MARCH, 1946

RADIO NEWS

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# MARCH, 1946



## DEPARTMENTS



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VOLUME 6 NUMBER 3 

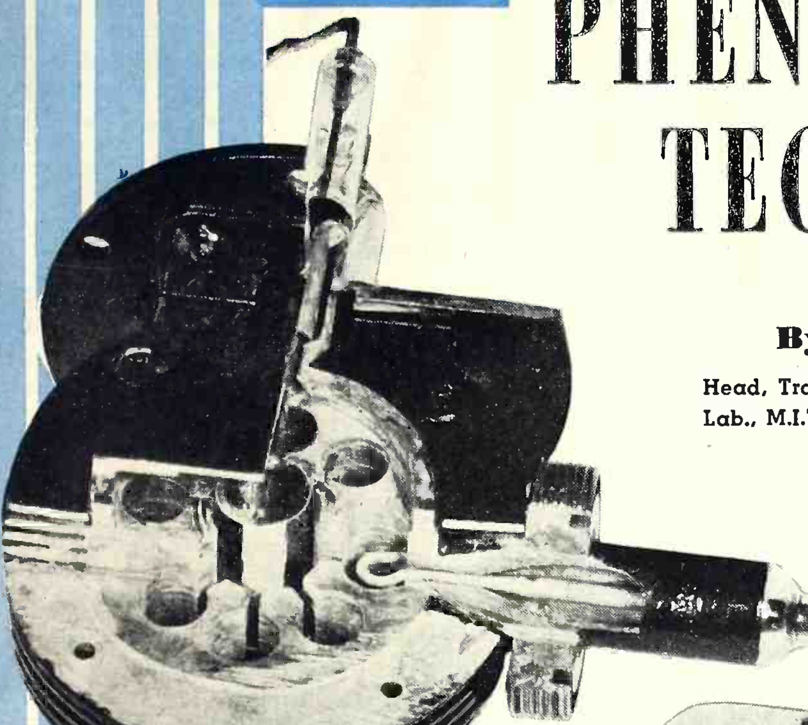
COVER PHOTO—Courtesy of Westinghouse Electric Corporation

Portable "beach umbrella" rotating radar antenna developed by the Westinghouse Electric Corporation for the U. S. Marine Corps. This antenna serves for both transmitting and receiving the radar pulses. The complete radar unit weighs only 400 lbs.

# Microwave PHENOMENA and TECHNIQUES

**By ALBERT G. HILL**

Head, Transmitter Components Div., Radiation Lab., M.I.T.; Assoc. Professor of Physics, M.I.T.



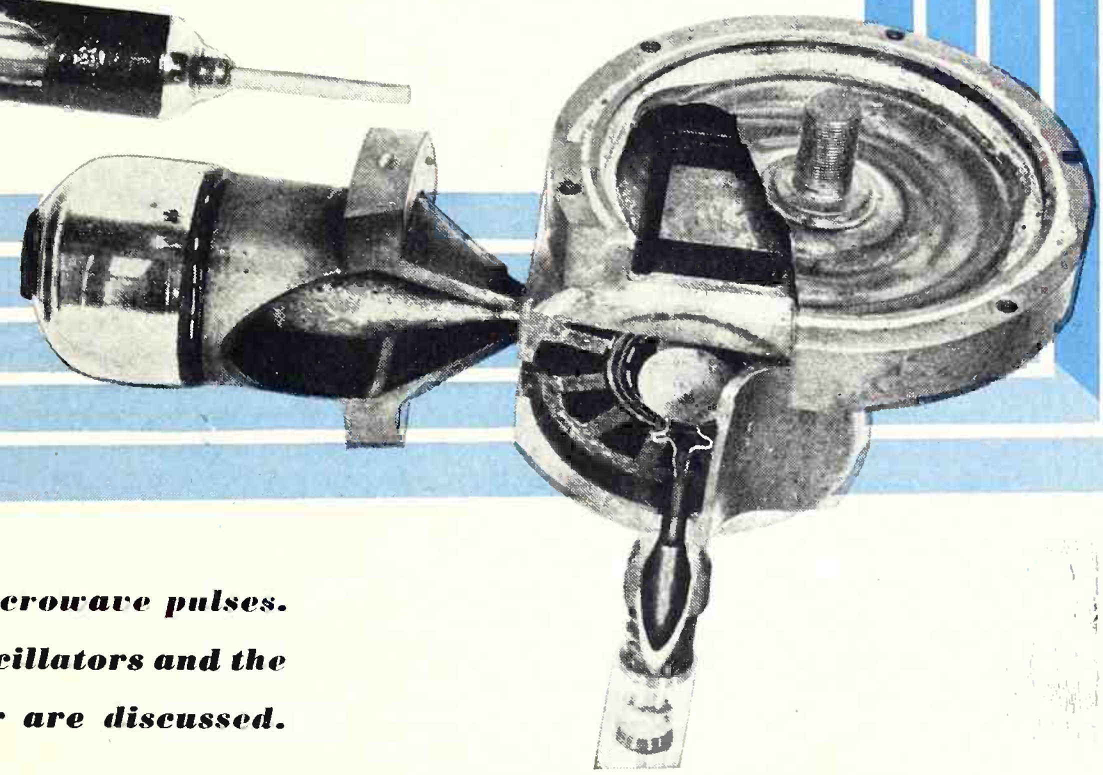


**Fig. 1. Above is shown a cut-away view of the 10 cm., type 2J32 magnetron. The photograph shown to the right is a cut-away view of the 1 megawatt, 10 cm., tunable magnetron type 4J77.**

***Generation and detection of microwave pulses. The magnetron and klystron oscillators and the crystal mixer or first detector are discussed.***

> EDITORS NOTE: *This is the second of six articles on microwave techniques, prepared especially for* RADIO-ELECTRONIC ENGINEERING *by members of the staff of the Radiation Laboratory, M.I.T. This paper is based on work done for the Office of Scientific Research and Development under contract OEMsr-262 with the Radiation Laboratory, Massachusetts Institute of Technology.*

WE HAVE seen[1] that the principal functions of a radar set are to produce and to radiate very short pulses of ultra-high frequency, to detect the reflections of these pulses from material objects and to display the information thus obtained by suitable indicators. In order to distinguish between objects separated by small angles, or small differences of range, it is necessary to have very sharp beams and pulses of short duration. The first requirement can be fulfilled by using frequencies of 2000 mc. and above (lower frequencies lead to prohibitively large antennas for beams of 5 degrees and less in width), and the second requirement can be met by using pulsed oscillations of 0.1 to 2.0 microsecond duration. Of course, the range discrimination is greater the shorter the pulse, but since the average receiver power drops off directly as the pulse width, a suitable compromise must be made between discrimination and minimum detectable signal, which determines the maximum range of the radar set.

The present article will discuss the generation and detection of pulsed microwaves: the radiation and propagation of such waves will be the subject of a later article in this series.

The greatest single contribution toward the development of microwave radar was the British development of the multi-cavity magnetron. This tube, which is pictured in Fig. 1, made possible the production of very high power at high efficiency and relatively good stability. Normal operating figures for such a magnetron are given in Table I.

Maximal figures on production tubes at 10 cm. wavelength are 3000 kw. peak power, and 2 kw. average power. For special low power uses, magnetrons of 50 watts peak power have been constructed. The measured efficiency of a magnetron is the product of the electronic efficiency and the circuit efficiency. The first of these represents the ability to convert d.c. power into microwave power and values as high as 80% have been inferred from indirect measurements. The circuit effi-

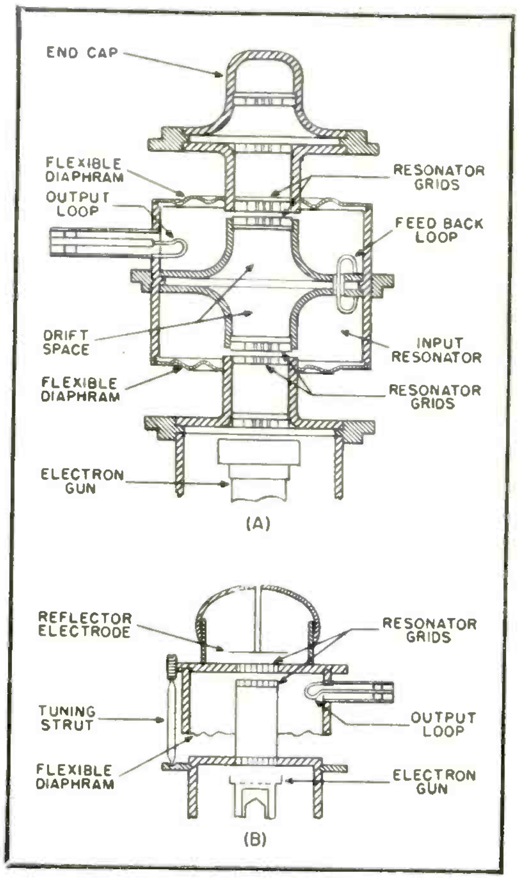



**Fig. 7. (A) Two cavity klystron. (B) Reflex klystron.**

to utilize the ultimate receiver sensitivity, it is very likely that the magnetron will be far enough off frequency some of the time to render the received signal outside the i.f. pass band. Some form of automatic frequency control is necessary, and since the magnetron is difficult to tune, it is convenient to let it shift frequency at will, but to keep the local oscillator in step with it. This is accomplished by using an i.f. discriminator and the electronic tuning property of the reflex klystron.

The reflex klystron is a very inefficient device, but this is of negligible importance for l.o. use. Typical operating characteristics for a reflex klystron at 10 cm. are given in Table II.

### Microwave Transmission Lines—Coaxial Lines

Transmission lines for microwaves must be shielded to prevent radiation leakage and impedance changes due to interactions with surrounding objects. Two general types are possible: (1) coaxial lines and (2) wave guides, although the first type may be considered as a special case of the second. The coaxial line permits the propagation of a "principal mode"; the mode in which the field vectors are completely transverse to the direction of propagation; the lines of $E$ being radial between the two conductors, and the lines of $H$ being circles concentric with the conductors. However, when the wavelength becomes smaller than the average circumference of the inner and outer conductors, higher modes having longitudinal components are possible. Whenever any discontinuity occurs in such a line the higher modes will be excited and the impedance relations will become very complex. For practical reasons, then, the largest size of coaxial line for the 10 cm. region is one in which the inner diameter of the outer conductor is 1½" and the outer diameter of the inner conductor is ⅝", for 52 ohms characteristic impedance. The corresponding limits for the 3 cm. region are approximately ½" and 3/16".

The characteristic impedance of a coaxial line is given by:

$$Z_o = \frac{138}{\sqrt{k}} \log_{10} \frac{a}{b} \text{ (ohms)} \quad (2)$$

where $a$ and $b$ are the outer and inner radii, respectively, and $k$ is the dielectric constant.

The attenuation due to copper losses in air-filled coaxial lines is given by:

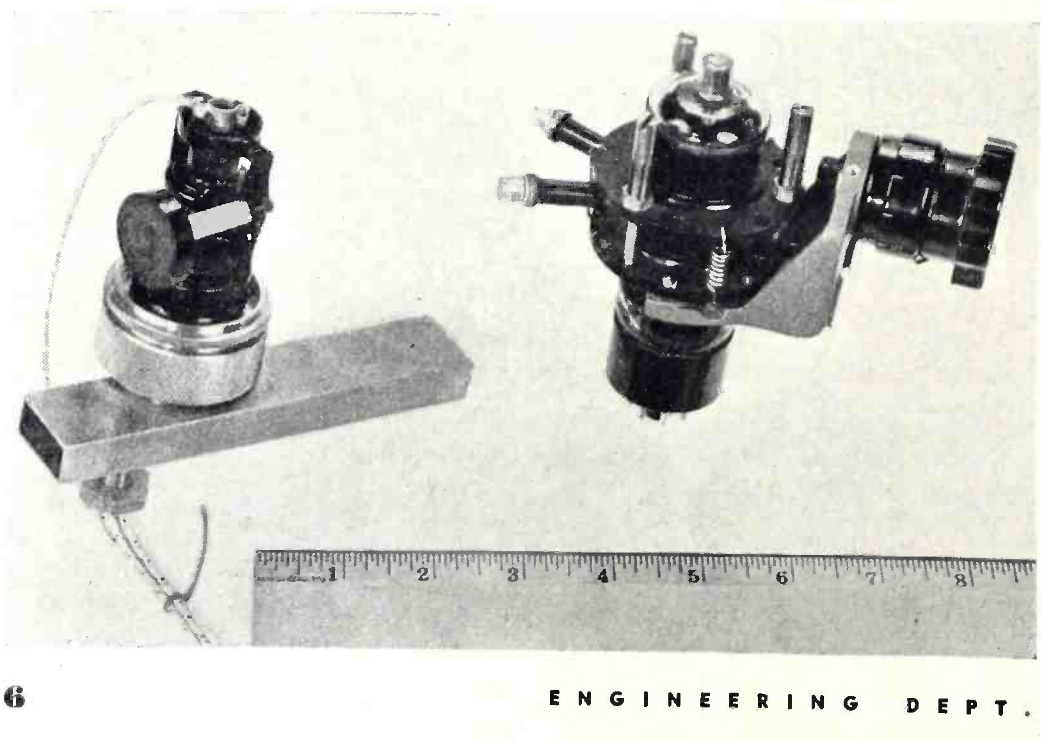
$$A = 23.8 \frac{\sqrt{\rho/\lambda}}{Z_o}\left(\frac{1}{a} + \frac{1}{b}\right) \text{ db./cm} \quad (3)$$

where $a$ and $b$ are the inner and outer radii, $\rho$ is the resistivity in ohm-cm., $\lambda$ the wavelength. For the 1½" line described above and $\lambda = 10$ cm., $A$ is .025db./ft. for brass.

The most difficult problem in the fabrication of coaxial lines is the support of the center conductor. Solid dielectric support greatly increases the attenuation since dielectric losses predominate in the microwave region. Dielectric beads give rise to reflections and consequent impedance mismatches, and further greatly reduce the power-handling ability, since breakdown across the dielectric is an ever-present source of trouble. Quarter-wave stub supports are by far the most satisfactory, and though inherently not broad-band, can be made so by the addition of small transformers on the inner conductor.

The ultimate limitation on the use of coaxial lines is the breakdown strength. Assuming 30,000 volts/inch as the breakdown strength of air at atmospheric pressure (a value which is nearly correct in the microwave region) the greatest pulse power which can be handled at 10 cm. in a 52 ohm coaxial line is theoretically about 3500 kw. Actually imperfections and discontinuities will cut this down, and a good working upper limit is about 1000 kw. These values are given for the 1½" x ⅝" coaxial line which is the largest practicable at 10 cm. wavelength.

Fig. 8. Wave guide mounted on 723A klystron (left). Right, 417A klystron (10 cm.).



### Wave Guides

In the general sense any transmission line is a wave guide, and the coaxial line is a special case. In the particular sense, and the one used here, the term wave guide is reserved for hollow pipes which usually are rectangular or circular in cross section. The wave guide most useful in practice is the rectangular one and we shall describe its properties briefly.

Because of the lack of inner conductor to terminate the lines of $E$, no principal mode is possible in a wave guide. This means that either $E$ or $H$ will always have a component in the direction of wave propagation. Referring to Fig. 10, let us discuss the case of a rectangular wave guide of inner dimensions $a$ and $b$, where $a > 2b$ (the usual case in practice). The lowest mode is one in which the lines of $E$ are transverse and parallel to the narrow dimension of the guide, and the lines of $H$ have both longitudinal and transverse components, but are always perpendicular to the lines of $E$

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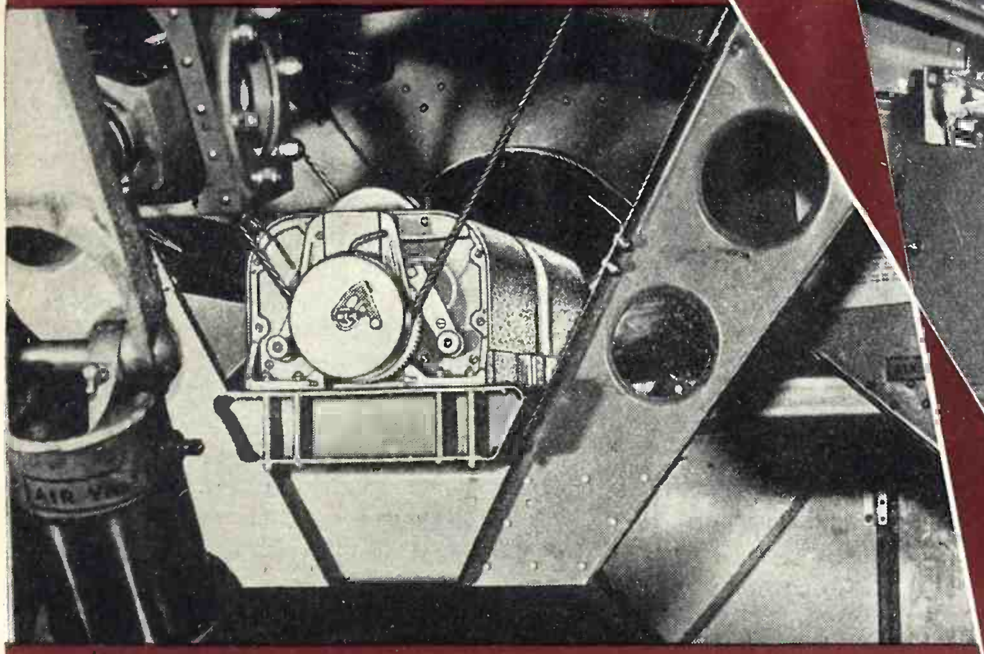
Fig. 1. Rudder and elevator servo installation.



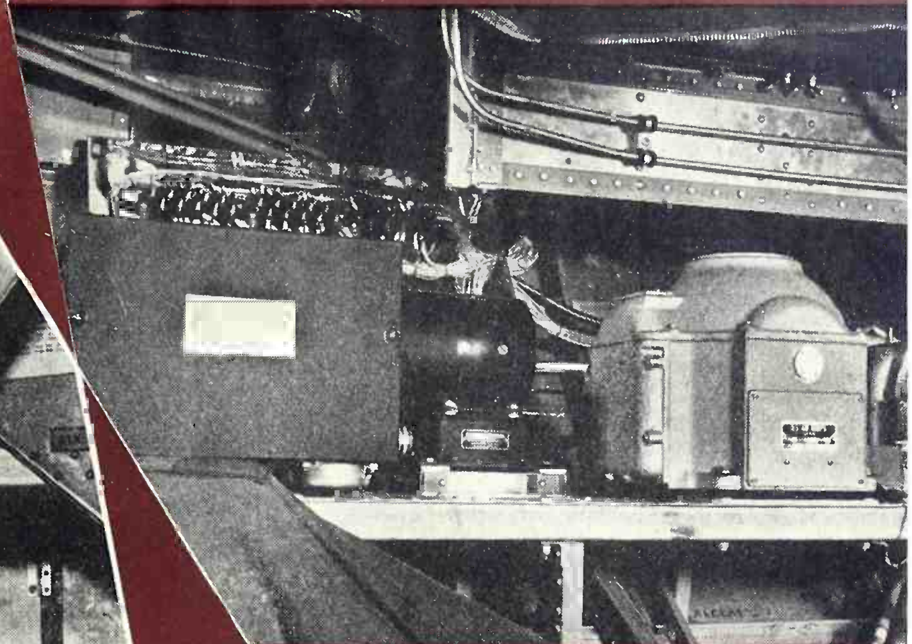


Fig. 2. Left to right, amplifier, inverter, vertical gyro, and aileron servo of autopilot in B-17.

# AVIATION ELECTRONIC CONTROLS

By JOHN D. GOODELL
Consulting Engineer, St. Paul

***Electronic circuits are utilized in liquid measure and autopilot controls in military and civilian aircraft.***

THE following electronic devices developed by the Aero Division of the *Minneapolis-Honeywell Regulator Company* are worthy of the attention of every engineer and technician. These basic principles may be broadly applied to the solution of almost any problem of control or measurement, and in the rapid expansion of electronic aids to industry they are destined to play a vital role.

Types of "sensing" methods may vary as widely as the problems to be solved. Given a dependable device for transducing the intelligence provided by the sensing mechanism into an intelligible indication, or into energy applied so as to perform the appropriate actions, every problem is resolved into the development of a suitable pick-up. In the following paragraphs a number of devices will be described, all having in common the use of resistance bridges as coordinating elements.

Devices designed for aircraft installation are subject to physical vibration and shock, as well as variations in temperature, humidity and altitude, under conditions where dependability is of more than ordinary importance. The initial thinking of most engineers would not suggest potentiometers as being particularly well suited for continuous operation under these rigorous requirements. This mistrust results largely from experiences with economy influenced designs.

The potentiometer developed by *Minneapolis-Honeywell* is illustrated in Figs. 3 and 11. The contact surfaces of the multiple wiper are made of Paliney #7 (containing platinum, gold, silver, copper and palladium) welded to the tips of five V-shaped flat phosphor-bronze spring blades. The nichrome wire resistance element is wound around a flat bakelite ring clamped to a flat bakelite block on which is mounted a flat metal collector ring. The contact points are arranged at an angle selected to produce optimum self-cleaning "snowplow" wiper action. This feature has virtually eliminated any difficulties from fouling of the resistance element. Triple contact is provided by the three longer blades, and the two short blades complete the circuit to the collector ring. This construction eliminates the need for flexible wire to the wiper arms. The design has proved its long life, minimum maintenance and serviceability under flying conditions in the B-29 Superfortress and other aircraft.

With the problem of dependability solved, the potentiometer is an unusually valuable tool for translating mechanical motion into an electrical signal. There are innumerable methods of connecting potentiometers in resistance bridges so as to vary the flexibility of control, coordinate intelligence from various sources and provide special effects of many kinds. A review of fundamental principles will facilitate understanding of specific applications that follow.

In Fig. 5A the voltage from an a.c. source is impressed across two potentiometers connected in parallel. It is clear that when the two wiper arms are electrically centered there will be no difference of potential between them, hence zero output voltage. If the arm of the control pot is moved away from center, the phase sensitive amplifier will develop an output voltage to operate the motor. Assuming a method whereby the direction in which the motor rotates depends on the phase of the signal to the amplifier, the mechanical connection between the armature of the motor and the balance pot may be arranged to

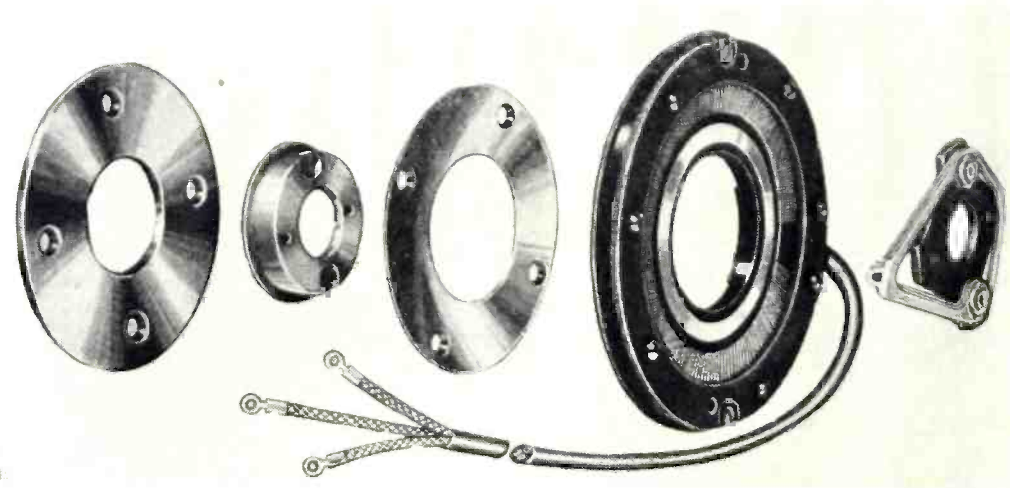


**Fig. 3. Exploded view of the potentiometer assembly used in various controls.**

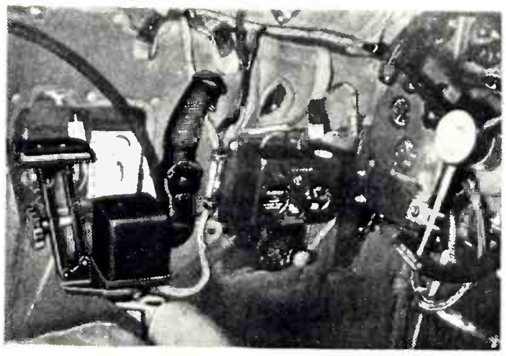


**Fig. 4. Formation stick autopilot control installation in a B-24.**

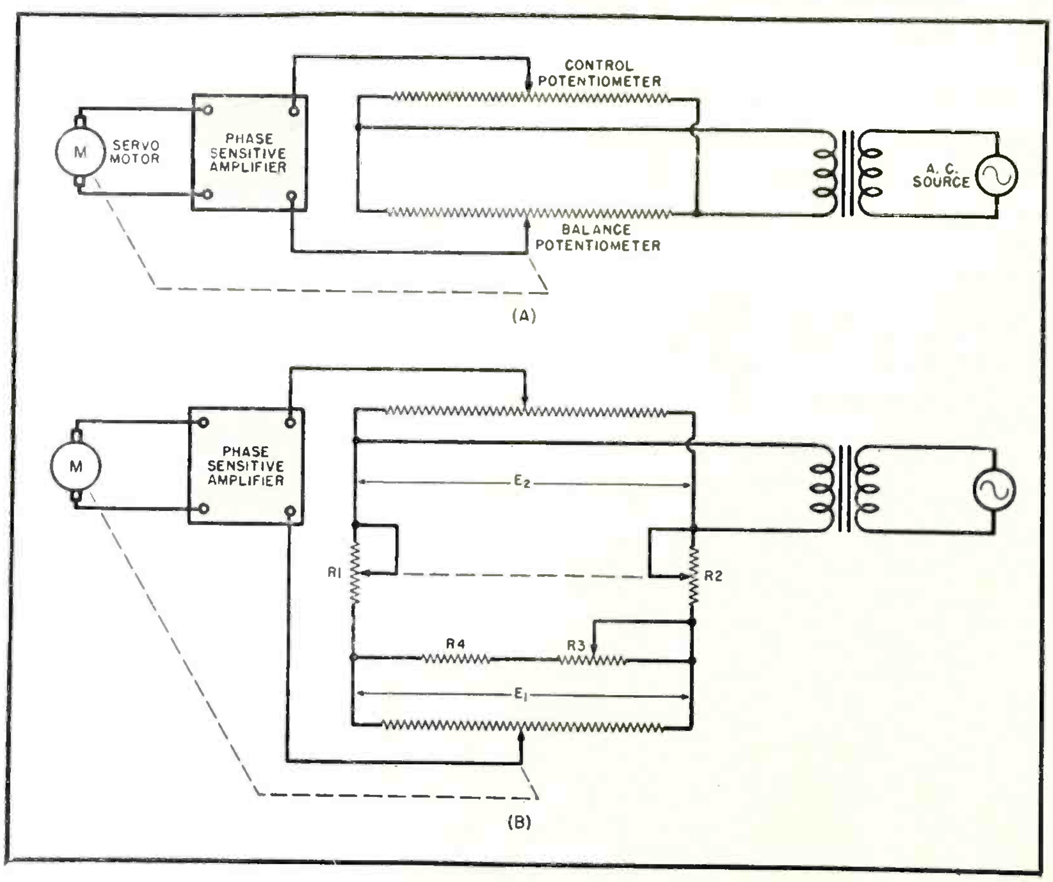
re-balance the bridge to zero output. Obviously there is no necessity of physical proximity between the components, and the arrangement is well suited to remote control requirements.

In Fig. 5B, $R_1$ and $R_2$ have been added to allow the electrical balance point to be shifted away from the physical center. The ratio $E_1/E_2$, termed the "control" ratio, is diminished by the addition of these resistances. In order that this ratio be adjustable, $R_3$ is introduced, while $R_4$ prevents any adjustment of $R_3$ from shorting out the balance pot.

A particularly interesting arrangement is shown in Fig. 7. The production of individual pots with accurate exponential tapers has always been expensive and difficult. Here the problem is solved simply by using two ganged pots. When the arms are centered, the potential across $R_1$ is zero. As the arms are moved away from center, $R_2$ applies an increasing voltage to $R_1$. At the same time the arm of $R_1$ picks off an increasing percentage of the voltage available. Thus, the output voltage varies as the square of the displacement of the arms.

One of the most ingenious recent applications of well known principles is represented by the electronic fuel gage. In this device the pick-up unit consists of three concentric metal tubes mounted upright in the fuel tanks. The outer tube functions as an electrostatic shield and is grounded. The two inner tubes are used as the plates of a capacitor, as shown in the basic diagram in Fig. 8. The dielectric constant of air is one, and the dielectric constant of gasoline is approximately two. Thus, the impedance of the concentric pipe capacitor is half as great when the tank is full as when it is empty. At intermediate points in the range from empty to full, the impedance is proportional to the amount of available fuel, providing the tank is symmetrical.

**Fig. 5. (A) Basic self-balancing bridge control. (B) Trimmers for this control.**




The circuit of Fig. 8 represents a capacitance bridge. When the arm of the bridge containing the fixed capacitor is of the same total impedance as the tank unit capacitor, the bridge is in balance and there is no output voltage between the center tap of the transformer and the junction of the capacitive elements. If the level of the fuel is raised or lowered, the impedance of the tank unit will change accordingly and there will be an output voltage applied to the phase sensitive amplifier. The phase will depend on whether the fuel has been increased or decreased, thus determining the direction in which the output of the amplifier will drive the motor. The motor is geared to drive an indicator calibrated in gallons, and at the same time to adjust the balance potentiometer in such a manner as to re-balance the bridge.

There are many obvious advantages to this instrument, such as the fact that no moving parts are used in the fuel tanks; the indicator maintains its reading even with the engines turned off; a 300-degree scale is available; and the needle stays at the failure point so that the available fuel may be estimated on a time basis if an electrical component becomes inoperative. A test button is provided to simulate an empty tank in order to determine that the unit is operating properly. In order to compensate for angular displacement of the tanks, several concentric pipe units are connected in parallel. Thus, if the fuel is shifted toward one side as a result of tilting the tanks, the quantity in one unit goes up proportionally as it goes down in another. Small oscillations of the fuel are damped out by using small entrance holes to the pipes. Finally, and perhaps most important, the dielectric characteristics of gasoline are such as to compensate almost completely for volumetric changes from expansion or contraction caused by variations in temperature. As the gasoline expands, the dielectric constant decreases.

In some parts of the world the ground temperature may be 140° F., while at 30,000 feet it may approximate —40° F., reducing the volume of the gasoline by approximately 12%. The energy available is a function of the weight of the gasoline rather than the volume. Where mechanical gages are used, it is necessary to carry a large quantity of gasoline as a safety factor to allow for changing temperatures affecting the indicator. In operating large aircraft with a capacity of 6000 gallons, the extra quantity required for this safety factor may be reduced as much as 900 gallons by taking advantage of all the added features of accuracy in the electronic instrument. This would permit an increase in payload of over *two tons.*

Calibration of the indicator in gallons is accomplished at a reference temperature of 77° F., and the dial face markings are divided in accordance with a curve based on the irregularities of shape in the various fuel tanks. There are many other possible applications for this method of liquid measure, such as fuel and oil aboard ships and the measurement of liquids in bulk containers. Even corrosive liquids may be safely measured by insulating the capacitor plates with a suitable sheath of protective substance and compensating for the added dielectric as a constant in the calibration procedure.

It is an interesting sidelight on the manner in which engineering developments take place to note that this instrument grew from an effort to devise a suitable ice indicator for exterior surfaces on aircraft. One approach to the solution of this problem involved the use of a capacitor mounted on the wing surface. The measurement was then made on the basis of the difference in dielectric constant between air and ice. This was abandoned because new developments in ice elimination minimized the need for such an indicator. Then the possibility of applying the same principles to fuel measurements became apparent and the instrument described above was designed.

### The Autopilot

In the Autopilot, the servo motor is used to drive cable drums that operate the control surfaces. Aircraft are controlled in three dimensional flight by displacement of the ailerons, the elevators and the rudder. A bridge of the type previously described is used for each of these controls, and the various controls are inter-connected in a suitable manner. The schematic drawing in Fig. 6 shows the functional relationship of components in the vertical flight assembly. The gyro case is fastened to the frame of the airplane and the pick-up potentiometer winding is fastened to the gyro case. The wiper arm is mounted in a fixed position with respect to the gyro rotor. Thus, if the airplane deviates from straight and level flight, the gyro case and the pick-up pot winding tilt with it, but the gyro rotor and the wiper arm remain vertical. This changes the position of the wiper arm on the pick-up pot and applies a signal to the amplifier. The output of the amplifier causes the servo motor to turn the cable drum which operates the control surface. At the same time the wiper arm attached to the cable drum is adjusted with respect to the balance pot so as gradually to diminish the amplifier signal to zero. The action of the control surface brings the plane back to level flight, which reverses the direction of displacement of the wiper arm on the pick-up pot and changes the phase of the amplifier input. This reverses the direction of cable drum rotation and operates the control surface back to its original position, simultaneously readjusting the cable drum wiper arm so as to re-balance the bridge at center.

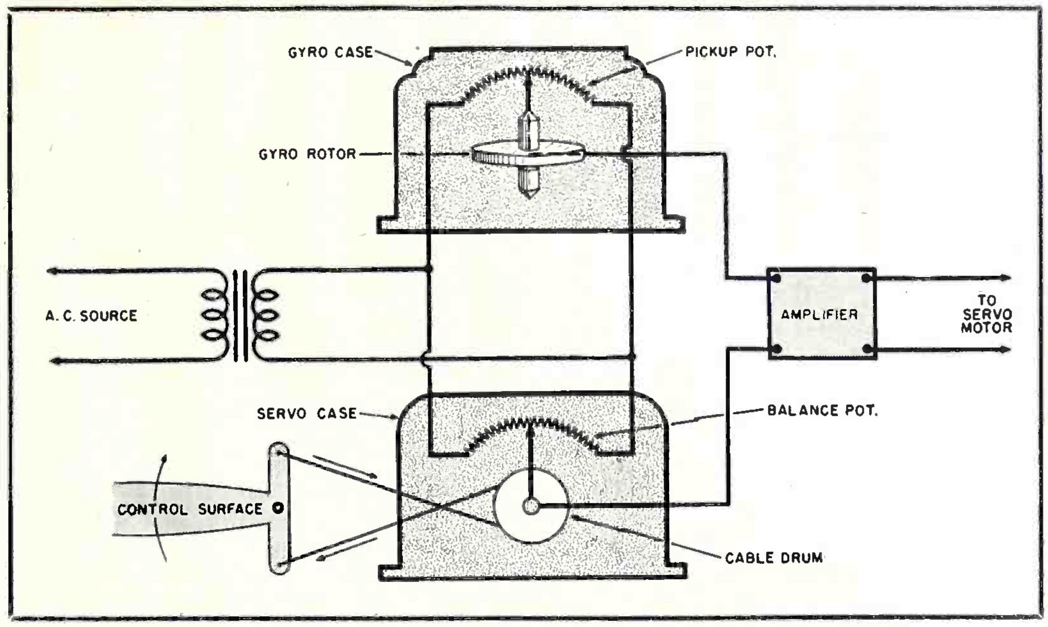



**Fig. 6. Gyro, servo and amplifier arrangement for operating control surface of plane.**

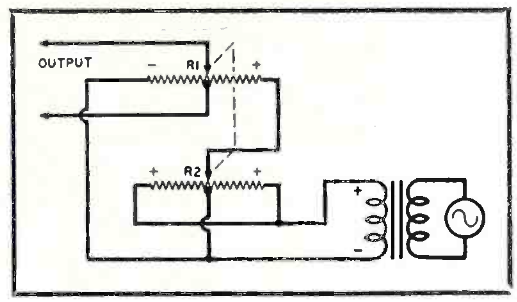
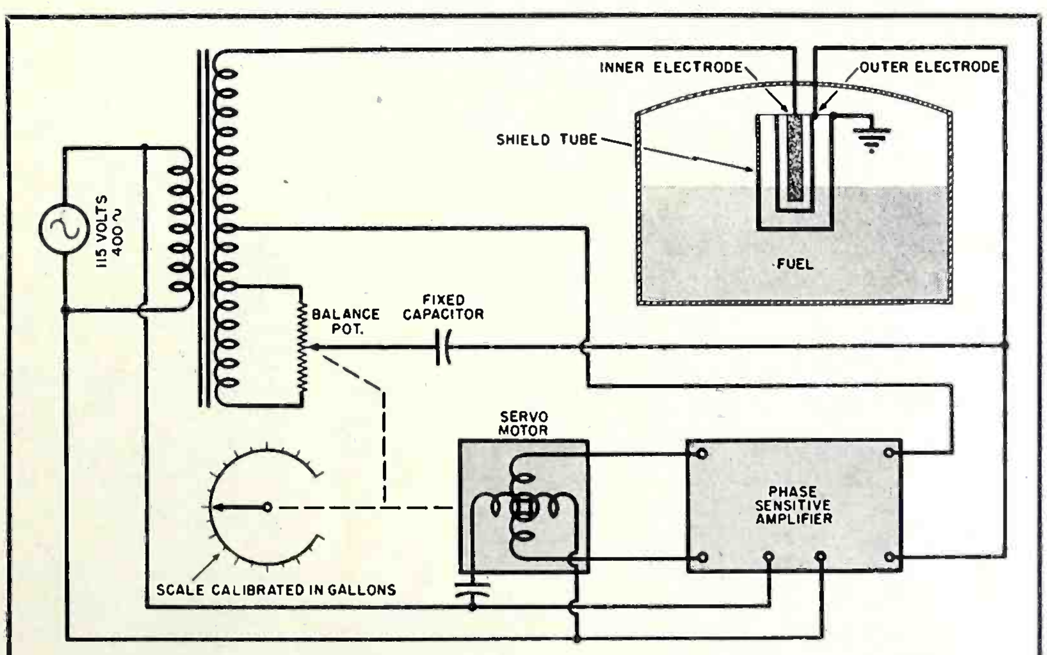



**Fig. 7. Ganged potentiometers connected to produce an exponential taper.**

The amplifier is not unusual electrically, but it is exceptionally well designed to provide flexibility and fine control with a minimum of components. The schematic diagram appears in Fig. 10.

In Fig. 6 it may be seen that the Vertical Flight Gyro controls four po-

**Fig. 8. Schematic showing arrangement of components of liquid level indicator.**



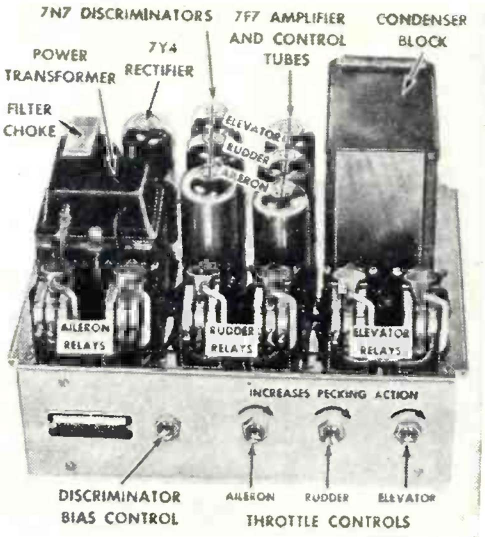



**Fig. 9. Autopilot amplifier.**

tentiometers, thus correlating its total information regarding the movement of the airplane and making the necessary corrections in the setting of various control surfaces. For example, if one wing should drop so as to make an appreciable change in the relationship between the Gyro rotor and the Gyro case, the wiper arms on the Aileron Pickup Pot, the Skid Pot and the Up-Elevator Pot will be operated so as to transmit signals to the aileron, rudder and elevator sections of the amplifier. Thus, the associated control surfaces are operated in exactly the correct manner to return the airplane to level flight. If the pilot wishes to execute a turn, he simply adjusts the Turn Control Knob to the direction of turn and the degree of bank desired. This results in the proper operation of ailerons and rudder to produce a perfectly coordinated turn without the effects of slipping or skidding that may result when a human pilot does not perform the operations perfectly. Banking the plane causes the Vertical Flight Gyro to operate the Aileron, Skid and Up-Elevator Pots so that the Aileron and Skid Pots are caused to cancel the signals to the aileron and rudder servo units. This streamlines the associated controls during the time of turning. The Up-Elevator Pot creates just the right amount of signal to adjust the elevators properly for maintenance of altitude. Upon completion of the turn, the Turn Control is set back to zero and the aircraft automatically levels off. The Turn Control contains a switch that energizes the Directional Arm Lock on the Stabilizer, preventing any interference with the turn from normal operation of the direction correcting characteristics of this unit.

The Autopilot Control Panel contains facilities for engaging or disengaging the system, and also permits trimming of the controls to compensate for varying load and flight conditions. The Pilot Director Indicator is a remote indicating instrument to provide the pilot with information regarding the proper trimming of the system and the airplane. When the Autopilot is set into operation with the PDI initially centered, subsequent corrections are made automatically.

In Fig. 10 a schematic for the Aileron Axis amplifier is shown with idealized oscillograms and $I_p/E_g$ curves for the tubes with the operating points indicated. In complete installations various additions and changes may be made in the bridge circuits in order to provide special facilities of various kinds. The first stage consists of a conventional triode amplifier operated Class "A." The second stage is called the "control" tube, and it operates with a composite grid bias from three sources. With no signal applied, the plate current is at saturation so that only the negative component of the input is effective. To eliminate the effect of very small signals, positive bias is applied through "increase sensitivity" control, which permits moving the operating point anywhere between "A" and "C" as indicated on the associated curve. Under these conditions a signal that was just large enough to drive the circuit would result in chattering of the relays or, conceivably, in not operating the relays at all. Hence, in order that the change-over point from too small a signal to an operating signal may be critically maintained, and still avoid the danger of chattering, a negative feedback voltage is developed across *RC* labeled "feed-back voltage," which cancels a portion of the posi-

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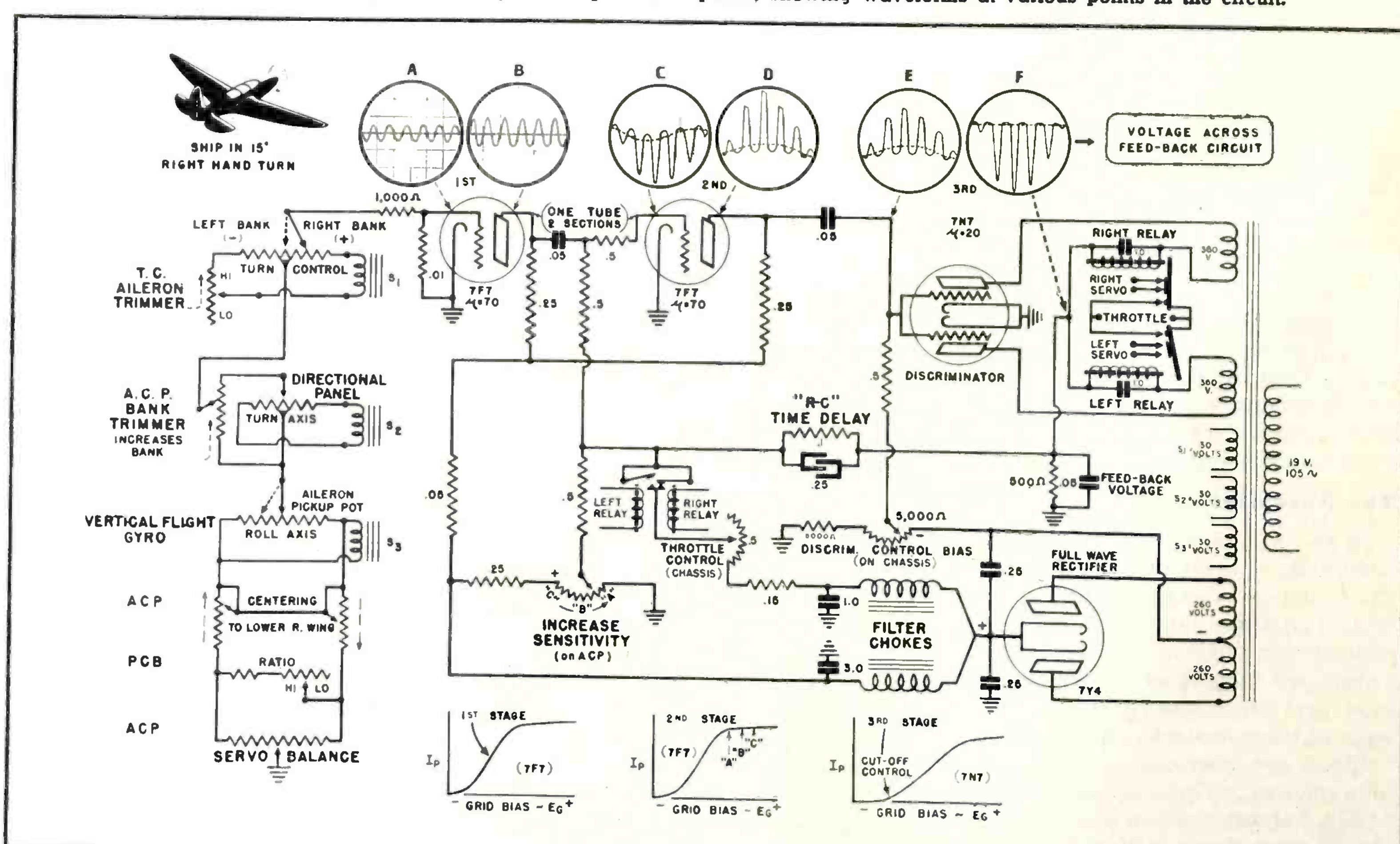
**Fig. 10. Schematic diagram of autopilot bridge and amplifier, showing waveforms at various points in the circuit.**



# Replacing JACK-STRIP in Broadcast Transmitters

***Suitable rotary switches are more reliable than jack-strip and patchord systems commonly used.***

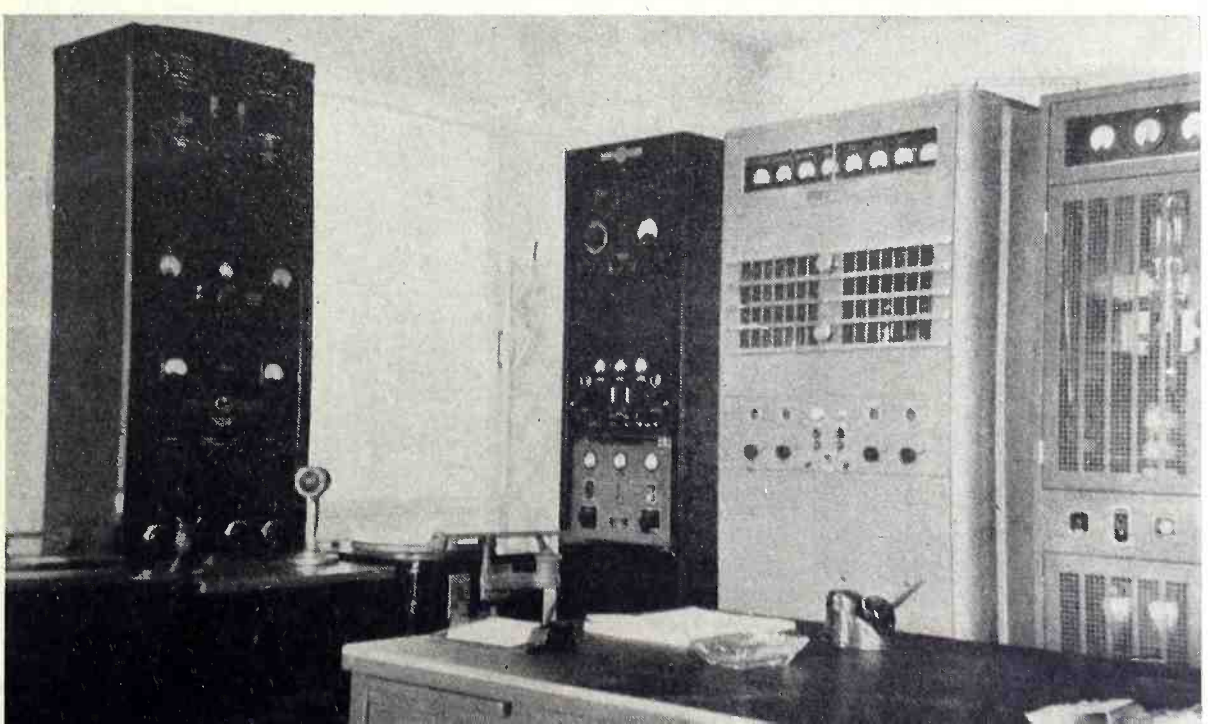
**By JESSE R. SEXTON**
**Chief Eng., Alexandria Broadcasting Co.**

IN PRACTICALLY all the 950 or more broadcast stations located in this country and its territories, will be found the jack-strip and patchcord system of shifting different pieces of regular and auxiliary equipment from one place in the circuit to another, generally for test purposes, or to circumvent bad apparatus, and also for bringing in remote program lines and feeding outgoing lines to local and regional networks. It will also be found that an extremely high percentage of these jack-strips have caused trouble at one time or another by making poor contact to the patchcord plug, or no contact at all, at a critical moment. The author recalls a case when most of a state network missed the first quarter of a football game because of poor jack and plug contact at the originating station. The operator at the originating station was convinced that the trouble was not in his territory since he had the cord patched into the correct jack, and it was not until all other possibilities had been exhausted that he condescended to investigate his own equipment, and rectify the fault. This is not an isolated case—it has happened often under slightly different circumstances. While the patchcords themselves are easy to keep clean, the jack-strip is almost impossible to clean properly, and the best job that can be done still leaves it in such condition as not to justify the reliance that must be placed on it when unfailing operation is the goal.

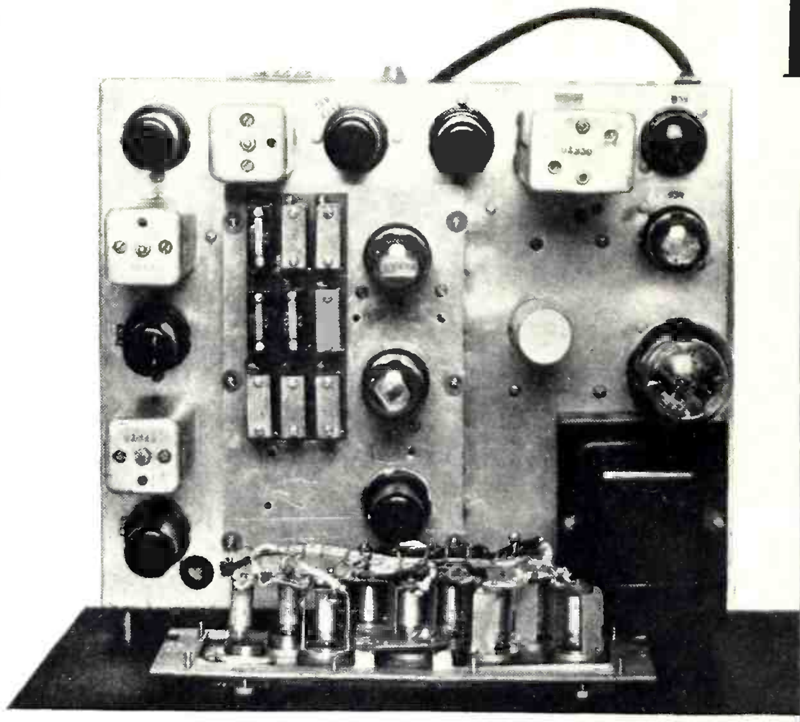
Rotary switches with heavy silver-plated contacts that have a swiping self-cleaning action when turned are as positive in operation as it is possible to make in a mechanical movement. Fig. 2 is a block diagram of a switch panel designed and built to replace the jack-strip. While this system takes up considerably more space than a jack-strip and possibly is not quite as flexible, nevertheless it does everything required of it, and its operation is absolutely dependable. Fig. 1 shows as much of the transmitting equipment as can be included in a photograph. The front panel of the switching system in operation is shown in the upper left hand corner of this picture, mounted above the modulation monitor. Referring to the diagram in Fig. 2, the mixer panel, limiting amplifier, etc., of course, are not mounted on the switch panel. The only controls on the switching panel are the eight rotary switches and the three key switches. No. 1 key switch selects either of two incoming program lines from the studio. No. 2 key switch, along with rotary switch No. 4, is used to throw the incoming program directly into the transmitter, bypassing the limiting amplifier, in case of amplifier failure. The key switch is placed in the lower position and No. 4 rotary switch is placed on No. 1 contact. At this particular installation, with this arrangement about 75% modulation can be obtained in the transmitter, and the amplifier can be serviced without losing time on the air. No. 3 key switch is used for selecting either of two program monitoring sources, one from the audio envelope of the modulation monitor, and the other from a small transformer placed in the cathode of the final Class B radio frequency amplifier. When this key switch is in the neutral position, the input to the program monitor amplifier is open for audition and testing purposes. Either of the turntables TT1 or TT2, or the local announce microphone, may be placed on the input of the monitor amplifier by rotary switches 5, 6, and 8, and the sound level is then controlled by volume control on the monitor amplifier. No. 7 rotary switch may be used to place the studio program lines on the monitor amplifier when the station is off the air, or when the program is originating at the transmitter. If both turntables are placed on the amplifier at the same time, a slight impedance mismatch occurs with some loss in gain, but no discernible loss in quality of reproduction. For future use, provision is made to connect both turn-

(*Continued on page* 39)

Fig. 1. A view showing as much of the transmitting equipment as possible. The front panel of the switching system in operation is shown in the upper left corner.



# CRYSTAL CONTROL for FM RECEIVERS



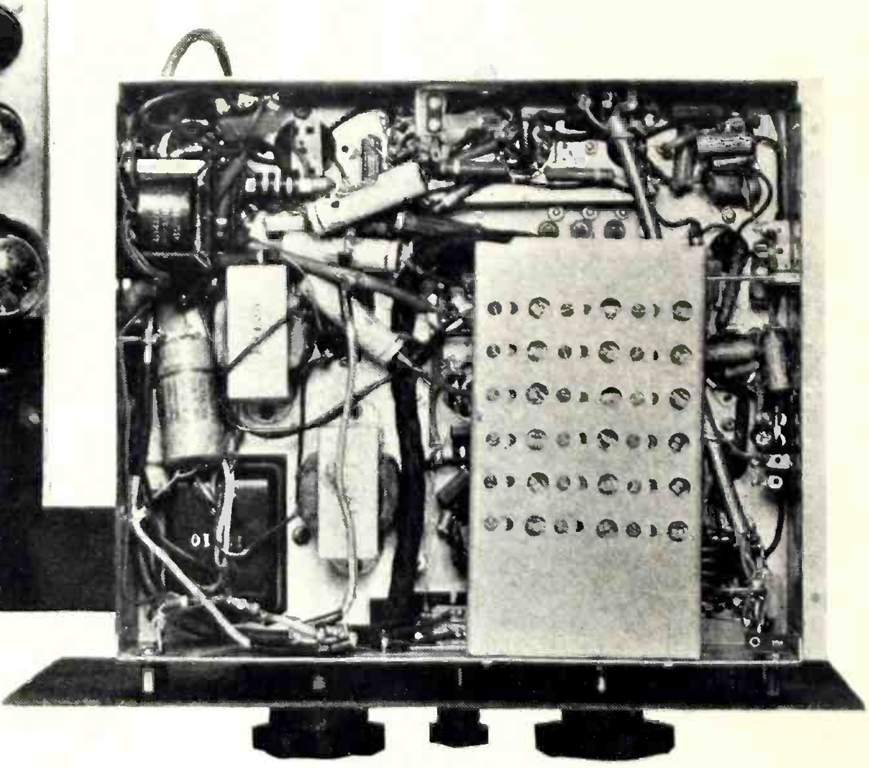


Fig. 1. (Above) Top chassis view. The crystals in type CR-1 holders are mounted in a group left-center.
Fig. 2. (Right) Bottom wiring view. Copper tubing has been used to shield all r.f. carrying leads.

By
**NORMAN L. CHALFIN**

Senior Application Engineer, Crystal Division, North American Philips Co.

***Crystals may be utilized for push-button tuning on FM receivers in the present band and in the new FM band.***

WRITERS of advertising material in the radio and electronic appliance fields have fired public imagination with postwar possibilities of application of devices which have played such dramatic roles in the winning of Allied victories. Among the devices used in wartime signalling applications have been piezoelectric quartz crystal oscillator plates. Most military communications installations have employed many quartz crystals as a guarantee of stable communications. The inherent properties of these units in stabilizing frequencies made them essential for communications channels.

With the establishment of higher frequency allocations for FM and television broadcasting, engineers engaged in the design of domestic radio receiving equipment face many problems requiring increased care with factors affecting circuit stability. Small dimensional changes resulting from thermal effects and the action of humidity can have considerable influence upon all circuits in general and on oscillator circuits in particular. In u.h.f. superheterodyne receivers the local oscillator is particularly susceptible to these atmospheric influences which affect its frequency stability. Design engineers will therefore be giving careful attention to compensatory mechanisms, stabilizing elements, and circuits for stabilizing the oscillator among other factors. Many circuits can be stabilized with a number of negative temperature coefficient devices. These operate within satisfactory limits for AM reception or perhaps for the television picture channel, although in the latter picture quality may suffer from oscillator drift and variations in i.f. components. In an FM receiver the effects of oscillator drift are particularly distressing to the listener in depriving him of the benefits of the noise-free, high-fidelity reception that FM can provide. It is, to say the least, annoying to have to retune an FM receiver several times within the first half hour of operation and periodically thereafter.

Table I. Crystal frequencies for present FM band in the New York area.

| Station | $F_s$ | $F_x$ | $F_o$ |
|---|---|---|---|
| WNYE | 42.1 Mc | 4.725 Mc | 18.90 Mc |
| W2XMN | 42.8 | 4.8125 | 19.25 |
| WNYC-FM | 43.9 | 4.950 | 19.80 |
| WGYN | 44.7 | 5.050 | 20.20 |
| WEAF-FM | 45.1 | 5.100 | 20.40 |
| WQXQ | 45.9 | 5.200 | 20.80 |
| WHNF | 46.3 | 5.250 | 21.00 |
| WABC-FM | 46.7 | 5.300 | 21.20 |
| WBAM | 47.1 | 5.350 | 21.40 |
| WABF | 47.5 | 5.400 | 21.60 |

The author has used at home a *Meissner* 9-1041-A FM receiver which will be remembered as one of the very first FM receivers on the market. This receiver was brought into the laboratory for study in application of quartz crystal control as an approach to stabilization in FM superheterodyne receivers. The results of this investigation are reported in this article.

The first approach is an application of the principle of the double superheterodyne. The operation of this circuit involves a single local oscillator operating at a frequency, $F_o$, coupled inductively to the first mixer. This signal beats with the desired carrier, $F_s$, to produce the first i.f., $F_d$ ($F_s - F_o = F_d$). This occurs in the first mixer (antenna) stage. The plate circuit of the first stage is tuned to $F_d$.

By capacitive coupling to the second mixer stage the components $F_d$ and $F_o$ are mixed to produce the second i.f., $F_i$, $(F_d - F_o = F_i)$. $F_o$ passes through the first mixer.

This system was considered for the reason that the local oscillator frequency is quite low compared to the signal frequency and that a lower harmonic order of the crystal frequency would be required to obtain the oscillator frequency. Furthermore, whether for the existing FM band (where the set under discussion operates), or for the newer band, the crystals would fall in an easily manufactured frequency range and the fundamental frequencies could be readily multiplied.

For the existing FM band, crystal frequencies $(F_x)$ were chosen such that their fourth harmonics were equal to the local oscillator frequency $F_o$. Since the i.f. of the Meissner set is 4.3 mc., then the formula for the crystal fundamental frequency becomes $F_x = (F_s - 4.3)8$ or, for any second intermediate frequency, $F_i$, $F_x = (F_s - F_i)/2n$, where "$n$" equals the harmonic multiplier, because

$$F_o = (F_s - F_i)/2.$$

The list of crystal frequencies for tuning stations in the New York area on the present FM band is given in Table I, together with the fourth harmonic frequency, $F_o$, which is the local oscillator frequency.

The circuit diagram for the double superheterodyne r.f. section is shown in Fig. 4. Photographs of the layout are shown in Figs. 6 and 9. Twenty-seven trimmer capacitors are required to tune 9 stations (WNYE was eliminated since it is on the air infrequently). The three trimmers for each station tune the antenna coil to $F_s$, the oscillator coil to $F_o$ and the antenna—first mixer plate circuit, to $F_d$. Note that the tuning of the frequency, $F_d$, is accomplished by $C_3$ and $C_4$ in series with the second mixer grid at the junction between them. This permits running the tuning capacitor $C_4$ to ground in spite of the placement of the coil in the plate circuit of the tube and provides capacitive coupling of $F_d$ and $F_o$ to the second mixer grid. Switching the stations is accomplished by a ceramic wafer rotary selector switch. Five (5) wafers are required to switch: 1) antenna tuning, 2) oscillator tuning, 3) crystal, 4) second mixer tuning, 5) the panel lamp indicators. The two mixer stages are 6AC7 tubes and are conventional. The oscillator is also a 6AC7 and its circuit is a development of W. Maron of this company.[1] The crystal oscillating circuit is in the control grid and utilizes the screen as anode. The suppressor voltage is positive and the plate is tuned to the fourth harmonic. The r.f. choke and its capacitor tune the cathode to a frequency below 1 mc. Coupling to the first mixer stage can be accomplished two ways: direct, or capacitive, coupling by a small capacitor, about 10 μμfd., to the grid of the first mixer; or, the first mixer grid inductor and the oscillator plate inductor can be wound on the same form with enough space to provide loose coupling. The latter was used in this receiver. The crystal harmonic oscillator plate coil should be wound to provide the highest possible $Q$. A higher oscillator voltage (at the harmonic frequency) is developed in this way and the rejection ratio between the desired harmonic and its nearest adjacent harmonic is greatest. Care must be observed in parts placement to provide the shortest possible leads to the selector switch wafers. The inductance of the leads involved can give considerable difficulty. The most efficient mounting would be one in which the wafers are mounted so that the plane of rotation of the wafers is at right angles to the plane of the shaft rotation and actuated by beveled gears. In this way all capacitors can be mounted radially about the wafer, with the shortest possible leads to the contacts. Easier access is obtained for adjustment, also. In addition to the other advantages, the wafer could then be mounted directly under the

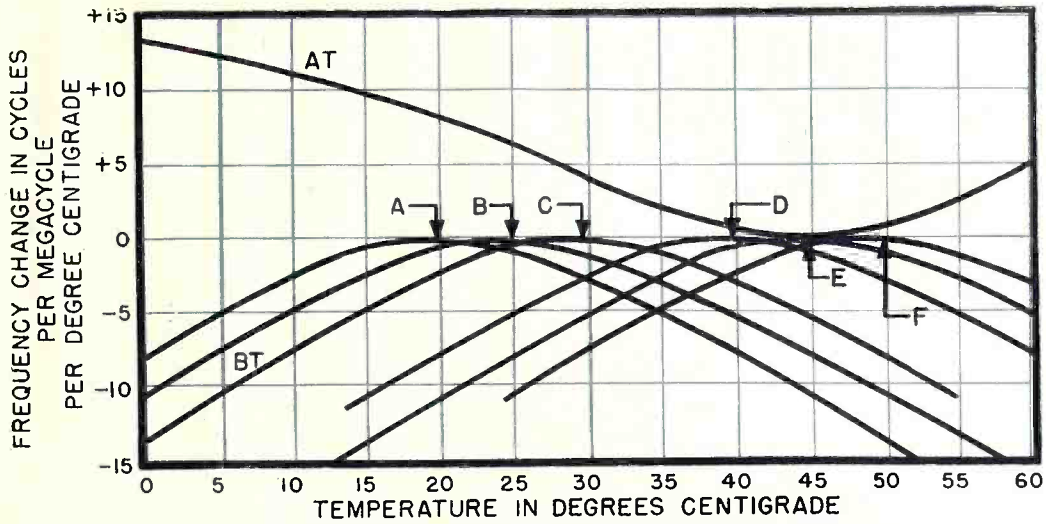
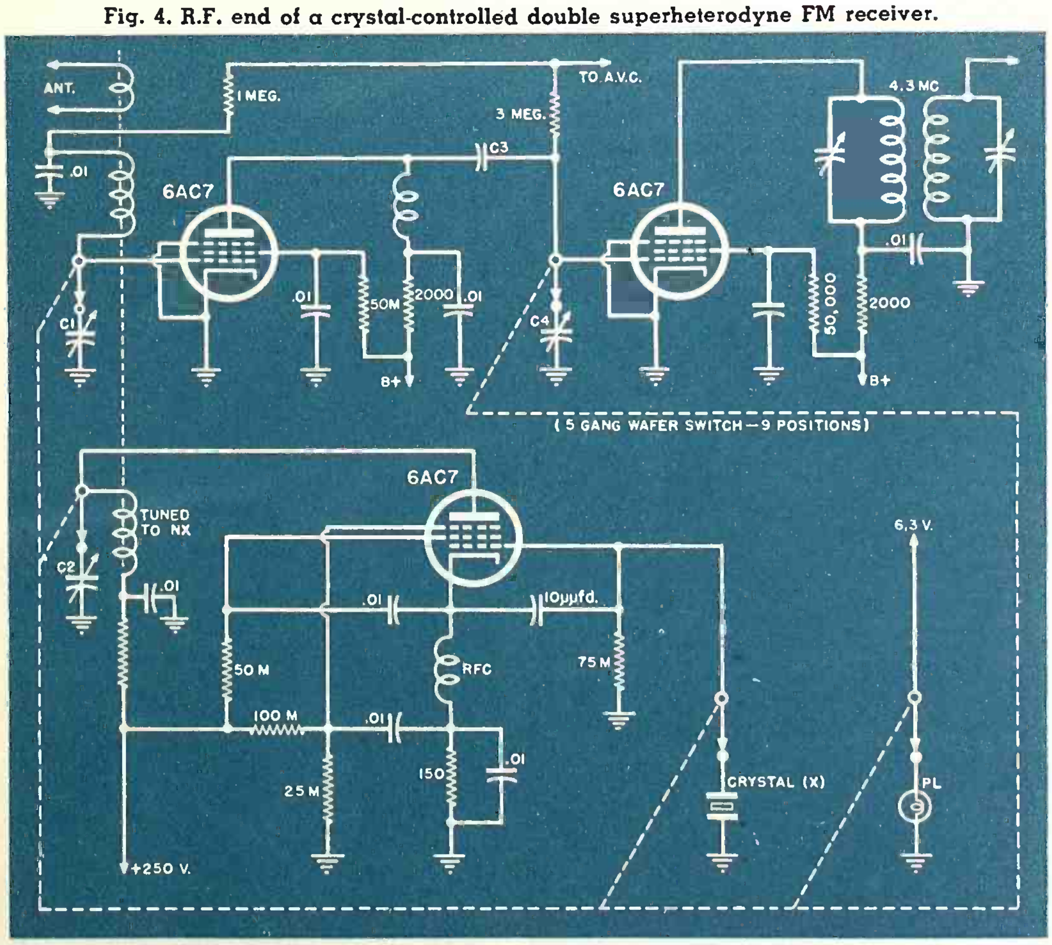



Fig. 3. Temperature coefficient of frequency crystal chart for anticipated home range.

Fig. 4. R.F. end of a crystal-controlled double superheterodyne FM receiver.



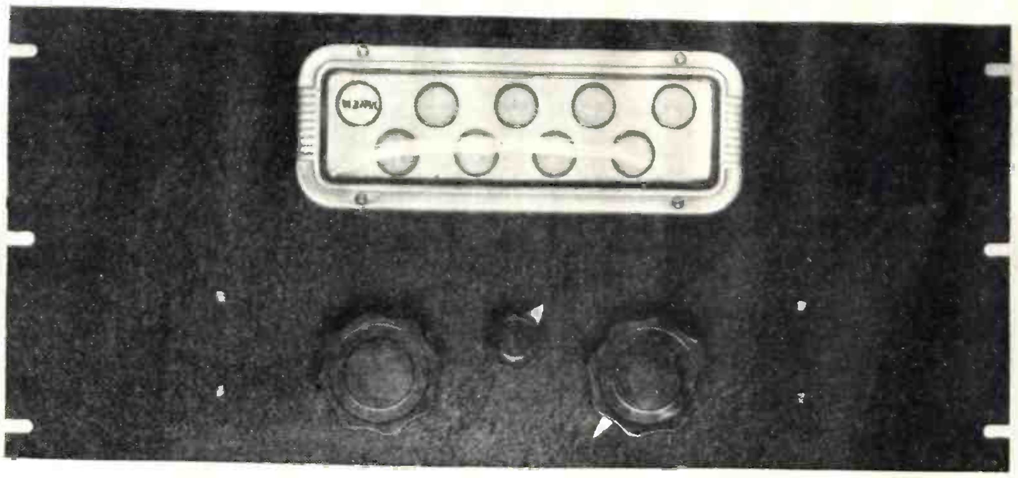


Fig. 5. Front view of receiver. Pilot lamps have jewels lettered with station call letters.

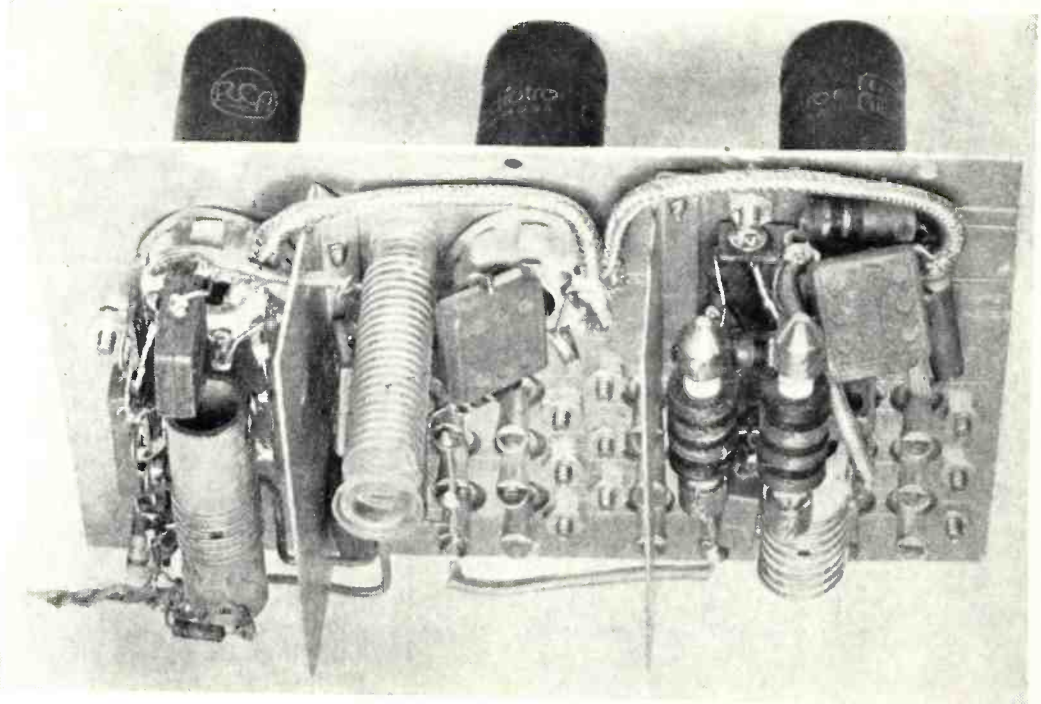


Fig. 6. R.F. chassis; bottom views before assembly to selector switch and tuning capacitors.

tube involved giving shorter wiring in the critical places.

A second type of circuit is drawn in Fig. 10. The photographs of the completed receiver are of this set. It is a conventional superheterodyne with 4.3 mc. i.f. Only two tuned circuits are required and tune the mixer grid, and oscillator plate, respectively. The eighth harmonic of the same crystal frequencies were used as listed in Table I. The oscillator circuit is the same, except for the resonant frequency range of the plate *LC* combination. The *Q* of the oscillator plate inductor measured with a commercial *Q*-meter was 390. The close-up of Fig. 7 shows this coil. It consists of No. 12 tinned solid copper wire wound ¾" diameter and is self supported. The circuit of this oscillator and harmonic accentuator has been used up to the 15th harmonic, the output voltage being less as the harmonic order increases. For any harmonic frequency of a crystal in any circuit having any i.f. frequency, the calculation of the required crystal frequency can be made from the formula

$$F_x = (F_s - F_i)/n$$

where

$F_x$ is the crystal fundamental oscillating frequency

$F_s$ is the desired carrier frequency

$F_i$ is the intermediate frequency

$n$ is the harmonic multiplier.

As can be seen in the photographs (Fig. 7 and Fig. 8) the antenna coil is at right angles to the oscillator plate tank coil. With this arrangement 4 volts are developed at oscillator frequency measured on the grid of the 6AC7 mixer. This is more than adequate for good conversion. The only coupling between oscillator and mixer is due to stray couplings through the surrounding air and components. The coils are separated at least 3 inches. The voltage measured across the oscillator plate tank at the eighth harmonic of the crystal frequency was from twelve to fifteen volts depending upon the activity of the individual crystals. In the laboratories at Irvington, New York, there was sufficient sensitivity in the set to fully saturate the limiter on all stations. When the set was moved to our home location on the Hudson in uptown Manhattan, W2XMN's 40 kw. transmitter across the river at Alpine, New Jersey, and WHNF across the river at Palisades Amusement Park spilled over into adjacent channels. This was found to be due to too close coupling of the antenna primary and mixer grid coils. The antenna primary is a 2 turn loop concentric with and near to the mixer grid coil. Readjustment of the antenna coupling loop completely remedied the difficulty. No further adjustment has been required in 6 months of operation.

The *Q* of the mixer grid coil measured as mentioned above is 400. It is wound in the same manner as the oscillator plate tank with one turn less. The high *Q* of these coils is necessary to obtain optimum results from the crystal controlled circuits. When adjusting the circuits they are found to be needle sharp but remain so ad-

(*Continued on page 34*)

Fig. 7. Close-up of oscillator plate tank coil (lower center).

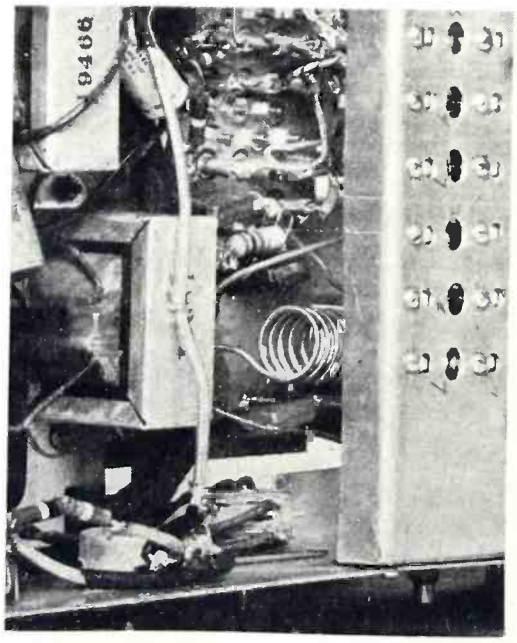
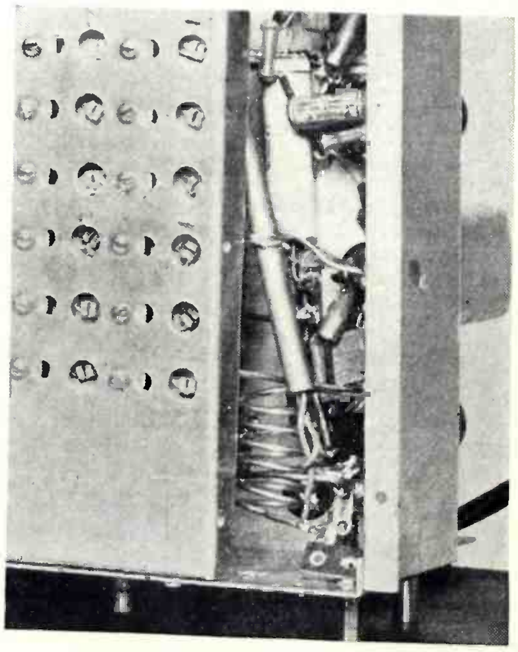


Fig. 8. Closeup view of antenna coil (lower center).



# The Cavity MAGNETRON

***An authoritative discussion of this important device for generating r.f. power in the range of frequencies above three thousand megacycles.***

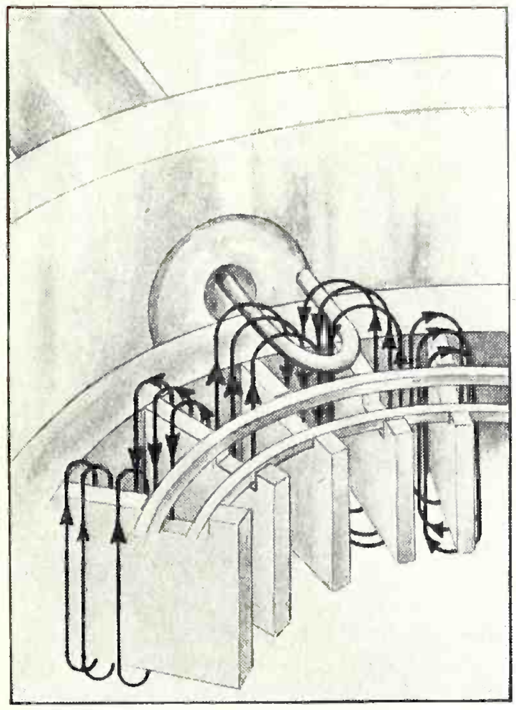


Fig. 2. Loop feeding out r.f. power by coupling to magnetic flux. The double-strip strapping is also indicated.


Fig. 1. Cavity magnetron of the 2J22-2J34 series. This tube operates at 10 cm. Output pipe fits into a coaxial transmission line.

**By LEON FLANDERS, Jr.**

Test Engineer, Sylvania Electric Products, Inc.

LONG-WAVE radar (several meters) had proved itself in the Battle of Britain. For accurate determination of plane direction, or for very precise gun-laying with land or sea targets, radio waves of near-optical properties were required. The beams had to be very sharply focused. This meant microwave frequencies. One of the major, almost decisive, factors in the resulting success of microwave radar was the perfection of the magnetron as a practical high-power microwave oscillator.

In radar service, during each pulse, magnetrons are required to operate at very high powers for very short periods of time. The high powers are needed because of the extreme weakness of the echo. Magnetrons are used because of the high efficiencies (25-60%) obtainable even at microwave frequencies, and because they can be operated under the pulsed conditions described. Other types of microwave oscillators, such as velocity-modulated tubes (klystrons), could not fulfill these conditions in the usual pulsed radar system, and are most effective in low-power work. The efficiencies are lower, and limitations on the density of the electron beams keep even pulsed power outputs relatively low. The magnetrons, on the other hand, gave instantaneous peak powers measured in kilowatts or even megawatts. The corresponding instantaneous plate currents were in the range of amperes or hundreds of amperes. Fortunately, since the tube operated only during the pulse, the average power drain and plate dissipation were much lower. Magnetrons are very small and very light indeed for the outputs they furnish—an important asset in airborne applications.

In this article we shall survey the progress in both practice and theory made during the war. In particular we find ourselves chiefly concerned with one type, a transit-time magnetron with rotational electron coupling.

### History of the Magnetron

In broad terms we may define a magnetron as a vacuum diode with a magnetic field, usually constant and uniform, superimposed parallel to the cathode. Generally, it will be in the form of a coaxial cylinder. Since the pre-war history is covered in several places,[1,2,3] only a few of the highlights will be mentioned here. First reported

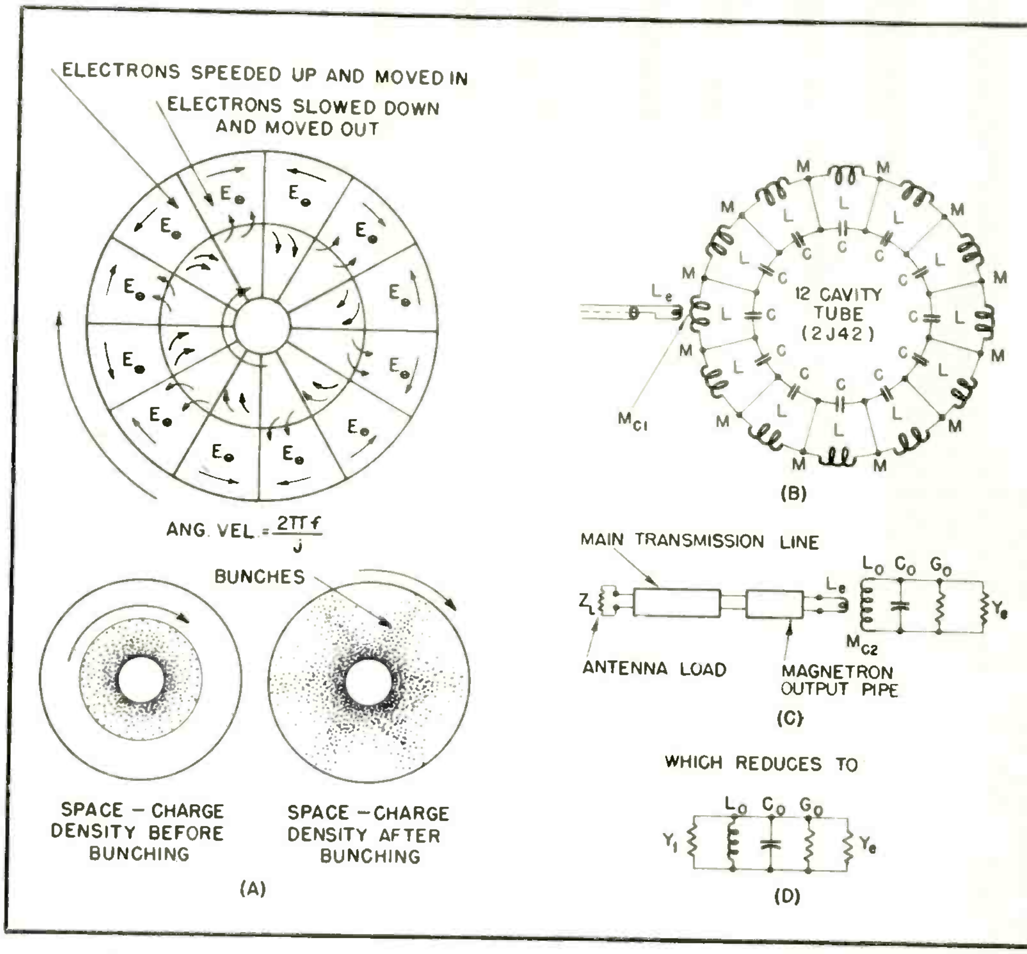



**Fig. 3. (A) Diagrams showing bunching in the 2J42 magnetron. (B) Equivalent circuit of magnetron-cavity resonators in $\pi$ mode, strapping not indicated. (C) Oscillating magnetron connected to load. (D) Same as (C), reduced.**

in 1921 by Hull in the static form,[4] the magnetron remained chiefly an academic exercise in electron ballistics until the discovery of various oscillating types in 1924 and 1925.[5,6,7] A milestone made its appearance in 1928 when H. Yagi of Japan obtained good efficiencies at very high frequencies by using a split-anode construction with transit-time tubes.[8] From then on, extensive work on all types was carried out in many countries by a host of such researchers as Posthumus,[9] Linder,[10] Kilgore,[11] and Cleeton and Williams.[12]

Unfortunately, the pre-war literature on magnetrons, although voluminous, is in an unsatisfactory state because much of the behavior was not understood, and because most of it was for isolated designs.[13]

About 1939, the Germans, the Russians, and the Japanese[14] had reported successful microwave magnetrons using cavity resonators as the oscillating elements. In 1940, Professor Oliphant and co-workers at the University of Birmingham in England brought forth a cavity magnetron that could be pulsed at higher powers. This development gave the Allies a lead in radar which neither the Germans nor the Japanese were able to surpass. Hartree, in the cooperative research that went on in England, did an excellent job on the fundamental theory, and the present microwave transit-time cavity magnetron began to take shape.

As a result of a British scientific mission to this country, the National Defense Research Committee established a far-reaching radar program. Although various commercial, government, and university laboratories made very large contributions, if research was centralized anywhere, it was at the government-sponsored M.I.T. Radiation Laboratory; the work was started by Professor J. C. Slater of M.I.T., and continued in greater volume by the Transmitter Group under Dr. G. B. Collins. The principles of magnetron scaling were discovered, so that designing of new magnetrons was facilitated. Later it was found how to strap magnetrons to make the operation more reliable and to increase the efficiency. The problem of the effect of load variation on tube performance was next investigated. Stabilizing cavities were applied to reduce frequency shift under load variation without sacrifice of power, and magnetrons tunable in frequency, as well as the usual fixed-frequency models, were evolved.

The large-scale production and developmental facilities of various companies in the electronics industry then made these magnetrons available in quantity for the armed services.

### Types of Magnetrons

The various types of magnetrons may be classified as follows:

1. Static magnetron.
2. Oscillating magnetrons.
   a. Feedback magnetron.
   b. Habann magnetron (also called negative-resistance, dynatron, or quasi-stationary magnetron); has split-anode.
   c. Transit-time magnetrons.
      (1) Radial electron-coupling magnetron.
      (2) Rotational electron-coupling magnetron; has split-anode.

The only magnetrons in practical use—the Habann oscillator and the rotational electron-coupling transit-time oscillator—both require a split-anode construction, but operate on entirely different principles and should be distinguished. The wartime magnetron of interest to us is one of the rotational models.

The prototype of all magnetrons is the static magnetron, in which electrons emitted by the cathode are attracted radially by the plate voltage,

**Fig. 4. One stage of assembly of 2J27, showing cavities and split-anode construction.**

but are curved by the magnetic bending-force at right angles to the path. If the magnetic field and plate voltage have the correct values, this curvature may be sufficient for the electrons to miss the anode altogether and return to the cathode, leading to a sharp *cut-off* of current, as evinced in Fig. 13.

The feedback magnetron,[5,15] limited to audio frequencies and with no advantages over conventional oscillators, is not used. The Habann magnetron,[6,11,16] however, is a very practical oscillator. It furnishes continuous-wave outputs of about 100 watts with efficiencies of from 15 to 65%. Kilgore adapted it for the 300-600 megacycle range in particular.[11] In this tube the electron transit-time is negligible compared to the period of the oscillation, so that any frequency up to about 600 mc. may be obtained by merely adjusting the external circuit. The plate voltage and magnetic field must be at or beyond cut-off (Figs. 13C and D). Operation may be explained as arising from a negative resistance produced by the preference of electrons for paths ending at the more negative anode segment; when r.f. voltages are impressed on the segments, the electrons tend to sideslip along the equipotentials in cycloidal paths. See Fig. 15. Frequencies greater than 600 mc., such as are needed for microwave ràdar, are excluded because then the output tapers off from electron transit-time interference just as in conventional vacuum tubes.

In the transit-time magnetrons, as in velocity-modulated tubes, this electron transit-time is not detrimental, but is actually utilized to furnish the oscillations. It also determines the wavelengths obtainable. We first examine the radial-coupling tube.[7,17] We notice in the static magnetron, that, as the electron pursues the cardioid-shaped path of Fig. 13C, it goes through a radial out-and-in motion as it moves out from the cathode and back. If the external circuit is tuned to the correct frequency for synchronization with this motion, sustained oscillations can occur. In practice, the allowable wavelength will be given by the empirical relation $\lambda = 13{,}000/H$ ($\lambda$ in centimeters, $H$ in gausses). For each value of magnetic field in this equation, the voltage must be correspondingly adjusted to cut-off. Low outputs at efficiencies of only 1%, however, long ago caused this tube to be supplanted by the rotational type.

In the latter, the precession of the electrons around the cathode, accompanying the radial reciprocational motion, may also furnish oscillations. An angular asymmetry is produced by a split-anode construction.[14,18] The r.f. fields of these anode segments segregate the electrons into bunches rotating around the cathode. These in turn generate the power by inducing alternating charges on the segments as they sweep by them. The wavelength (to which the external circuit must be tuned) now depends in a complicated way on both the plate voltage and magnetic field, and of course on the tube and the load. Although tuning is feasible over a limited range (±5%), operation is usually under fixed conditions. Many details of the pre-war tubes may be found in the literature. The present state, however, is best described by referring to two typical successful wartime cavity magnetrons, the relatively high-voltage ten-centimeter model of the 2J22-2J34 series, and a low voltage three-centimeter model, the 2J42. These tubes are shown in Fig. 1 and Fig. 11, respectively. Various details of the construction are shown in the accompanying photographs.

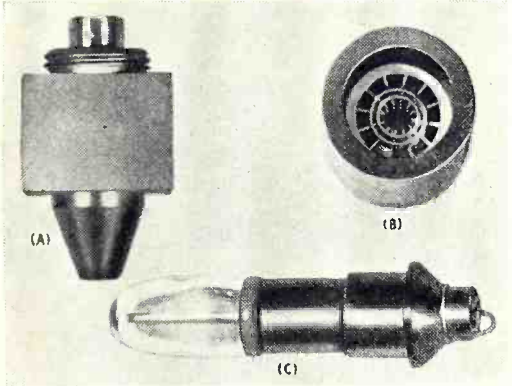



Fig. 5. Details of construction of 2J42. (A) Iron pole piece. (B) Cavity resonators (with double-strip strapping). (C) Output pipe.

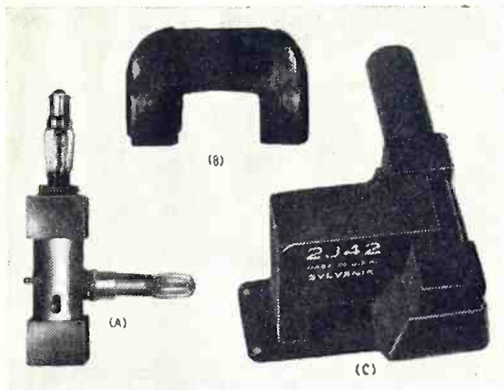
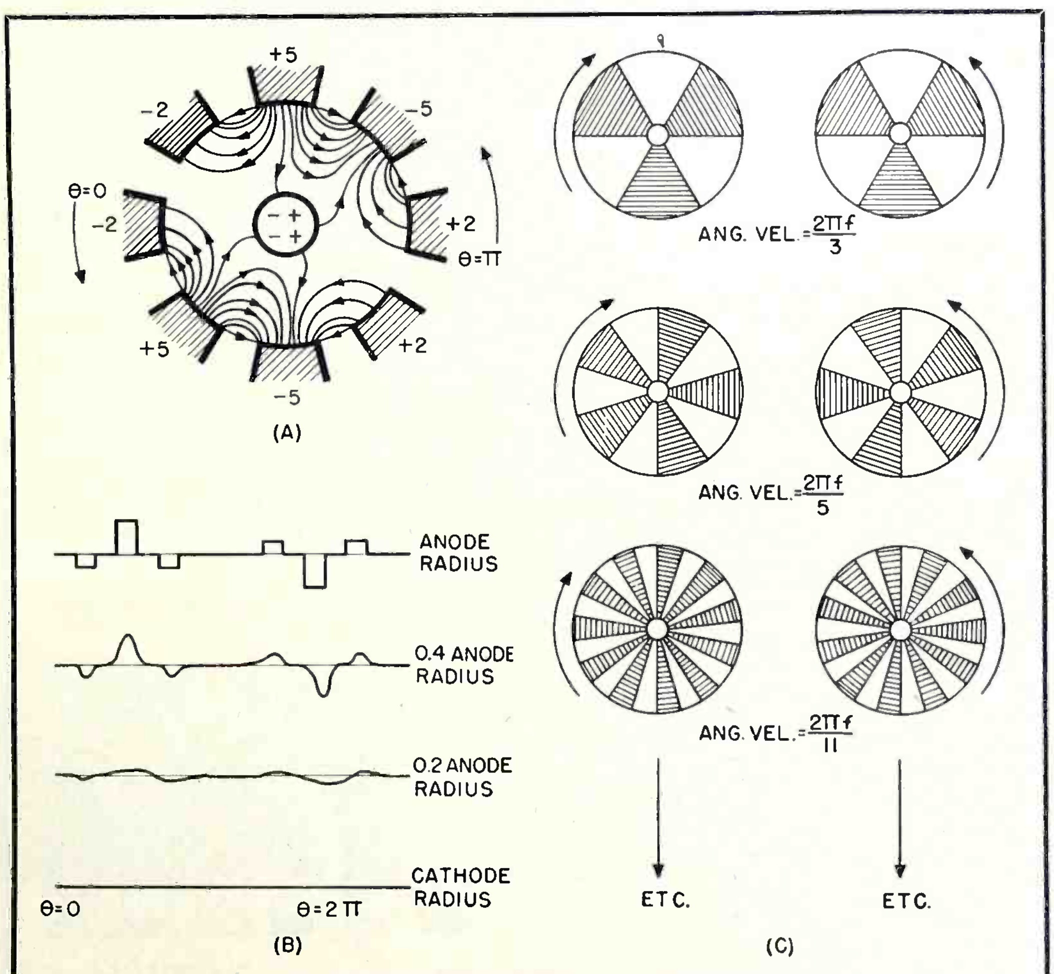



Fig. 6. Assembly view of 2J42. (A) Tube body with iron pole-pieces in place. (B) Permanent magnet. (C) Completed tube.

## Cavity Magnetrons

Lower frequency models of the rotational type (Fig. 12) are well-described in the published articles,[1,2,3,13] and are almost always operated as c.w. oscillators. They are to be looked upon as special cases in which resonant elements other than cavity resonators maintain the r.f. field patterns, with consequent limitations on the frequencies observed. In principle, there is no

Fig. 7. Analysis into Hartree Harmonics (n = 3 mode of 8 cavity tube). (A) Instantaneous electric field pattern. Numbers indicate relative strength of charges. (B) Tangential electric field components as a function of $\theta$ for various radii. (C) Resolution into Hartree Harmonics.



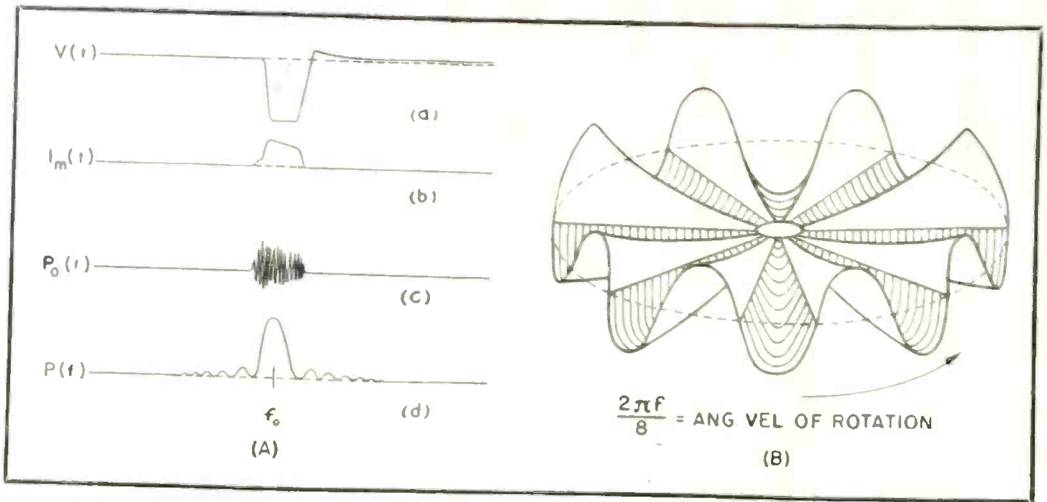



Fig. 8. (A) Magnetron pulses. (a) Trapezoidal voltage pulse to drive magnetron. (b) Resultant magnetron current pulse. (c) Resultant r.f. power output. (d) Frequency spectrum of power output. (B) Special Model of a Hartree Harmonic.

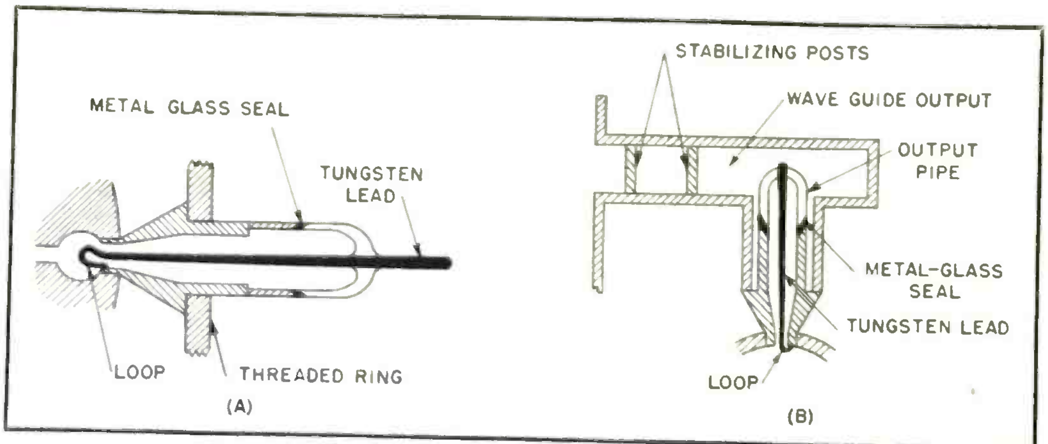



Fig. 9. Cross-sections of output pipes. (A) 2J22—2J34 series. (B) 2J42.

difference between c.w. and pulsed magnetrons, of course. A typical cavity magnetron is constructed as follows: A series of cavity resonators, formed by drilling and cutting various holes or slots in the anode block, is arranged around the anode periphery so as to form the split-anode design. The photographs of Fig. 4 and Fig. 5 display this construction. Eight cavities are apparent in the ten-centimeter tube and twelve in the three-centimeter 2J42. The cathode is concentric with the anode and is supported by the heater and cathode leads. (These leads are brought out through the filament pipes.) Space is provided above these cavities to permit them to be linked to each other by mutual magnetic flux set up when they oscillate. By coupling to a part of this flux with a loop introduced in or near one of the cavities, the power may be led out to the load as illustrated in Fig. 2 for the 2J42.

The output pipes consist of tapered coaxial lines with this loop in one end (Fig. 9). In the ten-centimeter tube, the inner conductor extends out at the other end to fit into the inner conductor of the coaxial transmission line. Connection to the outer conductor is then made by the threaded ring in Fig. 1. In the 2J42 with the wave guide feed, the inner conductor of the pipe extends up into a rectangular wave guide. (Here, being aligned with the $E$-vector, it launches the $TE_{1,0}$ mode.)

The arrangement of the output pipes and the filament pipes is shown in Figs. 4 and 6. The 2J42 has a single axial filament pipe, it will be noted. It also has two tapered iron pole-pieces set on each end of the tube body to concentrate the external magnetic flux. The construction is clearly demonstrated in the view of Fig. 6A of one stage in the assembly. Moreover, a factory-adjusted permanent magnet of the Alnico type (Fig. 6B) is furnished as a part of the tube (Fig. 6C). This is the so-called "package" design, which results in a very compact tube.

As is common with ultra-high-frequency generators, shorted quarter-wavelength wave-traps prevent the escape of r.f. energy by way of the filament leads. Each lead forms the inner conductor of a shorted coaxial line located inside the filament pipe.

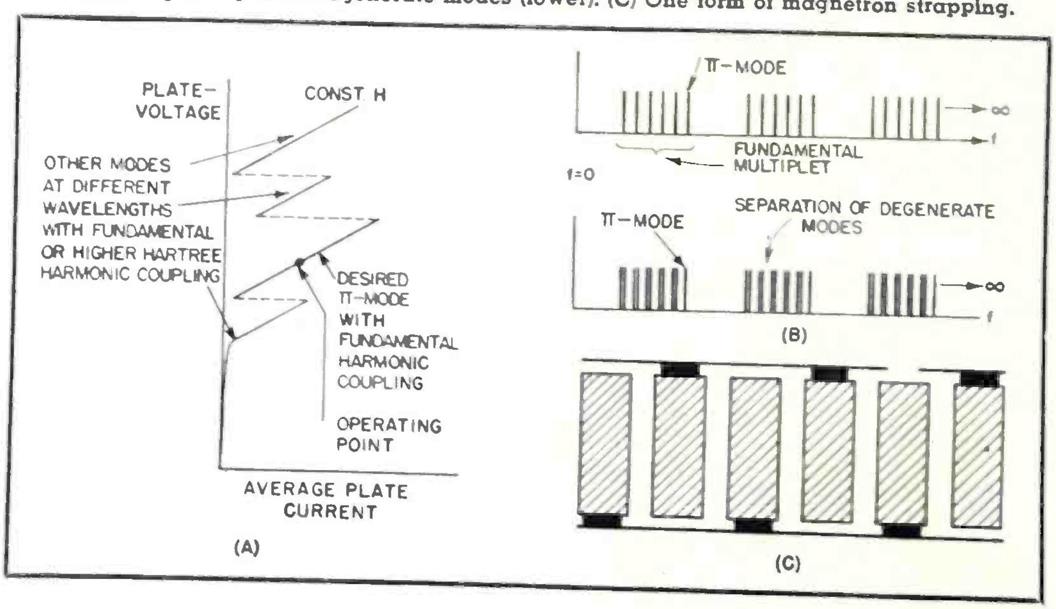
The only glass in these tubes is for insulation in the output and filament pipes. For this purpose, a low-r.f. loss glass is used, and is sealed to the metal of the pipes and leads. The seal is often made using kovar metal, because it has the same temperature coefficient of expansion as the glass, and will produce seals that do not crack.

The reason for so little glass is the use of the heavy copper anode block to dissipate the heat. The latter may, perhaps, be supplemented by cooling fins (Fig. 1). The axial length of this block is less than a half-wavelength. Rather than the tungsten filament, common in most pre-war tubes, a large indirectly-heated oxide-coated cathode is noted. See Fig. 16. No small part of the success of this magnetron is due to the high current densities this cathode can furnish.

The end-plates welded to the ends of the cathode are to keep electrons from escaping from the theater of action. On low-frequency transit-time tubes, charged end-plates (or tilting of the magnetic field) are sometimes employed to remove out-of-phase electrons. Thus the function of the end-plates is entirely different in the two cases.

Next we consider the operating conditions. A typical radar modulator for pulsing the magnetron is shown in Fig. 17. It develops the trapezoidal voltage pulses of Fig. 8A, which also portrays

Fig. 10. (A) Magnetron plate current vs. plate voltage. (B) Frequency spectrum of magnetron resonances for symmetrical unstrapped magnetron (above) and same with asymmetry to separate degenerate modes (lower). (C) One form of magnetron strapping.



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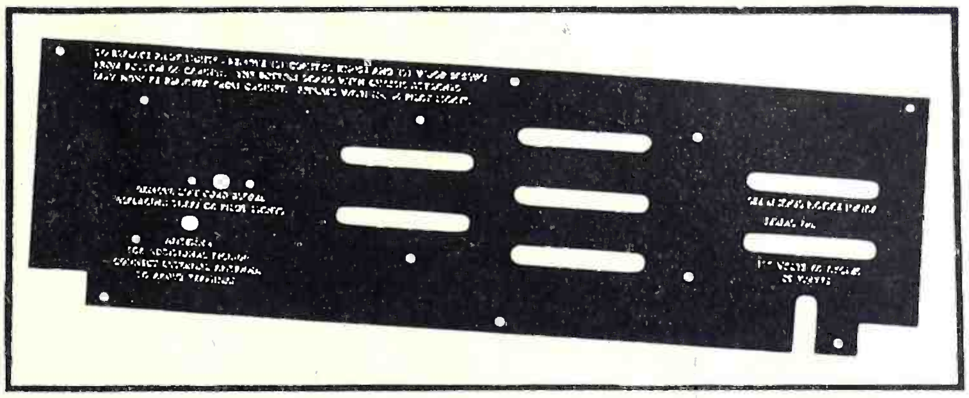

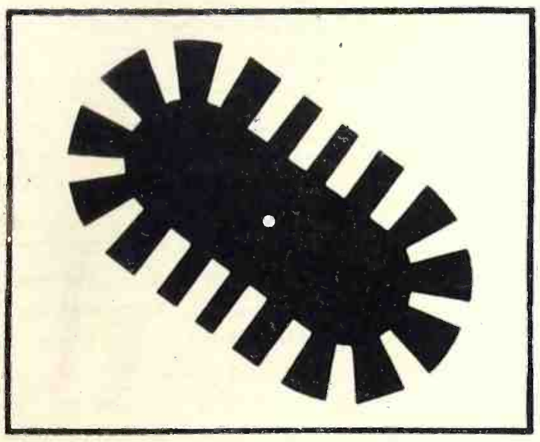

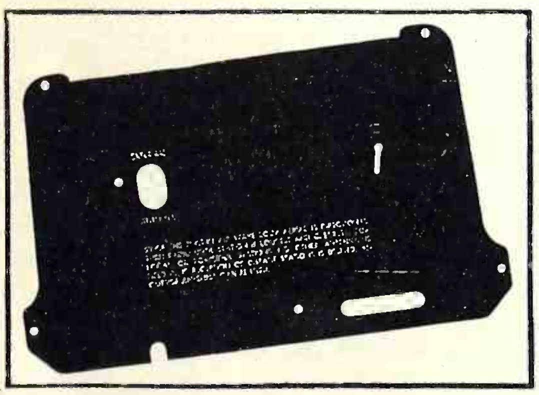

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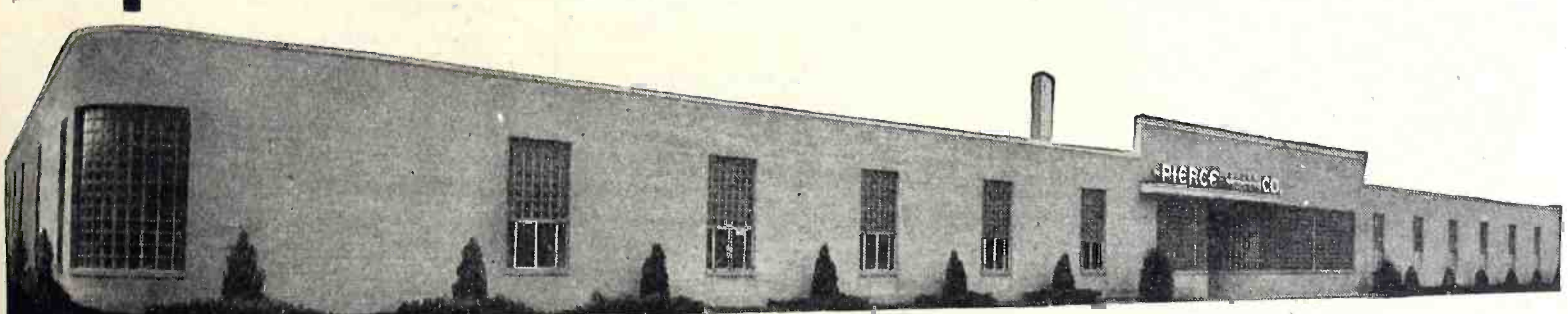

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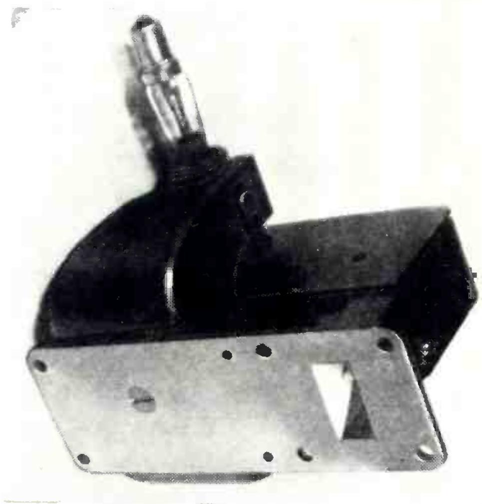


Fig. 11. Cavity magnetron (2J42).

the corresponding current and r.f. power surges. For safety reasons, the anode is run at ground potential, since it is to this electrode that the r.f. transmission line is connected. The usual pulse width ($t$) ranges from ¼ to 2 microseconds. The repetition rate ($f_r$) will be from 500-4000 pulses per second. The ratio between peak and average values, which determines the plate dissipation, is called the duty cycle ($= tf_r$ with $t$ in seconds and $f_r$ in p.p.s.). Ordinarily it is about 0.001.

For the 2J22-2J34 series, members of which differ in the wavelength produced, the operating conditions are as follows:

- magnetic field = 1900 gausses (or 2400 for some models)
- pulsed plate voltage = 20 kilovolts
- peak current = 30 amperes
- peak power output = 240 kilowatts minimum
- pulse width = 1 microsecond
- pulse repetition frequency = 1000 p.p.s.
- output frequency = about 3000 mc., depending on the model
- tube life = 500 hours minimum

For the 2J42 we have:

- magnetic field = adjusted at factory for proper operating characteristics
- pulsed plate voltage = 5.5 kilovolts
- peak current = 4.5 amperes
- peak power output = 7 kilowatts minimum
- pulse width = 1 microsecond
- pulse repetition frequency = 2000 p.p.s.
- output frequency = 9375 mc.
- tube life = 250 hours minimum

Some variation from these conditions may be permitted, but should not be great. The manufacturer's recommendations on tube ratings and on the applied pulse should be carefully followed for best results. Incidentally, a 15 kw. version of the 2J42 is under development.

In production, tubes may be pretuned to within ±½% of the desired output frequency by mechanical adjustment. The method used in the 2J42 is to introduce a tuning screw into one of the cavities.

The spectrum or the r.f. power output is of interest. With the tube operating for the usual duration of about 1 microsecond per pulse, it displays, not a single sharp line, but a small continuous frequency spread centered about the operating frequency (Fig. 8A). This behavior is a direct result of the pulsing, as may be shown by Fourier analysis. The resulting frequency spread—the r.f. bandwidth—is about 2 or 3 mc.

An unusual and important cathode phenomenon takes place in the magnetron. This is the violent back-bombardment of the cathode by returning electrons. Secondary emission ensues and the cathode heats up, so that the heater current may often be reduced after starting. Indeed, sometimes it may be completely turned off without stopping oscillations! Usually an automatic heater current-regulating circuit is not needed to control this phenomenon, but the manufacturer's recommendations should be followed in any case.

Having seen some of the practical details of the tubes, we should like to know more about the mechanism of power generation.[19] Something has already been said about this. The story may be summarized as follows: The complicated construction of the cavity magnetron permits the cavities to resonate and be excited at many frequencies. These different frequencies and resultant r.f. field patterns may be excited by the electrons, the ones chosen depending on the plate voltage, magnetic field, etc. This excitation occurs when the electrons are formed by the field pattern into bunches of space-charge rotating around the cathode and, as they sweep by, inducing alternating charges on the segments.

This coupling between the field patterns and the electrons is very interesting. When the magnetron resonates, electromagnetic waves as specified by Maxwell's equations and the boundary conditions are set up in all parts of the tube, among them the cathode-anode space. The r.f. field patterns in this space are very complicated. Fortunately, however, they may be resolved by a kind of Fourier analysis into an infinite number of

(*Continued on page 37*)

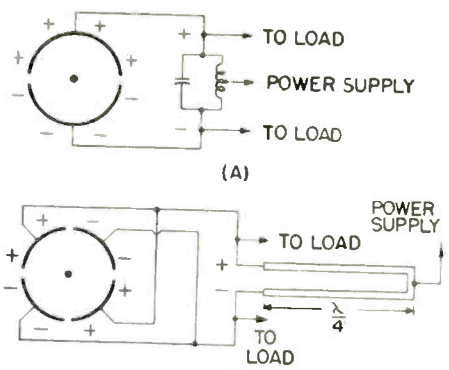
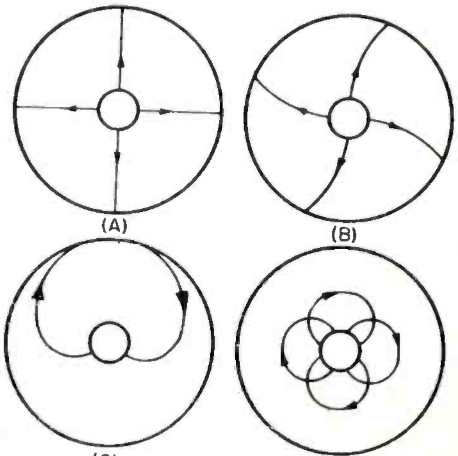



Fig. 12. Low frequency pre-war rotational transit-time models.

Fig. 13. Electron orbits in static magnetron. (A) No magnetic field. (B) Cutoff not reached. (C) Cardioid-shaped path at cut-off. (D) Beyond cut-off.



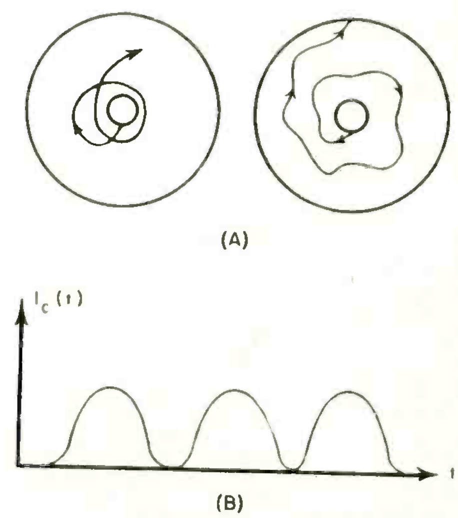
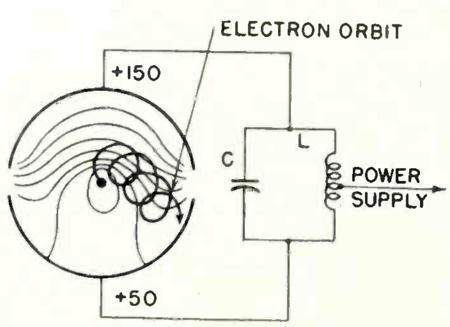




Fig. 14. (A) Electron orbits in oscillating magnetron. (B) Conduction current to anode segments as a function of time.

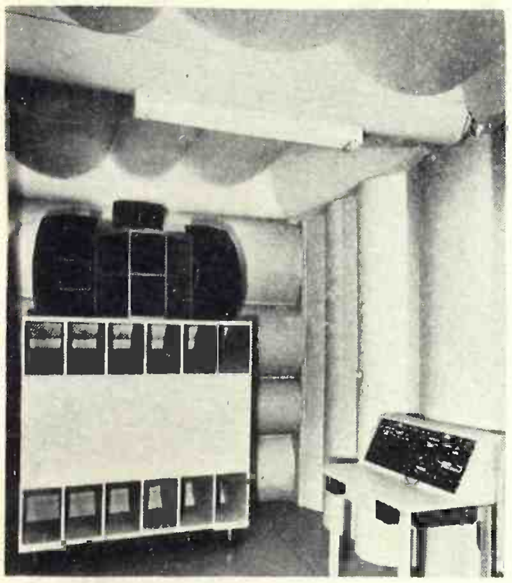
Fig. 15. Electron orbit in Habann oscillating magnetron. Electrons are seen to spiral along the equipotentials to the more negative element.



# Industrial Review

## Diffuse Sound Room

THE diffuse sound room, in which the noises heard in a plane during flight are realistically reproduced, was built to permit the testing of microphones, amplifiers and headsets in an intense and diffuse sound field. Using electronic devices connected with amplifiers and loudspeakers, the noises which are heard in an airplane during flight could be faithfully reproduced.



The walls of the room are lined with many sections of cylinders, each of a different diameter and running in a different direction on each wall. A battery of loudspeakers produced the sounds which were reflected randomly from the cylinders, thus producing an intense and diffuse sound field in the room. Microphones, amplifiers and headsets for use in airplanes and amphibious vehicles (which are often noisier than airplanes) were tested in this intense noise field before being sent to the Military Services for flight testing. The development was made at the Electro-Acoustic Laboratory at Harvard.

* * *

## Goodrich—75th Anniversary

THE *B. F. Goodrich Company's* recent 75th anniversary celebration included the breaking of ground for new research laboratories at Brecksville, Ohio. A group of eight ultramodern research laboratories will be constructed. Fifty years ago, the company's first research laboratory—and the first in the rubber industry—was established by Charles Cross Goodrich. The B. F. Goodrich anniversary is highly significant for Akron as well as for the company, because it was the founding of that organization that introduced the rubber industry to Akron—then about 10,000 in population—and started it on its way to becoming the rubber capital of the world. In addition to the many important rubber products produced by this company, perhaps its outstanding contribution to the national welfare was its role in connection with the vital wartime synthetic rubber program.

* * *

## Tape Recorders

L*EAR, INC.,* has recently announced that its development work along recording lines has produced a better, less expensive method of recording on metal-impregnated tape which will be an exclusive feature of their home radios.

The tape recording which will be used on the Learecorder units in Lear's home radios, as well as in commercial and industrial models, has a number of distinct advantages over wire. On the tape, it is not necessary to rewind, as in the case of the wire spool, and it is much more efficient for replay or for picking out certain spots on the recording. It is less expensive; it eliminates possibility of breakage and has greater fidelity of sound.

* * *

## Progress in Insulation Design

PROGRESS in insulation is illustrated by the three magnet coils

shown which have been aged at 250° C. The coil on the left, which failed after 200 hours aging, was insulated with cotton and mica, then treated with an asphalt type varnish. The center coil was insulated with glass and mica, and treated with an alkyd-phenolic varnish. It is shown after aging 3000 hours. Although electrical failure has not occurred, thermal degradation of the insulation has progressed to a point where failure is imminent. The third coil, which has aged over 5000 hours without failure or appreciable insulation degradation, was insulated with glass, mica, and silicone materials. These tests were reported by *Westinghouse Electric Corp.*

* * *

## Relay Element

SPEEDING up directional-element action in relays has been accomplished by *Westinghouse* engineers who designed an eight-pole, induction-disc element. The eight poles are arranged on both sides of the disc to utilize practically the entire disc to produce torque, resulting in high-speed operation with low-energy requirements, while vibration on heavy-torque conditions is practically non-existent. Speed of operation is less than 1/60 second over wide ranges of current and voltage.

By changing coils, the element can be made into other types of relay elements, for example, an instantaneous current or instantaneous voltage type. An important feature is that they can be directionally controlled without using auxiliary relays. Complete data on the unit is available upon request to the *Westinghouse Electric Co.,* 306 Fourth Avenue, Pittsburgh.

* * *

## Radar Jammers

THE radar jammer, TDY-2, manufactured by the Electronics Department of the *General Electric Company,* was announced recently by the Army and Navy as radar countermeasure equipment that completely disorganized enemy radar frequencies. Manufacture of the radar countermeasure equipment was carried on under a "crash" basis by the various divisions of the department. The Tube Division manufactured the tubes while the Transmittter Division produced the related transmitting equipment. The equipment was on its way to the Pacific ten days after the Navy first disclosed the need for a new type of equipment. These sets were destined


for action against the Japanese in the Pacific, then later in the European invasion.

(*Continued on page* 26)

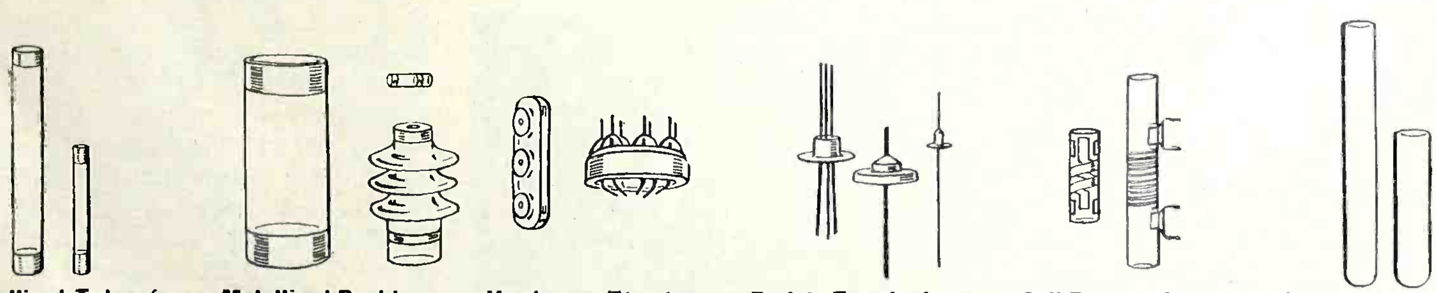
# IN SMALL PLACES

MANY of the new electronic devices are small, and it is hard to wire them efficiently where the leads have to come out of a hermetically sealed unit. Corning headers like the ones shown take the grief right out of such installations, making it easier for the designer and simplifying the assembly operation.

They are available either with or without metallizing, depending on whether or not you want a true hermetic seal. In either case they are economical of space, time and labor. For with them you can get a number of leads in a small space, and yet they assemble in one operation. And they're rugged, resisting thermal shock and soldering. They have a high insulation resistance and a low loss factor. And they can be made quickly in large quantities.

You know best what your own problems are. So look at the products shown below. If hermetic seals or assembly troubles are dogging you, there's probably a Corning Electronic product to do the job for you. To make sure, write, wire or phone The Electronic Sales Department, A-3, Technical Products Division, Corning Glass Works, Corning, New York. One of our engineers will be knocking at your door immediately to see if he can help. Don't put it off. Get in touch with us today.

**NOTE**—*The metallized Tubes and Bushings, Headers and Coil Forms below are all made by the famous Corning Metallizing Process. Can be soldered into place to form true and permanent hermetic seals. Impervious to dust, moisture and corrosion.*



**Metallized Tubes** *for resistors, capacitors, etc. 20 standard sizes 1/2" x 2" to 1 1/4" x 10". Mass-produced for immediate shipment.*

**Metallized Bushings.** *Tubes in 10 standard sizes, 5/16" x 25/32" to 1" x 4 7/32" in mass production for immediate shipment.*

**Headers** — *The best way to get a large number of leads in a small space for assembly in one operation.*

**Eyelet Terminals** — *Single or multiple eyelets permit design flexibility. Standard items readily available in quantity.*

**Coil Forms**—*Grooved for ordinary frequencies—metallized for high frequencies. In various designs and mountings.*

**VYCOR Brand cylinders**—*very low loss characteristics. Stands thermal shock up to 900°C Can be metallized.*

"VYCOR", "CORNING" *and* "PYREX" *are registered trade-marks and indicate maufacture by Corning Glass Works, Corning, N. Y.*

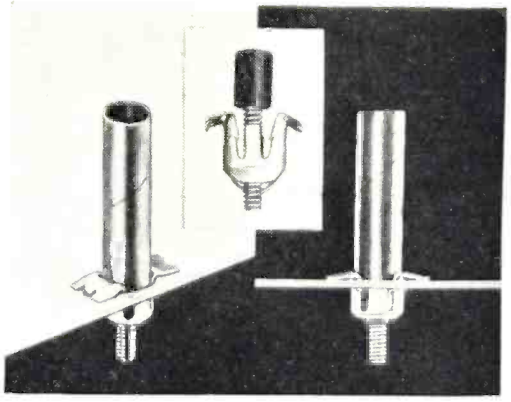
# *Electronic Glassware*

TRADE MARK VYCOR REG. U.S. PAT. OFF.
T.M.REG. CORNING U.S. PAT. OFF.
T.M.REG. PYREX U.S. PAT. OFF.

# NEW PRODUCTS

### SPEED NUT FASTENER

A new speed nut coil tube fastener has just been announced for more rapid and secure mounting of coil tubes in radio chassis assemblies. This new fastener performs three functions: It holds the iron core in posi-



tion; provides a firm, spring tension grip on the core screw to maintain accurate, vibration-proof adjustment; and mounts the coil tube securely to the radio chassis. Assembly is easily and quickly accomplished by turning the core screw into the speed nut, inserting coil tube into speed nut and then snapping the complete assembly into the hole in the radio chassis. These fasteners are available to attach $\frac{9}{32}$″ O.D. coil tubes to panels from .015″ to .065″ in thickness, and $\frac{3}{8}$″ O.D. coil tubes to panels from .034″ to .062″ in thickness. Further information may be obtained by writing to the manufacturer, the *Tinnerman Products, Inc.,* 2126 Fulton Road, Cleveland 13, Ohio.

### TERMINAL BLOCKS

*The Curtis Development & Manufacturing Company* has recently announced a new type terminal block which is specifically designed for installations where it is necessary to conserve space. Any number of terminals may be assembled from one to twenty-four and held rigid in a metal channel. To insure against terminal screw grounding, the screw holes are

not completely through the block, thus permitting the base to be one solid insulator adjoining the metal channel.

When other type blocks consisting entirely of phenolic material are mounted, screws and particularly rivets sometimes damage the block. In this new "M" type block, however, the mounting holes are in the metal channel, only one in each end, thus eliminating this chance of damage. They have ample clearance and creepage distances for circuits carrying up to 300 volts, 10 amperes. Because of the small size of the type "M" Terminal Block, an unusual feature is the well designed mounting of a marker strip along the top of the desired length of terminals. The block can be supplied with or without the marker strip.

Kits are being made up of individual terminals together with various length mounting channels.

The type "M" Terminal Block is supplied by the *Curtis Development & Manufacturing Company,* One North Pulaski Road, Chicago 24, Illinois.

### CARDIOTRON

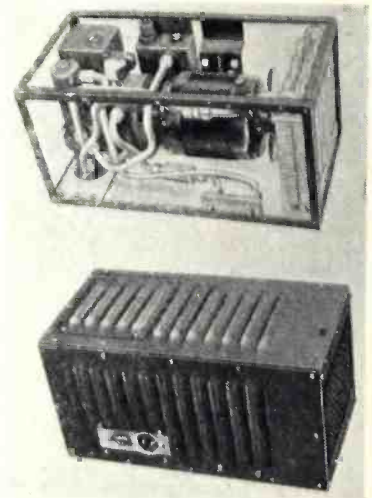
The Cardiotron, first direct-writing electrocardiograph, developed by Paul Traugott, president and chief engineer of Electro-Physical Laboratories, Inc., a division of *Electronic Corporation of America,* 45 West 18th

Street, New York, was announced recently.

The machine instantly and permanently records on paper the minutest heart action or variation. An electrically manipulated stylus traces the cardiac action on an especially processed paper which feeds out of the machine at controlled speeds. The machine is portable, easily operated and used with a.c. current, or with d.c. current with the aid of a lightweight converter, and makes cardiographic examination possible as a routine part of medical diagnosis.

### HEAT DISSIPATING UNIT

A new heat dissipathing unit for use in television, radar, short wave radio communication, high pressure mercury lamps, x-ray tubes, induction heating units and many similar products is announced by the *Eastern Engineering Company* of New Haven, Connecticut.



The units were originally designed for the ground, airborne and water services of the armed forces. They are now being manufactured for commercial heat dissipating applications. The unit shown will dissipate up to 1200 watts with a constant controlled temperature, irrespective of surrounding temperature, within a close heat control range of 2 degrees C. Complete information may be obtained by writing to the manufacturer.

### RUGGED RECTIFIER

The *Chatham Electronics Company,* 475 Washington Street, Newark 2, New Jersey, recently announced a new 4B32 rectifier. The 4B32 rectifier meets the need for a rectifier having low voltage drop, high current capacity and ability to function in exposed locations with auxiliary heaters and controls. Xenon filled, the 4B32 performs in ambient temperature from −75° to +90° C. Mechanical construction is especially rugged and well adapted to all mobile, airborne and similar applications where immunity to severe shock and vibration are essential.

### NOISE & FIELD INTENSITY METER

The *Stoddart Aircraft Radio Company* announces its production of a Noise and Field Intensity Meter, model NMA-4, single band frequency range 100 - 400 mc. It is useful in locating and indicating in microvolts the amplitude of "radio noise" causing disturbance to radio reception in aircraft, landcraft, seacraft and other

(*Continued on page* 35)


1946 Resolution
that every American
buy and hold
U. S. Savings Bonds
ASSIST in building the prosperity of your nation and your own industry—make the wise New Year's resolution to promote the continued sale of E, F, and G Savings Bonds through your Payroll Savings Plan! U. S. Savings Bonds, purchased regularly, form the thrift habit—and enable Americans to secure educational advantages for their children and achieve financial independence in old age.

# Personals

**E. FINLEY CARTER,** formerly vice president in charge of Industrial Relations, *Sylvania Electric Products, Inc.*, has been named vice president in charge of Engineering following the resignation of Roger M. Wise. Mr. Carter was assistant chief engineer of the Radio Div. for a number of years. Earlier, he had been engaged in radio development for *General Electric Co.* He is a Fellow and a Director of the Institute of Radio Engineers.

**R. E. MECKLENBORG** has resumed his position as instrumentation specialist on the engineering staff of the *Automatic Temperature Control Co., Inc.*, Philadelphia, after two years of European service with the Signal Corps. A graduate of Drexel and member of A.I.E.E., his previous seven years' association with ATC, now augmented by familiarity with radar and other electronic equipment, will form an excellent background for his new duties.

**E. R. NARY** has been announced as assistant to *Westinghouse* vice president Walter Evans with broad responsibilities for operations of the Industrial Electronics and X-Ray Divisions at Baltimore, Maryland, and the Home Radio Division at Sunbury, Pa. A veteran of more than 30 years' service with *Westinghouse,* Mr. Nary comes to his new post after three years as manager of manufacturing for the Baltimore Division.

**PHILLIP J. PRITCHARD,** responsible for many radio tube developments during forty-five years' service with the Lamp Department of the *General Electric Co.*, retired from active service recently. Mr. Pritchard, 74, was the only septagenarian executive of the Lamp Dept. He retires as manager of the Cuyahoga Plant and Tube Development Laboratory. P. J. Johnson succeeds him as manager of this plant.

**J. B. SCHAEFER** has been announced plant manager by the *New York Transformer Co.* Mr. Schaefer will direct all engineering and manufacturing activities at the company's plant at Alpha, New Jersey, and will be in charge of reconverting their plant from war to peacetime production. He was formerly associated with the *Sperry Gyroscope Co.*, as engineering manager. He was responsible for several of Sperry's most important war projects.

**DAVID B. SMITH,** director of the Philco research division since 1941 and an outstanding authority on radio, radar and television, has been appointed vice president in charge of engineering of *Philco Corp.* Mr. Smith joined *Philco* in 1934, after receiving the degrees of S.B. and S.M. in electrical engineering from M.I.T. He is credited with a number of patents and patent applications, covering inventions in radio, radar and television.

## Industrial Review

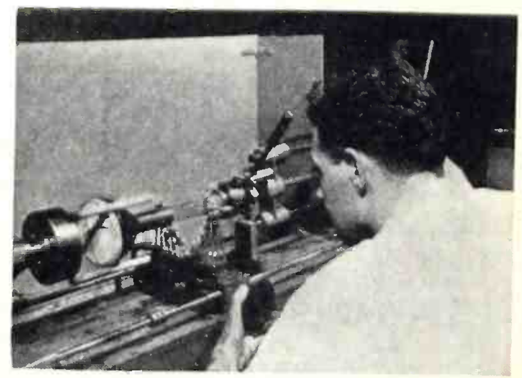
(*Continued from page* 21)

Radar jamming dates back to the inception of radar. However, when the Navy needed new equipment to neutralize ever-improving enemy radar, a large forward step was made in the development of an electronic tube — the CW magnetron — which would generate large amounts of continuous power at enemy radar frequencies. This was accomplished in cooperation with G.E. scientists and engineers. Untold thousands of American and British lives were saved by this equipment.

* * *

### Glass Blowers Art

DURING the war, the *North American Philips Company, Inc.*, Dobbs Ferry, N. Y., plant cooperated wholeheartedly with the Government's slogan "Don't waste a thing" and salvaged even the few rejects that occurred among the thousands of cathode-ray tubes produced every day.



The operator in the photo is "sealing-on" a new tube neck. This is made necessary by a preceding step wherein the "gun" assembly was removed. After the cathode-ray tube is rebuilt, it must meet the same rigid specifications as before. Thus, it was able to do its part in beating the Axis. Now, in a world at peace, the cathode-ray tube (heart of radar) will bring television to millions.

* * *

### Radar Generator with Good Wave Form

TO SAVE weight on large airplanes with large radar loads, an engine-driven 400-cycle generator that would maintain good wave form was built at the Small Motor division of the *Westinghouse Electric Corp.* Such a machine would save much weight by generating the a.c. power in the first place instead of d.c. generation and subsequent d.c. to a.c. transformation, thereby eliminating the weight of the inverters. Also the radar energy would be obtained more efficiently because the losses of the rotating electrical transformations would be obviated.

The resulting 8-kva. machines

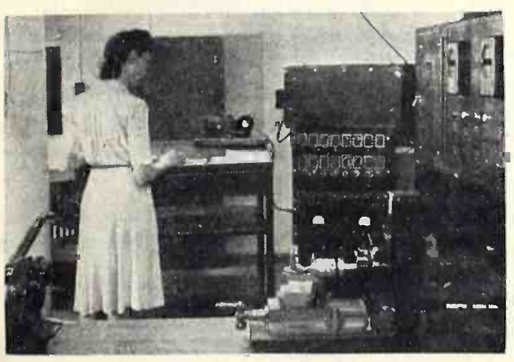
weighed but 48 pounds, which in one installation represented a reduction in weight of 250 pounds using inverters. To obtain the 400 cycles at the minimum alternator speed of 4000 r.p.m. 12 poles were required. For obvious space reasons these had to be placed on the stator, requiring a rotating armature. To achieve the good wave form under all conditions of radar load from a machine only six inches in outside diameter required every trick in the designer's "book." It meant crowding into an exceedingly small machine all the wave-form control features employed on large machines where space is not severely limited, including damper bars.

* * *

## Direct-Reading Spectrometer

AN INSTRUMENT which electronically measures the concentration of elements in alloys and automatically records the results has been developed by the *Dow Chemical Company,* Midland, Michigan. This direct-reading spectrometer, as it is called, has been in use in the company's magnesium alloying plant for several months, where alloy analyses can now be made in 40 seconds, a fraction of the time required when using the standard spectrograph. The substitution of an electronic method of measuring the intensity of spectrum lines eliminates the necessity for photographic and developing equipment and an expensive microphotometer, and avoids the errors commonly encountered due to film variation. The entire operation is fully automatic from the time the metal samples are placed in the instrument until the analysis is recorded on paper. Up to 14 elements can be determined simultaneously.

The development of the direct-reading spectrometer will be significant in



all metal industries, and in any chemical process where close and constant spectroscopic control is desirable. In melting, alloying and casting of metals it will lower costs by reducing the time a melt must be kept at temperature while waiting for analytical reports. Accuracy is equal or superior to that possible by spectrographic methods.

# NEWS BRIEFS

### NEW RESEARCH LABORATORY

The *General Precision Equipment Corp.* has announced the establishment of General Precision Laboratory, Inc., to conduct centralized research for the Company and its subsidiaries. The laboratory company has contracted for the purchase of the Manville estate at Pleasantville, New York. Dr. R. L. Garman, formerly with the M.I.T. Radiation Laboratory, will head the staff. The activities of the laboratory will be devoted chiefly to research and development in the fields of precision mechanics, optics, electronics, supersonics, hydraulics, motion picture, television, and industrial process control.

### SYLVANIA RESUMES PRODUCTION

The Radio Tube Division for *Sylvania Electric* has resumed its peacetime operations at the Johnstown, Pennsylvania, plant. During the war the plant served as a feeder of specialized electron tube mounts for proximity fuse tubes. Peacetime operation will be complete radio receiving tube production including exhausting and finishing.

### IRE ELECTS NEW OFFICERS

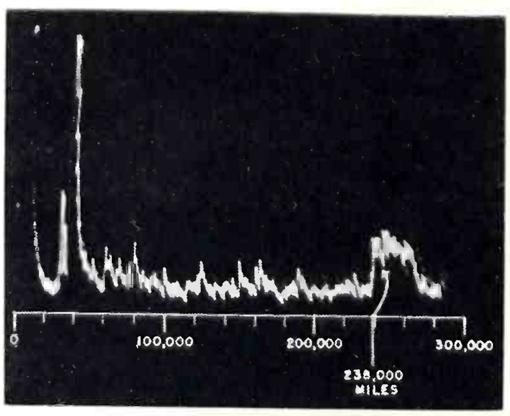
Dr. Frederick B. Llewellyn of Summit, New Jersey, has been elected president of the Institute of Radio Engineers for the year 1946. He succeeds Dr. William L. Everitt, head of the Department of Electrical Engineering of the University of Illinois.

Dr. Llewellyn, a consulting engineer on the staff of Bell Telephone Laboratories, is an international authority on the design of vacuum tubes used for communication and electronic control purposes. He is the inventor of the ultra-high-frequency oscillator tube, and is also known for his work on stabilized oscillating circuits used in radio and telephony. He is a graduate of Stevens Institute of Technology.

As president of the IRE, he will direct, on behalf of its 16,000 members, a program of activity which has been enlarged by peacetime utilization of wartime developments in radio and electronics. Em. M. Deloraine, president of the *International Telecommunication Laboratories* of New York was elected vice president. Three directors were also elected: Dr. Walter R. G. Baker, vice president of *General Electric Company,* Syracuse, N. Y.; Dr. Donald B. Sinclair, assistant chief engineer of *General Radio Co.,* Cambridge, Mass.; and Virgil M. Graham, plant manager of *Sylvania Electric Products, Inc.,* Williamsport, Pa. This marked the thirty-fourth election in the history of the Institute, which was established in 1912.

### MOON REACHED BY RADAR

The *Evans Signal Laboratory* at Belmar, New Jersey, recently announced that they had succeeded in detecting radar reflections from the moon. A conventional radar set 5CR-




271 was rebuilt for this experiment, certain alterations being necessary because of the long distance involved.

The radar equipment was operated at 111.6 megacycles, with a 64-dipole array for both transmitting and receiving. Pulse width was ½ second, and the time between pulses was varied from 3 to 5 seconds.

The accompanying photograph shows the trace on the radar 'scope. The time required for the radar pulses to travel to the moon and return was about 2.45 seconds, indicating that the total distance traveled was about 480,000 miles.

Transmitter power used in this experiment was 3 kw., and the receiver was sensitive to a signal of one ten-thousandth of a micromicrowatt. Receiver bandwidth was 50 cycles.

### RADIO SALES TO RISE

According to the consensus of sales leaders in the Radio Manufacturers Association, radio dealers can look forward to their businesses becoming among the most substantial in the retail field. The elimination of too liberal trade-ins and other sales tools which decreased the profit margin before the war, is pointed to as a big step in putting retail radio selling on the strongest merchandising foundation in its history.

The heavy demand for radio sets, sure to continue for many months, in combination with government pricing formulas, places practically all dealers on the same footing as far as sales and profit opportunities are concerned.

### RESISTANCE WELDING CONTEST

The cash prizes to be awarded in 1946 by the Resistance Welder Manufacturers' Association for outstanding papers dealing with resistance welding subjects was recently announced. The total amount of the awards is $2,000 and a wide choice in subject matter is allowed. The contest judges will be appointed by the American Welding Society, and awards will be made at the 1946 Fall meeting of the Society. The contest is open to anyone, without restriction, and further information may be obtained by writing to the American Welding Society, 33 W. 39th Street, New York 18, N. Y.

### G.E. SHIFTS TUBE ACTIVITY

Tube Development Laboratory, a wartime activity of the Lamp Dept. of *General Electric Co.,* has terminated its activities at Nela Park, Cleveland. Cathode-ray tube operations carried on in this laboratory will be continued by the Electronics Dept. of G.E. at Buffalo. Employees of the Nela Park plant will be absorbed by the Cuyahoga Lamp Works, which will be engaged in peacetime lighting manufacture and will be primarily a testing ground for new production methods.

### EXTENDED FREQUENCY SPECTRUM

The original frequency spectrum for power-line carrier was 50 to 150 kc., which is about one tenth the frequency range used in radio broadcasting (550 to 1500 kc.). This frequency band provided adequate channel space for carrier installations for many years, however, with the advent of large interconnected power systems to insure an uninterrupted flow of power to many industrial plants, the increased use of carrier by power companies for communication and control functions as well as high-speed relaying has raised the problem of providing more channel space for new installations.

*Westinghouse* has provided carrier equipment for three frequency bands; from 20 to 50, 50 to 150, and 150 to 300 kc. All the equipments have 19-inch wide panels for mounting on standard relay racks and are therefore interchangeable.

The designers of *Westinghouse* carrier apparatus have also produced a novel single-sideband scheme of the requisite simplicity, to meet the problem of how to provide more channels for power-line carrier. The new system generates only the desired single-sideband, creating nothing that must be eliminated later. The crux of the scheme is to use two sets of small dry-type rectifiers and some phase-shifting impedances all connected in such a way that only one sideband of frequencies appears in the output. In addition to having the effect of doubling the frequency spectrum available for power-line carrier (sometimes the gain is more than two to one) the new single-sideband carrier provides a gain in signal-to-noise ratio of nine decibels. The single-sideband system can be added to modern *Westinghouse* amplitude-modulated equipments or AM systems can be installed with the thought of adding the sideband equipment later.

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**NEW LITERATURE**

*Bendix Radio Engineer*

The January issue of "Bendix Radio Engineer," a quarterly edited for the electronic and aviation engineering fraternity, is devoted to a thorough survey of radar in a series of articles that describe many of the important wartime radar developments. A copy of the "Bendix Radio Engineer" is obtainable by forwarding 50 cents to the Technical Publications Section of *Bendix Radio*, Baltimore 4, Maryland. Subscription rate is $2.00 per year.

*Western Elec. Oscillator*

The first peacetime edition, December 1945, of the *Western Electric* "Oscillator," successor to their pre-war magazine "Pick-Ups," contains articles concerning both wartime and peacetime electronic developments. The "Oscillator" is distributed to the Company's customers in the communications and electronics industry.

*Sheffield Catalog*

A new catalog which illustrates and describes the Sheffield Universal Precisionaire Instruments has been published by the *Sheffield Corp.*, Dayton 1, Ohio. Copies are available to engineers and industrial executives upon request.

*Amer. Transformer Price List*

The latest price list of American Transformer Ballasts for fluorescent lighting is available upon request to *American Transformer Co.*, 178 Emmet Street, Newark 5, New Jersey.

*Aireon Catalog*

The *Aireon Manufacturing Corp.*, Kansas City, Kansas, has published a new descriptive catalog with specifications and general information on their piezoelectric crystals and crystal holders.


**APRIL**

27—**Products of Tomorrow Exposition,** at the Chicago Coliseum, scheduled to run 22 days. Further information may be obtained by writing on company letterhead to Chicago Coliseum, 1513 S. Wabash Ave., Chicago 5.

**MAY**

13, 14, 15, 16—**Radio Parts and Equipment Shows, Inc.** This trade show will be held at the Stevens Hotel in Chicago. Exhibitors will be limited to members of the four sponsoring groups, which are Parts Division of RMA, National Electronic Distributors Association, Association of Electronics Parts and Equipment Manufacturers, and Sales Managers Club, Eastern Division.

* * * *

**MONTHLY MEETINGS**

**Institute of Radio Engineers,** Chicago Section. L. E. Packard, Secretary, 920 S. Michigan Ave., Chicago. Wabash 3820.

Dinner, 5:30 P.M., main dining room, 38th floor, Civic Opera Building. Program, 6:45 P.M., 6th floor, Civic Opera Building, 20 Wacker Drive.

March 15—6:45 P.M., "Development and Trends in Radio Tubes," by Dr. L. G. Hector, Director of Research, National Union Corp. 8:00 P.M., "Postwar Trends in Non-Communication Electronics," by E. E. Moyer, Electronics Section, Industrial Control Dept., General Electric Co.

* * * *

**American Institute of Electrical Engineers,** Chicago Section. L. R. Janes, Secretary, 72 W. Adams St., Chicago 3. Randolph 2500.

Supper, Ford Hopkins Cafeteria, 3rd floor, Civic Opera Building. Food served from 5:30 to 6:15 P.M.; no reservations required. Program, 7:00 P.M., 6th floor, Civic Opera Building, 20 Wacker Drive.

March 7—Communications group, "Some Interesting Aspects of Deep Sea Cable Operations," by I. S. Coggeshall, General Cable Supervisor, Western Union Telegraph Company, New York.

April 4—Electronics group, "Ultrasonics," by Frank Massa, Electro Acoustic Consultant, Cleveland, Ohio.

## Microwave Techniques

(*Continued from page 6*)

as pictured. This mode can be thought of as made up of two plane waves moving down the guide at angles of + and − $\theta$ to the direction of the axis as shown in Fig. 9C.

The phase and group velocities will be different in a wave guide than in free space. The phase velocity, for air-filled guide, is given by:

$$V_{phase} = \frac{c}{\sqrt{1 - (\lambda_0/2a)^2}} \quad (4)$$

where $c$ is the velocity of light and $\lambda_o$ is the free space wavelength.

The group or signal velocity is equal to $c^2/V_{phase}$.

The measured wavelength in the guide is associated with the phase velocity and is,

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - (\lambda_0/2a)^2}} \quad (5)$$

When $\lambda_o$ exceeds $2a$ the above expression (5) becomes imaginary, and the wave will not propagate. The cut-off wavelength for the mode in question is $\lambda_o = 2a$; waves of lower frequency cannot be carried by the guide.

The next higher mode can be propagated when $\lambda_o$ becomes less than $a$. We have then the important fact that for $a < \lambda_o < 2a$ one and only one mode can be propagated. Let us illustrate by an example. For a guide of dimensions 1.34" x 2.84", the lower mode cut-off wavelength is 14.4 cm., the next higher mode is possible at $\lambda_o = 7.2$ cm. and below. For $\lambda_o = 10$ cm., $\lambda_g = 14$ cm. It is good practice not to work too closely to either of these cut-off limits; actually very satisfactory transmission lines have been made with this size guide for $\lambda_o$ between 8.0 and 12.0 cm.

The impedance of a wave guide is a rather complicated function of frequency and guide dimensions. In practice the guide impedance can be taken as about 550 ohms. The attenuation in a wave guide is approximately one-half that of the largest possible coaxial line, at a given wavelength. For the guide discussed above and $\lambda_o = 10$ cm., $A = .012$ db./ft., for brass.

Although wave guide transmission is somewhat more difficult to understand than coaxial line transmission, there are many advantages possible in using wave guides for microwaves. To list a few:

(1) Much lower attenuation
(2) Much easier fabrication
(3) About 4 times the power-handling limit.

In practice wave guides are used almost exclusively at frequencies greater than 6000 mc., where coaxial lines become impossibly small. Where light weight is essential and power-handling ability is not limiting, coaxial lines are often used in the region from 6000 to 1500 mc./sec. Below 1500 mc. wave guides become very large and coaxial lines are generally preferable.

| | |
|---|---|
| Wavelength | 10 cm. |
| Peak Power Output (Average power during oscillation) | 250 kw |
| Average Power Output | 250 watts |
| Efficiency | 45% |
| Pulse Voltage | 20 kv |
| Pulse Current | 27.5 amps. |
| Duty Cycle $\left(\frac{\text{Pulse duration}}{\text{Time between pulses}}\right)$ | .001 |
| Heater Power | 10 watts |
| Magnetic Field | 1800 gauss |

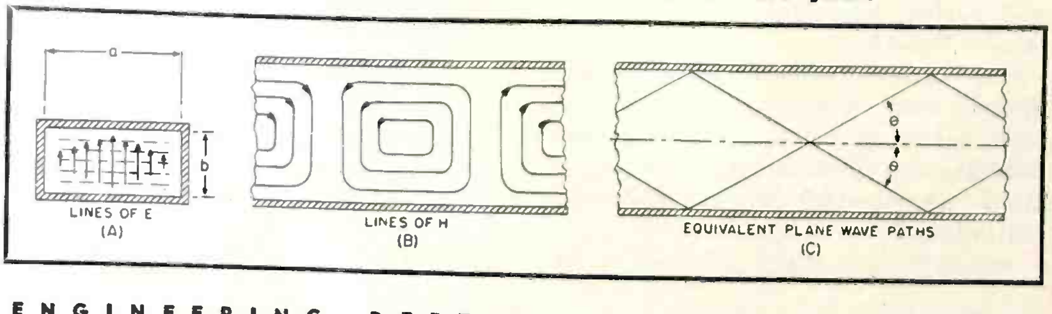
Table I. Normal operating figures for a multi-cavity magnetron shown on page 3.

### Impedance Measurements in Transmission Lines

As mentioned earlier the natural measure of impedance in microwave lines is the determination of the magnitude and phase of the voltage standing wave ratio (VSWR) introduced by the element or discontinuity in question. Such a measurement of course determines the impedance of the element relative to the characteristic line impedance, but this is generally the information required. The information so obtained, when used in connection with impedance charts such as pictured in Fig. 6, enable us to completely describe the impedance of line components.[2]

In determining standing wave ratios we must be certain that we do not disturb the pattern in the transmission line. This means that we must cut slots in the line in such a manner that no appreciable power is coupled out of the line, and also we must use probes which introduce no appreciable discontinuity themselves. The first of these conditions can be met by cutting narrow slots parallel to the axis

Fig. 9. Lowest mode patterns in a rectangular wave guide.



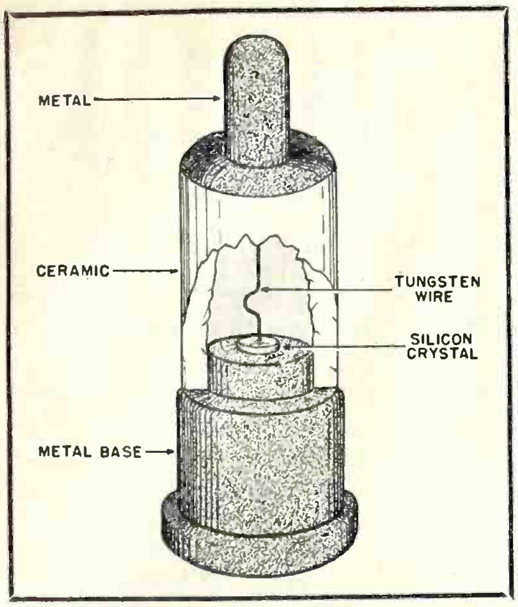



Fig. 10. Cross sectional view of a crystal cartridge used for microwave detectors.

of coaxial line or along the center of the broad face of the wave guide. The second condition is met by using very small probes and very sensitive detecting equipment.

**Moving Joints in Transmission Lines**

In radar systems it is almost always necessary to move the antenna beam either for searching purposes or for following a target once it is found. Since it is seldom possible to move the whole r.f. part of the system, some means of moving the antenna relative to the transmitter must be used. The most widely used device is the rotary joint, by which means one end of a transmission line can rotate relative to the other. At frequencies below the microwave region, rotary joints can be made by equipping one set of conductors of a line with contact fingers which rotate smoothly on another set of fixed conductors. At microwave frequencies contact fingers always give trouble, so it has been necessary to develop the so-called choke joint.

This joint can best be explained by referring to Fig. 11. Here a choke joint in the outer conductor of a coaxial line is illustrated. The break in the metallic conductor, being one-quarter wavelength long, produces no break in the r.f. conductance of the joint. A better choke joint can be made by using one-half a wavelength and folding the choke back along the axis of the line, as illustrated in the wave-guide choke joint in Fig. 11. Fig. 4 illustrates a coaxial rotary joint with folded chokes instead of finger contacts. A good deal of misalignment can be tolerated in wave-guide choke joints, and hence they are also very useful in making "wobble" joints. That is, one end can be wobbled freely, through small angles (20° or less).

**Duplexing**

In radar, duplexing means the use of one antenna for both receiving and transmitting. The advantages of such a scheme are two-fold. First, the mechanical problem of keeping two antennas always trained on a single target, or searching over a single area, are considerable. The complication in the transmission lines with duplicate sets of rotary joints is a considerable factor. Secondly, since the wind resistance and weight of the antenna are two of the most critical factors in radar, perhaps the most important limiting factor in airborne systems, the use of a single antenna gives effectively twice the area for both the transmitting and receiving antennas. Referring to Eqt. (4) of the previous article[1] in this series (repeated as Eqt. (6) here) we see that a doubling of $A$ leads to an increase of 40% in $R$. This is the equivalent of quadrupling the transmitted power, or a gain of 6 decibels.

Table II. Typical operating characteristics for a reflex klystron at 10 cm.

| | |
|---|---|
| Beam Current | 40 ma. |
| Beam Voltage | 300 volts |
| Reflector Voltage | 120 volts |
| Useful Electronic Tuning Range | 20 mc. |
| Electronic Tuning Rate | 2 volts/mc. |
| Power Output | 80 mw. |
| Efficiency | 0.7% |
| Heater Power | 5 watts |

$$R = \left[\frac{FA}{\lambda}\right]^{1/2}\left[\frac{\sigma \Gamma_T}{4\pi P_{r\ min}}\right]^{1/4} \qquad (6)$$

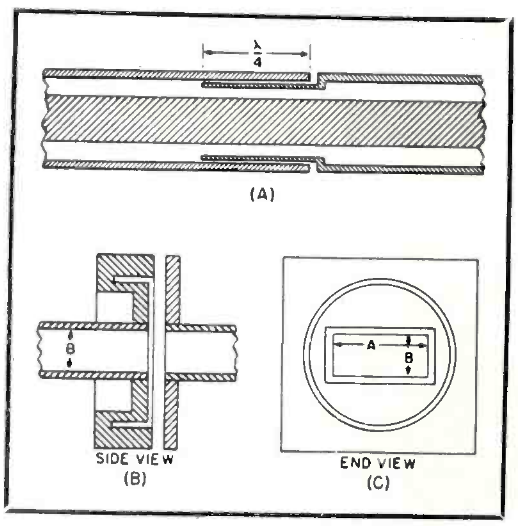
where $R$, the maximum range, and $A$, the antenna area, are the quantities concerning us here.

Granted that duplexing is desirable in radar, how is it accomplished? Two general requirements must be met: namely, one, the receiver must be disconnected from the antenna line during the high power pulse; and two, the transmitter must be disconnected from the antenna all the rest of the time. The first requirement is necessary to protect the receiver against burnout and overloading, and the second to prevent loss of signal power into the transmitting element during reception. In microwave radar practically all receivers use a silicon crystal as the detecting device, and such crystals are subject to burnout and saturation at power levels of the order of 250 milliwatts. To protect this crystal against burnout and to insure otherwise satisfactory operation of the radar, a rapidly acting switch, generally called a *TR* tube, must be designed with the following characteristics:

| | | |
|---|---|---|
| 1) | Attenuation in receiver line during pulse | $> 60$ db |
| 2) | Time of firing | $< .01$ μsec. |
| 3) | Time of recovery (negligible signal loss | $< 10$ μsec. |
| 4) | Insertion loss (to signal) | $< 1$ db |
| 5) | High power loss | $< .3$ db |
| 6) | Voltage standing wave ratio (when fired) | $< 1.2$ |

Such a tube is illustrated in Fig. 12; this particular tube is used with an external cavity to form the complete resonance circuit as shown. The tube is filled with a mixture of hydrogen and water vapor to a total pressure equivalent to about 15 mm. of Hg. When placed at a high voltage point in the line a very high r.f. voltage is built up across the gap causing the gas to break down and effectively cause a short circuit to the receiver line. The hydrogen is chosen because of its rapid breakdown time; the purpose of the water vapor is to "clean-up" the ions in the gap after the discharge has taken place, and so to minimize the recovery time. The "keep-alive" electrode is used to insure that a minimum number of ions are in the gap to enable speedy breakdown to take place.

Fig. 11. (A) Coaxial choke. (B, C) Side and end views of wave guide choke.




The requirement on a duplexing system that there be no absorption of received signal by the transmitting tube can be met in two ways. One, if the cold (non-oscillating) impedance of the magnetron can be specified to be within certain limits the distance from the receiver junction to the magnetron can be so chosen that the received signal is reflected completely into the receiver branch. Two, if the magnetron cold impedance can not be specified, or if it is inconvenient to keep the magnetron-receiver distance within certain limits, an *ATR* or anti-*TR* tube may be used. The *ATR* tube can be identical with the *TR* tube, but it is mounted in a somewhat different cavity. The assembly is placed in such a position in the guide that during transmission, when the tube is fired, negligible power is reflected toward the magnetron; while on reception, the unfired case, the signal is almost completely reflected from the magnetron branch into the receiver branch. This is true regardless of the cold impedance of the magnetron. Typical operating conditions for an *ATR* are:

| | |
|---|---|
| Signal loss | $<$ .9 db. |
| High power loss | $<$ .3 db. |
| High power voltage standing wave ratio | $<$ 1.2 |

The requirements on time of firing and recovery time are not stringent since no receiver protection or signal transmission loss problem is involved.

It would seem that the 6 db. gain for duplexing claimed earlier would have to be reduced somewhat; by 2.5 db. under adverse circumstances. Actually, in a dual antenna system the losses due to misalignment would probably at least balance this, and the writer feels 6 db. is a good working figure. Fig. 3 schematically shows the essential microwave components of a typical radar system.

## Detection of Microwaves

At frequencies above 2500 mc. the rectifier crystal is almost exclusively used for detection. The crystals operate in a manner similar to the galena crystals of the 1920 era, but silicon has been found a far better material. (Germanium is sometimes used.) Heterodyne detection methods are some 30 to 40 db. more sensitive than single detection methods for such crystals. Diode detectors and r.f. amplifiers in general introduce far more noise than crystals, so that the ultimate receiver sensitivity is impaired. Special tet-

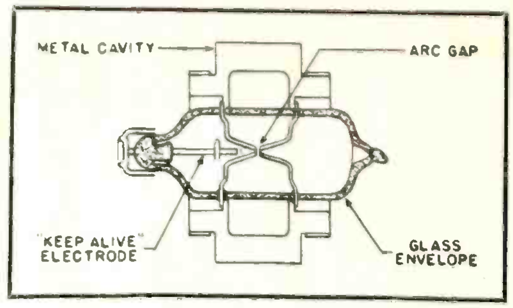



Fig. 12. 1B27 Type TR tube and cavity.

rode amplifier tubes have been made which compete with crystals in ultimate sensitivity, but the manufacturing and tuning requirements are such that the tubes are difficult to make and exceptionally difficult to tune.

A typical crystal (1N21 type) is illustrated in Fig. 10. The sensitivity and noise figure are set and measured, and the crystal cartridge is sealed off before leaving the factory. The resulting crystal is very rugged mechanically, but is subject to burnout at low powers.

The ultimate sensitivity of the radar system can never exceed the theoretical lower limit of thermal noise which is present in the initial stages (the detector and the first i.f. stage) of the receiver. This theoretical lower limit is equal to $kTB$, where $k$ is the universal Boltzmann constant equal to $1.37 \times 10^{-23}$ joules per degree Centigrade absolute (°K), $T$ is the absolute temperature and $B$ is the bandwidth in cycles per second. For one mc. bandwidth and 300°K this factor is equal to $4.11 \times 10^{-15}$ watts, or we can say that the ultimate receiving sensitivity is $4.11 \times 10^{-15}$ watts per mc., or 144 db. below one watt per mc. bandwidth.

The measure of goodness of a receiver is the closeness with which the above figure, appropriate to the bandwidth of the receiver in question, can be reached. Theory shows that the following expression gives this overall receiver noise figure, $NF_R$.

$$NF_R = L + 10\log_{10}(NF_{i.f.} + T - 1)\text{ db.} \qquad (7)$$

where $NF_{i.f.}$ is the noise introduced by the i.f. circuit expressed as a ratio,

$T$ is the noise introduced by the crystal expressed as a ratio to thermal noise.

$L$ is the conversion loss of the crystal in db.; that is, the loss in signal power in converting from r.f. to i.f., usual values being 3000 mc. and 30 mc.

Typical values of these quantities for microwaves are:

$L = 6$ db.
$T = 1.5$
$NF_{i.f.} = 1.5$
$NF_R = 9$ db.

For a 3 mc. bandwidth we can obtain in practical systems, signals equal to noise about 130 db. down from one watt, as the above figures indicate. Although a signal loss is always present in a crystal, the ultimate sensitivity is much better than with tube converters because of the very low noise. The lack of gain in the r.f. stage can always be restored in the i.f. or video stages.

Another source of noise is in the side-band of the local oscillator. At 3000 mc. r.f. and 30 mc. i.f. this is much less than 1 db. and can be neglected. At 9000 mc. r.f. and 30 mc. i.f. this noise can contribute 3 db. to the overall receiver noise, but with a 60 db. i.f. the l.o. contributes only 1 db. As the ratio of r.f. to i.f. becomes large this source of noise becomes increasingly important and in many cases it pays to use balanced mixing circuits to eliminate it.

### Crystal Impedances

Both r.f. and i.f. impedances of crystals are apt to vary over wide limits. However, at the factory the crystal conversion loss and noise figure are measured in a fixed-tuned mixer circuit with definite r.f. impedance and i.f. capacitance. Crystals with widely varying impedances will be rejected in such a mixer as below specification limits. In any event since the constants of the test circuits are known, the radar mixers can be designed accordingly, and the crystals will not be badly mismatched in the radar receivers.

### Conclusion

In this article an attempt has been made to describe, in a very short space, some of the problems and accomplishments in the microwave field as applied to radar systems. It has been necessary to omit many interesting results and to limit explanations to the barest minimum. Now that the wartime security regulations are being relaxed, many important technical papers and books are beginning to appear, and those readers who are interested in the more technical details are referred to them.

**REFERENCES:**


1. White, Milton G., "Microwave Radar", *Radio-Electronic Engineering edition of Radio News*, February, 1946.
2. Smith, P. H., "Transmission Line Calculator"; *Electronics*, January, 1934.


**COMING!**

"Microwave Radar Antennas," by E. M. Purcell, Radiation Laboratories, M.I.T.

"High Power Pulse Circuits," by M. G. White, Radiation Laboratories, M.I.T.

"Radar Indicators," by L. J. Haworth, Radiation Laboratories, M.I.T.

"Electronic Applications in Meteorology," by Robert Endall.

"Control and Timing Circuits," by John D. Goodell, Consulting Engineer, St. Paul.

WATCH FOR THESE FEATURES!

# TECHNICAL BOOKS

**"ELEMENTARY ENGINEERING ELECTRONICS"** by Andrew W. Kramer. Published by *The Instruments Publishing Company, Inc.*, Pittsburgh, Pa. 334 pages. Price $2.00.

This book is designed for the electrical or mechanical engineer whose training and/or working experience has not prepared him for the field of industrial electronics.

Since industrial electronics is the application of the proper vacuum tube to the job to be done, this book deals with the characteristics and operation of various types of vacuum tubes applied to certain industrial problems.

Included in the discussion are triodes and their uses, thyratrons, tetrodes and their applications, phototubes, mercury-arc rectifiers, and cold cathode tubes. Special emphasis has been placed on the science of electronics as applied to instrumentation, measurement and control.

The book is clearly written and well illustrated with diagrams, pictures and graphs.

**"FUNDAMENTAL THEORY OF SERVOMECHANISMS"** by LeRoy A. MacColl. Published by *D. Van Nostrand Company, Inc.*, New York. 128 pages. Price $2.25.

Because of the increasing importance of various types of servomechanisms as applied to control problems, this book by Dr. MacColl of the *Bell Telephone Laboratories* forms a valuable background and bridge, dealing as it does with many wartime developments and improvements in servomechanisms.

The text deals with elements of the steady-state theory of the servomechanism, auxiliary formulae from the theory of transients in linear systems, stability of servomechanisms, Nyquist's Criterion, performances of servomechanisms, servomechanisms with more complicated feedback paths, servos with alternating current motors and oscillating control servomechanisms, sampling servomechanisms, and alternative approaches to the theory of linear servomechanisms.

This book supplements and extends Dr. H. W. Bode's "Network Analysis and Feedback Amplifier Design" and is a valuable addition to the literature covering the subject of servomechanisms. The book is written at an engineering level.

# Crystal Control

(*Continued from page 14*)

justed indefinitely. The 18 trimming capacitors are Centralab negative temperature coefficient ceramic units. The proof of the success of the stability of this set is that from the instant it is turned on, throughout a full evening's listening, there is no change in the sound quality, as there had been before the conversion to crystal control. It is also much more convenient to tune stations with a flick of the wrist than to have to make very careful and accurate adjustments. Most listeners do not tune receivers carefully enough to get the best out of them. This is one of the many advantages of preset, fixed tuned, push button or rotary selector mechanisms. In FM reception tuning must be accurate. This is all the more true for the new FM bands. The use of fixed tuned, crystal controlled, station selector systems for FM is one pathway to the better enjoyment of the advantages of FM reception.

There may be some interest in the disposition of the tuning dial of the original receiver. A set of "bulls-eye" panel indicator lamps was inserted in the space occupied normally by the tuning dial. Inside each jewel there is lettered the call letters of the station to which the rotary selector is set. The lettering can be seen only when the jewel is lit. This is an expensive item when using individual units, but, with

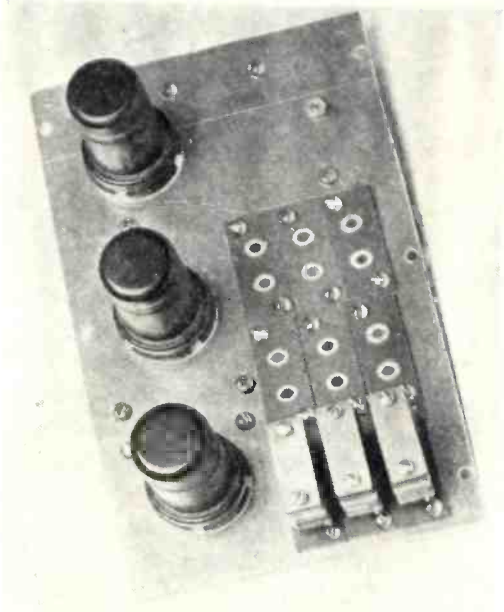


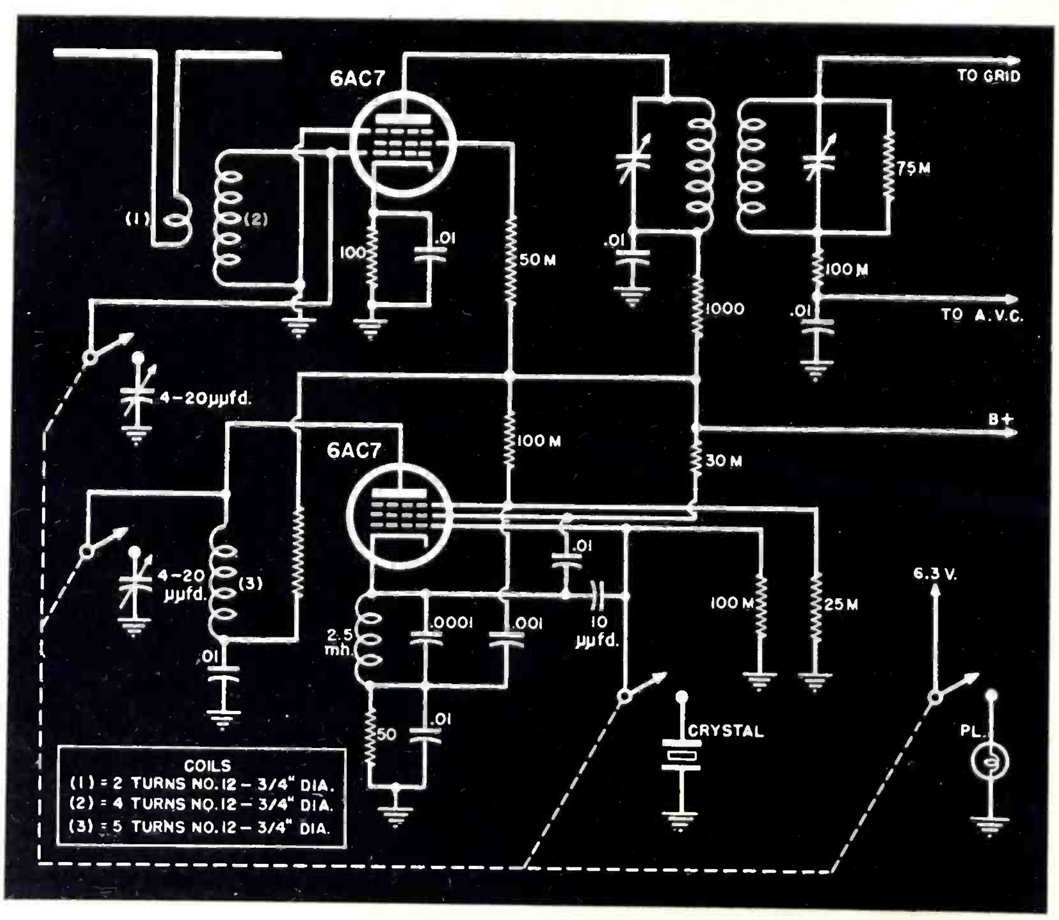
Fig. 9. Top view of r.f. chassis.

plastics and attractive industrial design this may be a very practical inexpensive indicator.

There were some over-all circuit changes from the original Meissner receiver in addition to the crystal controlled r.f. section. The major change was the installation of cascade limiters.

The intermediate frequency standard for the new FM bands has been established at 10.7 mc. Based upon this choice the considerations for crystal frequencies will involve the following: In the band covering 88-108 mc. (including educational transmissions) oscillator frequencies (on the

Fig. 10. R.F. end of crystal-controlled FM receiver rebuilt from Meissner 9-1041A.




| Harmonic Number to Be Used | Range of Crystal Frequencies | | |
|---|---|---|---|
| 8th | 9.6625 Mc | to | 12.1625 Mc |
| 9th | 8.588888 | to | 10.811111 |
| *10th | 7.7300 | to | 9.7300 |
| 11th | 7.027272 | to | 8.936272 |
| 12th | 6.441666 | to | 8.108333 |

* PREFERRED. The actual frequencies for each station are calculated from formula (7).

Table II. Crystal frequencies for use in the new frequency modulation band.

low side) will have to cover 77.3 mc. to 97.3 mc. Table II lists the frequency ranges in which particular crystals must fall so that specific harmonics are useful for the 88-108 mc. band in receivers employing 10.7 mc. intermediate frequency amplifiers.

The industry established a drift or deviation tolerance of plus or minus 5 kc. for satisfactory FM operation at 50 mc. This represents a value of 1 part in 10,000. The tolerance represents over-all drift or deviation and can be the algebraic sum of all the deviations in the r.f., local oscillator, i.f. and discriminator circuits. Sometimes these are compensatory and the drift or deviation is small.

The crystals ground for the sets described above are all within 50 cycles or less of the designated frequency. This was measured at room temperature. Since they are *BT* cuts with a "crossover" at room temperature the drift expectancy of this crystal is insignificant. At the eighth harmonic the variation of the oscillator frequency is no more than about 1500 cycles over-all in several hours of continuous operation. Fig. 3 is the curve of temperature coefficient of the *BT* and *AT* crystal orientations. The temperature range in which crystals will have to operate in a reasonably well ventilated chassis can be estimated at from plus 10° C. to about 40° C. The maximum deviation of frequency in this range would be fewer than ten cycles, per megacycle, per degree C. at the fundamental crystal frequency. This must be multiplied by the number of the harmonic used. It should also be noted that the thermal variation in the average radio set once it reaches operating temperature will not be more than a few degrees on either side of this value. A reasonable statement, therefore, of the frequency change with crystal control of the local oscillator at values up to the 10th harmonic can be set at plus or minus 1500 cycles (using *BT* orientation). This will leave considerable room for the variations resulting from other circuit combinations.

**REFERENCE**

1. *William Maron, "Crystal-Tuned FM Receivers," Electronics, p. 138, Oct., 1945.*

# Aviation Controls

(*Continued from page* 10)

tive bias from "increase sensitivity" as soon as a signal appears that is large enough to cause an output fluctuation of the control tube plate voltage. Thus, the bias point is automatically shifted far enough to the left to cause positive operation of the relays.

The third voltage applied in the form of bias is developed across the "throttle control." When the output from the discriminator tube closes either the right or left servo relays, it also closes a relay that applies the throttle voltage to the grid circuit of the control tube. This is a positive voltage that shifts the operating point to the right. When the operation of the servo motor has adjusted the wiper on the balance pot sufficiently to lower the output signal to an amplitude that is insufficient to drive the control tube at the bias point created by the throttle voltage, the servo relays open, the servo motor stops and the throttle voltage relays open the circuit applying this added positive bias. The *RC* Time Delay circuit maintains the operating point for approximately 15 cycles after the throttle relay opens, after which the bias drops so that the signal is again sufficient to operate the relays. The time delay circuit functions to hold the throttle voltage in application long enough to prevent chattering of the relays. When the signal again drives the control tube and the output of the discriminator closes the relays, the servo motor operates again momentarily but is stopped as soon as the throttle voltage is re-applied. Thus, the servo motor is caused to operate intermittently as the balance point is reached. This "pecking" action prevents overshooting and functions to produce smooth control over small and large deviations in the flight of the airplane.

The discriminator circuit is conventional with a.c. applied to the plates of the discriminator tube from the same source as the signal to the input of the amplifier. The phase of the input signal is synchronized to produce an output from one or the other side of the discriminator circuit in such a manner as to correspond with left or right deviations of the potentiometer wipers in the bridge circuit, thus operating the appropriate relays.

A separate circuit of this kind is used to operate each of the control surface assemblies, i.e., ailerons, rudder and elevators. Fig. 9 is a photograph of the three-channel amplifier. This compact unit used a single rectifier to supply high voltage to the circuits, and a total of six additional tube

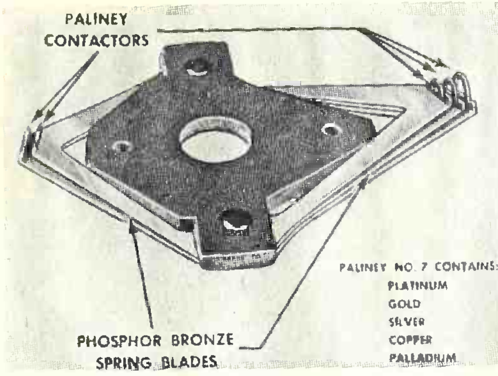



**Fig. 11. Potentiometer wiper showing multiple contact construction.**

envelopes perform all of the required functions. The heater of the rectifier operates in parallel with a balancing resistor. The heater of each discriminator tube is connected in parallel with its associated amplifier and control tube. These four parallel circuits are connected in series with an r.f. choke to the direct current supply from the airplane's battery, with circuit opened and closed by the Autopilot master switch.

These few tubes and components function to provide a.c. to the control pots in the bridges of the Vertical Flight Gyro, the Directional Panel, the Turn Control and the Servo Units; amplify the signals from the bridge circuits caused by flight deviations of the airplane; analyze the input so as to reject small signals, build up borderline signals, pass mid-size signals intermittently and large signals continuously; determine the direction of control surface movement necessary to correct flight deviations, and close the proper relay to operate the indicated Servo Unit in the proper direction.

This is an excellent example of the complex functions which may be handled efficiently by a simple, but well designed, electronic control amplifier. Figs. 1, 2, and 4 are views of actual installations of the Autopilot in various aircraft.

**REFERENCES**

1. *"Handbook of Operation and Service Instruction," C-1 Autopilot, Aeronautical Division, Minneapolis-Honeywell Regulator Company.*

2. *Albert E. Baak and Richard A. Franzel, "Latest Developments in Aircraft Controls and Instrumentation." Paper presented at the meeting of the American Society of Mechanical Engineers, Los Angeles, June 14, 1945.*

# New Products

(*Continued from page* 24)

receiver locations, in determining the effectiveness of filtering and shielding electrical apparatus which produces

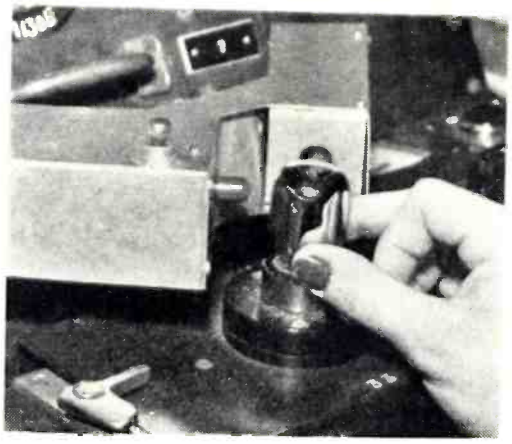
radio noise at ultra-high frequencies, and for indicating and recording in microvolts/meter the field intensity of AM, FM, and television transmitters.

Additional information may be obtained from *Stoddart Aircraft Radio*

*Co.*, 6644 Santa Monica Blvd., Hollywood 38, California.

**AUTOMATIC TAPPERS**

Solenoid-operated tube tappers for uniform control of force, angle and timing of blows on electron tube en-



velopes to detect shorts, r.f. and audio noises, and other faults due to tube structure have been developed by *Sylvania Electric Products, Inc.*, Emporium, Pa.

Specially designed to eliminate variations resulting from the use of hand mallets by individual operators, these solenoid tappers provide six timed strokes which are alternately applied between two points on tube envelopes. The force, angle and timing of automatic blows may be adjusted to meet test requirements of different receiving tube types.

**NEW ELECTRONIC TESTER**

The "B" Sweep Calibrator Model No. 8127 for commercial use in radar and television test work has been announced by *United Cinephone Corpo-*

*ration*, Torrington, Connecticut.

The instrument provides calibration marks for use in calibrating the sweep speed of a synchroscope or triggered sweep oscilloscope. The markers consist of short video pulses, of less than ½ microsecond duration, spaced apart by a known number of microseconds. The unit was designed in collaboration with the Radiation Laboratory, M.I.T.

**NEW G. E. TUBES**

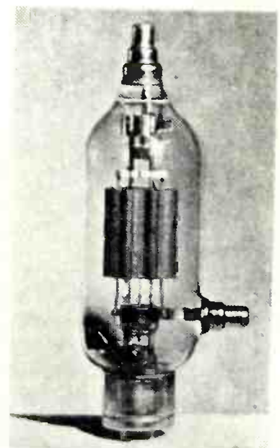
A new transmitting tube, type GL-9C24, a triode, has been announced by the Tube Division of *General Electric Company's* Electronics Department. Designed particularly for application in a grounded-grid circuit as a class *B* r.f. amplifier and a class *C* r.f. amplifier oscillator, the tube will be used in television and FM operation at the higher frequencies.

Another new transmitting tube, Type GL-592, has also been announced by this company. The type GL-592 has been designed for use in amateur radio and industrial applications which require power in higher frequency ranges.

Technical information on both tubes, type GL-9C24 and type GL-592, may be obtained on request to the Tube Division, *General Electric Company's* Electronics Department, Schenectady, New York.

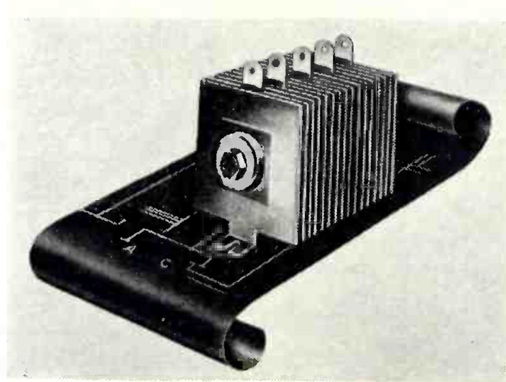
**NEW POWER TRIODE**

*Lewis* of Los Gatos, California, a subsidiary of the *Aireon Mfg. Corp.*, is now manufacturing a new air-cooled, power triode, the Lewis 4C32. It is especially suitable for high frequency diathermy and industrial heating uses. In its use as an unmodulated class *C* radio-frequency amplifier, typical operating conditions are—d.c. plate voltage, 2000; power output 400 watts. However, the maximum input is 900 watts, maximum plate dissipation 200 watts. Upper frequency limit of the tube with maximum power input is 60 mc. For further information and catalog sheets, inquiries should be addressed to *Lewis Electronics,* Los Gatos, Calif.



**NEW RECTIFIER REQUIRES NO FAN**

The *Benwood-Linze Company* of St. Louis has announced the development of a dry disc metallic rectifier which does not require forced cooling. This rectifier is rated 50 amperes for 6 volt automotive battery taper charging. Two rectifiers may be operated in parallel from separate transformer sec-

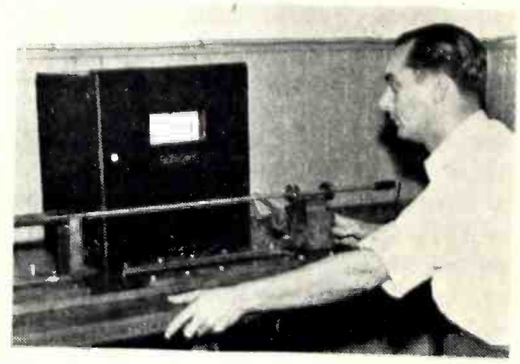


ondaries to provide 100 amperes maximum charging rate without a fan.

Battery chargers of this type operate from the usual 110 volt a.c. power supply, to deliver the required rating of d.c. to the battery. This new rectifier makes possible the design of fast battery chargers rated 50 amperes without any moving parts.

**ELECTRONIC BORE GAUGE**

A new electronic bore gauge utilizing direct contact to measure the diameter of tube, gun and other cylindrical interiors with an accuracy of



one-half a ten thousandth of an inch, will be introduced soon by the *Chrome Gauge Corp.*, Philadelphia. The new device, said to offer 100 per-cent greater accuracy, is expected to be marketed in the chemical, petroleum, metallurgical and other industries that either manufacture or make use of tubes and pipes, and for processes where pipe and tube interior surface imperfections affect the process and product.

**HERMETICALLY-SEALED RESISTOR**

A new small-size unit rated at 0.5 watt and only ⅞" long by ⅞" in diameter has been added to the line of hermetically-sealed Shallcross Akra-


Ohm fixed accurate wire-wound resistors made by the *Shallcross Manufacturing Company,* Jackson and Pusey Avenues, Collingdale, Pennsylvania.

Known as Type 1101, the new resistor is designed for style RB12A under JAN specification R93. Maximum resistance value when wound with nickel chromium wire is 350,000 ohms, maximum voltage 420 volts.

Resistance element, winding form and protective ceramic shell form a rigid, integral unit. No internal leads or "floating" wires are used, and hermetic-sealing is obtained without use of ferrule caps or glass drawing by a special solder process. This, as well as the company's complete line of accurate fixed wire-wound resistors for industrial applications are described in a new edition of *Shallcross* Resistor Bulletin R, copy of which will be sent on request.

**RECORDING SYSTEM**

A new recording system, which will enable producers to record any of the standard original or release type of sound tracks on either 35mm or 16mm film has been announced by the Electrical Research Products Division of the *Western Electric Company,* 195 Broadway, New York 7, N. Y.

Features of the new design are simplicity of mechanical parts and freedom from critical adjustments, more rapid threading of film, adaptability to either variable area or density recording, and the reduction of flutter to extraordinarily low values. Its construction permits flexibility in meeting a variety of recording requirements including changing from 35mm to 16mm in a matter of minutes by the use only of a screw driver.

## Cavity Magnetrons

(*Continued from page* 20)

simple rotating fan-shaped field patterns called Hartree harmonics. The scallop-shaped spacial mode of Fig. 8B may help to visualize one of these harmonics. The analysis just described of one of the involved possible r.f. patterns into the corresponding fundamental and higher Hartree harmonics is carried out in Fig. 7.

Now, half of these harmonics rotate clockwise and half counter-clockwise. Those spinning against the electrons flash by them so rapidly as to have no effect; of those spinning with the electrons, however, it may occur that a fundamental or some higher harmonic will rotate with an angular velocity near that of the electrons. Then a stable grouping of the space charge into rotating bunches will occur. (The bunches rotate with the same speed as the harmonics.) Electrons speeded up by the electric field of the harmonic retreat to the cathode because of the increased magnetic bending-force resulting, and those slowed down move out toward the anode where they are collected. This bunching, which is slightly different from that in klystrons, is illustrated in Fig. 3A for the 2J42.

We notice that it is the over-all space-charge that is bunched, and that individual electrons may slip in and out of the bunches without effect, as long as others take their places. This is why the bunches will be rotating with the speed of the harmonic although the individual electrons are not. (Fig. 14A.)

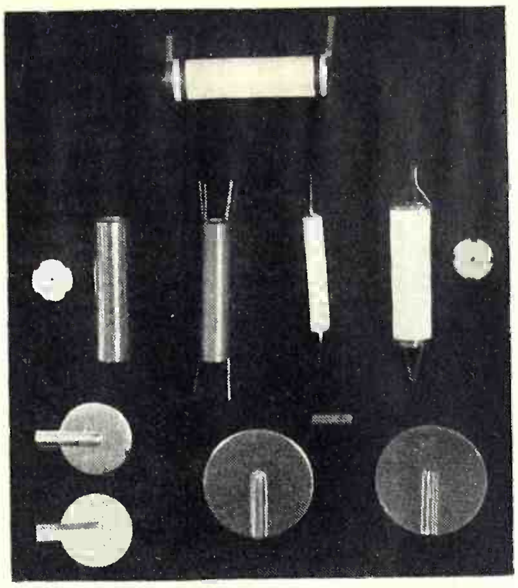


**Fig. 16. The oxide-coated unipotential cathode with heater in various stages of assembly (2J22-2J34 magnetrons). The completed cathode is at the top.**

As a result of the bunches, there are two kinds of current to the anode segments. One is the conduction current as electrons from the bunches reach the anode. The other is a displacement current, of the same type familiar to us as the internal current between the plates of any condenser. As the bunches sweep by a given point in the cathode-anode space, they naturally cause the space-charge at that point to vary with time, and hence the electric field set up by the space charge. This time-varying electric field then constitutes a displacement current of density J by the definition:

$$J = \epsilon_o(\delta E/\delta t)$$

$J$ = displacement current density
$\epsilon_o$ = electric inductive capacity
$E$ = electric field at a given point.

The conduction current is in spurts (Fig. 14B). The d.c. component is the average d.c. current from the radar modulator. The Fourier component at the oscillation frequency acts like current to a load; the electrons themselves drain some of the power they furnish. The behavior of the stronger over-all displacement current, however, is like that from a generator. It is the real source of power.

This viewpoint, proven during the war, is much more fundamental than the single-electron explanation usually given.

Magnetrons are commonly designed to operate with such an r.f. field pattern that the instantaneous charges on adjacent segments are equal and opposite ("plus-minus-plus-minus" as we go from segment to segment). In magnetron terminology this is the "$\pi$-mode." By a mode we mean the operation of the magnetron at a particular frequency with a particular kind of electronic coupling and r.f. field pattern. In pre-war literature when only this $\pi$-mode was known, if an electron just moved from one gap to the next in one period of oscillation, we were said to have "oscillations of the first order." If more than one period occurred during an intergap electron movement, we had "oscillations of high order." This partition into orders does not seem to be fundamental, being merely the difference between coupling to the fundamental Hartree harmonic or to one of the higher ones. (As noted in Fig. 7 the latter rotate more slowly.)

The unusual behavior of the average plate current with varying plate voltage is shown in Fig. 10A. As the plate voltage is increased, the angular velocity of the electrons is changed. When the velocity is near enough to that of one of the Hartree harmonics, the magnetron will operate in the mode corresponding to that harmonic, and will continue to do so even though the velocity is changed. The increasing plate voltage then makes the bunches more dense and increases the power in that mode. There finally is reached a point with increasing plate voltage, however, where the electron velocity is such that it is now easier for the electrons to couple in another mode of operation. Abruptly the magnetron then jumps to the new mode and continues until other modes are preferred. Each mode at a given magnetic field obeys an empirical equation of the form:

$V_{ko} = C_k (H - H_{ko})$

$V_{ko}$ = plate voltage at which oscillation will start for the *kth* mode

$C_k, H_{ko}$ = constants for *kth* mode

$H$ = magnetic field

No such formula for wavelength as that of the radial-coupling tube may be given. In practice, we usually start with a magnetron model developed experimentally to give good efficiency and power output, and apply certain scaling principles to give the desired tube at the new frequency or power level. (These principles are discussed in M.I.T. Radiation Laboratory reports.) All we can say is that:

1.) Conditions must be set at or beyond cut-off by the plate voltage and magnetic field, and
2.) that the electron velocity determined by these parameters be sufficiently near that of one of the Hartree harmonics—fundamental or higher—of any of the r.f. patterns the resonant oscillating elements can establish.

Having examined the mechanics of power generation, we shall want to see what the modes referred to above may be.[20] The modes the magnetron can operate in are found at the frequencies the cavities will resonate at. The frequency spectrum displays an infinite number of resonances above a certain frequency gathered into groups called multiplets (by analogy to spectroscopy and atomic structure). Reference to Fig. 10B will show these multiplets. Many of the resonances occur in pairs, members of which have the same frequency in the symmetrical unstrapped magnetron and are hence called "degenerate modes." Of the multiplets, only the first, the so-

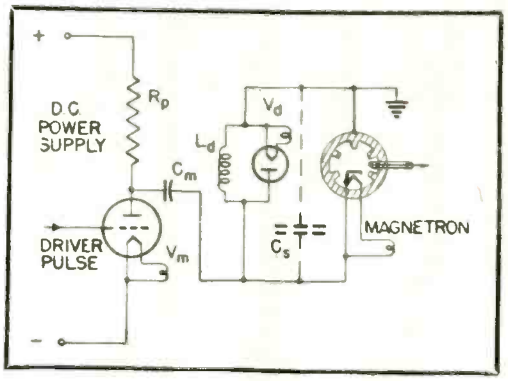



**Fig. 17. Schematic diagram of a conventional magnetron modulator circuit.**

called "fundamental multiplet," has any practical importance. Each mode in the multiplet is known according to the angular periodicity of the corresponding fundamental Hartree harmonic, a periodicity indicated by the "*n*-number" or number of complete angular cycles in the harmonic (Fig. 7C). Although an asymmetry will resolve the degenerate modes (Fig. 10B), this ordinarily does not occur, and we find four *n*-numbers for the eight-cavity magnetron (2J22-2J34) and six *n*-numbers for the one with twelve (2J42). The customary $\pi$-mode operation is at the $n = 4$ and $n = 6$ modes, respectively.

The use of strapping to make the operation in the desired mode more reliable is very important. Since, under the usual loading, the *Q*'s of the modes in the multiplets are of the order of 100, adjacent modes may overlap. Unwanted wavelengths may then be produced as well as the desired one, and the efficiency will be poor. Thus the $n = 3$ mode adulterates the desired $n = 4$ mode in the unstrapped eight-cavity tube. This difficulty may be overcome by strapping, in which the various anode segments are connected in the proper fashion. Strapping functions by separating the wavelengths of the modes in the multiplet so that overlapping does not occur. One form is shown in Fig. 10C. Other forms exist, such as the double-strip strapping of the 2J42 (Figs. 2 and 5B).

An equivalent circuit for the cavities in the $\pi$-mode appears in Fig. 3B. The electrons act as if they were connected in parallel with the segments. Other modes in the multiplet would correspond to more complicated electron and mutual inductance connections.

The one remaining important problem is that of the load connection. The equivalent circuits of Fig. 3C and D will help. The output pipe acts like an impedance transformer. By varying the loop, and by different constructions of the output pipe, we may change the effective admittance coupled in from the outside. This external load, which is an antenna in a radar set, usually has the main transmission line matched to it to prevent corona and breakdown. Thus the load is fixed. By properly designing the output pipe and loop, however, the admittance coupled in under the conditions of match described, may be made just the correct value to transfer the desired power to the load under stable conditions.

If the loop is coupled too tightly, however, another effect may occur. Load variations may cause an excessive shift in operating frequency that could not be compensated by the automatic frequency-control circuits. This would occur from a strong reflection from a mast or wing strut or a defective rotating joint in the radar transmission line itself. The radar might become blind. This phenomenon is known as frequency pulling. (It is usually limited to frequency variations over a maximum range of 15 mc. when the voltage-standing-wave-ratio, looking into the load in the main transmission line, is set at 1.5 and varied through all phases.) It was found at the M.I.T. Radiation Laboratory how to keep the pulling low and still have good power output. See Fig. 9B for the 2J42. Two shorting posts (parallel to the *E*-vector) are placed a half-wavelength apart in the wave guide portion. With a matched load, the posts resonate and their reflections just cancel. When the load changes and the tube is pulled, they set up reflections to compensate for the external impedance change and keep the admittance coupled into the cavities relatively unchanged. By this means the pulling in the 2J42 may be decreased by 50% without lowering the output more than 5-10%.

We have discussed the present state of the magnetron from both practical and theoretical viewpoints. The future will see the peacetime application of radar to marine and aviation navigation and control. Because of the many channels and the selective beaming possible, communication at microwave frequencies will have wide application, too. In all these fertile fields,

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the magnetron will clearly become a common and useful tool.

The author wishes to acknowledge the great help of Dr. Rieke of the M.I.T. Radiation Laboratory staff in the preparation of this article.

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**PHOTO CREDITS**

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3, 4, 5, 6.....Radiation Lab., M.I.T.

7, 8, 10, 35. Minneapolis-Honeywell Regulator Co.

15, 16, 17, 20, 37..Sylvania Electric Products, Inc.

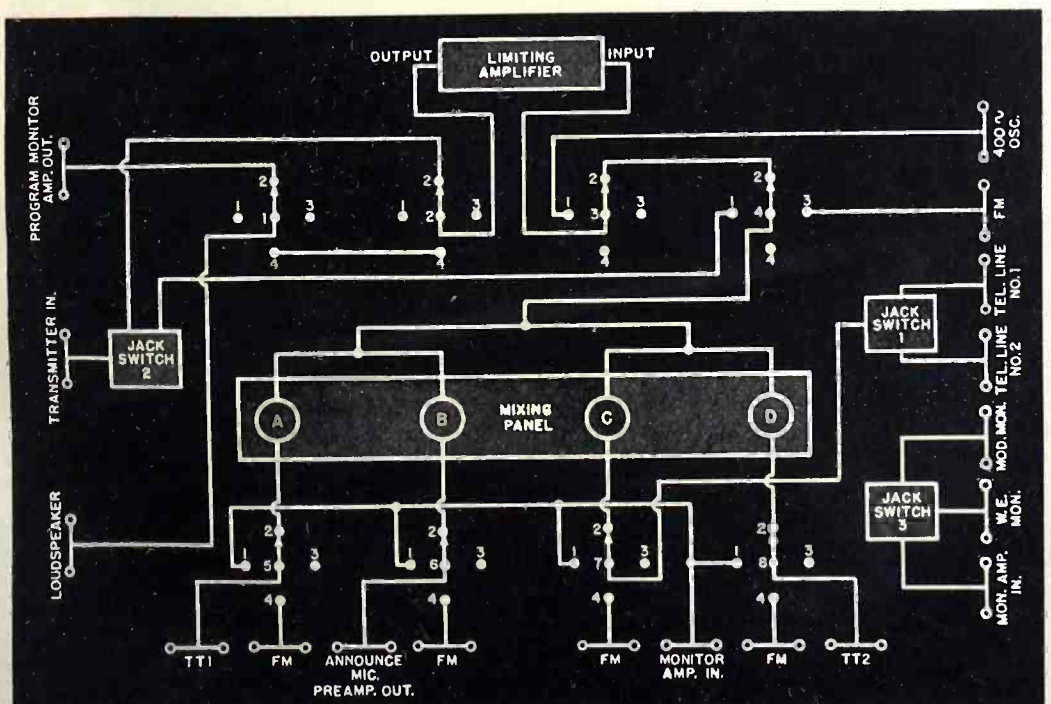

# Replacing Jack Strip

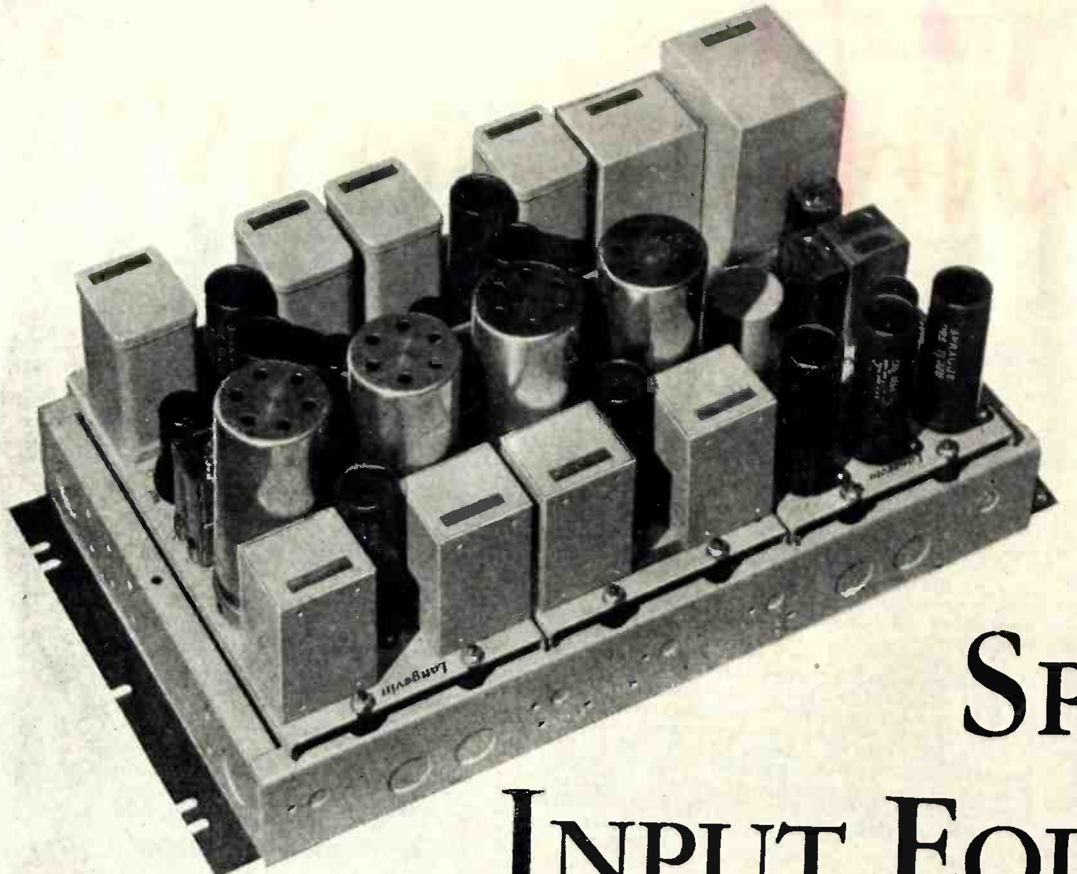
*(Continued from page 11)*

tables and the microphone, or the entire fader panel output, to an FM transmitter. All the rotary switches contain blank contacts for future expansion. Both input and output of the limiting amplifier may be switched around as desired with switches 2 and 3, while the loudspeaker may be placed on the output of the limiting amplifier for testing with switches 1 and 2. A large number of switching combinations are possible. The 400 cycle audio oscillator may be placed on the input of the limiting amplifier for distortion tests, level then being adjusted with the control on the oscillator. The system is arranged so that all rotary switches are placed on No. 2 contact (straight up) for normal operation. A glance at the panel is all that is necessary to know that everything is right.

A similar installation is used at the studio to handle incoming remote program lines, outgoing lines, and recording lines. In over three years operation, a failure has never been experienced that could be attributed to the switching panel.

**Fig. 2. Block diagram of switch panel designed to replace the jack strip.**

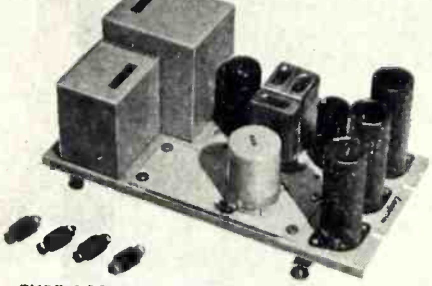




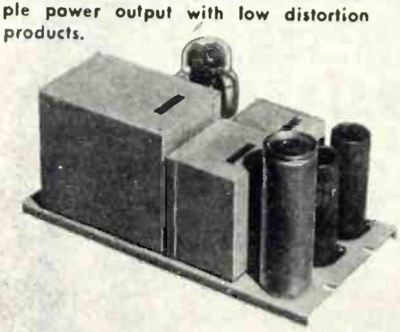
AT LEFT. Two Langevin Type 111-A Dual Pre-Amplifiers and one Langevin 102-A Line-Amplifier mounted on a 3-A Mounting Frame. This unit provides four pre-amplifiers and one line-amplifier, or three pre-amplifiers, one booster-amplifier and one line-amplifier, all in 10½" of rack mounting space. External power supply such as the Langevin 201-B Rectifier, as shown below, is required.

# SPEECH INPUT EQUIPMENT

## *Worthy of an Engineer's Careful Consideration*



**TYPE 102A Amplifier** is one of the 102 Series Line Amplifiers of which four different types are available. The "A" is mostly used to drive the line after the master gain control. It is quiet, has excellent frequency characteristic and ample power output with low distortion products.

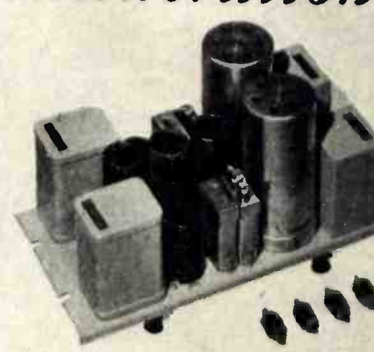


The 201-B Rectifier is one of the 201 Series Rectifiers, of which two types are available, the "B" having additional filtering, thereby giving a slightly lower ripple content than the "A." This unit is capable of supplying power for one 102 Series Line Amplifier and three 111 Pre-Amplifiers (six pre-amplifiers).

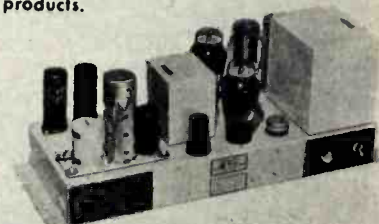
Every unit of Langevin speech input equipment is held to a rigid standard of performance. These units may be cascaded in accordance with good engineering practices and still be well within the allowable limits of FM requirements as to frequency response, noise and distortion products.

All Langevin speech input equipment units are mounted on standard 5¼" x 10¼" chassis. Three of these units can be mounted on a Langevin 3-A Mounting Frame, which occupies 10½" of space on any standard rack. Wall mounting steel cabinets for housing these units are also available.

We are proud of the products which bear the name ***Langevin***. It will only appear on good apparatus.



The 111-A Amplifier consists of two individual pre-amplifiers on a single chassis for use in high quality speech input equipment. Its compact unitized construction saves rack space. Input impedances of 30, 250 and 600 ohms; output impedance 600 ohms. It is quiet and has excellent frequency characteristics and ample power output with low distortion products.



The 108-A Amplifier is one of the 108 Series Monitor Amplifiers, of which four different types are available. The "A" is ordinarily used to drive a monitor system from a 600 ohm or bridging source. Its distortion is low for this type of service. It is quiet and has ample power with excellent frequency characteristics.

**The Langevin Company**
INCORPORATED
SOUND REINFORCEMENT AND REPRODUCTION ENGINEERING

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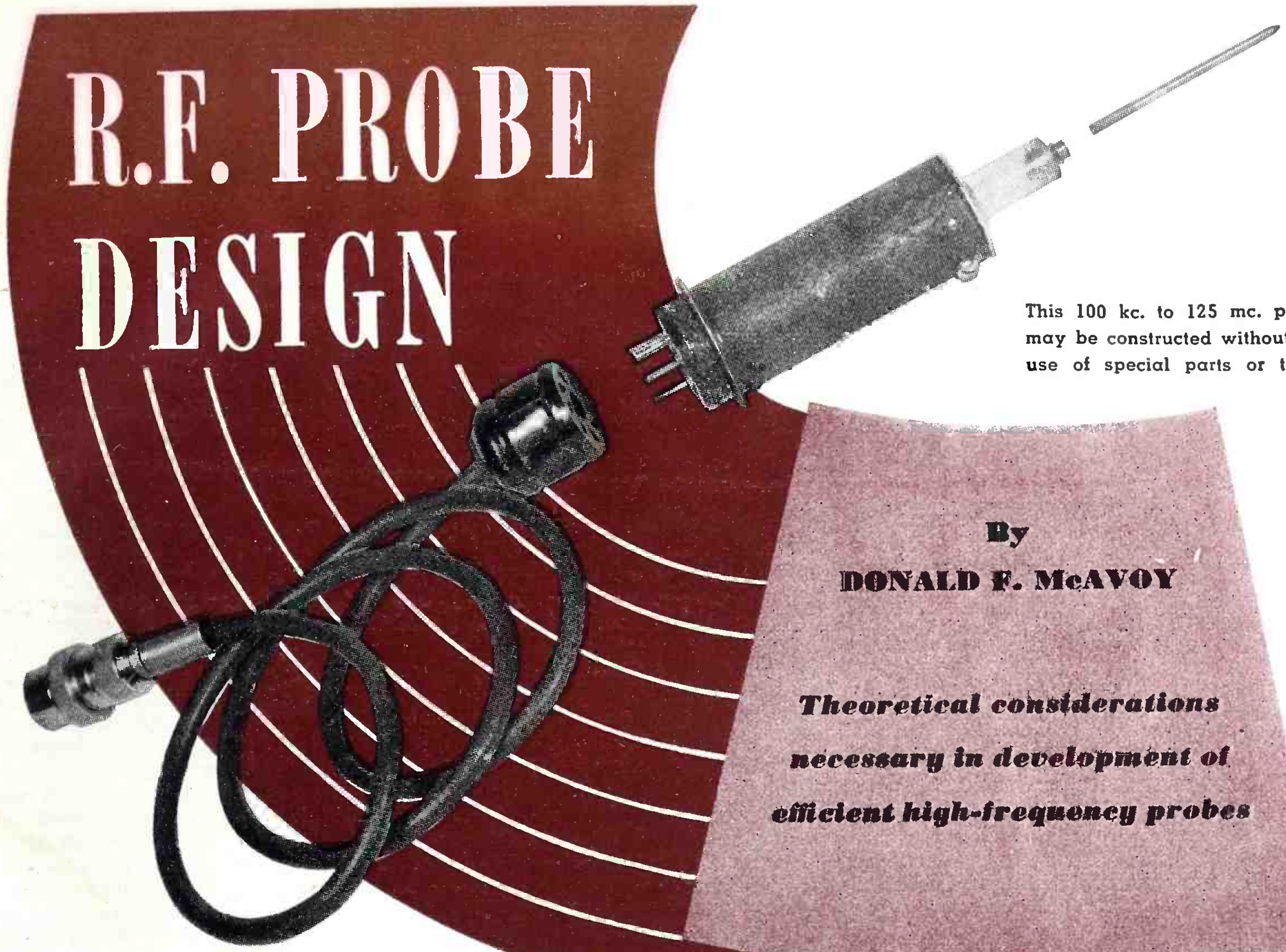
# R.F. PROBE DESIGN



This 100 kc. to 125 mc. probe may be constructed without the use of special parts or tools.

By
**DONALD F. McAVOY**

***Theoretical considerations necessary in development of efficient high-frequency probes***

THE probe described in this article is primarily designed for use with a multi-range, d.c. electronic voltmeter which has an input resistance of 10 megohms (or more) and a sensitivity of 3 volts (or less) full-scale deflection on its low-voltage range. Thousands of such d.c. instruments are in use today. When so used, the combination makes available an excellent signal tracing device which is usable at any frequency between 60 cycles and 125 megacycles.

At frequencies above 100 kc. the rectified d.c. output of the probe is equal to the peak value of the applied voltage. For voltages with sinusoidal waveform, the peak value is equal to 1.414 times the r.m.s. value. For voltages of non-sinusoidal waveform, such as square wave, pulse, and saw-tooth voltages, the peak value may or may not equal 1.414 times the r.m.s. value. The probe will, however, allow measurement of the peak value of any voltage regardless of its harmonic content, providing the frequency is between 100 kc. and 125 mc.

At frequencies below 100 kc., the rectified d.c. output of the probe gradually falls off in amplitude until, at 60 cycles, it is approximately 20% of the peak value of the applied voltage. This attenuation with frequency occurs because, at the lower frequencies the *RC* time constant of capacitor $C_1$ and the load resistance becomes shorter in comparison with the time required for a period (1 cycle) of the applied voltage. The attenuation can be eliminated by the use of a large value of capacitance for $C_1$ but this means an increase in the physical size of the capacitor. The increase in physical size, as is explained later in this article, decreases the efficiency of the probe at the higher frequencies. In any event, the attenuation does not appreciably detract from the usefulness of the probe at the lower frequencies because comparison measurements of voltages are usually sufficient for signal tracing or stage gain tests when performing service work.

Another advantage of the probe is that its maximum efficiency begins at 100 kc., the upper frequency limit at which the majority of test oscilloscopes are capable of checking signals of low voltage levels.

The input impedance of the probe is so high, even at the higher r.f. frequencies, that measurements may be taken without appreciable loading or detuning of the circuit under test. This input impedance is a complex function of the frequency of the applied voltage and consists of resistive and reactive components.

*Resistive component.* The presence

Fig. 1. Cross-sectional illustration showing details of probe assembly.