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THE CROSSBAR SWITCH
J. N. REYNOLDS

COAXIAL SYSTEM:
CARRIER SUPPLY
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GROUP TERMINALS
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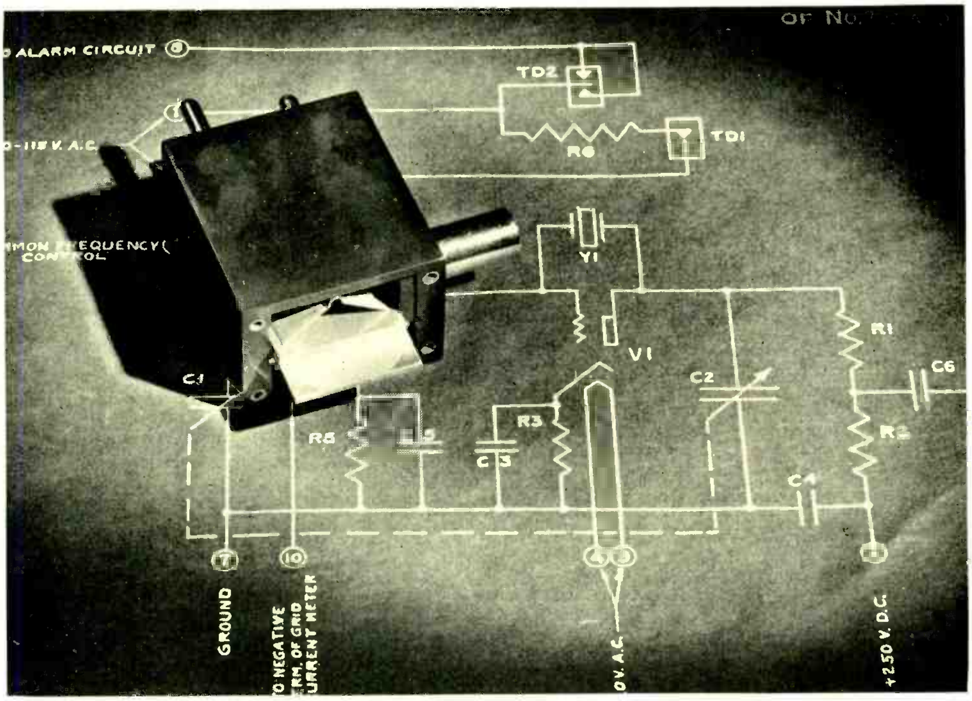


A Western Electric quartz plate unit photographed on a blueprint of a crystal-controlled oscillator circuit

JULY, 1937

VOLUME FIFTEEN—NUMBER ELEVEN

The Crossbar Switch

By J. N. REYNOLDS
Apparatus Engineer

THE problem of telephone switching, or how best to connect any one telephone line to any other, has always been of fundamental importance to telephone engineers. It is an extremely complicated problem, however, and may be subdivided in various manners, depending on the aspects to be particularly stressed or the degree of detail with which it is to be studied. One convenient division is into systems problems and apparatus problems. The first group arises primarily because of

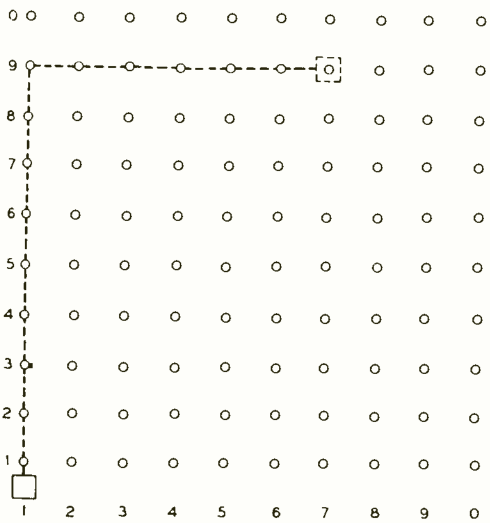


Fig. 1—The step-by-step switch includes 100 groups of terminals and one brush

the very large number of lines that must be capable of being interconnected, and considers trunking schemes and circuits. The second is concerned with the actual switching apparatus used to make connections between lines and trunks. The two phases of the main problem are not unrelated, since the form of circuits and system employed may affect the type of apparatus required, and conversely the type of apparatus available affects to a considerable extent the type of system that must be provided.

In the crossbar switch there is made available a distinctly different type of switch, and one that offers very definite advantages over previous types. Its most effective utilization will require a somewhat different system of trunking and different circuits, but neither of these latter aspects need be considered in pointing out the essential nature and advantages of the crossbar switch itself. It is necessary, however, to indicate the basic characteristics of the earlier forms of switching to illustrate the specific difference of the crossbar type.

The type of switch that is used almost exclusively in manual telephone systems (using "switch" in the broad sense as any means of connecting one wire or circuit to another) is the plug and jack. A trunk or line is permanently connected to a jack, and another trunk or line is connected to a plug—either directly or through some other connecting device; and to make the desired connection, the operator picks up the plug, locates the jack of the line or trunk desired and pushes the plug into it. When mechanical methods of switching were developed, they followed the basic principle of

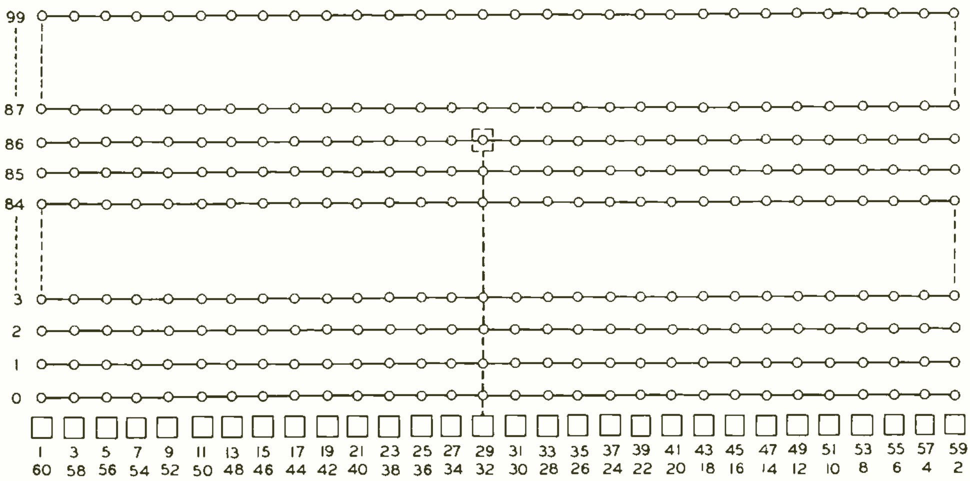


Fig. 2—The panel unit consists of 60 multipled terminals in each of 100 rows, and a brush is provided for each of the 60 terminals of the multiple

plug and jack, but the jacks were replaced by small metal terminals arranged in compact banks, and the plugs were replaced by brushes. These were made to slide along the terminals of the bank until they reached the terminal of the desired line, when a connection would be made. Two forms of machine switching have been widely used in this country: the step-by-step, and the panel system. In the step-by-step system one brush is employed for each bank, and it moves both vertically and horizontally until the desired terminal is reached. With the panel system, the brushes move only vertically, but the banks are larger, and accommodate a number of brushes operating over parallel vertical paths.

The arrangement of the step-by-step switch is illustrated in Figure 1. Terminals for one hundred lines or trunks are arranged in a bank consisting of ten rows of ten sets of terminals each. One brush is provided for each such bank, and when not in use it rests below the bottom row of terminals at the extreme left of the bank. The terminals in the bank correspond to the jacks of the manual system, and the brush corresponds to the plug. To establish a connection the brush is moved: up by the action of a magnet, which lifts it one row for each operation; and then across the row horizontally by another magnet which moves it one contact in the horizontal direction for each operation. To connect the trunk associated with the brush of this bank to trunk 97, for example, the brush would be "stepped" up to the 9th row

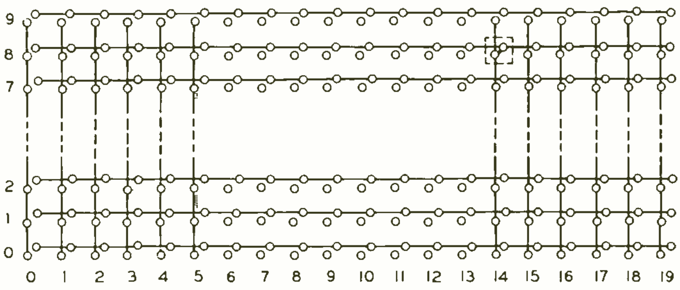


Fig. 3—In the crossbar unit two sets of terminals are mounted in place of the one set that is used in the step-by-step and panel systems and sliding contacts are eliminated

and then over to the 7th terminal.

The banks of the panel system also, for the most part, have terminals for 100 lines, but instead of being arranged in a square array they are all mounted one above the other, and the banks are thus one hundred sets of terminals high. There are sixty sets of terminals in each horizontal row—thirty on one side of the bank and thirty on the other. All the terminals in the same row, however, are connected together so that they represent only one line or trunk. Instead of one brush at the bottom, as with the step-by-step switch, there are sixty—one for each column of terminals on each side as indicated in Figure 2. The brushes on one side are assigned even numbers and those on the other side, odd numbers. Here, as in the step-by-step system, the terminals in the bank correspond to jacks, and the brushes, to plugs. The brushes are driven upward at a uniform rate by a motor-driven friction drive at the bottom of the frame, which usually consists of five such banks, each with its own set of brushes.

Both of these systems work very satisfactorily under conditions for which they are most suitable. There are two respects, however, in which improvement seemed possible. One is that with either system a comparatively complex mechanism is required to operate the brushes. The other is that a sliding contact is required, and the terminals and brushes must be of some durable metal to withstand the wear. Unfortunately, the harder metals do not have as low contact resistance as the softer precious metals such as silver, and are more subject to the formation of poorly conducting surfaces. The crossbar switch brings improvement in both of these conditions. It avoids sliding contacts and thus facilitates the use of precious metal contacts, and it accomplishes the required connections with a much simpler mechanism. It does this by employing an entirely different and much more direct method of switching.

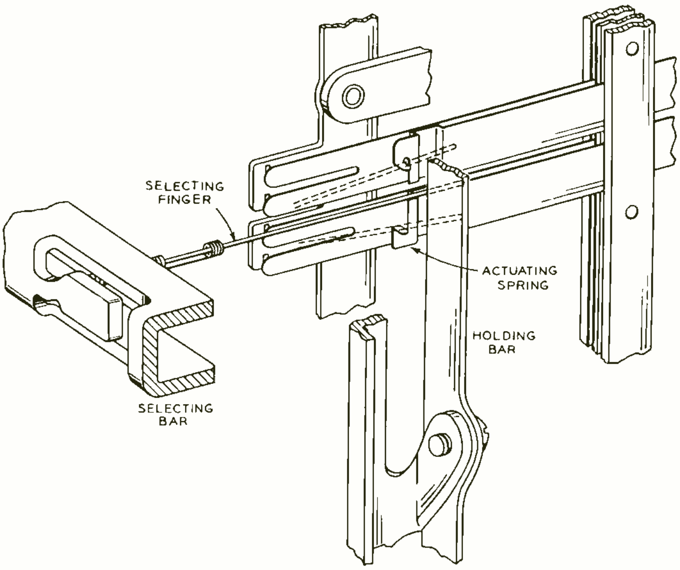


Fig. 4—Simplified schematic of the selection elements of a crossbar switch

In the manual system, and in both the step-by-step and panel systems, which resemble it in this respect, the members of one set of terminals are banked together, and the members of the other set, which are to be connected to those of the first, are arranged to be moved up into contact with them. In the crossbar system all such necessity of motion is avoided by mounting a pair of contacts at each position in the bank, and by eliminating the

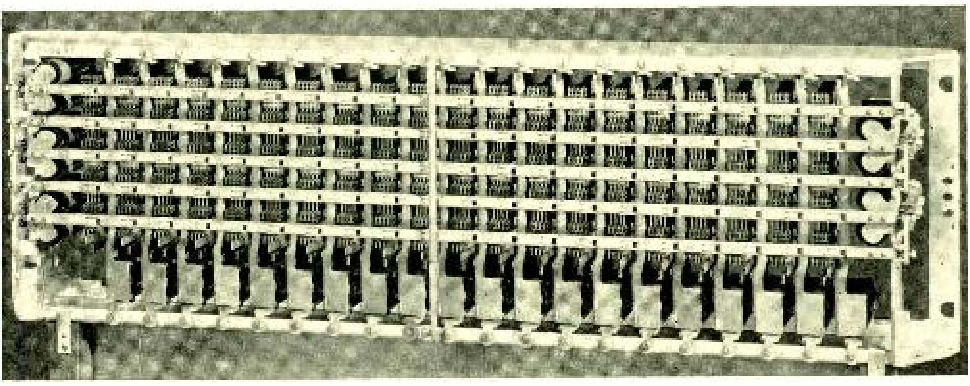


Fig. 5—The crossbar switch has 5 selecting bars and thus 10 horizontal rows of contact groups, and up to 20 holding bars and thus 20 rows of vertical contact groups

brushes completely. The arrangement is as shown in Figure 3. One contact of each pair is multipled with the corresponding contacts of the other pairs in the same column, and the other contact of each pair is multipled with the corresponding contacts of the other pairs in the same row. The horizontal multipling corresponds to that of the panel system, while the vertical multipling is as though the brushes of the panel bank had been provided in multiple with as many brushes in each column as there were rows. Instead of moving up a brush, therefore, it is necessary only to close the contacts at the proper position in the bank to make the desired connection. The motion of the brush is avoided. The only movement required is that of a mechanical link to close the required set of contacts.

How this is accomplished is indicated by the simplified diagrammatic sketch of Figure 4. Between each pair of horizontal rows is a bar running completely across the bank, which may be rotated a small amount in either direction around its axis by the action of two magnets and armatures at one end. Wires projecting inward toward the contacts are attached to these bars at each intersection with the vertical columns. With the horizontal, or selecting, bars in their mid-positions these wires, or selecting fingers as they are called, lie between the two rows of contacts, but when the bar is rotated in one direction the fingers move up to lie across the backs of the contacts in the row above it, and when it is rotated in the other direction, the fingers are moved to lie across the backs of the contacts in the row below, as indicated by the dotted lines in Figure 4.

Along each column of contacts is a vertical, or holding, bar which—when rotated by a magnet and armature at one end—moves a vertical bar inward to press against all the selecting fingers in that column. If none of the selecting bars are operated when the holding bar moves in, the fingers will merely be pushed down between the rows of contacts and no connection is made. If one of the selecting bars is operated, the fingers of that bar will lie across the backs of one row of contacts, and when the holding bar operates, the contact at the intersection of the selecting and holding bars that are operated will be moved into contact by the action of the holding bar against the finger which, in turn, lies across the back of the contact spring. The holding bar remains operated during the period of the call, but the selecting bar returns to normal immediately after the holding bar has operated. When the selecting bar returns to the central position, all the fingers return with it except the one held by the holding bar, thus leaving the selecting bar free for another selection with a different holding bar. The fingers are small and readily flex over the small arc of rotation of the selecting bars.

The actual appearance of a crossbar unit is shown in Figure 5, and in partially schematic form in Figure 6. There are five selecting bars, and thus ten horizontal rows of contacts; and there are twenty holding bars, and thus twenty vertical rows of contacts, although other numbers of holding bars may be used. The contacts themselves are similar to those of an ordinary relay and each contact in Figure 3 represents several contacts in the actual switch. Similarly each of the contact points indicated in Figures 1 and 2 really represents a group of contacts in the step-by-step or panel banks. In the crossbar system, moreover, twin contacts of precious metal are provided, thus giving greatly increased assurance that a good connection will be made.

The gain in simplicity of operation is very obvious. In the step-by-step system, for example, the upward motion of the brush is caused by one magnet operation for each row the brush passes over, and similarly for the horizontal motion. In the panel system upward motion is caused by operating a clutch at the bottom of the frame, and then the brush is driven upward at a uniform speed by a power drive. The upward motion is actually accomplished in two steps, separated by a slight pause. In the crossbar switch, however, only two magnet operations, one immediately following the other, are all that are required.

The avoidance of sliding contacts in the crossbar system is equally obvious. The contacts are merely pressed

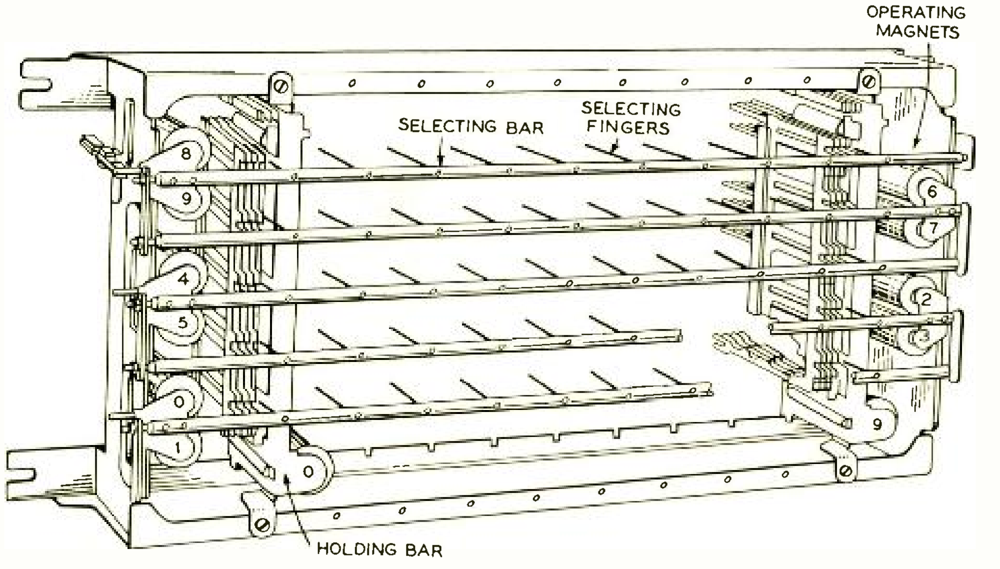
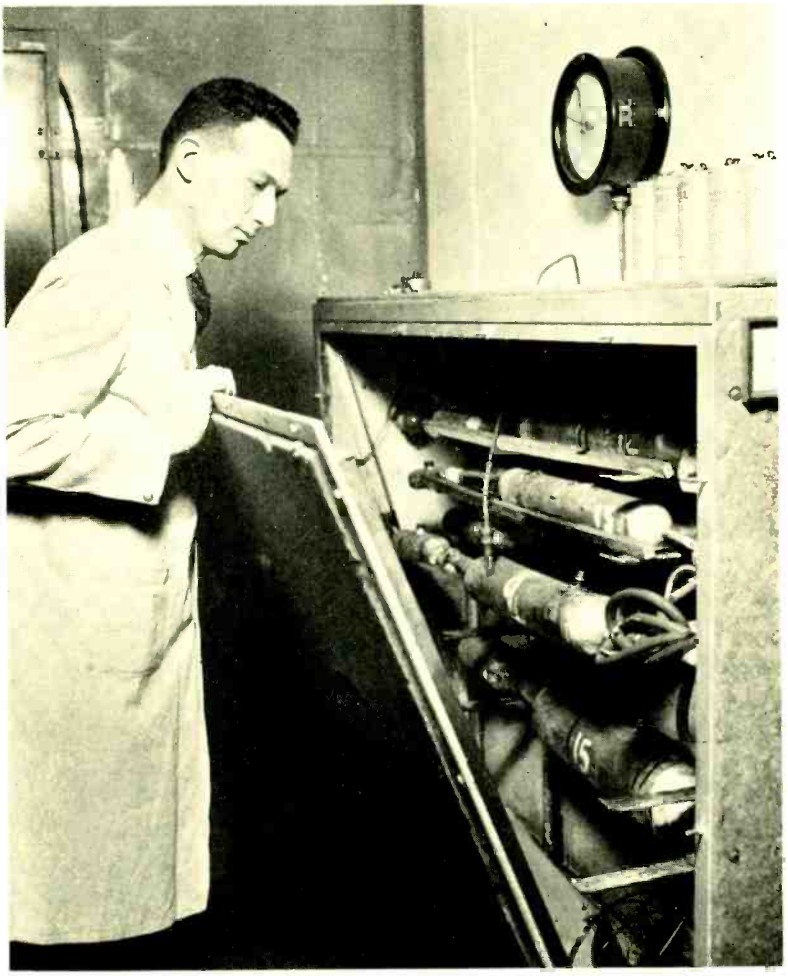


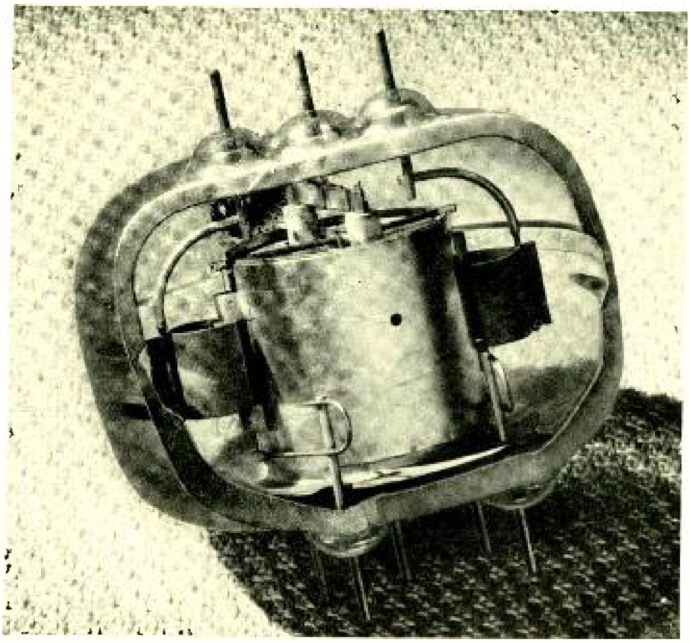
Fig. 6—Partial perspective of the crossbar switch

together as in a relay when a connection is made, and no sliding in the ordinary sense occurs.

By this adoption of a new basic scheme of switching, and by the provision of a suitable mechanical method of operation, it has been possible to provide a distinctly new type of dial switching. It is much too early to make predictions as to the extent of its ultimate use or the net improvements that will accrue from its employment, but it offers opportunity for shortening the switching time and for decreasing the maintenance. Apparatus has been manufactured, and the first trial installation in a dial central office is now going forward.



Several specimens of pressure-testing plugs are being subjected by H. Baillard to life tests at elevated atmospheric temperatures



A Power Amplifier Tube for Ultra-High Frequencies

By A. L. SAMUEL
Vacuum Tube Development

THE development by the Laboratories of an amplifier tube capable of handling a moderate amount of power at frequencies as high as 300 megacycles per second now makes possible an appreciable extension of the usable portion of the radio-frequency spectrum. The use of conventional vacuum tubes at these very high frequencies has been found unsatisfactory because of certain effects which at lower frequencies are of secondary importance. For an appreciation of these effects, certain concepts are necessary.

One of them has to do with the time required for the electrons to travel from the cathode to the anode within the tube structure. This time is the so-called electron-transit time. At low frequencies it can be neglected; at high frequencies it must be considered. One effect it produces is a lag in the phase of the output current with respect to the grid potential. The calculation of this delay is complicated by an important distinction which must be drawn between the rate of arrival of electrons at the plate and the plate current. As an electron approaches the plate it induces in that plate an image charge. The magnitude of this charge varies with the proximity of the electron to the plate. The flow of current in the conductor to provide this charge actually constitutes the plate current. Viewed in this light the component of plate current due to any given electron commences to flow when this electron leaves the cathode and ceases to flow at the instant of the electron's arrival at the plate. Nevertheless, the net effect of the transit time, as may be shown by a detailed analysis, is to produce an appreciable phase difference between the grid potential and the plate current.

A further consequence of the finite transit time is that under operating conditions (that is with alternating potentials on the tube electrodes) the electrons arriving at the plate will usually have velocities greater than the velocity corresponding to the potential of the anode at the instant of their arrival. The excess energy corresponding to the greater velocity is obtained from the alternating component of the electrode potentials, and its dissipation at the plate in the form of heat decreases the useful output obtainable from the tube. Part of this energy comes from the grid circuit, and is responsible for the so-called input impedance or active grid loading. The practical effect of this input loading in an amplifier is to increase the power demands placed upon the input supply. Its effect is by no means negligible even at only moderately high frequencies, and at ultra-high frequencies this input loading becomes of major importance.

A second important concept for the correct understanding of ultra-high-frequency tube design has to do with the increased importance played by the interelectrode capacitances and the lead inductances. The difficulties encountered in the use of the simple three-element tube as an amplifier at moderately high frequencies as a result of feedback or singing caused by the interelectrode capacitances are, of course, well known. Such difficulties are greatly increased at higher frequencies. They may be largely overcome by the use of a multi-element tube structure. At ultra-high frequencies, lead inductances common to both input and output circuits produce a similar effect, and so must be avoided in the tube design.

The large charging current required by the interelectrode capacitances at high frequencies affects the cathode design. At low frequencies the rate at which electrons leave the cathode at any instant is identical with the rate at which they arrive at the anode. At high frequencies this is no longer true. The peak instantaneous emission may greatly exceed the value that would be required for operation under identical voltage conditions but at a lower frequency. The high charging current is also responsible for an increase in the resistance losses in the tube leads. The resistance of these leads is, of course, greatly increased at high frequencies because of the so-called "skin" effect. Resulting losses decrease the efficiency

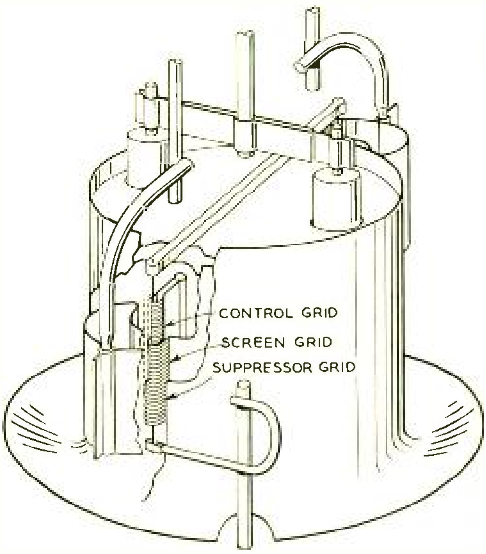


Fig. 1—Perspective sketch of the new high-frequency double pentode

of the tube and may, in a power tube, produce enough local heating to cause a more or less rapid deterioration of the lead-to-glass seals, which may ultimately destroy the vacuum. Short, heavy leads are therefore required for ultra-high-frequency operation.

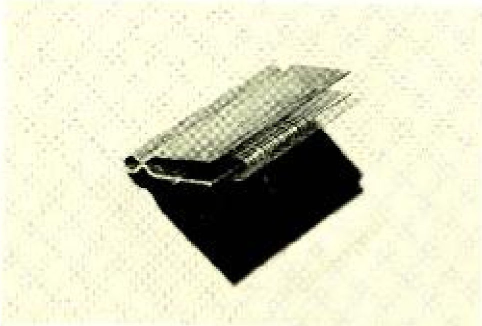


Fig. 2—One of the grid structures of the new tube shown slightly more than three times actual size

The interelectrode capacitances together with the lead inductances are responsible for still another difficulty. The frequency to which the input and output circuits of an amplifier may be tuned is set by the natural frequency formed by the interelectrode capacitances and their associated lead inductances. For most practical purposes the operating frequency of an amplifier must be well below these values. This places an upper limit on the permissible values that the interelectrode capacitances and lead inductances can have.

Many of the factors which have been discussed can be compensated by reduction in dimensions. It can be shown, in fact, that if all the dimensions of a vacuum tube are reduced in the same proportion, the trans-conductance, plate current, and amplification factor for fixed electrode potentials will remain unchanged while the values of interelectrode capacitances, lead inductances, and electron-transit time will be reduced in direct proportion to the reduction in size. Unfortunately, a reduction in dimensions without a corresponding reduction in all operating voltages is possible only at the expense of an increased demand on the emission capabilities of the cathode. The required emission per unit area must vary inversely as the square of the linear dimensions. Added to this is the increased demand caused by the high-frequency charging currents already discussed. The available emission is fixed by the character of the cathode surface, and cannot easily be increased. A proportionate reduction in cathode dimensions, therefore, is not feasible. Furthermore, the proportionate reduction of the anode dimensions would require an increase in the power dissipation per unit area—again inversely proportionate to the change in linear dimensions. While the heat-dissipating ability of the anode can be increased in a number of ways, most of these will increase the tube capacitances. The high grid temperatures which may result from the reduction in dimensions also makes necessary the introduction of cooling provisions. Because of these effects one must combine a reduction of dimensions with the introduction of special mechanical arrangements to overcome the otherwise harmful effects of this reduction.

All these factors have necessarily been taken into account in the development of the new tube. As may be seen in Figure 1, and somewhat in the photograph at the head of this article, it consists of two relatively large concentric metal cylinders and two sets of tube elements diametrically opposite each other outside the outer cylinder. The cylinders act as a tional pentodes of similar ratings at much lower frequencies. Stable operation with some gain has been obtained at frequencies as high as 500 megacycles. When operating as a class A amplifier at 150 megacycles, an output of 1 watt is obtained with the distortion 40 decibels below the fundamental. Under these conditions the stage gain is 20 decibels. Outputs of 10 watts with a plate efficiency of 60 to 70 per cent and a gain of 10 decibels are secured when this tube is used for class B operation.

The development of this tube demonstrates that power amplifier tubes of the negative-grid type are usable at higher power levels and frequencies than have been reported previously. This type of development removes a practical barrier which, up to the present, has prevented the successful utilization of frequencies that extend above one hundred megacycles.

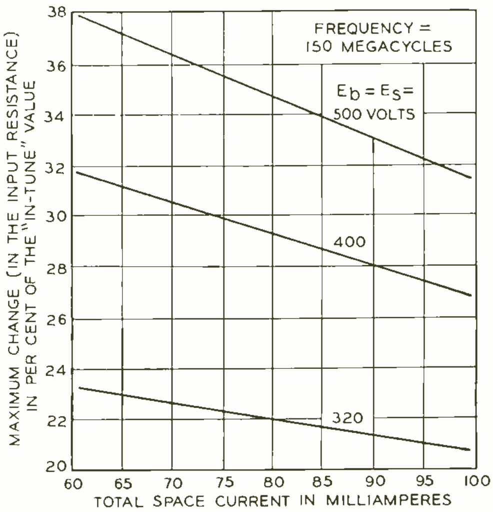
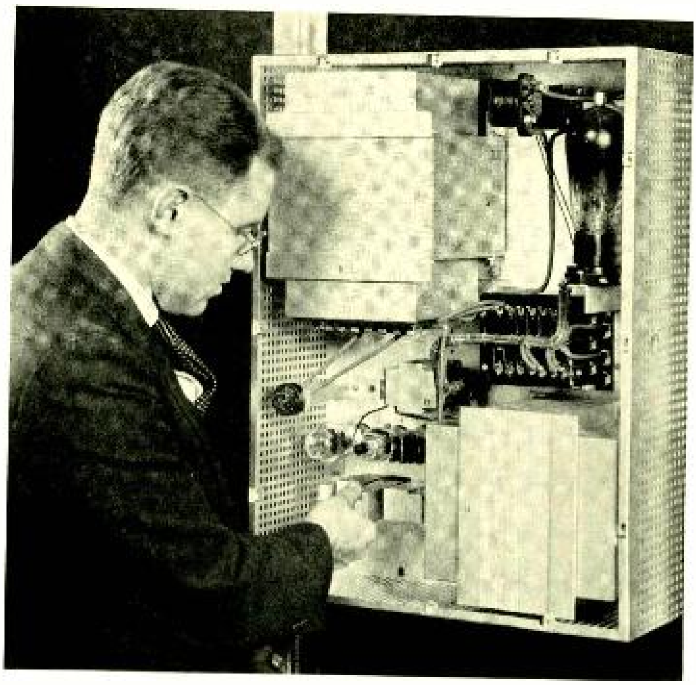


Fig. 5—Input-output reaction determined experimentally at 150 megacycles



Rectifier for Telephone Power Supply

By D. E. TRUCKSESS
Equipment Development

IN small central offices the storage battery which supplies power for the telephone equipment is usually charged with a rectifier, such as the Tungar rectifier. Chargers of this type are equipped with two-element tubes and require a regulating device, usually including a rheostat, which is wasteful of power and frequently requires manual control to maintain the voltage within the limits required by the telephone circuits.

It is often not practicable to provide manual control, particularly in outlying offices, and for such situations a device is required which does not demand continuous attention. This need has been effectively met by a new type of rectifier with grid-controlled tubes, which automatically maintains the charge in the battery, regulates its voltage and recharges it when necessary.

The success of the device depends on the use of grid-controlled rectifier tubes, a recent development which has greatly extended the application of rectifier tubes to power problems. The addition of the grid does not give continuous control of the plate current as is the case in conventional three-element vacuum tubes but it makes it possible to control the time when the plate current begins to flow. This occurs when the grid voltage becomes less negative than the critical breakdown grid voltage of the tube. With grid voltages more negative than the critical value, plate current cannot flow. As soon as the current starts, however, the grid loses control and the magnitude of the plate current is determined by the load impedance and plate voltage.

In this case the current will continue to flow until the plate voltage is reduced to zero, hence an alternating-current voltage applied to the plate lets the grid regain control every cycle. This makes it possible to control the output current of the tubes by changing the relative phase relations of the voltage applied to their grids and plates. When the grid voltage is in phase with the plate voltage the tubes will deliver maximum current by starting them at the beginning of each cycle, and when 180 degrees out of phase they will deliver no current since the plate voltage is zero when the tubes are to be started. The phase relation of the grid voltage can be changed by varying the resistance in one arm of a phase-shifting bridge circuit, which is the method used to regulate the rectifier's output voltage.

The details of the circuit are shown on Figure 1. The output of the plate transformer T1 is applied to the grid-control tubes V1 and V2. Retardation coil L1 is used in the rectifier circuit to filter the direct-current output. Automatic control is obtained by applying the battery voltage to the screen-grid vacuum tube V4 which amplifies the fractional volt changes to several volts. The plate of this tube is connected to the grid of the three-element vacuum tube V3 whose plate-cathode resistance constitutes one arm of a bridge-type phase-shifting circuit, which includes two windings of the transformer T2 and the condenser C1. The voltage across the bridge is applied to the grids of the rectifying tubes through the transformer T3. As the battery voltage varies the regulator tube V4 varies the bias on the phase shifting tube V3, and changes its plate-cathode resistance. This shifts the phase of the grid voltage of tubes V1 and V2, thus changing the output current from the rectifier in a direction to cause the battery voltage to return to the desired value, and in this way maintain a constant battery voltage. For manual control of the output the vacuum tubes V3 and V4 are disconnected and a rheostat is substituted for V3.

If the rectifier output current exceeds its capacity the rectifier is converted to constant-current operation and the battery is charged at a constant rate until its voltage reaches the

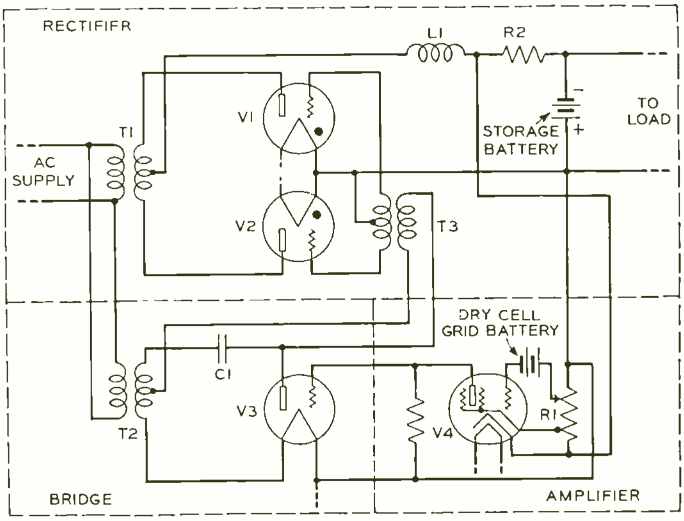
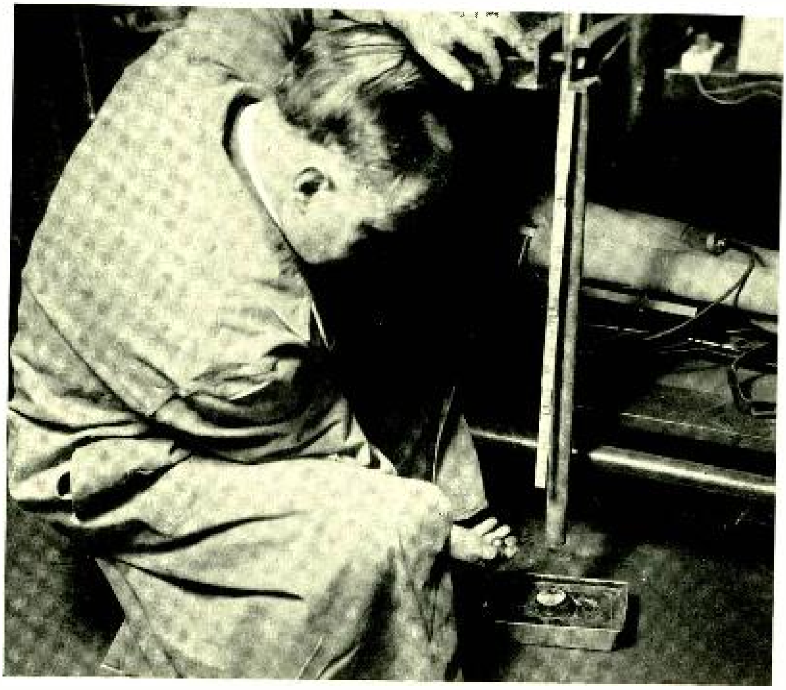


Fig. 1—These rectifiers have two three-element grid-controlled mercury-vapor tubes whose output is automatically regulated by changing the phase relations of the voltages applied to their grids and plates

desired overcharge value. This is accomplished automatically by the operation of a transfer relay, actuated by a current relay in series with the output of rectifier, which transfers the grid of tube V4 from resistor R1 to the series resistor R2, in the negative output lead. The regulator maintains a constant voltage drop over R2 and thus a constant current output. When the desired overcharge voltage is reached a high-voltage alarm relay releases the transfer relay and returns the circuit to constant-voltage operation. This permits the rectifier to be used in unattended offices as it can start automatically after a power failure, charge the battery and return to normal floating operation without any adjustments from an attendant. It also permits the rectifier to be used in other than telephone power plants where the load on the battery may vary from no load to several times the capacity of the rectifier.

The headpiece shows a rectifier of this type which has a DC output of 8 amperes. It can be used at 132, 142, or 152 volts with only an adjustment of taps on the R1 resistance.

This regulating circuit will maintain the battery voltage constant within ± ¼ per cent for line voltage changes of ±10 per cent, for load changes from no load to full capacity, and for room temperature changes from 10 to 40 degrees Centigrade. This is much better control than can be attained with unregulated rectifiers equipped with two-element tubes.



In this impact test for goggles, W. S. Hayford is observing the effect of dropping a steel ball upon the glass from any desired height in a metal tube shield between the input leads to the control grid and the output side of the tube, as supports for the screen and suppressor grids and as a radio-frequency by-pass condenser between them, and as low-impedance leads interconnecting the two sets of screen and suppressor grids. The control grids are of an unusual design, consisting of a cooling fin to which are attached loops of tungsten wire encircling the thoriated tungsten filament. One of these is shown in Figure 2. These control grids project through the slots in the cylinders and are in turn surrounded by loops of wire attached to the inner and outer cylinders and acting as the screen and suppressor grids respectively. The control grids are supported directly on their leads which project through one face of the tube envelope. The semi-cylindrical anodes are also supported directly on their leads which project through the opposite face of the tube envelope. This unusual construction is made desirable by the ultra-high-frequency requirements which have just been described.

In spite of the unusual form of the tube, electrically it is the equivalent of two conventional negative-grid, pentode tubes. Its performance at frequencies as high as 300 megacycles is quite comparable with the performance of conventional tubes at much lower frequencies.

Operating characteristics and constants are listed in Table 1. Special attention is directed to the values of interelectrode capacitances and lead inductances. It will be observed that while the interelectrode capacitances are low they have not been reduced in proportion in the reduction of operating wavelength. A more important feature, however, is the reduction of the lead inductances.

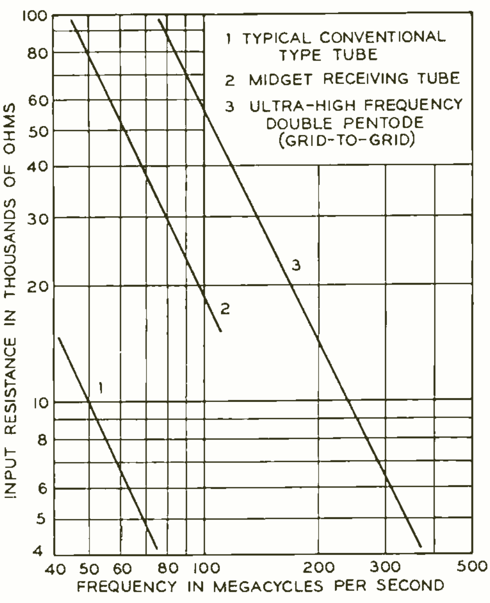


Fig. 3—Push-pull input shunting resistance as a function of frequency

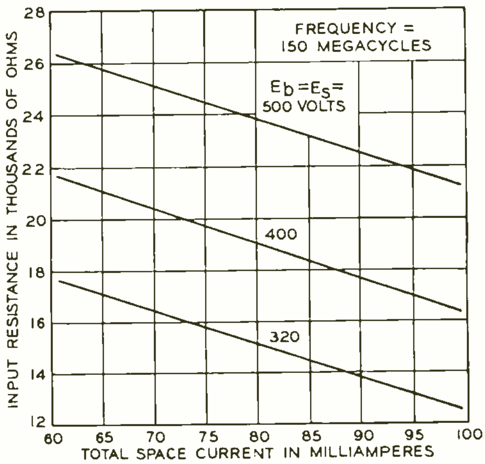


Fig. 4—Variation in input resistance with operating conditions at 150 megacycles

For a tube which is to be used at ultra-high frequencies, certain characteristics not ordinarily considered are of particular significance. One of the most important of these is the active grid loss which, as already mentioned, comes about because of appreciable electron transit time. Figure 3 gives a plot of the push-pull input shunting resistance of this tube as a function of frequency. The value of 30,000 ohms at 150 megacycles is to be compared with 2,000 ohms, a typical value for two conventional tubes in push-pull. At 300 megacycles the input resistance of the twin pentode is still above 6,000 ohms, while for conventional tubes it is so low as to make them entirely inoperative. The variation in the input resistance with the operating conditions of the tube for a constant frequency of 150 megacycles is shown in Figure 4. It is evident that if a high value of input resistance is to be realized, high anode potentials with low space currents must be used. The reduction in the filament-grid spacing made possible by the unusual construction is in a large measure responsible for the improvement in the input resistance just noted.

A characteristic measurable only at the operating frequency is the interaction between the input and output circuits which results from the residual value of the grid-plate capacitance. This reaction differs from that predicted for the low-frequency capacity measurements on a cold tube because of the inductance of the screen-grid lead, and because of the electron space charge. The reaction can be measured by observing the variation in the input impedance resulting from the tuning and loading of the output circuit. Experimentally determined values are given in Figure 5.

The double pentode tube has been found useful as a high quality class A amplifier, as a class B amplifier, as a frequency multiplier, and as a modulator at frequencies of 300 megacycles per second and below. Its performance in these various modes of operation is quite comparable to the performance of conven-

TABLE I

Operating Characteristics and Constants of the Double Pentode Tube

Filament current (each side)	5.0 amperes
Filament potential (each side)	1.5 volts
Rated anode dissipation (each anode)	15 watts
Rated screen dissipation (each side)	5 watts
At Anode and Screen Potentials of 500 Volts and Anode Current of 0.030 Ampere—Characteristics of each Side	
Transconductance	1250 micromhos
Anode resistance	200,000 ohms
Normal control grid potential	−45 volts
Interelectrode Capacitances (When Properly Mounted)	
Direct control grid to control grid	0.02 micromicrofarad
Direct plate to plate	0.06 micromicrofarad
Total control grid to ground (each side)	3.8 micromicrofarads
Total plate to ground (each side)	3.0 micromicrofarads
Control grid to plate (each side)	0.01 micromicrofarad
Lead Inductances	
Total grid to grid	0.07 microhenry
Total plate to plate	0.08 microhenry
Rating as Class A Amplifier	
Maximum direct plate potential	500 volts
Maximum direct screen potential	500 volts
Maximum continuous plate dissipation (each)	15 watts
Maximum continuous screen dissipation (total)	10 watts
Maximum output at 150 megacycles with distortion down 40 decibels	1 watt
Nominal stage gain at 150 megacycles	20 decibels
Nominal control grid potential	−45 volts
Rating as Class B Amplifier	
Maximum direct plate potential	500 volts
Maximum direct screen potential	500 volts
Maximum space current (total)	150 milliamperes
Maximum continuous plate dissipation (each)	15 watts
Maximum continuous screen dissipation (total)	10 watts
Maximum output at 150 megacycles	10 watts

I

Early experimental crossbar switching equipment installed for development at the Laboratories.

II

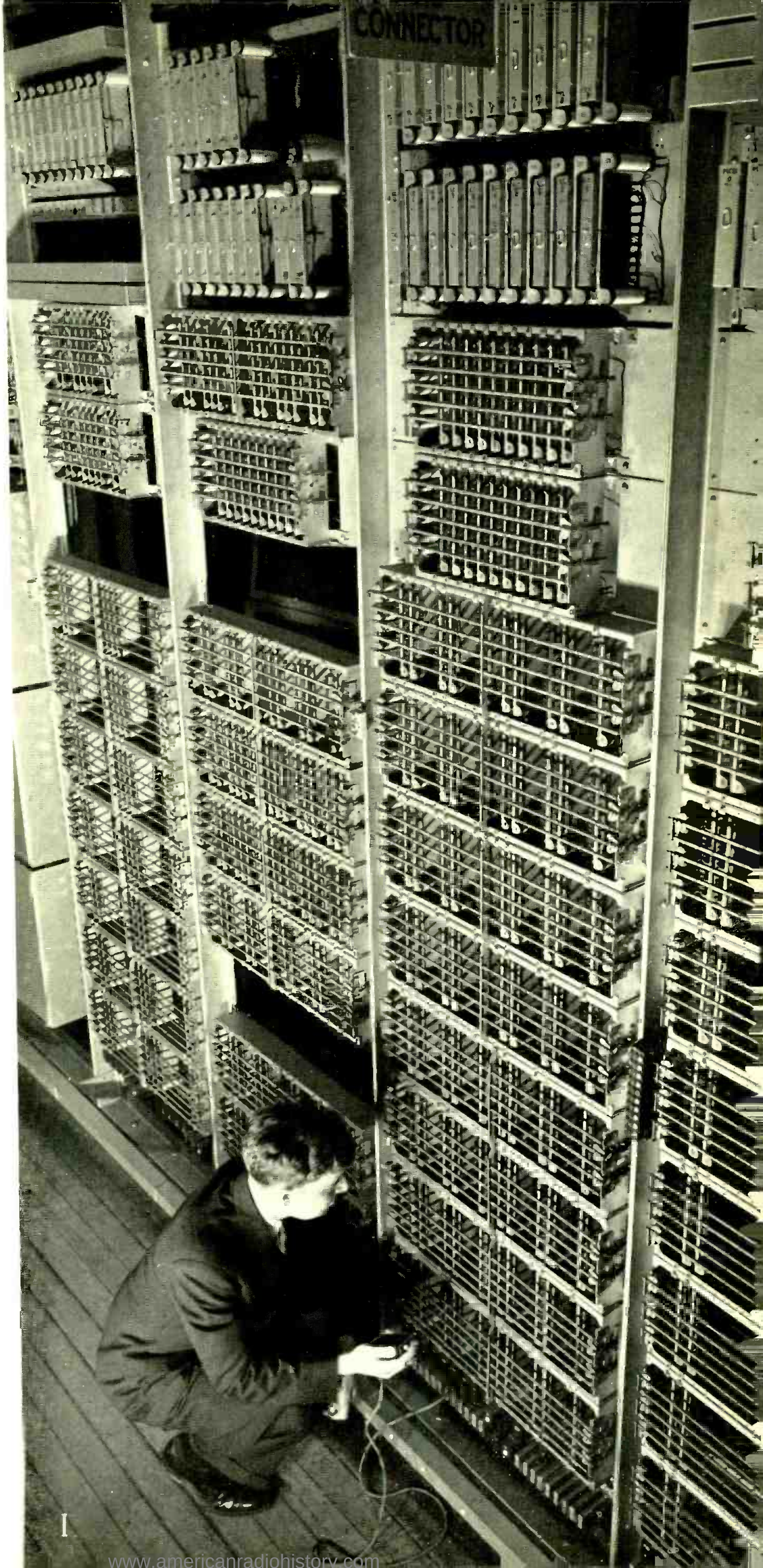
Effects of molecular strains in metals are studied with this X-ray spectrometer.

III

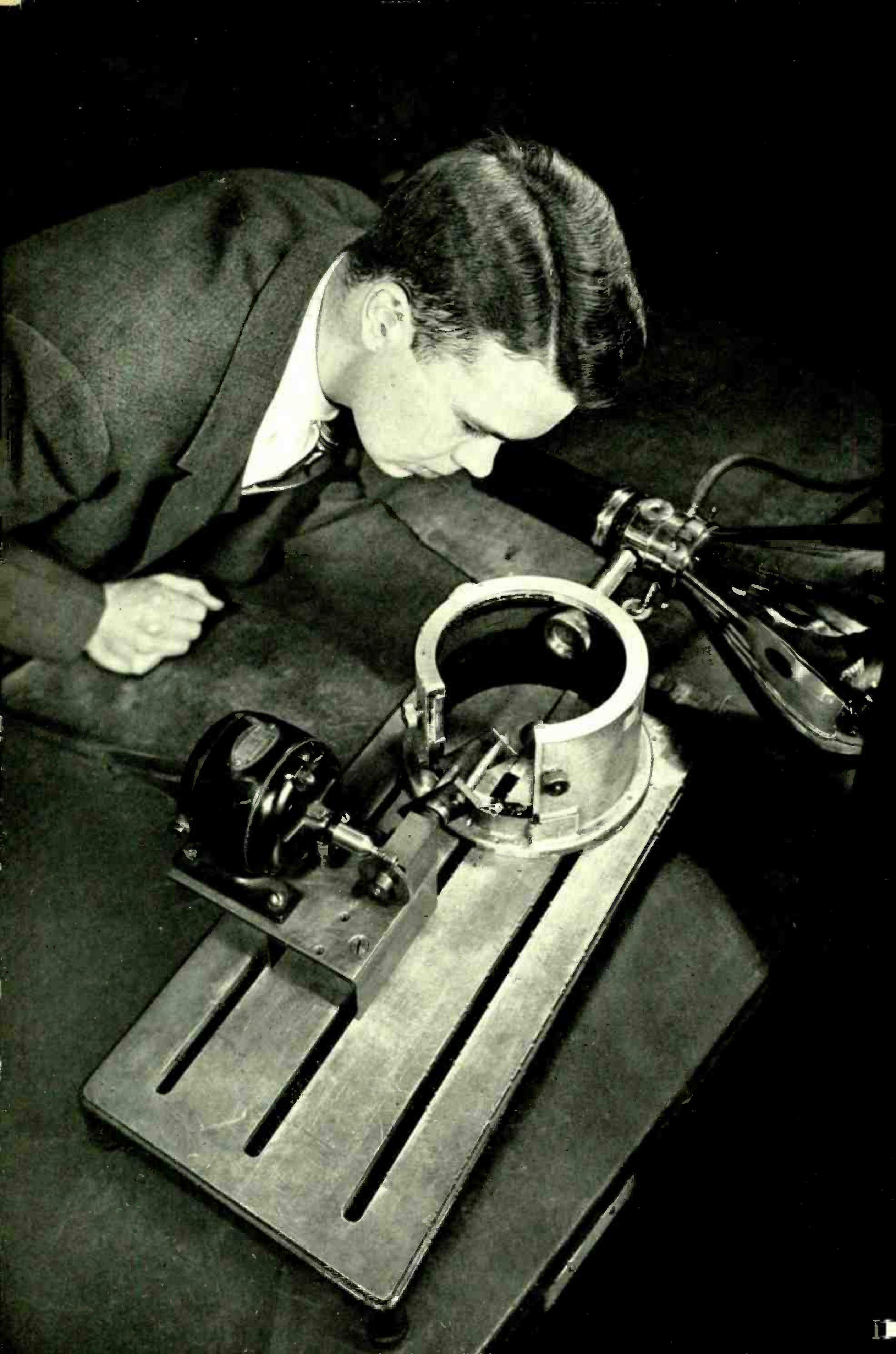
Testing the holding power of a drop-wire clamp.

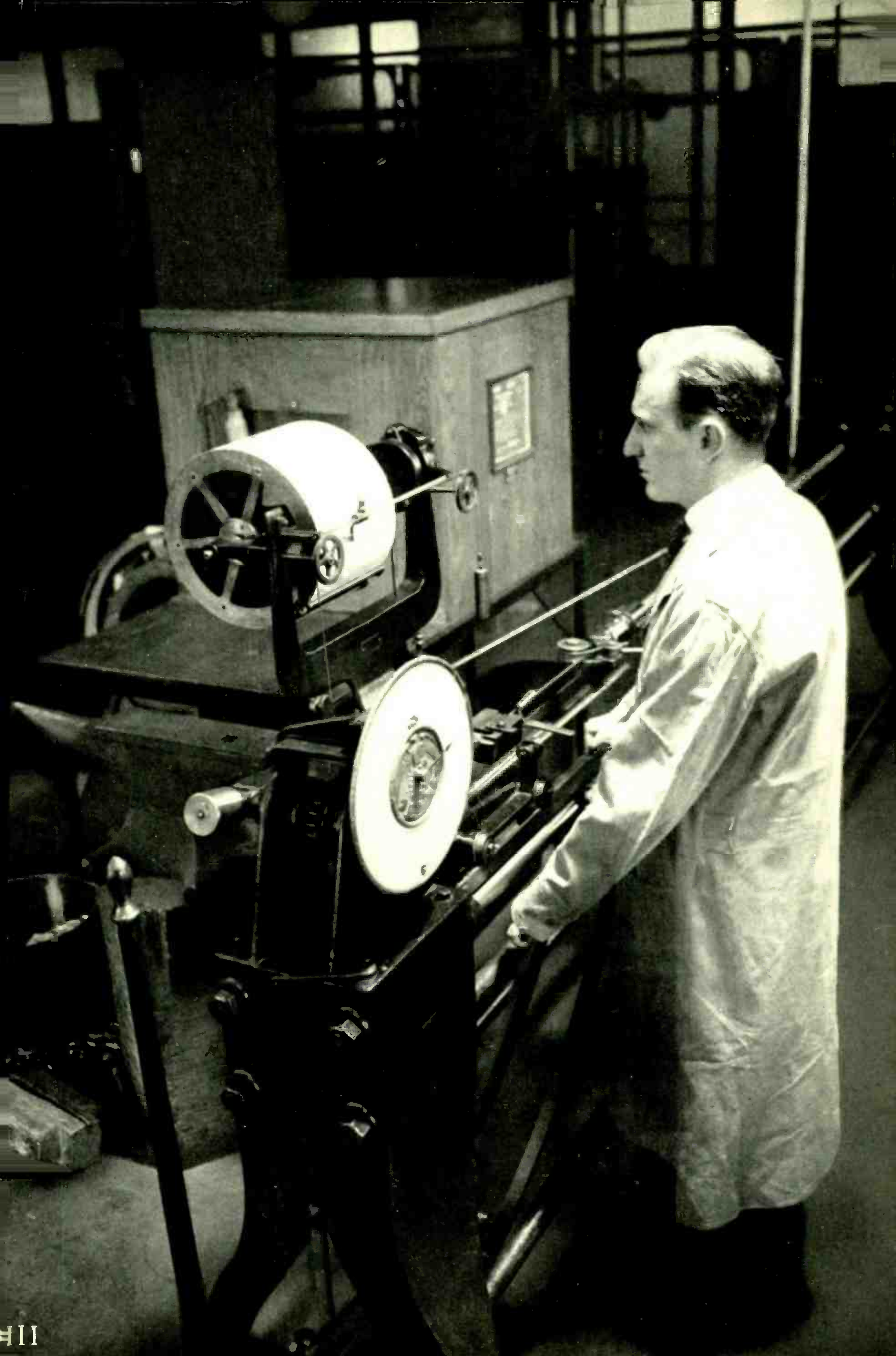
IV

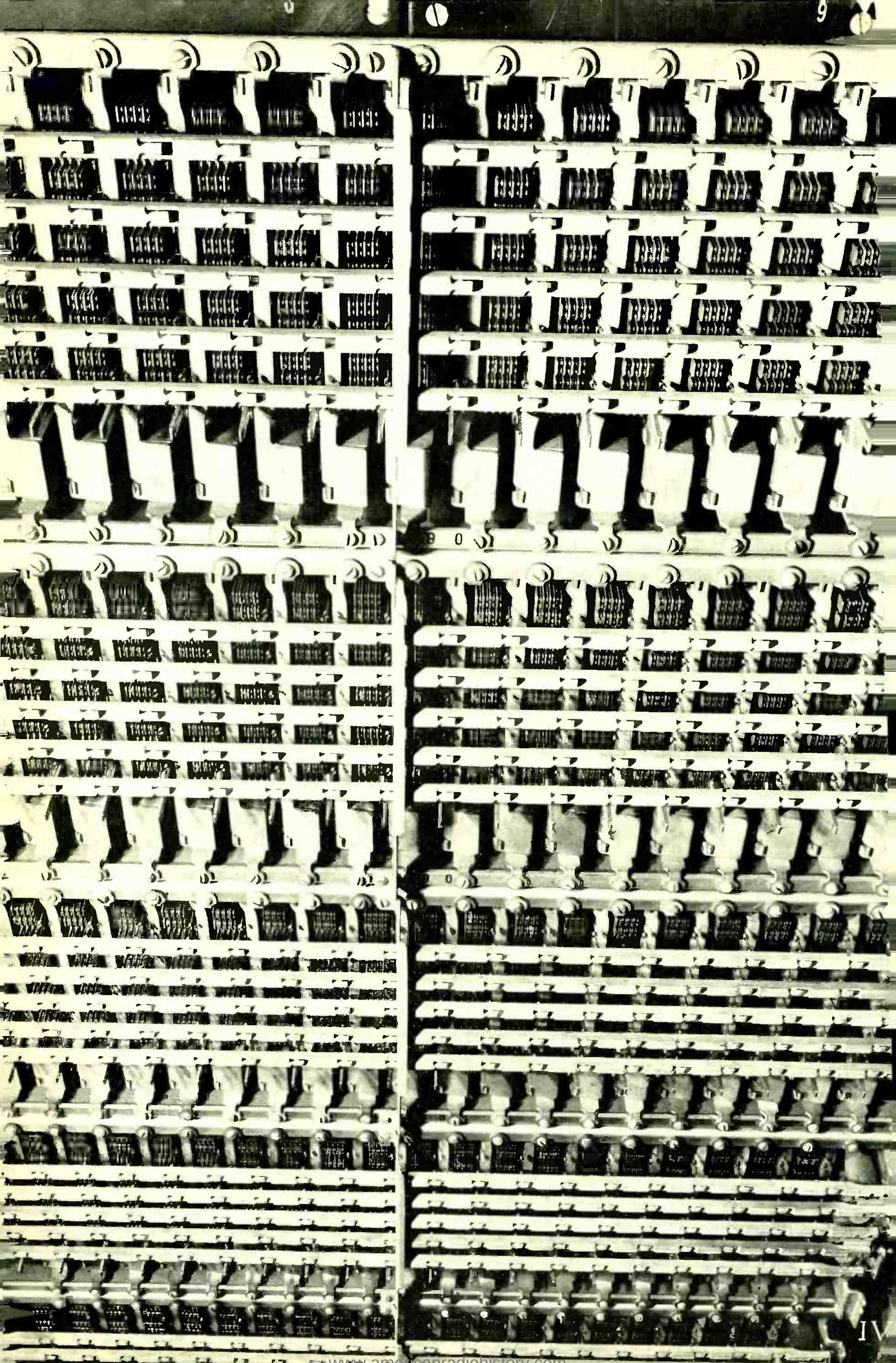
The later crossbar switching equipment in a trial installation at the Troy central office, Brooklyn.



I







A High-Quality Headset for Monitoring

By F. S. WOLPERT
Transmission Instruments Development

IN connection with electrical recording, transmission, and reproduction of speech and program material in the sound picture and broadcast fields, the ability to monitor in a satisfactory manner at various points is essential in the production of a high-quality performance. When recording sound for a talking motion picture, for example, it is essential to be able to determine at the time the recording is made as nearly as possible how the sound will be reproduced in the theatre when the picture is shown. In other words, it is desirable to see the action on the set and to hear the corresponding sound as it would come from the loudspeakers in the theatre. For this purpose, a monitor room or portable monitor booth is frequently provided on the sound recording stage. There are many circumstances, however, such as outdoor locations, where the use of a monitor room or booth is impossible. It is also recognized that greater facility of recording operations may be obtained on the sound stage if the mixer can be seated in the open alongside the director rather than in the booth or distant monitor room. For these purposes, it is necessary to use a pair of headphones for monitoring in place of the usual loudspeakers.

The work of a mixer consists in determining whether the sound picked

Fig. 1—The D-97689 moving-coil receiver as part of the D-97690 high-quality headset used for monitoring in the sound picture and broadcast fields

up by the microphone will make a suitable sound record, adjusting the volume to a suitable amount, and making sure that no undesirable sounds are picked up. In addition to his own personal judgment of sound quality he must be equipped with sound reproducing apparatus capable of giving him a faithful indication of the sound transmitted to the recording machine. Very similar to the sound recording job is the work of the technician in operating speech input equipment in broadcast studios or remote pickup points. In transmitting the program material over telephone lines, such as the extensive nationwide networks, it is important that the test room forces at the various intermediate offices be able to check the quality of transmission in connection with identifying and locating troubles and other service difficulties. Up until recently it has been necessary, in order to monitor on a high-quality basis, to make use of loudspeakers comparable with those used in theaters and high-grade radio receiving sets. The headphone receivers which have been available for monitoring purposes have not been satisfactory for a quality job. Most telephone receivers in common use give rather low response at low frequencies, a high peak in the neighborhood of 1000 to 2000 cycles, and extremely low response at frequencies above these.

Considerable progress has been made within the past few years in the development, design, and manufacture of moving coil receivers for various applications. These receivers are characterized by a wide frequency range, uniform response, and very little non-linear distortion, so that they are particularly suitable for use in monitoring sound records. A receiver of this type, known as the D-97689, has recently been developed particularly for this purpose. It is intended to replace the less efficient and more expensive moving coil receivers previously available. A photograph of the new receiver forming part of the D-97690 high-quality headset is shown in Figure 1.

The construction of the receiver is shown in Figure 2. The moving coil element is made of aluminum ribbon wound on edge and insulated with a varnish enamel which serves also as an adhesive for holding the adjacent turns together. It is cemented rigidly to the diaphragm and the leads are brought out between paper insulating washers. The coil is located in the air gap of the magnetic field produced by a permanent magnet of cobalt steel. The gap is between an outer pole plate and an inner dome-shaped pole piece, which are concentrically aligned to make the gap uniform.

The diaphragm is made of duralumin and has a dome-shaped center portion which extends to the inner edge of the coil. Beyond the coil the diaphragm is so shaped that its effective radiating area and its efficiency are increased. The flexible outer surface is held around its periphery by the clamping elements of the receiver frame. The diaphragm and coil vibrate substantially as a piston throughout the desired frequency range and are relatively free from other modes of vibration.

The action of the diaphragm under the influence of the varying current in the moving coil depends on the characteristics of the diaphragm, of the air chambers in front of and behind it, and of the air chamber formed between the cap and the ear. The overall frequency response characteristic of the instrument depends largely on the design of these elements. By suitably proportioning these parts the response may be made to approach very closely to the necessary requirements for modern sound picture recording.

The characteristics of the diaphragm and coil alone can be represented electrically as a simple resonant circuit of resistance, inductance

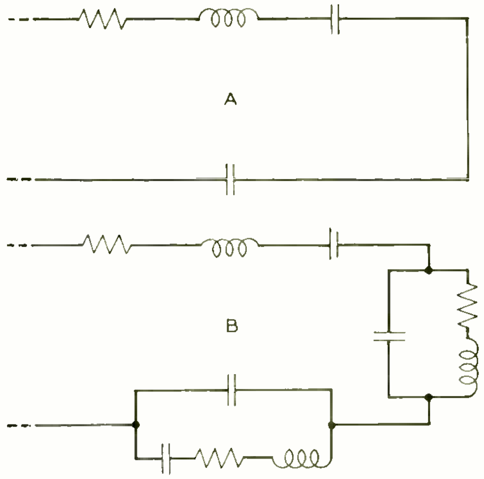


Fig. 3—Equivalent electric circuits corresponding to the moving-coil receiver: above, for the coil, diaphragm, and ear cavity; below, circuit for the complete receiver

and capacitance, as shown in the upper part of Figure 3. The inductance represents the mass of diaphragm and coil. The two capacitances repre-

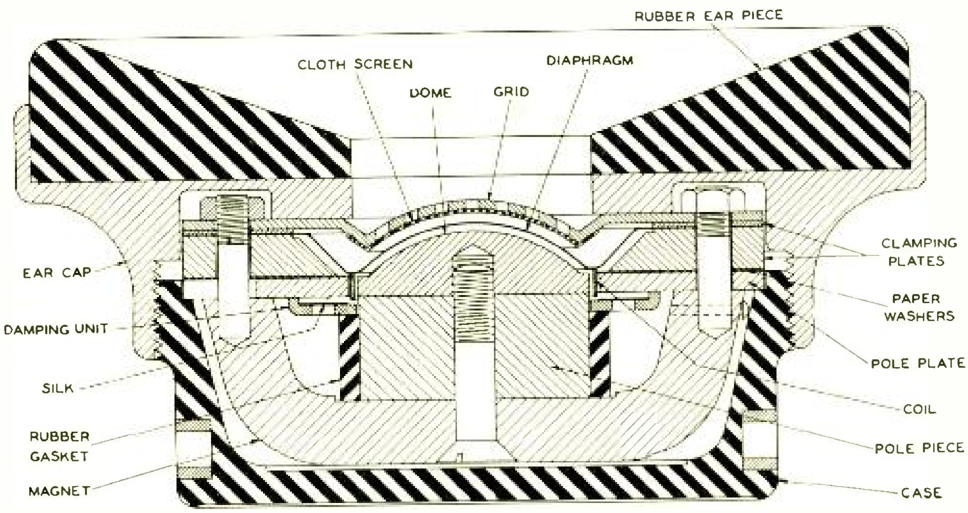


Fig. 2—Cross-section of the D-97689 moving-coil receiver

sent the stiffness of the diaphragm and that of the ear cavity. The response of these elements, as measured on a closed coupler, would be similar to the Curve A of Figure 4.

The chamber below the diaphragm is totally enclosed except for an acoustic resistance element consisting of a series of holes covered by a silk screen. A rubber gasket is provided to seal off this air chamber and to hold the acoustic resistance unit firmly in place against the pole-plate.

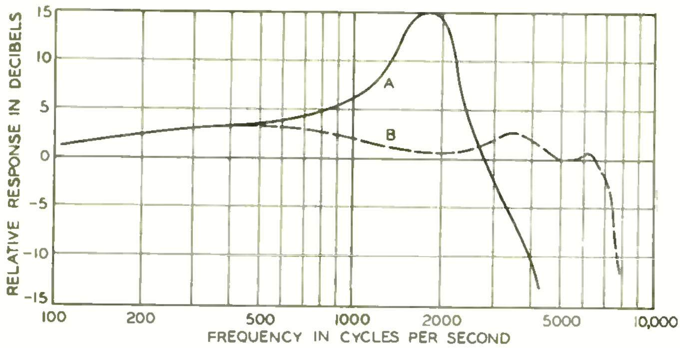


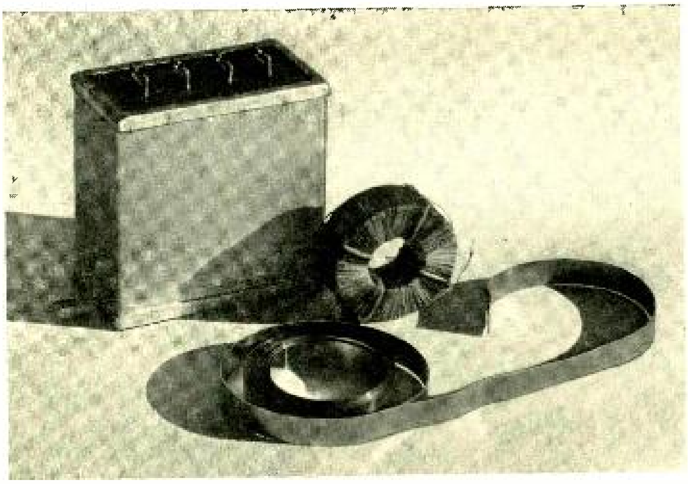
Fig. 4—Frequency-response characteristics for the D-97689 receiver: curve "A" shows the response of diaphragm, coil, and ear cavity alone; and curve "B" shows the response characteristic of the complete receiver

The air chamber in front of the diaphragm is enclosed except for a group of small holes in the dome-shaped center portion of the cap grid. It is through these holes that the sound waves pass after leaving the receiver diaphragm. They also provide additional resistance, mass, and stiffness, which affect the response of the receiver. A layer of bolting cloth placed over the grid holes excludes metallic dust from the interior of the receiver and helps to protect the diaphragm from injury. The equivalent electrical circuit for the complete receiver is shown in the lower part of Figure 3. Curve B of Figure 4 shows a typical frequency-response characteristic curve for a receiver of this type.

The characteristics obtainable with a moving coil receiver are very flexible since the design of the acoustic networks associated with the diaphragm may be readily modified without changing the overall dimensions. Once the fundamental requirements to be met by a receiver are known, it is possible to obtain the characteristics desired by changing the design of these elements. In the D-97689 monitoring receiver they were adjusted to produce substantially uniform pressure in the ear chamber over a frequency range from 100 to 6000 cycles.

The receiver unit is housed in a black phenol plastic case with spring contacts to engage flat strips terminating the coil leads on the receiver. A sponge rubber ear-piece is cemented to the metal cap, and serves to reduce external noise and also to improve the low frequency response by providing a tighter seal between the receiver and the ear. The receiver is slightly larger than the monitoring receivers of previous design, but it is about 15% lighter.

Many favorable comments have been received from sound technicians in the motion-picture field on the performance of these receivers when used with monitoring circuits. Considerable thought has been given to simplifying their manufacture, and their resulting lower cost, compared with moving coil receivers of previous designs, opens up many fields of use, particularly where high quality is of prime importance.



Carrier for Coaxial Groups

By L. C. PETERSON
Carrier Transmission Research

IN the million-cycle experimental coaxial system, twenty groups each comprising twelve voice channels can be transmitted over the line. One of the groups is transferred directly to the coaxial conductor, but the other nineteen are passed through group modulators, which raise them to successive positions in the frequency spectrum, resulting in a top frequency of 1020 kilocycles. A large number of carriers is needed to supply these modulators and demodulators, and the photograph at the head of this article shows what might be called the heart of the carrier supply. It consists of a small ferromagnetic coil with a core of permalloy tape weighing only three grams. Despite its small size, this coil supplies one complete system terminal, consisting of nineteen group modulators and demodulators, with sufficient carrier power without amplification.

The frequencies of the carriers are the odd harmonics of 24 kilocycles, extending from the ninth to the forty-fifth, inclusive, and the problem in designing the carrier supply was to produce the carriers at approximately equal levels and of such magnitude as to give proper modulator and demodulator performance; about six milliwatts of each carrier is required. After a careful study of the requirements, it was decided that the most satisfactory method would be harmonic production by use of a ferromagnetic coil.

The circuit for such a method is shown in somewhat simplified form in Figure 1. Here E is a source of fundamental frequency, R1 the internal resistance of the source, and R2 is the

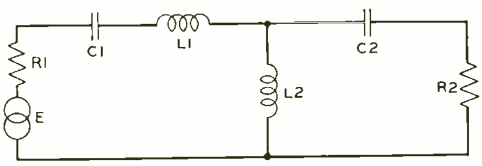


Fig. 1—Simplified schematic of the harmonic producer circuit

load resistance. The condenser C_1 and coil L_1 form a sharply tuned circuit to make the output of the generator practically a pure sine wave of the proper frequency, and also to prevent harmonics generated by the harmonic producer from flowing back to

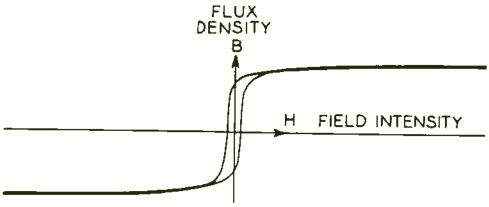


Fig. 2—Variation of magnetic flux with current in the harmonic producing coil

the generator. The coil shown in the photograph at the head of this article is L_2, and this coil, in conjunction with condenser C_2, supplies the harmonics that are desired.

The relation between the magnetic flux density of such a coil and the current flowing in the winding is shown in Figure 2. Increasing currents follow the right-hand side of the loop shown, and decreasing currents, the left. The area of the loop itself, which represents hysteresis loss, is of secondary importance in this application. The inductance of the coil which is of primary concern here is proportional to the slope of the curve, and thus is very high for low values of current, and then within a very small range of current becomes nearly zero as the curve itself becomes horizontal. Since this coil is connected across the output of the fundamental frequency of 24 kilocycles, its inductance changes from high to low and from low to high twice for each cycle. This inductance is high while the current through it is low and low for the longer period after the current has passed the knee of the magnetization curve.

As a result of this change in inductance with change in current, the current flowing into the condenser C_2 and hence through the load resistance R_2, is as represented in Figure 3. At the beginning of a cycle the current into L_2 will be small, and the inductance of the coil will be high, so that the coil exerts very little shunting action, and most of the output of the generator will flow into the condenser C_2 to charge it. This is the interval A-B of Figure 3. As the knee of the magnetization curve is reached, however, the inductance of the coil rapidly falls, and hence it quickly introduces a greater and greater shunting effect, with the result that not only does practically all of the output of the generator flow into it, but the condenser discharges through it, as well, thus producing the large peak in the interval B-C. For the rest of the half cycle, the coil continues to be practically a short circuit, so that the cur-

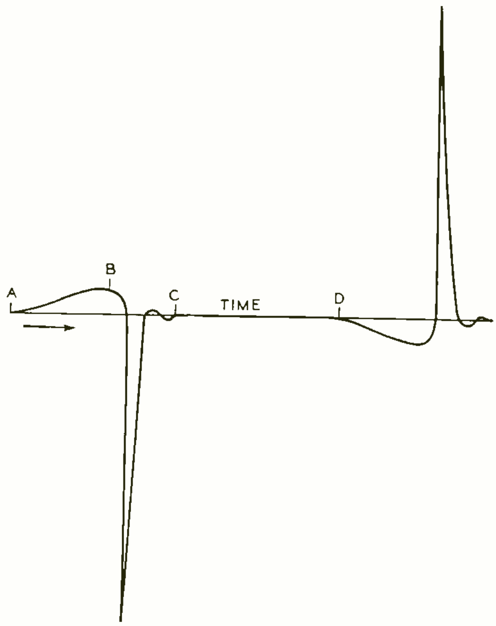


Fig. 3—Wave form of current in the output of the harmonic producer

rent through the condenser remains zero. When the second half of the cycle begins, at point D, a similar cycle of current begins, which is identical to the first except for the fact that the direction of the current is reversed.

A peaked wave such as shown in Figure 3, where the actual current cycle occupies only a small fraction of half the period of the fundamental frequency, includes odd harmonics of the fundamental, and the harmonics will all be of approximately equal value up to very high frequencies. By use of a group of crystal filters in the output circuit, the odd harmonics from the ninth to the forty-fifth are selected to form the carrier supply. The sharp peak of the current curve passes through the coil while its core is saturated. Since there is no change of flux with time in the saturated region, there is no contribution to the eddy current loss by the core, and thus the efficiency of frequency transformation is high.

The arrangement of the circuit for the experimental system between New York and Philadelphia is shown in Figure 4. The source of supply is the harmonic producer of the channel terminal, from which a 24-kilocycle current is selected by the band-pass filter. Following this the fundamental is amplified by two power pentodes in push-pull connection. The amplifier works in an overloaded condition to insure good stability with respect to small variations in the 24-kilocycle input. The amplifier output consists of a tuned transformer, which has a large attenuation for harmonics of 24 kilocycles. Further discrimination is obtained by the tuned circuit consisting of C1 and L1. The harmonic producing coil itself has two windings, so that the impedance of the primary matches the amplifier at the fundamental, and that of the secondary matches the filter for the harmonic frequencies. The coaxial jack shunting the resistance in the primary circuit provides a means of measuring the primary current and thus of checking the tuning condition.

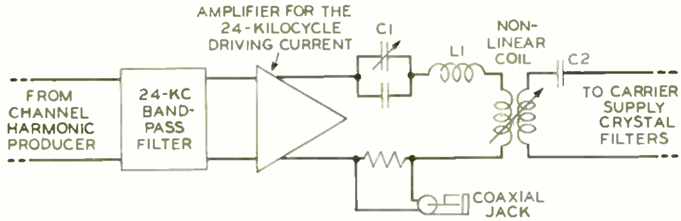


Fig. 4—Harmonic producing circuit for the coaxial installation between New York and Philadelphia

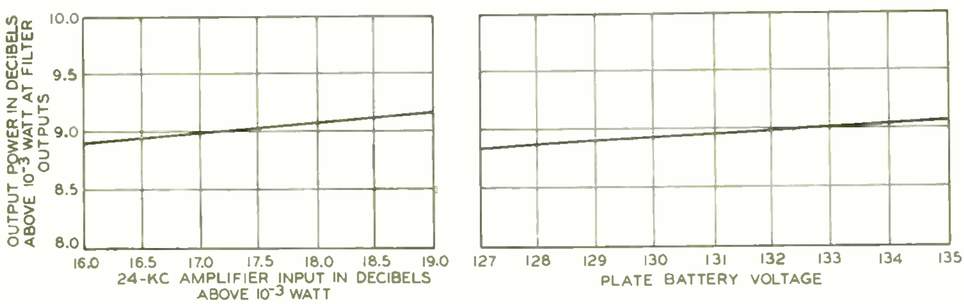


Fig. 5—The harmonic output remains nearly constant with appreciable changes in level of the input frequency and of the plate-battery voltage

This new harmonic producing circuit has proved very satisfactory. Measurements have shown not only that the harmonic output is very uniform, but that its stability with respect to variations in the 24-kilocycle input power and plate-battery voltage is high. Actual curves for the twenty-first harmonic are shown in Figure 5, where the small variation of the output with battery voltage and with 24-kilocycle input is plainly evident.

Service Trial of Coaxial System

A service trial of the coaxial-cable system between New York and Philadelphia was initiated April nineteenth by routing over it twenty-seven toll message telephone circuits. Sixteen of these terminated in Philadelphia and eleven were to other points farther south. During the trial the regular facilities were held in readiness for return to service.

The operation was generally satisfactory for the first four weeks of the trial and only a few troubles of short duration occurred. About May twentieth some variations in transmission appeared which demanded detailed investigation and a return of the circuits to their original facilities. Most of the troubles were associated with the automatic devices for regulating transmission. The defective parts were replaced and the circuits again routed over the coaxial system from May twenty-seventh to June first, when the system was required for other development tests.

During this period, there were several days on which one of the coaxial channels supplied facilities for commercial voice-frequency telegraph circuits. These telegraph circuits operated satisfactorily and created no disturbances on the telephone channels. The coaxial channels were also used for the experimental transmission of some telephotographs. This transmission was satisfactory except for some extraneous patterns introduced by the sixty-cycle power supply of the amplifiers along the route.

In general the troubles which were experienced, although they were individually unpredictable, were all of types normally to be expected with a radically new system. They do not affect the ultimate development of a satisfactory system for commercial service.

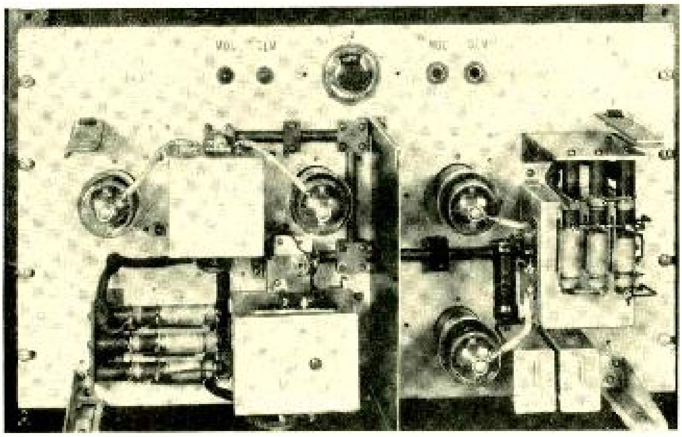


Fig. 2—The group modulator, demodulator, and group filter used with the coaxial system

greater than 2, this modulation product will be greater than f and less than kf, and will thus fall back into the transmitted group. It was only after a consideration of all such factors that a satisfactory frequency arrangement for double modulation could be determined. Another controlling factor is the desirability of having all the carrier frequencies harmonics of a fundamental frequency so as to insure a constant relative frequency.

Even with the most careful selection of the channel and group carriers there will always be higher order products falling right back into the sideband to be transmitted, and the modulators must be designed in such a way as to keep these products some 60 or 70 db below the wanted sideband. With a single-channel modulator, the requirement in this respect is only 30 or 40 db. The design finally decided on for the group modulator is a balanced vacuum-tube circuit of very much the same general type as the earlier single channel modulators used with the type C carrier systems. Because of the higher frequency range and broad band, however, many special precautions had to be taken in the choice of tubes, the design of transformers, and in the selection of operating levels to meet the stringent requirements.

A simplified diagram of a group modulator and demodulator is shown in Figure 1, while Figure 2 shows the finished modulator-demodulator. It is of the conventional conjugate input type, which allows the carrier to be balanced out in the output. The tubes used in the modulator are so-called power pentodes, which have an inherently small grid-to-plate capacity and therefore lend themselves to work at these frequencies without undue feedback between grid and plate circuit. Even so, a special resonant circuit is inserted in the mid-band of the plate circuit to minimize carrier feedback. To produce a good impedance

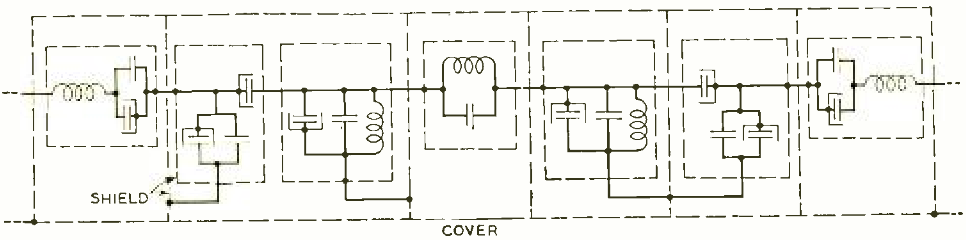


Fig. 3—Schematic circuit of the group filters used with the coaxial system

match between the circuits connected to the modulators and the modulators themselves, the input and output transformers are designed with as high a step-up as possible consistent with maintaining a properly flat transmission level through the band.

The carriers used for these modulators are produced as odd harmonics of 24 kilocycles by a special carrier generator followed by selective carrier filters, and are supplied through tuned transformers as shown in the diagram. Each carrier is located 60 kilocycles above the upper edge of the transmitted sideband. In group modulator No. 5, for example, the carrier frequency used is 408 kilocycles, thus producing a wanted lower sideband located from 300 to 348 kilocycles and an unwanted upper sideband from 468 to 492 kilocycles. The upper sideband is cut off by the group filter following the modulator.

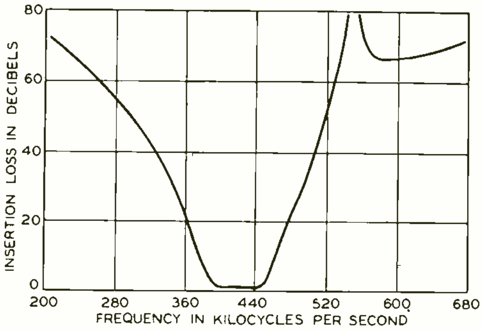


Fig. 4—Attenuation-frequency characteristic of the group filters

A schematic circuit diagram for the group filter is shown in Figure 3. Although the arrangement of the elements is conventional, it has been necessary to take special precautions in shielding the elements and their leads so as not to destroy the transmission characteristics by the distributed capacitances of the elements to ground. The attenuation-frequency characteristic is shown in Figure 4.

As already mentioned, the function of the group filters is to cut off the upper sideband resulting from the group modulation, and since this upper sideband is 120 kilocycles from the lower sideband, the cut-off of the filter need not be very sharp. In this respect, therefore, the gradually sloping sides of the filter are satisfactory. The impedance characteristic of the filter, however, is roughly the same as the attenuation characteristic. Over the pass band the impedance is low and it increases gradually on each side. As a result it is still low for some distance beyond cut-off, so that if the filters for all groups were connected in multiple, each filter would have more or less of a shunting effect on the filters on each side of it.

To avoid this condition, the groups are divided into two sets—one consisting of the odd, and the other of the even, numbered groups. These two sets are separated by hybrid coils, so that the frequencies from each set of groups can pass readily to or from the line but not into the other set. The resulting arrangement of the terminal equipment is indicated by Figure 5, which is a block schematic of equipment provided for the experimental project. Here it will be noted that each group of both sets has its group filters in both incoming and outgoing sides, and that the equipment of all groups is alike in arrangement except for groups 1 and 2. The difference in arrangement of these two groups is made necessary for two reasons. First the separation between groups 1 and 2 is only 400 cycles instead of the 1000 cycles between all the other groups. The upper frequency of group 1, which does not undergo a second, or group, modulation, is 107.8 kilocycles, while the lowest frequency of group 2 is 216—107.8, or 108.2 kilocycles, as already explained.* As a result, sharper discrimination is required between these two groups than between any of the other groups.

The second point of difference is that since there is no group modulation for group 1, the level of the incoming signals in group 1 will be less than that of the other groups by the amount of amplification provided in the demodulator. To make up this difference, an amplifier is provided in the incoming side of group 1. The additional discrimination is obtained by employing crystal low-pass filters for group 1, and crystal high-pass filters, in addition to the band pass filters, in group 2. The entire discrimination between all other adjacent speech channels is provided by the sharp edged crystal filters which are part of the channel equipment.

Although the coaxial system is designed to handle 240 channels in twenty groups, equipment for only seven groups has been provided in the experimental installation. These are groups 1, 2, 6, 8, 9, 10 and 20 as indicated in Figure 5, but by connecting groups of twelve voice channels to these various groups, it is possible to gauge the performance of the entire system. The complete group equipment for the experimental installation is mounted on three bays; the installation at the New York terminal is shown at the head of this article.

The input of the modulators and output of the demodulators are all carried to special coaxial jacks shown on the jack panel on the center bay. On this jack panel also are trunks from the channel equipment, and trunks to the terminal amplifier bays. This jack panel therefore serves as a general patching field for interconnecting the different channels and groups, and for connecting the terminal to line and repeater equipment.

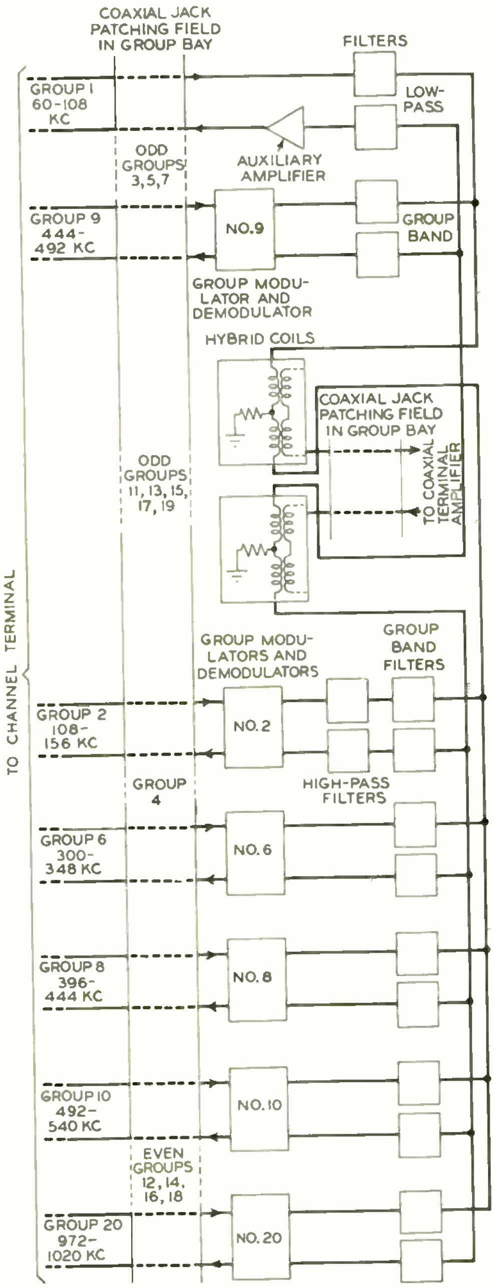


Fig. 5—Block schematic of the group terminal equipment

*Record, *May*, 1937, *p.* 274.

Contributors to this Issue

A. G. Jensen received the E.E. degree from the Royal Technical College in Copenhagen in 1920, and remained there for a year as instructor before coming to this country. During the winter of 1921-1922 he took post-graduate work at Columbia, and in the summer of the latter year joined what is now the Research Department of these Laboratories. Until 1926 he was at the field laboratory at Cliffwood, New Jersey, engaged in radio-receiving studies and in the design of field-strength measuring sets. He then went to London to initiate short-wave reception from the United States, and remained there four years in charge of the test station during the development of trans-atlantic short-wave service. In 1930 he returned to this country to work on the development of the coaxial system, taking charge of the development of terminal and measuring equipment.

A. G. Jensen

D. E. Trucksess joined the Technical Staff of the Laboratories in 1926, the same year in which he graduated from Pennsylvania State College with the degree of B.S. His work here, which has been with the Systems Development Department, has been concerned primarily with the development of power apparatus including regulated rectifiers to which he has recently given particular attention.

A. L. Samuel, after getting an A.B. degree from the College of Emporia (Kansas), went to the Massachusetts Institute of Technology where, as the result of a coöperative course

D. E. Trucksess

A. L. Samuel

J. N. Reynolds

F. S. Wolpert

L. C. Peterson

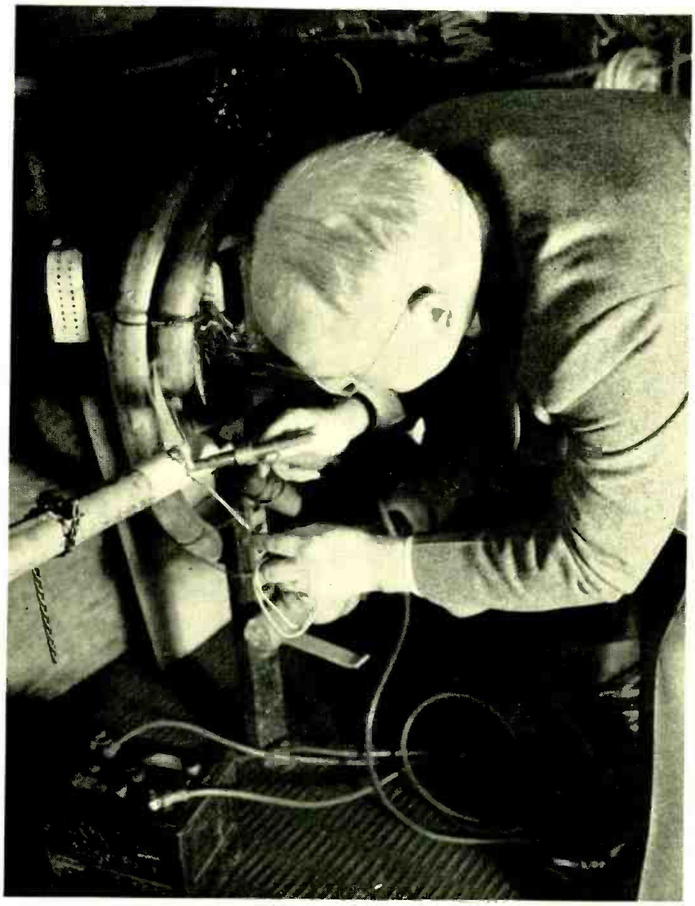
with the General Electric Company, he received an S.B. degree in 1925 and an S.M. degree the following year. He remained as an instructor in the Electrical Engineering Department for two years. In 1928 he joined the technical staff of the Laboratories, working on the early development of gas-filled tubes until 1931. Since then he has been engaged in research and development work on vacuum tubes that are intended for use at ultra-high frequencies.

J. N. Reynolds graduated from Purdue University in 1904 with the degree of B.S. in E.E. In 1907 he received an E.E. degree. Mr. Reynolds had his first taste of telephone apparatus development one summer while still a student at Purdue University. After his graduation he had another, and the following summer he returned to the Bell System permanently to engage in the development of dial apparatus with which, in both creative and supervisory capacities, he has been associated ever since. His early contributions to the art include the friction-roll drive, clutches and sequence switch of the panel system, and the use of brush tripping to select one particular brush on a rod. He had charge of apparatus development for the early semi-automatic and call-distributing installations at Newark and at Wilmington, and for subsequent panel system development. As Special Studies Engineer he heads a group concerned with the development of automatic switching equipment, and particularly with devising new and improved switch mechanisms and associated electromagnetic devices. A total of sixty-seven United States patents have been issued in his name.

F. S. Wolpert was graduated from the Newark College of Engineering in 1927 with the B.S. degree in Electrical Engineering. After a year of sales engineering work with the Weston Electrical Instrument Corporation, he joined the technical staff of the Laboratories and became associated with the Apparatus Development Department in the preparation and issuance of manufacturing specifications.

In 1930 he transferred to the Transmission Instruments Group in the Research Department, where he has been engaged in the development and design of receivers both of the moving coil and magnetic types.

L. C. PETERSON received the E.E. degree from the Chalmers Technical Institute in Gothenburg, Sweden, in 1921 and then continued his studies in Berlin and Dresden, Germany. After coming to this country he spent a year with the General Electric Company, and in 1926 joined the Department of Development and Research of the American Telephone and Telegraph Company where he engaged in work on inductive interference. In 1930 he transferred to the Laboratories to engage in developing the coaxial system—working chiefly on transmission studies and on carrier supply. Since the completion of the trial installation of the coaxial system he has been engaged in studies of vacuum tube behavior.



A method of repairing ring cuts on cable sheath, using a carbon-electrode soldering outfit, is demonstrated in the laboratory by V. B. Pike