 2E24, is designed for use as a plate modulated r.f. power amplifier in class C telephony and as an r.f. power amplifier and oscillator in class C telegraphy.

The pentode power amplifier oscillator is type 2E22 for class C r.f. amplifier or oscillator service and as a suppressor modulated class C amplifier. The miniature beam pentode, type 2E30 is suitable for use as a class A1, AB1 or AB2 a.f. power amplifier and modulator; r.f. power amplifier and oscillator in class C telegraphy; and as an r.f. power amplifier in class C telephony.

Receiving Tubes

Three new receiving type tubes have also been announced by *Sylvania*. They



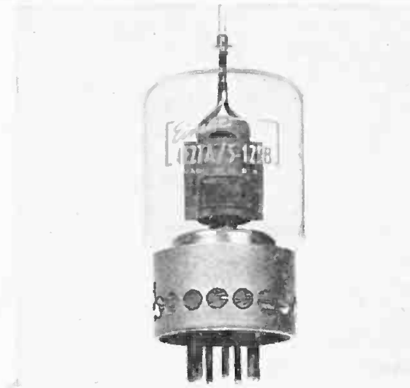
are an audio frequency amplifier, type 12AY7, an r.f. amplifier for television, type 6BC5, and a horizontal deflection amplifier for television, type 6BQ6GT.

Type 12AY7 is a T6½ miniature, medium-mu duotriode particularly suitable for use in the first stage of an a.f. amplifier where absence of noise and microphonism is desirable. The r.f. amplifier is a T5½ miniature sharp cut-off pentode having high mutual conductance, designed for r.f. and i.f. amplifier applications in television receivers. Type 6BQ6GT has been designed and processed for transformer operated sets where high peak interelectrode voltages are encountered.

REDESIGNED PENTODE

The Application Engineering Department of *Eitel-McCullough, Inc.*, San Bruno, California, has announced a radically redesigned 4E27 type pentode including such features as a moulded-glass header, shell type base, low-loss leads, non-emitting grids and a Pyrovac plate.

Designated 4E27A/5-125B, its physical size and basic electrical characteristics make it directly interchangeable



with type 4E27. It is rated at 125 watts plate dissipation and although designed for v.h.f. service, is well suited for television service and air-navigational aids, as well as for general r.f. and audio applications.

GE TUBES

Wide-Angle TV Tube

Production in limited quantities on a new wide-angle 16-inch metal television picture tube has been announced by *General Electric's* plant in Syracuse, New York.

Type 16GP4 is five inches shorter than conventional tubes of this size to allow for development of more compact home receivers for the larger picture. Also featured is a "filter-glass" face plate which is said to improve picture contrast and clarity by reducing halation and cutting down reflections from surrounding light sources.

Miniature Tube

Also announced is the 6BC5 miniature tube designed primarily for use as a radio-frequency and intermediate

frequency amplifier in television and FM receivers now in production.

The 6BC5 is an improved version of the 6AG5 and is interchangeable with that tube. The chief difference is an increased transconductance which was obtained with a plate voltage of 250 volts and a screen voltage of 150 volts, thus raising the transconductance from 5000 to 5700 micromhos.

V. H. F. Tank Design

(*Continued from page 9*)

well at low frequencies and where the tube interelectrode capacities are small. At higher frequencies, or with tubes having high interelectrode capacities, the added tuning capacity often results in sharply reducing the effective physical length of the tank and a consequent reduction of efficiency.

2. A variable shorting bar provides a tuning method which is essentially a means for electrically lengthening or shortening the tank to the desired frequency. While its approach is simple and straightforward, the mechanics for smooth positive operation may become somewhat involved. The mechanics of the shorting bar action must also assure that there will be no arcing or appreciable wear at the shorting points. Since these parts are usually silver-plated this requires a heavier plating of silver because of the wear encountered.

3. Varying the surge impedance of the tank is being used advantageously in several pieces of commercial equipment which are now on the market. Fig. 4 shows the power amplifier of a *Gates* 3 kw. FM transmitter. This was the first commercial transmitter to utilize this method of tuning.

As was shown in Eqt. (4), the resonant frequency of the tank circuit is also dependent on the characteristic surge impedance. The characteristic surge impedance is lowered by the presence of a metal plate or plane parallel to the tank. As this plane is brought closer, the surge impedance is rapidly lowered which results in a consequent increase in resonant frequency. Referring to Fig. 5, it will be seen that in practice this metal plate or vane is bent in a "U" shape and pivoted at the shorted end of the tank. The top end is swung in to increase the frequency and swung out to decrease the resonant frequency. This has the obvious advantages of eliminating all r.f. wiping contacts, while simultaneously providing a simple positive mechanical arrangement which maintains complete circuit symmetry. In common with the shorting bar method, the physical length of the tank is kept long enough to maintain highest efficiency.

4. The introduction of a variable dielectric material between the tank legs or elements provides another method of tuning a tank circuit. The dielectric serves to decrease the propagation constant and change the surge impedance. Probably a pivot arrangement similar to Fig. 4 would serve as a convenient mechanical method for varying the dielectric between the legs of the tank. To the writer's knowledge there is yet no commercial adaptation of this on the present market.

Since the tank circuit and its shielding are so closely related, the design of the tank should encompass this as well. An effective shield enclosure of the tank and/or tubes provides an often mandatory degree of isolation required for stability and freedom from oscillations which might otherwise occur. Often this enclosure can conveniently serve as part of the cooling system. The radiation losses from a balanced type push-pull tank may be reduced to a negligible amount by using highly conductive shielding material. Fig. 5 illustrates such an enclosure. It is interesting to note that a high degree of isolation for increased stability is provided by this construction, as is an efficient tube cooling system. Further examination will disclose that flat type tank elements are employed and the variable surge impedance method of tuning is used in conjunction with semi-fixed capacitor plates at the bottom of the tank. The tuning vane affords a fine or vernier tuning range of several hundred kilocycles, while the capacitor plates serve to extend the lower frequency limit enabling coverage of the complete 88-108 mc. FM band.

Since the flow of r.f. currents is confined to the surface at v.h.f., due to skin effect, it is paramount that this surface present low r.f. resistance. Silver offers the lowest resistance and is to be preferred. It is, however, quite expensive and for this reason silver plating is usually employed for the conducting surface. As brass takes a fine even plating and is very machineable, it is often used.

It is necessary that the plating be smooth with a highly polished surface as a spongy plated surface is little better than the brass itself.

In laboratory and experimental work the polished brass or copper surface will often suffice. A coating of very thin clear lacquer will assist materially in keeping the surface bright and free from tarnishing.

Aluminum also has high conductivity. While its conductivity is not quite as good as that of silver, the writer has used it successfully in several experimental models. Fig. 1 illustrates one such experimental unit in which sheet aluminum was used as the tank elements.

Aluminum is favored by several manufacturers for fabricating the shield enclosures of the plate and grid tanks of their equipment. The plate tank enclosure of Fig. 3 is of all aluminum welded construction. Aluminum is easily and beautifully finished by a simple etching process. A thin coating of clear lacquer will retain the finish almost indefinitely.

TECHNICAL BOOKS

"ACOUSTIC MEASUREMENTS" by Leo L. Beranek, S.D., D.Sc. (Hon.). Published by *John Wiley & Sons, Inc.*, 440 Fourth Avenue, New York 16, N. Y. 914 pages. $7.00.

Dr. Beranek, vice-president of the Acoustical Society of America, has written this clear and concise exposition of acoustic measuring techniques as an aid to five main groups of research workers; the acoustic physicist, the communications engineer, the psychologist, the otologist, and the industrialist.

It is an encyclopedia of acoustic measuring techniques which presents the source of the theory of many electroacoustic phenomena, and a detailed description of the basic types of acoustic measuring devices. Topics range from the calibration of microphones and loudspeakers to evaluation of over-all audio systems, and to chapters on the audiometer, speech articulation tests and the sound level meter.

The material in this book, which is one of the few of this nature published, is of prime importance to all concerned with acoustics in any phase of their work or study and will be equally valuable to the graduate student or research worker.

"ELECTRICAL ENGINEERS HANDBOOK," Volume 1, Electric Power, by Harold Pender and William A. Del Mar. Published by *John Wiley & Sons, Inc.*, 440 Fourth Avenue, New York 16, N. Y. 1698 pages. $8.50.

This is the fourth edition of Pender's "Handbook for Electrical Engineers," which first appeared in 1914. This fourth edition, as was the third, is divided into two volumes: one on electric power and the other on electrical communication and electronics. Tables and fundamental theory are duplicated in the two volumes in order that each might be complete and independent of the other.

Seventy-one specialists in their respective fields have contributed to this edition which is entirely rewritten. Subjects including circuit stability and symmetrical components, electronic rectifiers, aircraft equipment, heat pumps, servomechanisms, permanent magnets, plastic insulating materials, and induction and dielectric heating apparatus, all of which have become of increased importance, are thoroughly covered.

Although a greater degree of specialization in the various phases of electrical engineering have necessitated enlarging both volumes, these books have been kept compact and readable.

"INDUSTRIAL ELECTRONICS" by Andrew W. Kramer. Published by *Pitman Publishing Corporation*, 2 West 45th St., New York, N. Y. 311 pages. $6.00.

Here is a valuable book for the practical man in industry who is interested in all the various new uses of electronics. A complete description of electron tubes, how they were evolved, and how they work is given as an invaluable aid in determining how the new methods and equipment can be used for improving maintenance and operations in the industrial plant.

The book begins with a brief historical background and a consideration of electron theory presented in a simple, clear, language. The fundamental principles of electronics are explained without the use of mathematics and the application of these principles in industry is clearly shown. The book also supplies necessary information on the operation and maintenance of electronic equipment.

The basic material of this volume appeared first as a series of articles on electron tubes in *Power Plant Engineering*. All the original material has been revised and a great deal of new material added to bring the entire work up to date.

D. C. Amplifier

(Continued from page 13)

to ground). In this case, it can be shown that the gain of one stage working into infinite load impedance is one-half the amplification factor of the tube used, whether the cathode resistors are bypassed or not. A formula giving the gain for finite load impedances will be given later. This formula shows that bias cells may be useful to avoid degeneration in the cathode resistors.

The use of pentodes with a floating power supply permits the realization of extremely high d.c. stage gains (up to 4000) into loads of high impedance, such as tube grids or cathode-ray deflection plates. Fig. 2 shows how constant screen voltages of about 70 volts may be obtained by means of small neon bulbs.

Many variations on the original scheme are possible. As an example, Fig. 7 shows a stable low-impedance driver circuit with output at zero d.c. level. This is the equivalent of a compensated cathode follower, and is useful to drive recorders, indicating devices, and similar instruments.

Application of Feedback

Since both input and output voltages of the new amplifier constitute positive and negative excursions with respect to a zero d.c. reference level, the application of feedback over one or more stages is especially easy. In Fig. 3 regeneration over two stages and degeneration over three stages is shown; this is a typical balanced feedback circuit[4] and reduces distortion in the output stage to a minimum. Fig. 2 shows how a high-gain pentode stage is stabilized through the use of inverse feedback.

Experimental Results

An electronic voltmeter connected to the output of the three-stage amplifier in Fig. 3 did not show any noticeable deflection when the *B* supply was switched *on or off* after careful balancing. Changes of 20% in the filament voltage had similarly little effect on the balance. Long-term drift seems to depend largely on the stability of the resistors used in the circuit.

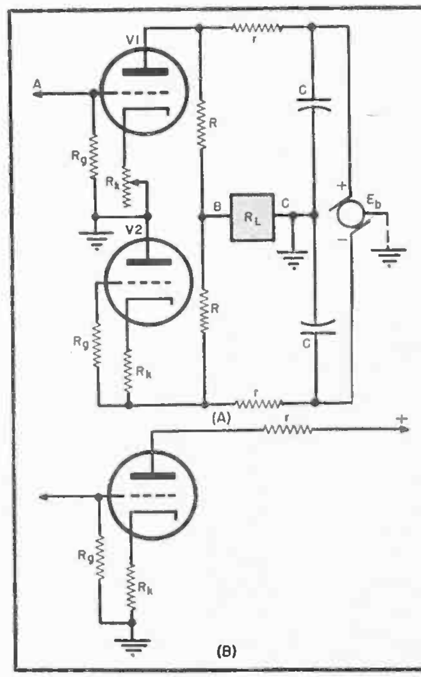
Circuit Analysis of the Bridge-Balanced Amplifier

It can be shown from the equivalent circuit of the amplifier that the circuit design equation for the case of the floating power supply is:

$$E_o = \frac{-\mu R_L}{(\mu + 1)\ R_k + R_p + 2 R_L + R} E_i$$

which is independent of plate and filament voltages. For very large load re-

Fig. 6 (A) Simplest form of the new amplifier. Power supply is shown with centertap grounded. (B) Conventional amplifier stage for computing gain. The gain of (A) is exactly half that of (B).



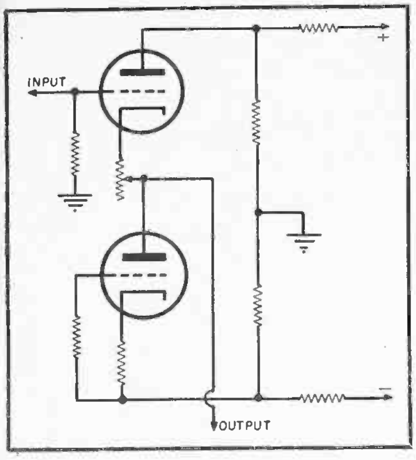


Fig. 7. A stable low impedance driver circuit with output at zero d.c. level.

sistances R_L may be expressed as:

$$\frac{E_o}{E} \approx -\frac{\mu}{2}$$

From the equivalent circuit of the amplifier with a center-tapped power supply, it can be shown that the gain is:

$$E_o = \frac{-R_L r \mu}{[R_p + R_k(\mu+1)]r + Rr + 2R_L[R_p + (\mu+1)R_k + r]} E_i$$

for $R_L = \infty$, this reduces to

$$E_o = \frac{-E_i}{2} \; \frac{\mu r}{R_p + (\mu+1) R_k + r}$$

which is just one-half of the gain of the amplifier shown in Fig. 6B.

For a perfectly balanced condition of the bridge, the effect of slow plate and filament variations on the output will be very small.

The engineer, physicist and experimenter will discover many new uses for this simple circuit which is easily built with a minimum of circuit components and is particularly well-suited to portable battery-operated applications.

A few modern applications of the new d.c. amplifiers are suggested by the illustrations presented.

Acknowledgement

The project described in this article was carried out in May, 1947, under a grant from the Applied Mathematics Division, Brown University, Providence, R. I. The writers wish to thank Professors Krumhansl and Prager for their encouragement and cooperation, and to thank Mr. G. Heckler for his able assistance with the laboratory work.

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2. *Artzt, Electronics, August, 1945.*
3. *Ginzton, Electronics, March, 1944.*
4. *Ginzton, IRE Proceedings, November, 1948.*
5. *Raggazini et al., IRE Proceedings, May, 1947.*

Personals

WILLIAM B. BERGEN, director of the Special Weapons Department of *The Glenn L. Martin Company*, has been named chief engineer in charge of the company's engineering activities. A graduate of the Massachusetts Institute of Technology, Mr. Bergen received the Lawrence Sperry Award of the Institute of the Aeronautical Sciences in 1943 for his theoretical and experimental investigations of dynamic loads on aircraft.

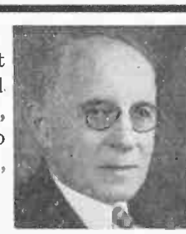
R. T. CAPODANNO has been appointed Director of Engineering at *Emerson Radio and Phonograph Corporation*, New York. Mr. Capodanno was previously connected with the University of Illinois as engineering adviser on technical devices for the hard-of-hearing, brain wave studies and spinal work. He is a member of RMA's Sound Systems Committee and has served as an engineer on communications with *Illinois Bell Telephone Co.*

DR. ALEXANDER ELLETT was recently elected vice president in charge of research by directors of *Zenith Radio Corporation*, Chicago, Illinois. Dr. Ellett, who has headed *Zenith's* research laboratories since 1946, was formerly head of Division 4 of the NDRC where he directed the development of the V-T proximity fuse for bombs and rockets for which he received the President's Medal for Merit. He was also formerly professor of physics at the University of Iowa.

CARL J. HOLLATZ, formerly vice-president of the *Belmont Radio Corporation*, has been retained as a consultant to the Sales division of the Tube Department of *RCA*. Mr. Hollatz will make his headquarters in Chicago. Prior to his connection with *Belmont*, Mr. Hollatz was Manager of the *Westinghouse Company's* tube operations in Indianapolis, and later President and General Manager of *Ken Rad Tube and Lamp Corporation.*

DR. THOMAS J. PARMLEY has been appointed to the staff of the National Bureau of Standards where he will do research in the x-ray laboratory of the Atomic and Molecular Physics Division. Before joining the Bureau in 1927, Dr. Parmley was a professor of physics at the University of Utah. He has done considerable research in nuclear physics, including investigations of the radioactivities of the heavier cobalt isotopes.

DR. FRANK B. JEWETT, for many years vice president of the *American Telephone and Telegraph Company* and former president of the National Academy of Sciences, passed away November 18. Dr. Jewett had been named to receive the 1950 medal of the Industrial Research Institute, Inc., in April.



D. C. Voltmeter

(*Continued from page 7*)

mer Avenue, Newark 4, New Jersey—and used to seal electronic components into metal cans. The leakage resistance of these beads is quoted at 10,000 megohms after a salt spray test. Before this test and as normally received these

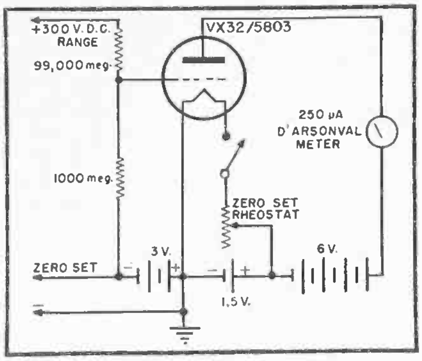
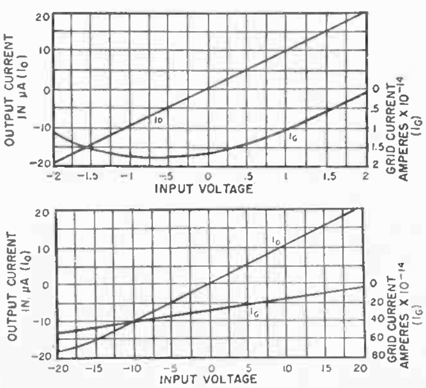


Fig. 3. Basic schematic of voltmeter. Basic voltmeter range is seen to be 3.0 volts full scale.

beads are of infinitely higher leakage resistance, probably on the order of 10^{12} ohms. To maintain this leakage resistance it is advisable to cover the bead surface with *Dow-Corning* DC4 if the instrument is to be used in a high humidity area or if other contamination is possible. Under no condition use any cleaning agent other than clean pure alcohol or carbon tetrachloride and a piece of clean cotton cloth, if contamination is suspected. If it is desired to use a plastic insulator then polystyrene should be used, but for the use indicated in this article a glass bead is to be preferred. Polystyrene is very difficult to clean and maintain in a clean state. It would require several pages to go fully into a cleaning technique for use with polystyrene but the following will generally prove adequate. Polish the polystyrene surface with ordinary paper towel to a brilliant surface. After installation wash the exposed leakage

Fig. 5. Calibration and grid current for the electrovolter circuit of Fig. 1. Top, 0-2 volt range; bottom, 0-20 volt range.



paths with carbon tetrachloride. If desired then coat with *Dow-Corning* DC4.

Electrometer tubes do not as a rule use over 6 volts on the plate, while the filament requires 1.1 to 1.5 volts with a filament current of 10 milliamperes. The plate current (VX32/5803) will be about 250 microamperes with zero bias and 6 volts plate supply. Two and one half volts bias will provide cutoff. For maximum sensitivity a plate current of 150 microamperes should be used and a balancing circuit utilized so that a plate current meter will indicate only the change in plate current. This will minimize any tube nonlinearity as well as provide very high gain. In cases where high gain and low drift are desired the filament should be lit a few seconds before the plate voltage is supplied. The input impedance on these circuits can be made so high that static electric charges, such as generated on a hair comb, can be measured.

One major factor which limits the usable input resistance is *RC*. In the design of these circuits, TIME in SECONDS to obtain a meter deflection is a product of resistance (in megohms)

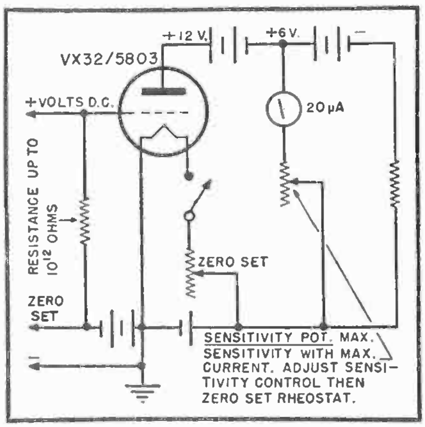


Fig. 4. An ultra-sensitive voltmeter.

times capacity in μfd. and is an important consideration. VX32/5803 electrometer tubes have an internal capacity of approximately 2.0 μμfd. An additional capacitance of 2.0 μμfd. can nominally be expected due to external wiring—even though great care is used. The product of 10^{12} ohms resistance times 4.0 μμfd. is some four seconds, 10^{11} (100,000 megohms) some 0.4 seconds. It is not considered good practice to have an instrument which requires over 1.0 second (*RC*) time, and it is preferable to have an *RC* time of 0.1 second. In actual practice time up to several seconds is not too objectionable providing the d.c. voltage to be measured is stable. To minimize capacity the electrometer tube should be in a probe (with its grid resistor) and an extension cable used to connect it to the D'Arsonval meter and batteries. Several circuits will be found in the text, any one of which will be suitable for measurements where very high input impedances are required.

New Products

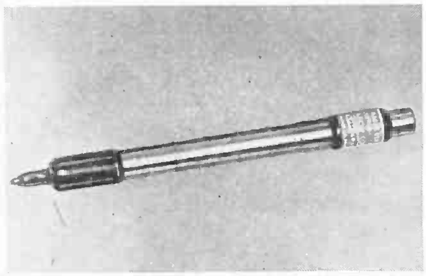
(*Continued from page 23*)

modulation in one unit, and are particularly well-suited for use in aircraft where there is a d.c. as well as an a.c. power source available.

A complete description of the Self-Excited Choppers appears in the company's Catalog No. 267 which may be obtained upon request.

RADIATION COUNTER TUBE

A new, thin metal wall Radiation Counter Tube for beta and gamma detection is now being manufactured by



Amperex Electronic Corporation, 25 Washington St., Brooklyn 1, N. Y.

Type 52N may be operated over a wide temperature range without affecting tube life or electrical characteristics, and accidental overvoltage will not harm this tube.

Complete data on the Radiation Counter Tube, Type 52N may be obtained by addressing an inquiry to Mr. Myron Smoller, Sales Engineer.

WELDING CONTROL EQUIPMENT

Westinghouse Electric Corporation, Pittsburgh, Pa., now has available two all-electronic, high-speed resistance welding control equipments for synchronous and non-synchronous operation. These equipments have no moving parts in power and control circuits except initiation and solenoid relays.

Basic control panels consist of the plug-in Rectox rectifier tube firing panel for non-synchronous units, or a heat-control firing panel for synchronous units. Space is also provided for the addition of auxiliary control panels such as a.c. forge timer, d.c. precision-type forge timer, wave-shape control, voltage compensator, initial-squeeze attachment, current regulator, temper sequence weld timer, dual weld attachment, interlocking relay attachment, dual weld interval attachment, and a Timatic control attachment.

Further information may be obtained by writing to *Westinghouse* at P.O. Box 868, Pittsburgh 30, Pa.

Antenna Pattern

(*Continued from page* 15)

taken when the equipment is used in measuring the pattern of an antenna on location. The principal advantage of measuring antenna patterns on location is the opportunity afforded to determine the effect of surrounding objects such as guy wires, smoke stacks, and other mounts.

Acknowledgment

The work described in this paper was carried out as a development program of the Naval Research Laboratory and a production engineering program of *Airborne Instruments Laboratory, Inc.*

Rugged Electron Tube

(*Continued from page* 11)

the tube structure as rigid as possible to avoid resonance with high-frequency vibrations. It is extremely important to employ low-strain designs at all points of glass-to-metal contact and to eliminate brittle materials wherever possible. It is often useful to carry out a theoretical analysis for an idealized structure approximating the structure of the tube under consideration. In this way, the designer can achieve a rough guide to the resonant frequencies of each tube element and an indication of whether or not a proposed design will be satisfactory.

High-Impact Shock Tests

Impact tests determine the ability of electron tubes to withstand rough handling and dropping. Shocks of this sort occur in shipment of tubes, in motor vehicles, in military operations, and in use with industrial equipment. Impact shocks result in tube failures of the same general type as those produced by vibration and resonance, but shattering of the glass envelope and breaking of brittle metal parts are more frequent.

The high-impact machine used at the Bureau consists of a test table, on which the tube is mounted, and a hammer suspended like a pendulum so that the energy imparted to the table will be a function of the angle from which the hammer is released. The table and hammer weigh about 75 pounds apiece, and the impact machine can test tubes weighing up to 25 pounds. Tubes may be mounted in any desired plane, and normal operating potentials or shorting indicators can be connected to the tube elements. Instantaneous accelerations up to a maximum of several hundred times the acceleration of gravity and down to a minimum of 50g may be readily selected. The duration of impact is less than a millisecond. Impact accelerations are measured with a quartz-crystal accelerometer and verified by means of streak photography.

Centrifugal Acceleration Tests

High-acceleration conditions are met principally in the application of electron tubes to electronic equipment in high-speed devices, where tubes receive large continuous forces for relatively long periods of time compared to the brief, transient-force conditions under impact. A tube which will withstand high accelerations must have great structural rigidity to prevent shifting and bowing of the various electrodes.

The motor-driven centrifuge now in use in the Electron Tube Laboratory of the Bureau can produce accelerations up to several thousand times the acceleration of gravity. Its rotational speed, as measured with a tachometer or with a stroboscopic pick-up, ranges up to 18,000 r.p.m. The centrifuge can be modified to increase the acceleration by evacuating the chamber so that the driven element will not be opposed by the resistance of the air. The speed of a centrifuge can be closely and easily controlled, making it possible to reproduce particular test conditions on different centrifuges. This cannot usually be done with other types of dynamic test equipment.

Objects weighing up to several ounces —and this includes almost all miniature and subminiature tubes—may be tested in the present centrifuge. As many as a dozen tubes can be placed in the chamber at one time. Tubes can be oriented at various angles to the direction of acceleration in order to study the differences in rigidity of components in different directions. Newer centrifuges permit connection of typical operating potentials to the tube elements so that the electrical performance can be studied during high acceleration. Centrifuges have been designed to give very high accelerations—the Beams type is notable in this respect. In the near future the Electron Tube Laboratory will place such a high-acceleration centrifuge into operation.

Centrifuge acceleration tests provide a good over-all quality check for electron tubes. The most common tube defects revealed by acceleration tests are high bending moments, inability of the glass envelope to support the internal structure, breaking of welds, bowing of elements, and interelectrode shorts. Taken together, the vibration, resonance, impact, and acceleration tests provide a useful picture of tube behavior when subjected to mechanical forces.

Testing and Design

The development of rugged electron tubes is a good example of the interdependence of testing and design. In a sense, the creation of rugged tubes is brought about through a series of successive approximations. The development of a rugged tube might begin by applying appropriate mechanical tests to an existing commercial type whose electrical characteristics suit the intended application. The results of these tests would show in what way this tube type fails to meet the ruggedness requirements. A preliminary revision of the tube design could then be made with the test results as a guide, and a handmade model constructed in the model shop. The same tests could then be repeated for this experimental tube. Usually the tube would turn out to be a vast improvement over the commercial type, but in some respects it might not yet fulfill the necessary ruggedness requirements. At this point the designer would probably have a clear idea of the direction to take in order to achieve a satisfactory rugged tube. It might involve a search for better materials for use in some tube elements, new methods of fabrication adapted to eventual mass production, or better geometrical configurations and alignment of tube elements for maximum rigidity. The influence of each structural element on the over-all strength of the tube would be carefully considered. Thus, through a succession of several trial designs a suitable rugged tube would be evolved.

At present the cost of rugged tubes is about three or four times more than conventional tubes. But it is not unreasonable to expect that as more is learned about production methods and materials applicable to rugged tube types the cost will be much less and all preferred tube types will eventually be available in ruggedized form.

PHOTO CREDITS

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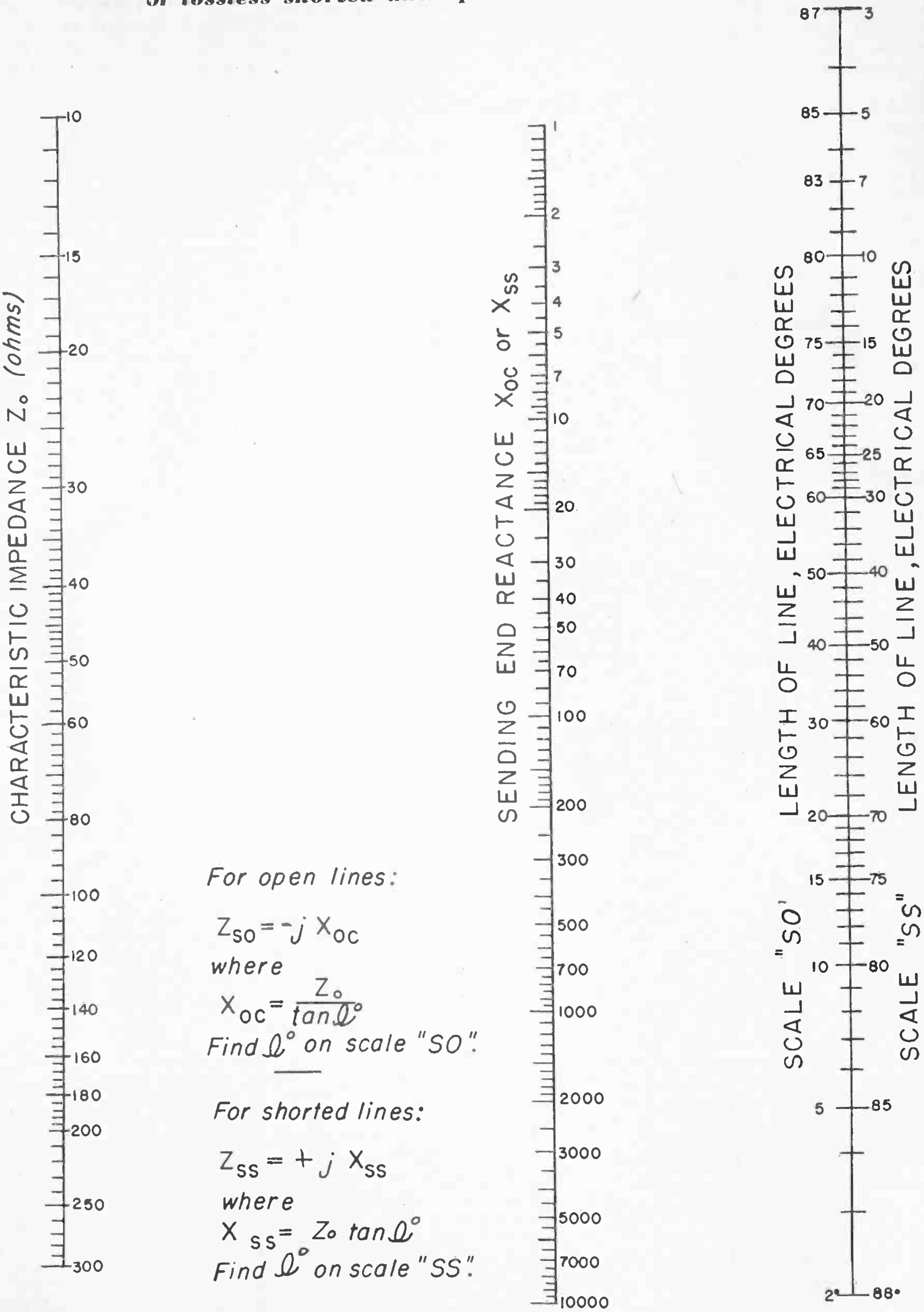
SENDING END IMPEDANCE OF UNIFORM LINE

This chart may be used to obtain input resistance of lossless shorted and open transmission lines.



For open lines:

$Z_{SO} = -j\,X_{OC}$

where

$X_{OC} = \frac{Z_o}{\tan \ell^\circ}$

Find ℓ° *on scale "SO".*

For shorted lines:

$Z_{SS} = +j\,X_{SS}$

where

$X_{SS} = Z_o \tan \ell^\circ$

Find ℓ° *on scale "SS".*

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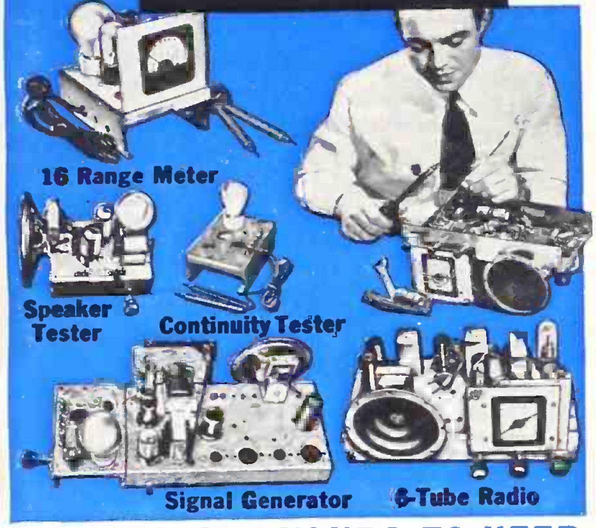

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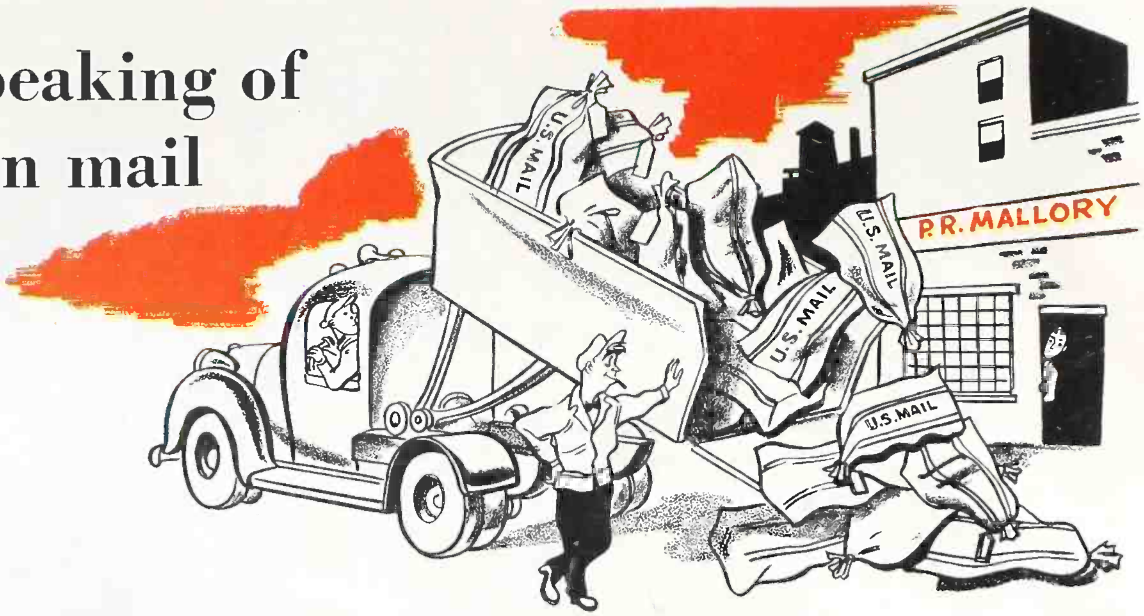

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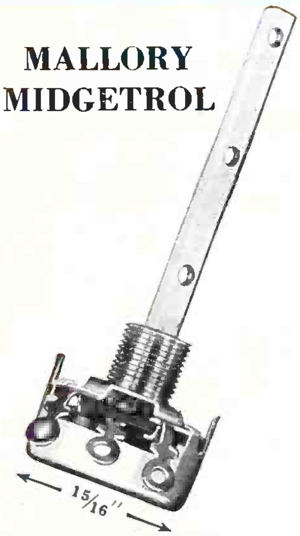

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