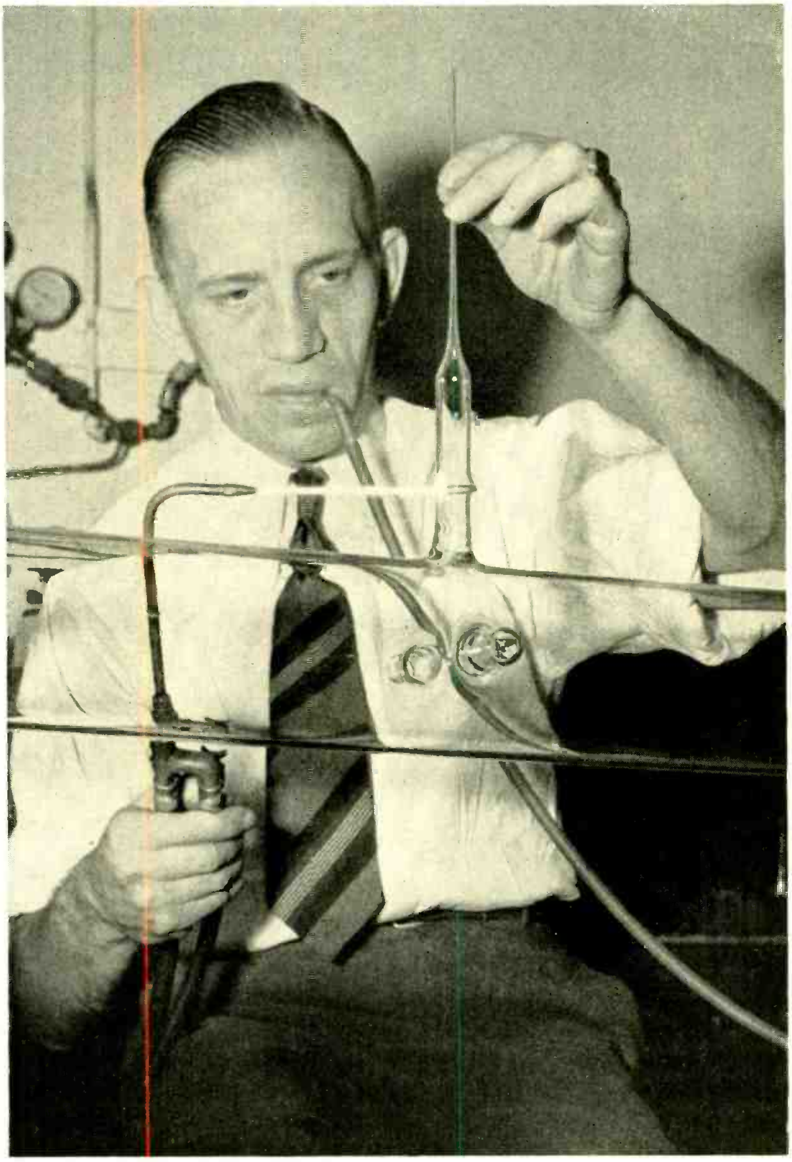
ELL LABORATORIES RECORD



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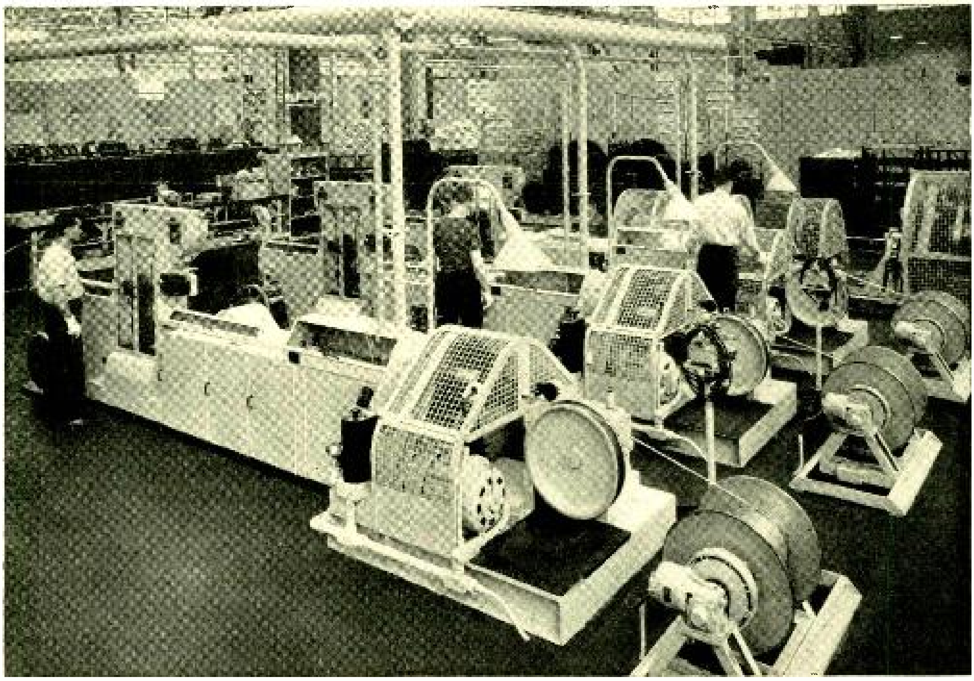
Constructing glass parts for large cathode-ray tube



Stevens Point-Minneapolis Coaxial Cable

By O. S. MARKUSON
Toll Cable Engineer

THE first commercial installation of coaxial cable in the Bell System is now being completed between Stevens Point, in central Wisconsin, and Minneapolis, Minnesota. The New York-Philadelphia twin coaxial cable, described in previous issues of the Record* was installed primarily for test purposes, and served to provide data required for engineering the present commercial installation. Even while the experimental project was still undergoing field tests, improvements were made in the method of constructing coaxial units, and these improvements have been incorporated in the new cable. Whereas the New York-Philadelphia coaxials had an outer conductor consisting of a number of separate interlocking tapes, the Stevens Point coaxials have a single-tape outer conductor, which is formed into a cylinder as it is pulled through a die, proper registry of the edges along the seam being obtained by the provision of projections or "teeth" along each edge of the tape. The tube so formed is held firmly by a serving of steel tapes which, in addition to its mechanical function, also increases the shielding effect of the outer conductor. This type of coaxial is known as a longitudinal-seam coaxial, and is both lower in cost and better electrically than the interlocking tape design, which was used in the experimental cable

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*Record, *July*, 1935; *May*, 1937; *February*, 1938.

between New York and Philadelphia.

The length of the Stevens Point-Minneapolis installation is approximately 200 miles. The cable contains four coaxial units in the center, and an outer layer of eighteen 19-gauge quads for voice circuits as shown in Figure 1. In the central space formed by the four coaxials, there are two 22-gauge pulp-and-paper insulated pairs laid together as a spiral-four quad, and in each outer interstice of the coaxial units there is a hybrid quad made up of one pair of 19-gauge and one pair of 22-gauge. These 19- and 22-gauge pairs are required for auxiliary services such as order-wire circuits and gas-pressure alarms.

Before the details of design were decided upon, preliminary experimental cables with different modifications of construction were manufactured and thoroughly tested. The rubber discs, for instance, were tested for a number of characteristics such as cold flow, softening with rise of cable temperature during the drying and lead-covering operation, and particularly for adherence of the discs to the wires under various handling conditions. The experimental cables were also subjected to rereeling tests, combined torsion and bending tests, and a pulley test which consisted in passing the cable under tension back and forth over a pulley of about eighteen inches diameter. In addition, the cable was subjected to tests that simulated the handling it would receive when placed in position in a manhole. In this preliminary work it was found that a cable could be designed and manufactured with the necessary factor of safety to withstand at least as severe handling as is normally required in the factory and in the field.

In addition to the handling tests, the experimental structures were also tested for their electrical characteristics. The effective resistance and inductance were determined at frequencies up to 5000 kilocycles to check values calculated from the dimensions of the inner and outer conductors. The dielectric constant of the composite dielectric of air and rubber discs was found from the tests of capacitance and the known dimensions of the conductors to be about 1.1 at 5000 kc. Particular emphasis was placed on the tests for conductance loss of the rubber discs. The increase in conductance with frequency

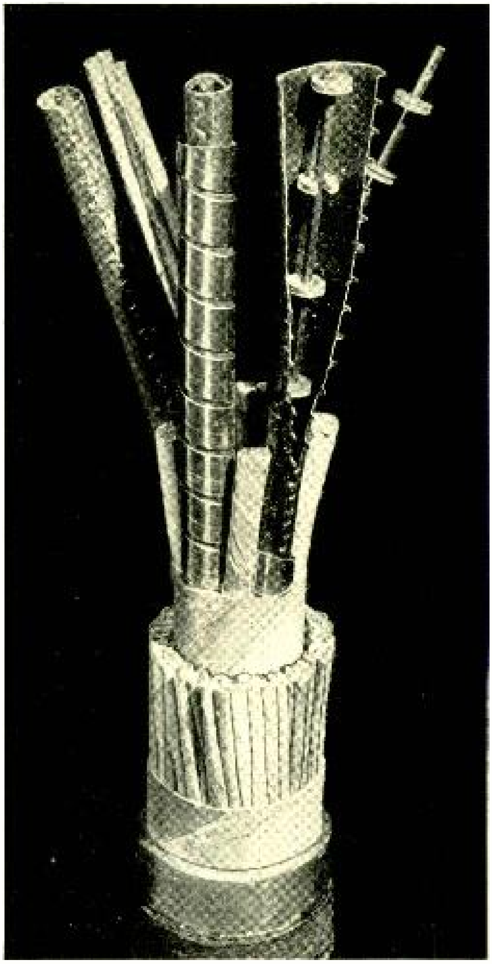


Fig. 1—The Stevens Point-Minneapolis coaxial cable structure

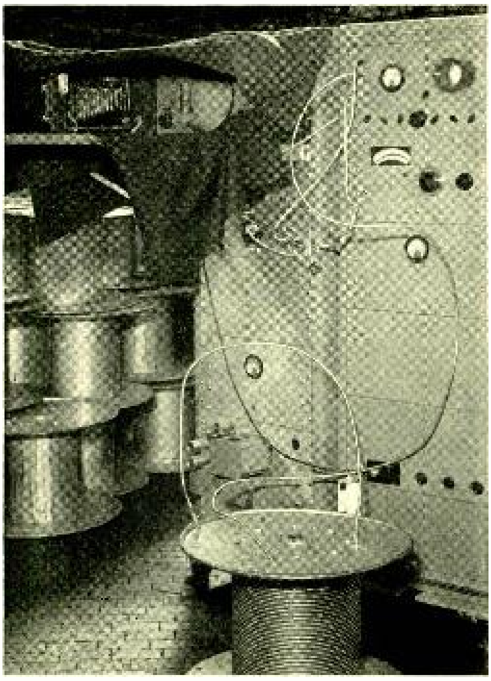


Fig. 2—Echo set and cathode-ray oscilloscope for determining the degree of uniformity of impedance within factory lengths of coaxial cable structure

and its change with temperature were determined over the range from 60 kc to 5000 kc. The test data showed that at 70 degrees Fahrenheit the conductance increases approximately as the 1.08 power of frequency up to about 1000 kc and as about the 1.02 power from 1000 to 5000 kc.

The dielectric strength became the subject of a somewhat extended investigation because the minimum breakdown potentials of the unit as first manufactured were appreciably below values desired from the plant standpoint, and were also below the values expected from the dimensions of the unit. Although it had been the practice to clean discs, wire, and tape before assembly, it was found that by a more drastic removal of foreign material and projections from the surfaces of the center wire and copper tape, and a more effective cleaning of the rubber discs, the dielectric strength could be improved sufficiently to permit a guarantee that the structure would withstand 2500 volts dc. Another characteristic, investigated in this preliminary stage, is crosstalk between the different units in the cable. Both far-end and near-end crosstalk were determined for factory lengths of the cable over a wide range of frequencies.

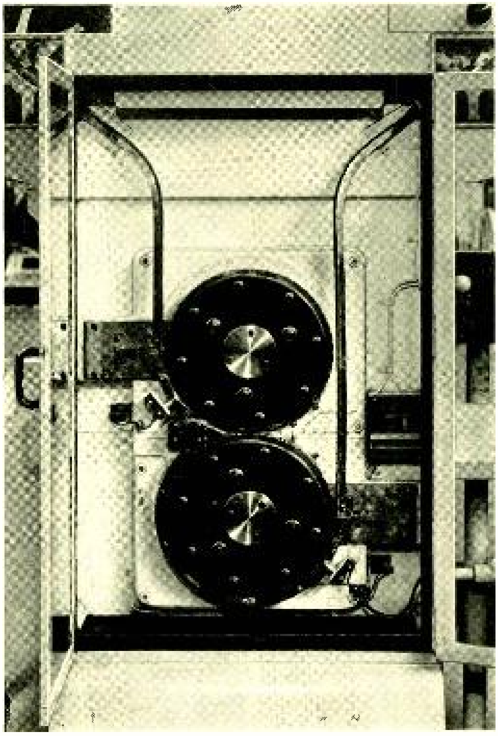


Fig. 3—Machine for placing insulators on central conductor of coaxial structure

Concurrently with the evolution of the design of the coaxial conductor, transmission studies were clarifying the requirements a conductor should meet as a transmission medium. An extraordinarily high degree of impedance uniformity as compared to other types of circuits was found to be important. Since impedance uniformity depends upon mechanical and physical uniformity of the coaxial, great care was taken in the design of the coaxial, and in the design and operating characteristics of the manufacturing equipment to assure a highly uniform product.

As manufacture got under way it became evident that there remained obscure causes of nonuniformity and, as a result, deviations of characteristic impedance within factory lengths and between different lengths became the outstanding feature on which additional development work was required. The degree of uniformity between different lengths was determined by measuring the inductance and capacitance of various factory lengths and calculating the RMS deviation of the ratio $\sqrt{L/C}$. Uniformity within a unit was determined with an ingenious circuit that shows the magnitude and location of irregularities on a cathode-ray oscilloscope. The equipment used for the purpose, shown in Figure 2, is known as an echo set.

The only possible variables that could be involved in the deviation of $\sqrt{L/C}$ at the higher frequencies were dielectric constant and ratio of inside diameter of the outer conductor to outside diameter of the inner conductor (D/d). A study of deviations of the product of inductance and capacitance (LC) showed that the deviation caused by variations in the composite dielectric constant of the air and rubber were too small to be an appreciable part of the total values obtained. With the ratio D/d, however, deviations of sufficient magnitude to account for the greater part of the deviations in $\sqrt{L/C}$ were found to exist.

One variable was, of course, the diameter of the center conductor. By introducing certain refinements, the Western Electric Company succeeded in producing wire with such small variations in diameter that the contribution from this source to the total deviation was relatively very small. The outstanding source of impedance deviations that remained was variation in the inside diameter of the outer conductor—D. This in turn was found to be due in large part to small variations in thickness of the copper tape, with variation in hardness playing a lesser rôle.

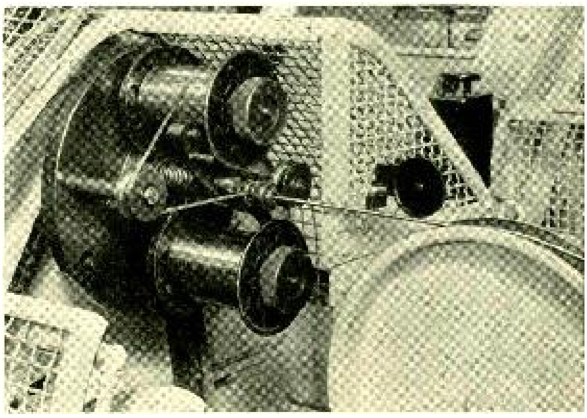


Fig. 4—Steel taping head that places steel tapes over outer conductor

By manufacturing coaxial units experimentally from tapes of different known dimensions and different degrees of variation from the average, a definite correlation was established between deviations in characteristic impedance and in thickness of the copper tape. As a result, oversize copper tape was purchased from the outside supplier with the usual commercial tolerances, and then drawn to the desired thickness of 10 mils by the Western Electric Company. This resulted in a reduction in deviation to less than a third of that found in the commercial product.

After the larger causes of deviation referred to above had been eliminated, a number of smaller contributing factors became prominent and required further efforts for their elimination. The engineering study of the details of design and manufacturing control during the production of this cable, undertaken in coöperation with the engineers of the Western Electric Company, has resulted in a transmission line structure for this installation with low deviations, and tests carried on in the field have shown very satisfactory transmission quality.

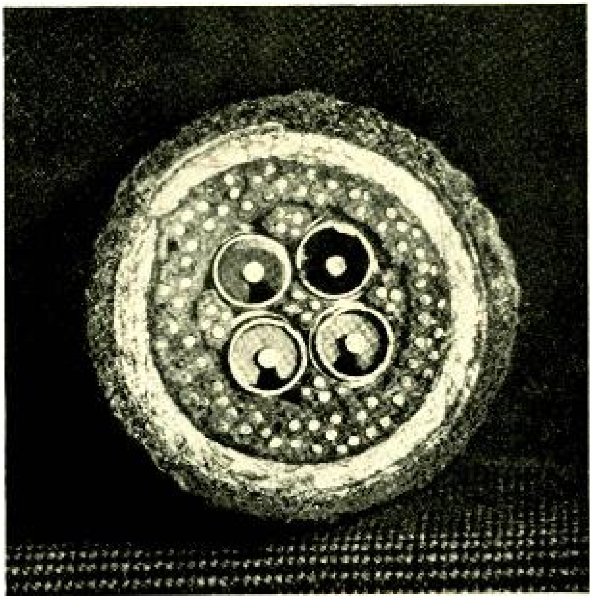
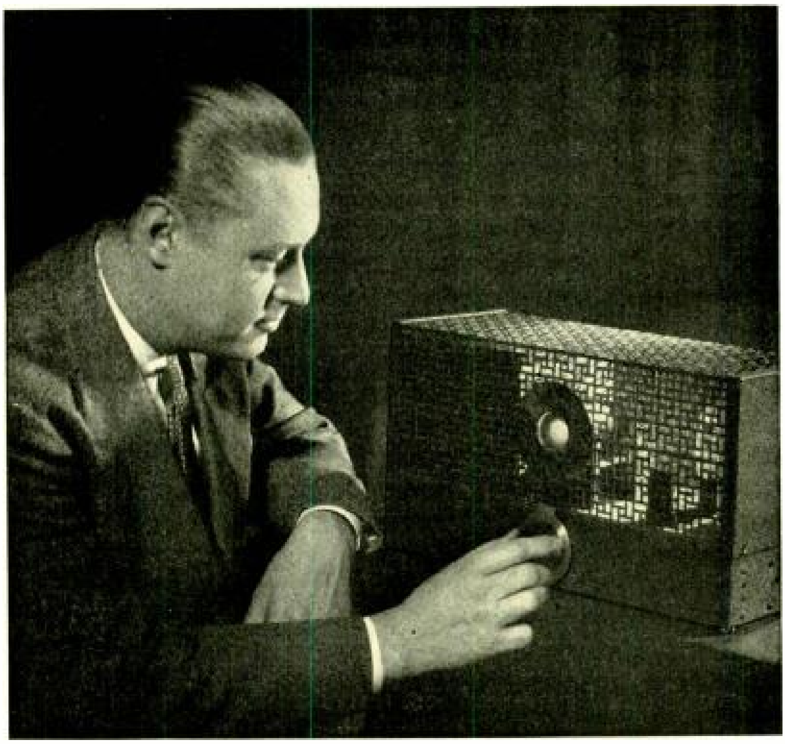


Fig. 5—A cross-section of the Stevens Point-Minneapolis cable reveals the four coaxial structures with two 22-gauge pairs in the central space and one 19-gauge and one 22-gauge pair in each outer interstice between them. Surrounding this assembly is a layer of eighteen 19-gauge quads



Measurements of Orchestral Pitch

By O. J. MURPHY
Research Department

THE pitch of the note A in the treble clef of the musical scale has been standardized at 440 cycles per second and it is of interest to know, from the point of view of instrument design and uniformity of performance, how closely this value is being adhered to in concert music. To this end equipment was set up which permitted the rapid and accurate determination of the pitch of this note during concerts, while being broadcast by radio. A series of measurements comprising some 750 observations was made on various types of musical programs available from American broadcasting stations. The mean value of the pitch for all observations was 441.3 cycles per second and the extremes observed were 434 for a dance band and 448 on two occasions for string quartets. Approximately seventy per cent of the observations were from 439 to 443 cycles per second.

Semi-permanently tuned instruments such as pianos and organs showed almost no variation in pitch during the course of a given performance and a relatively narrow variation from instrument to instrument. Orchestras varied at random as much as two cycles per second during a selection. This variation was generally due to different instruments in the group successively sounding A. Superimposed on this random variation there was a definite upward trend of pitch as the concert progressed, sometimes amounting to 2.5 cycles per second between the beginning and the intermission period. Symphony orchestras averaged more than one cycle per second higher in pitch than either light concert orchestras or dance bands, the mean values being 441.8, 440.6 and 440.4 respectively. String groups were consistently higher in pitch than any other class studied and showed a wide spread in the observed values. Miscellaneous solo instruments such as harp, guitar, violin and cello showed the widest variation in pitch but the average value of all these instruments taken together was 441.5 cycles per second. Brass bands gave an average value of 441.4.

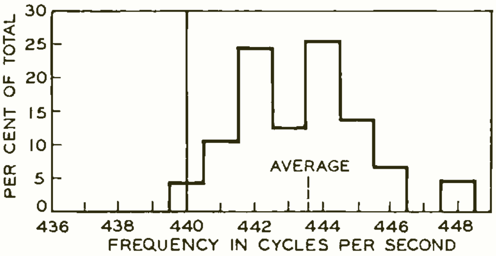


Fig. 1—*Pitch distribution of string instruments. The horizontal lines show, on the scale of ordinates, the per cent of all the observed values which fall within the frequency range covered by the corresponding abscissas. The average pitch of* 74 *observations was* 443.4 *cycles per second*

The measurements were made by filtering out the frequency band from 420 to 460 cycles per second from the voltage supplied by a radio set to its loud speaker. The voltage in this frequency range was applied to the control-grid of a cathode-ray tube in series with a fixed negative biasing voltage of such magnitude that the spot on the screen of the tube was visible only when the positive peaks of music voltage appeared. At the same time voltage from a highly stable oscillator, whose frequency was adjustable over the range from 420 to 460 cycles per second, was passed through a phase-shifting network to provide two components having a 90-degree phase separation and these components were then applied to the two pairs of deflecting plates of the cathode-ray tube. In the absence of bias and audio-voltage input on the control grid, these two quadrature components of voltage from the oscillator produced a luminous circle on the screen of the tube. The bias, however, prevented the spot from being visible except during positive half-cycles of incoming music voltage in the frequency range passed by the filter. When this voltage corresponded exactly in frequency to that of the oscillator a half-circle arc appeared on the screen of the tube in a stationary position; and when the two frequencies did not exactly agree the arc revolved in one direction or the other at a speed corresponding to the difference in frequencies. The direction of movement indicated whether the oscillator frequency was

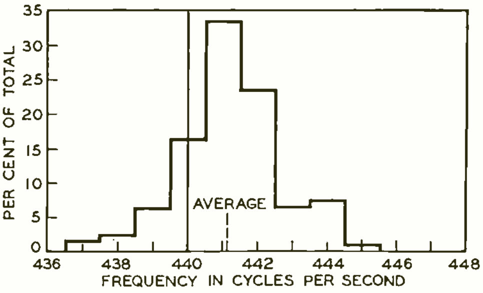


Fig. 2—*Pitch distribution of pianos, including the pianos that are used in dance bands. The average pitch of* 111 *observations was* 441.3 *cycles per second* higher or lower than that of the incoming music voltage. The arc could be brought to rest by adjusting the frequency of the oscillator and the oscillator frequency was then that of the incoming music voltage. This frequency was read from the calibration of the oscillator.

The oscillator had a vacuum tube of very high mutual conductance associated with a twin-T network of resistances and condensers. One of the resistances could be varied by the operator to adjust the frequency and another was thermally sensitive so that bridge-stabilized operating conditions could be achieved while maintaining a power output well within the Class A amplifier rating of the tube. Mica condensers of low temperature-coefficient were used. The oscillator was calibrated initially by comparison with the Laboratories' frequency standard and subsequent checks were frequently made, while the equipment was in use, by tuning in the Bureau of Standards Radio Station, WWV, at Beltsville, Maryland, which broadcasts the standard pitch of 440 cycles per second on a carrier frequency of five megacycles continuously twenty-four hours per day.

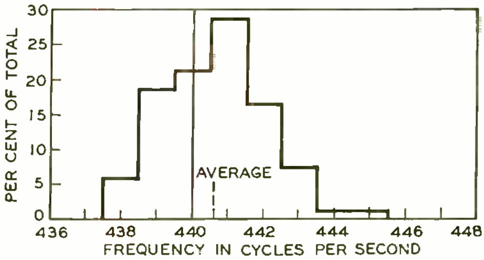


Fig. 3—Pitch distribution of light concert orchestras: average pitch of 85 observations 440.6 cycles per second

After a warming-up period of fifteen minutes the frequency did not vary more than ±0.1 cycle at any time during many ten-minute periods of checking against WWV. A long-time drift was observed amounting to approximately 1.5 cycles during the four-month period of observation. Correction of the data was made to take this drift into account and it is believed that the overall accuracy of the oscillator was always within the limits of ±0.1 cycle.

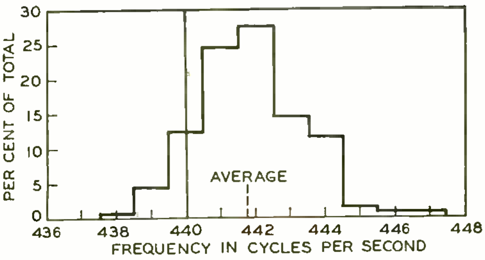


Fig. 4—Pitch distribution of symphony orchestras: average pitch of 207 observations 441.8 cycles per second

This study embraced musical organizations performing in many parts of the United States. No consistent regional difference was observed. The weekly recurring nature of many radio programs made it possible to obtain a series of observations over a period of time on several prominent musical organizations as well as detailed readings during the course of any one concert. Data for four important symphony orchestras on which extensive observations were made indicate that the maximum variation in average pitch during any one concert was about 2.5 cycles per second, while the maximum variation encompassed in sixteen concerts was approximately twice this amount. All four orchestras were very nearly alike in their range of variation. In nearly all cases where symphony orchestra and solo instrument combined in the performance the orchestra tended to adapt its pitch to that of the solo instrument, usually dropping slightly for piano and nearly always rising considerably for violin or cello. After the performance of a concerto the orchestra frequently returned to approximately its original pitch for subsequent selections. The effect of retuning during intermission was also observable in most cases. The orchestras usually returned to approximately the pitch with which they began the performance after having drifted upward during the first half of the concert. The tendency of the pitch to rise during the course of an orchestral performance was almost universal.

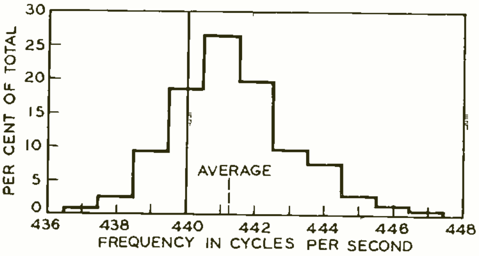


Fig. 5—Pitch distribution of all orchestras and instruments tested: average pitch of 749 *observations* 441.3 *cycles per second*

In the orchestral observations an attempt was made to average out the random variations, due to different instruments successively sounding A, and to obtain a mean value for the group as a whole. This was done by finding a setting of the oscillator dial which gave about as much movement of the luminous arc in one direction as in the other over a three or four-minute period of observation. With solo instruments, particularly organs and pianos, it was sometimes possible to make the arc stand still for several seconds at a time.

The mean of all observations, 441.3, is about 1/20 of a half tone higher than the accepted standard. The variation of 2.5 cycles per second, found during the performance of symphony orchestras, represents a variation of approximately one-tenth of a half tone. The extremes of the range for all observations, 434 to 448, represents approximately a quarter tone.

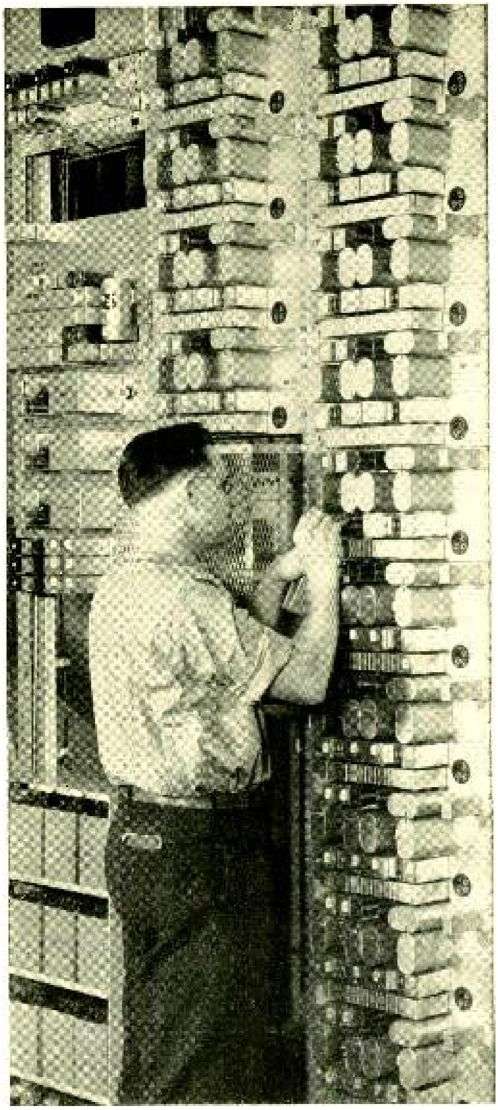
Some few measurements were made on singers with orchestral accompaniment. No significant difference was observed in orchestral pitch between vocal and nonvocal selections but the moment-to-moment variation in the singer's pitch was found to be so great that the results of these measurements seemed of questionable value and are therefore not included here.

The 1000-Cycle Ringer-Oscillator

By G. A. PULLIS
Switching Department

FOR ringing over toll circuits, signals of 20 cycles, 135 cycles, or 1000 cycles are usually employed, depending on the type of line. Neither the 20-cycle nor the 135-cycle signals, however, are amplified satisfactorily by voice repeaters. When these types of signals are used, therefore, provision generally must be made at each intermediate repeater station to repeat the signals around the voice repeaters. The 1000-cycle signals, on the other hand, are readily passed by the voice repeaters so that signal-repeating equipment is not required at the intermediate repeater-station locations.

For toll circuits with two or more intermediate voice repeaters, the use of 1000-cycle signalling generally is economical. The most attractive application is on those toll circuits that terminate in offices where the cost of the source of signalling currents can be distributed over a considerable number of toll circuits. This signalling source, which is a 1000-cycle voltage interrupted at a 20-cycle rate, is usually obtained from a 1000-cycle motor-generator furnishing interrupted output, or from the output of a 1000-cycle oscillator interrupted by means of an auxiliary 20-cycle circuit. The cost of these sources is fairly high, and thus where there are only a few toll circuits which would normally use the source, the cost per circuit becomes greater than desirable.



To permit 1000-cycle signalling to be used economically, even when only a single toll circuit is involved, the 1000-cycle ringer-oscillator has been developed. It avoids the cost of a central 1000-cycle supply by a design in which the receiving circuit, of which one is always needed for each trunk, is used also to generate an interrupted 1000-cycle current for signalling purposes. Various of the leads interconnecting parts of the circuit are brought to some forty contact springs on two relays, and when these relays are operated, the circuit is rearranged to supply 1000-cycle current interrupted at a 20-cycle rate. Normally the circuit—arranged to receive signals—is connected across the trunk. When an operator rings on the circuit, these relays are operated, and rearrange the circuit in the proper manner to transmit the desired signal.

The ringer-oscillator circuit is shown in both receiving and transmitting conditions in Figure 1, where the transmitting condition is shown in the bottom diagram and the receiving condition in the upper one. The apparatus shown in solid lines is the same for the two conditions, but the circuit connections are changed by contacts on the A and B relays. Only the apparatus shown in dotted lines is

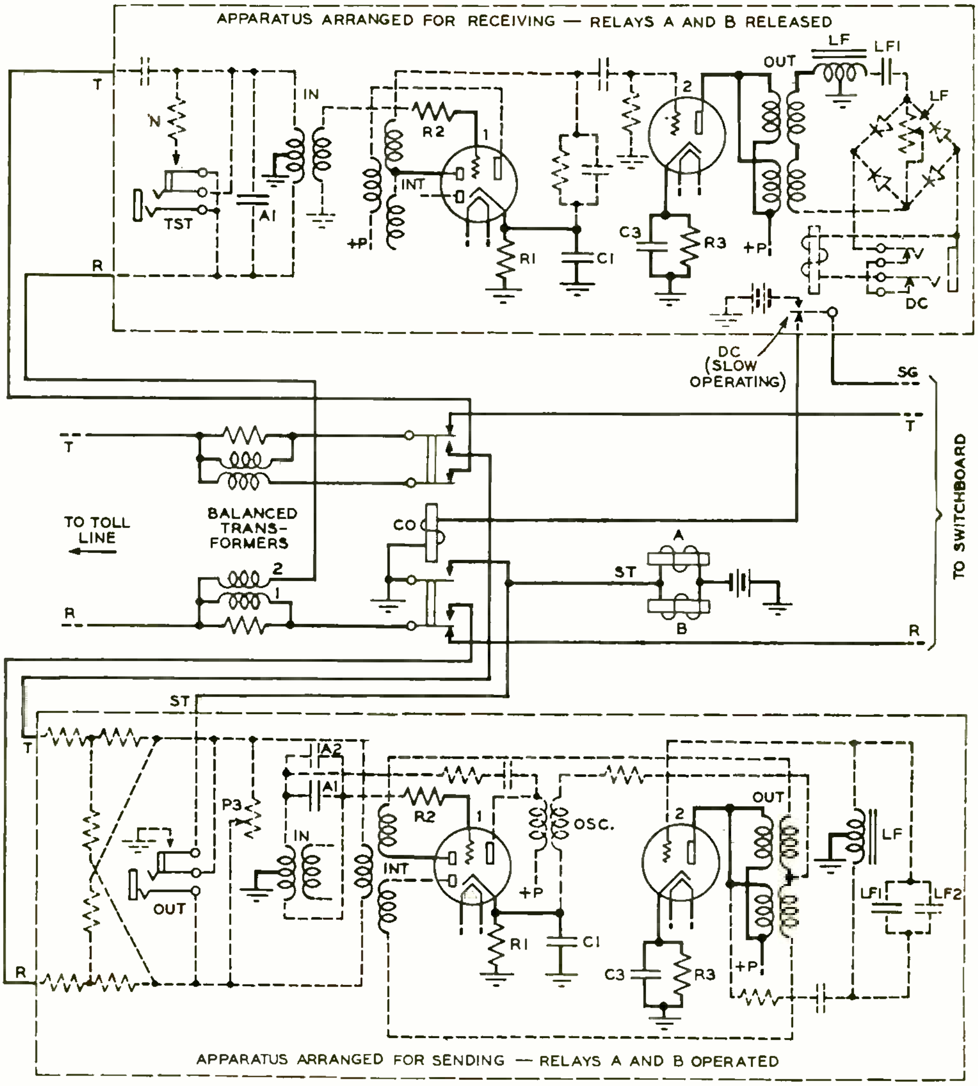


Fig. 1—The ringer-oscillator circuit arranged for receiving, above, and for sending, below

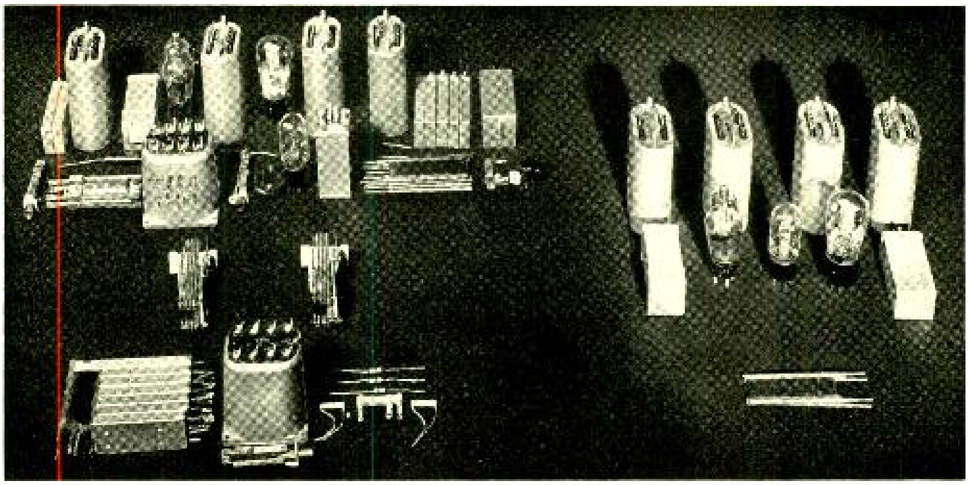


Fig. 2—Apparatus for receiving circuit, upper left, need be supplemented only by apparatus at lower left to form the complete ringer-oscillator circuit. Had complete receiving and sending circuits been provided, the apparatus at the right, including transformers and vacuum tubes, would have been needed in addition

not used in both arrangements, and for the most part these are minor and inexpensive elements. The saving in apparatus effected by this design is shown in Figure 2. The apparatus required for the receiving circuit is shown at the upper left. Only the transformer, condensers, and resistances shown at the lower left must be added to convert the receiving circuit to the complete ringer-oscillator circuit, the two relays at the left center being used to change from receiving to sending condition. If separate receiving and sending circuits had been employed, the apparatus shown at the right would have been required in addition to that shown at the left, and since for the most part this is expensive apparatus, chiefly transformers and tubes, the saving is substantial. Between the diagrams of the circuit in the two arrangements shown in Figure 1, are circuit elements used for both sending and receiving. The CO relay is normally unoperated; it is operated only when signals are being sent out over the trunk. Signals coming in over the toll line pass through the balanced transformer to the receiving circuit. This transformer is employed to prevent signals or echoes from the switchboard from affecting the receiving circuit. The action of the transformer has been described in a previous article.* Without it, the operation of the circuit might be affected by echoes of the incoming signal reflected by impedance mismatches. If the delay time of the echoes were just 1/20 of a second, for example, the reflected signal might tend to fill the interrupted period of the direct signal, and thus decrease the usable signal.

The incoming signal, after passing through the balanced transformer, reaches the "IN" transformer, the ring lead through a back contact—not shown—on the A relay, and the tip lead through a back contact in the CO relay. This IN transformer is tuned

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*RECORD, *Nov.*, 1939, *p.* 91

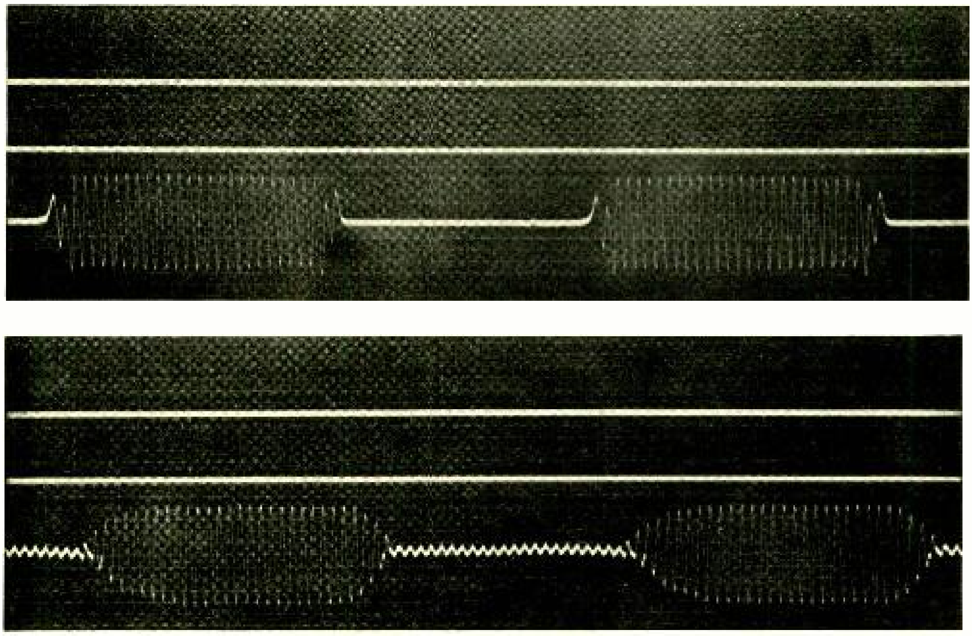


Fig. 3—Output of 1000-*cycle oscillator, above, and of ringer oscillator, below*

to 1000 cycles by the AZ condenser. Its output is impressed on the grid of vacuum tube 1, which acts as an amplifier. Through the secondary winding of the "INT" transformer, the amplified output is impressed on a diode plate in tube 1. The diode elements of this tube rectify the output, and thus the output is transformed to a pulsating current following the 20-cycle interruptions of the signal. This output, in turn, is impressed on the grid of tube 2, which acts as a 20-cycle amplifier, with its output feeding a 20-cycle tuned circuit through the "OUT" transformer. This 20-cycle output is then rectified by the copper-oxide rectifier and operates the slow-operate relay DC. When the relay operates, battery is placed on the SG lead, which causes the desired signal to appear before the operator.

When a voice frequency is used for signalling, it is necessary to design the receiving circuit so that it will not be operated on voice currents, since the circuit is connected across the line at all times. It is for this reason that the receiving circuit is provided with double tuning so that only 1000 cycles, either interrupted or modulated at 20 cycles, will operate it. It is possible, of course, that for very short periods there might be such a combination of speech currents, and it is to prevent operation of the circuit on such short-duration impulses that the DC relay is given slow-operate characteristics. The short-time appearance of a 20 and 1000-cycle combination that might appear in speech have no effect on it, while the sustained signal currents readily operate it.

When the operator wishes to signal over the toll trunk, she operates a key that places battery on the SG lead. The resulting current flows through the back contact of relay DC, and operates the CO relay. Operation of this relay grounds the winding of relays A and B and operates them. These relays control contacts that change the connections of the circuit to the arrangement shown in the bottom diagram. Operation of CO also connects the tip and ring leads of the outgoing trunk to the sending circuit as shown, and disconnects the ring lead from the IN transformer.

Each of the tubes of the circuit, when connected for the sending condition, acts as an oscillator—tube 1 as a 20-cycle oscillator and tube 2 as a 1000-cycle oscillator. The output of the 20-cycle oscillator is fed—through the OSC transformer—to the midpoint of the secondary of the OUT transformer where it divides, flowing through the two primary windings of the INT transformer to the two diode plates of tube 1. In passing through the OUT transformer, of course, the output of the 1000-cycle oscillator is imposed on the 20-cycle current. During the positive half of the 20-cycle current, the two diode plates are positive to the cathode, and current will flow. During the negative half of the 20-cycle current however, the diode plates are negative to the cathode and current will not flow. As a result, the output current in the secondary of the INT transformer is at 1000 cycles interrupted at a 20-cycle rate, and this signal current is sent out over the trunk through front contacts on the operated CO relay. The wave form of this signal is shown in the lower part of Figure 3, and above it is that for the 1000-cycle generator.

The circuit shown in Figure 1 is designed for the No. 3 switchboard, and in the receiving condition sends out a d-c signal to the switchboard. It is mounted on a panel as shown in Figure 4 and in the photograph at the head of this article. Some boards, such as the No. 1 toll board, however, require a 20-cycle current for signalling. To provide this, a 20-cycle applique circuit has been developed. It is shown directly below the ringer-oscillator in both the photographs. This is a small circuit that acts as an intermediary for sending and receiving 20-cycle current to and from the switchboard.

The ringer-oscillator circuit is designed for operating on the office battery, but to provide for places where a battery is not available, or where it is not desirable to place additional drain on the battery, a small power-supply circuit has been developed. The circuit of this unit is shown in Figure 5. It operates on a 110-volt 50 or 60-cycle source and provides plate and filament voltage and a rectified current for operating relays. A transfer circuit is also available, which on failure of the a-c supply will transfer the ringer-oscillator cir-

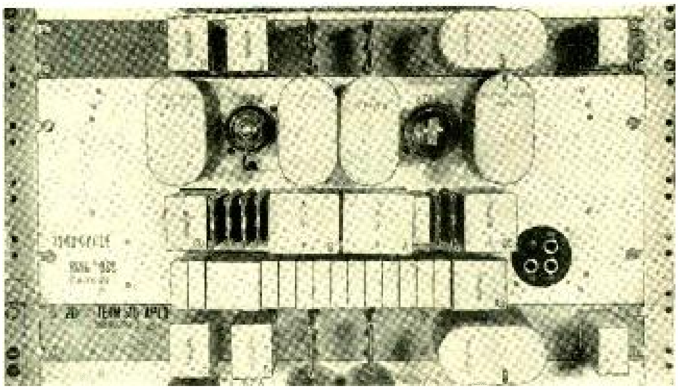


Fig. 4—One of the ringer-oscillator panels with an applique unit as installed in Du Bois, Pennsylvania

cuit to the battery for the duration of the failure.

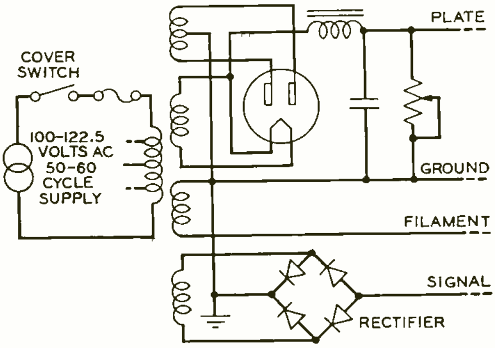
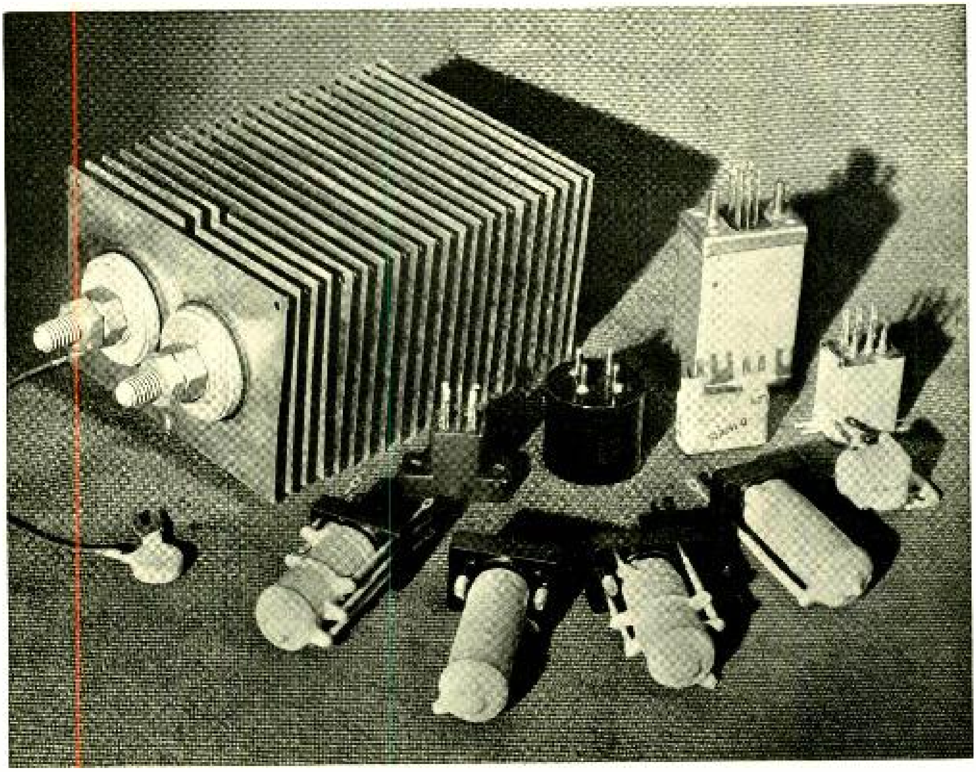


Fig. 5—Schematic diagram of power-supply circuit that has been developed for use with the ringer-oscillator circuit

To insure proper operation of the existing voice-frequency signalling circuit, a test panel is provided to measure its operate and non-operate range and time. This has been necessary because of the use of polar and round-type relays, the adjustments of which may vary widely. With the ringer-oscillator, however, the signalling range will remain fairly constant, and the operate time is not subject to any critical conditions. As a result, the test panel has been omitted, with resulting simplification. Certain simple tests are arranged for, however. The insertion of a dummy plug in the TST jack, for example, places resistance N across the input of the circuit, thus giving a loss of about 4 db. While the plug is inserted, the distant operator is requested to signal, and if the circuit operates normally, there is a signalling margin of at least 4 db. The DC and OUT jacks are also provided for maintenance purposes. The DC jack is used to measure the current in the DC relay, which can be changed if necessary by readjusting the LF resistor. The OUT jack permits the output signalling voltage to be measured, and this voltage can be changed by readjusting the P3 resistor.

The ringer-oscillator circuit has several other features which are of advantage in small offices. The present voice-frequency system, being based on large groups of circuits, is arranged with the equipment required for one toll line split into three separate circuits: the directional selection and cutoff relay circuit, the 1000-cycle signal-receiving circuit, and the battery-supply circuit. The ringer-oscillator is arranged to combine these three circuits into one, thereby resulting in a saving of space, a reduction of installation time and charges, and an equipment arrangement which may be moved easily from one office to another.

The ringer-oscillator was developed primarily to permit the use of 1000-cycle signalling on small groups of voice-frequency toll lines. There may, however, be some other uses for the circuit. Carrier-telephone systems usually require voice-frequency signalling, as do some radio telephone circuits. Since these systems are sometimes installed in small groups and in offices not equipped with a voice-frequency source or a test panel for the signalling circuits, the ringer-oscillator may prove economical. It is also likely that this new circuit will be found useful for some of the conditions that are often encountered in various special service applications.



The Copper Oxide Varistor

By WALTER H. BRATTAIN

Physical Research

THE copper oxide varistor is a useful and interesting circuit element because its conductivity may change by a factor of ten thousand as the sign of the applied potential is changed. This varistor consists of a layer of red cuprous oxide (Cu_2O) about 0.003 inch thick, grown on the copper. Discs or washers of suitable size are heated in air to a high temperature; on them cuprous oxide is formed in a continuous layer of uniform thickness. While the varistors are being cooled to room temperature, a layer of black cupric oxide is formed on the red. It plays no part in the varistor and is always removed. Connection with the external circuit is readily made at the copper side of the varistor. For the oxide side some special treatment is necessary such as a vaporized metal contact.

A typical current-voltage characteristic for a copper oxide varistor is shown in Figure 1. For curve A the direction of flow of electrons is from the copper to the oxide; and from oxide to copper for B. The rectifying action is evident from the fact that at one volt the current in one direction is about 4000 times as great as in the other direction.

Such a current-voltage characteristic as shown in Figure 1 is due to the fact that the copper oxide varistor is a combination of various distinct circuit elements in series and parallel. This can be seen better from curves showing dependence of resistance on potential. Such curves derived from Figure 1 are shown in Figure 2. Two curves are given since the resistance can be defined either as the ratio of the applied potential to current or as the ratio of the change in potential to change in current for very small changes in potential, *i. e.*, the differential resistance. Both resistances are significant and are shown in Figure 2 for comparison. For subsequent figures we shall always use the differential resistance. From Figure 2 we see that the resistance is large and has a maximum value for negative potentials on the oxide but the value of the resistance decreases rapidly for positive potentials, finally reaching a constant value.

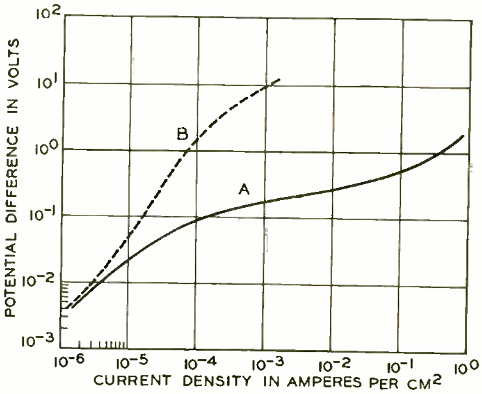


Fig. 1—Typical current-voltage characteristic for a copper oxide varistor

Experience has shown that the seat of the potential-dependent resistance is at the interface between the cuprous oxide and the copper. The electrical resistance across this interface is large when the potential on the oxide is negative and decreases without limit when the potential of the oxide is made increasingly positive. The limiting constant resistance for positive potentials in Figure 2 is just a measure of the ohmic series resistances in the circuit element.

The seat of most of the series resistance is in the oxide layer itself. This is illustrated in Figure 3. Here the oxide layer was intentionally grown quite thick and then thinned down step by step. Each such step reduced the constant part of the resistance at positive potentials without affecting the rest of the resistance curve. Each change in the thickness measures the resistance of the oxide layer removed. The table in Figure 3 gives these changes, and the resistivity (r) in ohm centimeters deduced therefrom for each layer removed. Instead of being constant throughout the layer of oxide as one might expect, the resistivity decreases in a regular manner from layer to layer. This be-

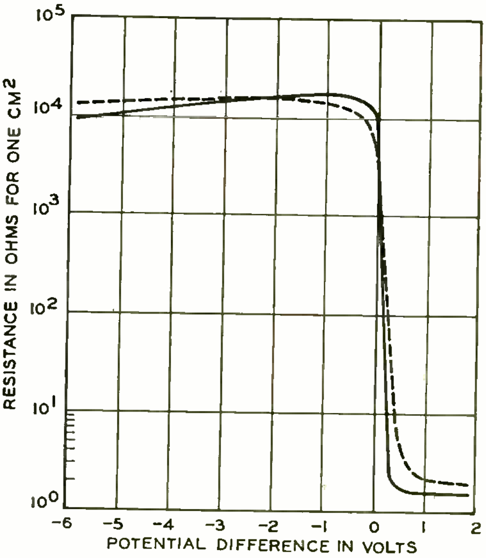


Fig. 2—Resistance vs. potential difference—dashed line, R = V/I; *solid line,* R = *dv/di*

havior is characteristic of the class of electronic conductors called semi-conductors whose specific resistance is greater than that of metals and less than that of insulators. Cuprous oxide is one of this class of conductors; its specific resistance not only may vary by a factor of ten or more in a single piece, but can and does vary by larger factors (a million or more) from piece to piece. In other words the resistivity of a semi-conductor is very sensitive to its past history or treatment. Also typical of semi-conductors is the phenomenon of rectification which has been found to occur at the oxide-copper interface in the copper oxide varistor.

Another source of series resistance is the other contact to the cuprous oxide. The two types of contact that have proven most useful are the vaporized metal contact and the older method consisting of a coating of colloidal graphite and a tinned lead washer held under heavy pressure. The resistance of the latter is somewhat variable but may be as large as 0.6 ohm for one square centimeter as compared to about 1.6 ohm for one square centimeter for a cuprous oxide layer 0.003 inch thick. The resistance of a good metal contact is much lower, 0.1

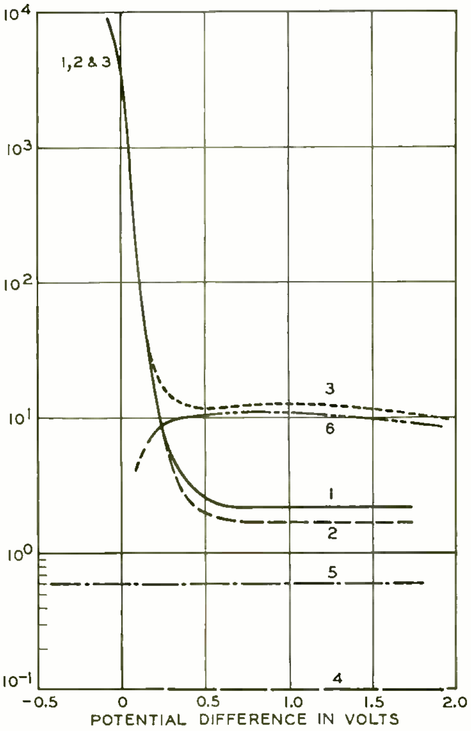
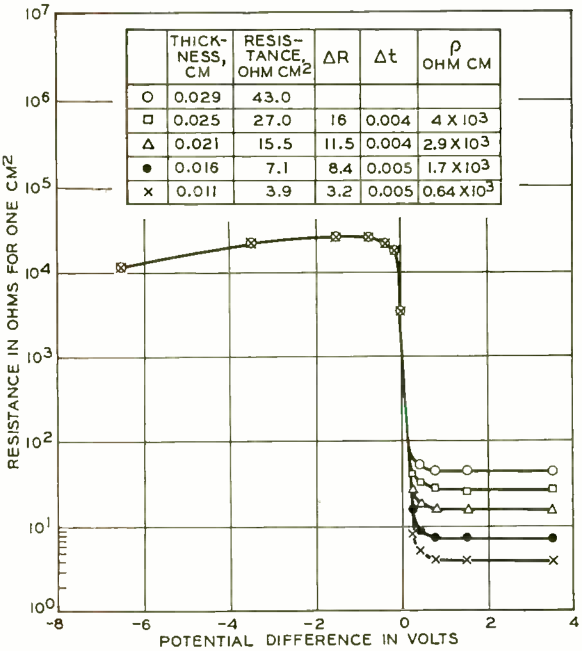


Fig. 4—Effect on resistance curve of various types of contact to the outer face of cuprous oxide. 1. *Curve for standard unit with graphite contact.* 2. *Curve for standard unit with good metal contact.* 3. *Curve for standard unit with rectifying metal contact.* 4. *Estimated resistance of good metal contact.* 5. *Approximate resistance of graphite contact (This is* 1 *minus* 2 *plus* 4). 6. *Approximate resistance curve of rectifying metal contact (This is* 3 *minus* 2 *plus* 4)



	THICKNESS, CM	RESISTANCE, OHM CM²	ΔR	Δt	ρ OHM CM
○	0.029	43.0			
□	0.025	27.0	16	0.004	4×10^3
△	0.021	15.5	11.5	0.004	2.9×10^3
●	0.016	7.1	8.4	0.005	1.7×10^3
×	0.011	3.9	3.2	0.005	0.64×10^3

Fig. 3—Resistance vs. potential curves, showing the results of reducing the thickness of the oxide layer

ohm for one square centimeter or less, and can be neglected in comparison with the resistance of the oxide layer. Special techniques are, however, necessary in making this metal contact. The metal must be vaporized on a clean cuprous oxide surface under high vacuum. This technique has been reduced to practice. Sprayed, sputtered and some vaporized metal contacts generally result in a rectifying contact at this surface of the oxide. This rectifier is opposed to the one at the oxide-copper interface. All these results are illustrated in Figure 4, where the part of the curve dependent on added series resistances is given on a larger scale.

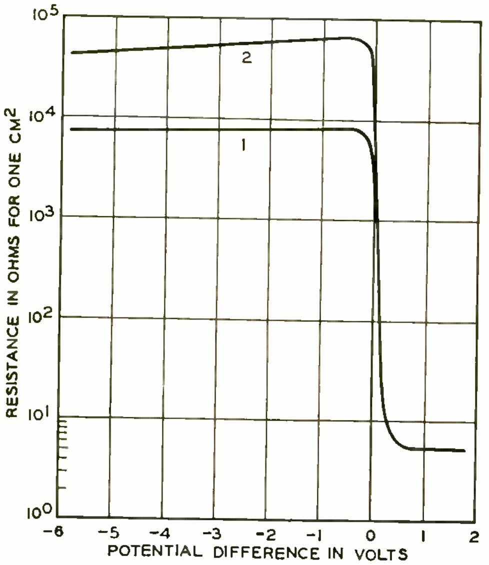


Fig. 5—(1) *Resistance curve with edge leakage.* (2) *Resistance curve when edge leakage has been eliminated by guard ring*

The high resistance for negative potentials is sometimes limited by parallel leakage resistance; however, experience has shown that the resistance reaches a maximum for this direction of current flow and does not increase without limit even when the leakage paths are removed. An example of a large parallel leakage occurs where the oxide-copper interface has been damaged around the edge of the unit by mechanical working. Such edge effects can be isolated by guard ring methods. A particularly bad case is illustrated in Figure 5. The leakage turns out to be a parallel ohmic resistance, in this case approximately 9.0 x 10^3 ohms. The reduction of this "edge effect" is particularly important commercially in the case of small units where the ratio of perimeter to the area of unit is comparatively large.

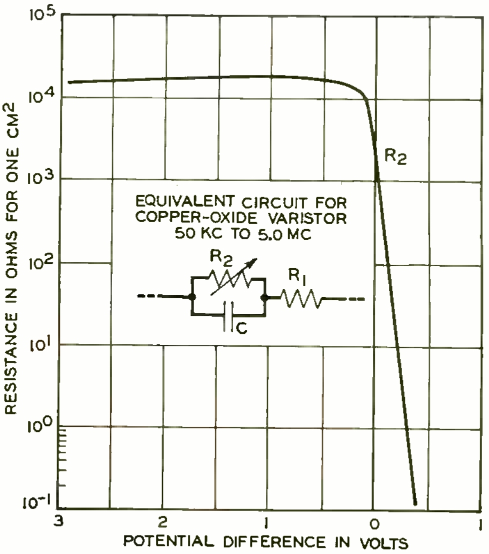


Fig. 6—*Equivalent circuit for copper oxide varistor in the frequency range* 50 *kilocycles to* 5 *megacycles capacity* = 2.0 x 10^{-2} *microfarads/cm*^{2} R_1 = 2.0 *ohm for one cm*^{2} *and* R_2 *is variable as shown by curve or by the relation:* $R = 2.3 \times 10^4\, e^{0.15V}\, (7.7\, e^{26V} + 1)$ *where* V = *voltage*

So far we have completed the discussion of the resistive elements whose combination makes up the overall resistance curve of the copper oxide varistor. Direct-current and low-frequency alternating currents applied to our varistor would reveal very little more. However, at a thousand cycles and higher we find that a capacity is also concealed in our varistor. This is of course to be expected in view of the high resistance layer (for negative potentials) at the oxide-copper interface. This capacity is approximately independent of frequency and about 2.0 x 10^{-2} microfarads per square centimeter. The way in which the capacity is associated with the resistive elements is not simple, and no one simple equivalent circuit is good for all frequencies. However, it has been found that from about fifty kilocycles to five megacycles the capacity acts as if it were connected in parallel with the potential-dependent resistance of the oxide-copper interface. This is illustrated in Figure 6. At lower frequencies the capacity appears to be in parallel with only a part of the potential dependent resistance of the varistor and the equivalent circuit is more complicated.

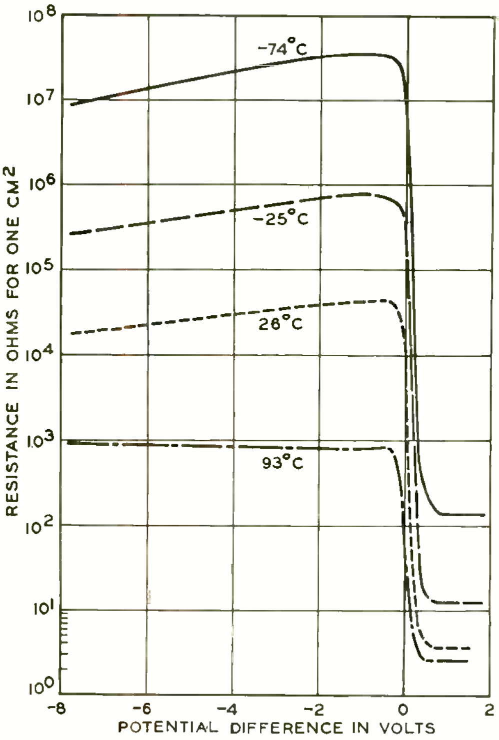


Fig. 7—Resistance potential curves for several temperatures

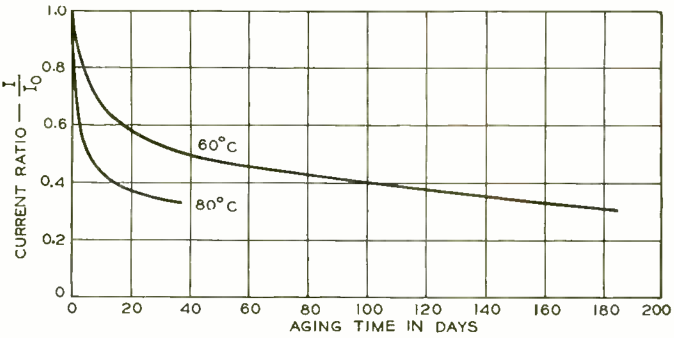


Fig. 8—Accelerated aging of copper oxide varistors (measured at plus 1.0 *volt)*

The resistances of the copper oxide units have rather large negative temperature coefficients. Resistance-voltage curves for four different temperatures are shown in Figure 7. One sees that the junction resistances at negative potentials change by much larger factors than those for the body of the oxide. Consequently the rectification increases as the temperature is lowered. The capacity, however, is not greatly dependent on temperature, so for high frequencies nothing would be gained even if the copper oxide units could be operated conveniently at low temperatures.

Copper oxide varistors age more rapidly than one might wish and, as one might expect, in the wrong direction. Certain uses do not involve very much dissipation of energy in the varistor. For such use the aging is mostly confined to an increase of the resistance of the cuprous oxide layer.

This increases the series ohmic resistance and thus decreases the rectification. Aging can be accelerated by keeping the units at a high temperature; curves showing this are given in Figure 8. One hundred days at sixty degrees Centigrade is equivalent to about eight years at 25 degrees Centigrade. On heavy load the junction resistance in the reverse direction decreases to about one-tenth its initial value. Since the rate of aging does decrease with time it is an advantage in certain cases to pre-age the units before they are used.

If a high reverse potential is applied to the varistor the current will increase with time, sometimes by a factor of seven in twenty minutes. If the potential is then removed for a time and reapplied it is found that the current has decreased; reversing the potential will accelerate the rate of decrease. The curves in Figure 9 illustrate these "creep effects." The curves are drawn for a forty-minute interval, the potential of −6.0 volts on for twenty minutes and then off for twenty minutes. Curve (1) is for a very fast "creeper." Curve (2) is about the average behavior of standard varistors and curve (3) illustrates the fact that occasional units have been made in which the current decreases with time when the potential is on. The major part of this "creep effect" is due to a slight polarization or electrolytic action at the oxide-copper interface. For units operating under a steady alternating potential the reverse current reaches an equilibrium value which, for most units, is several times larger than the initial current.

So far we have discussed the electrical properties of copper oxide varistors, all of which were made from a single kind of copper and given a definite heat treatment. The electrical properties are dependent on these two

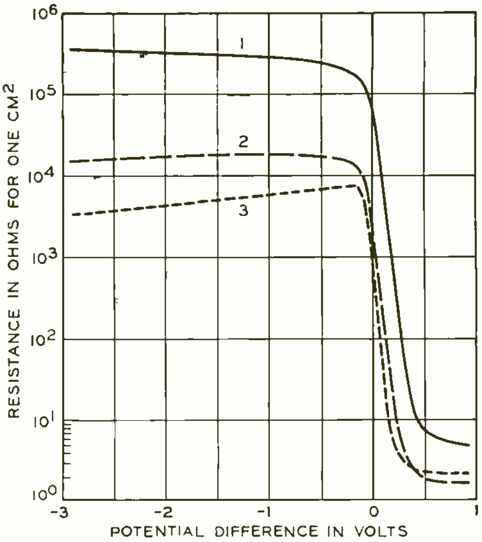


Fig. 10—Dependence of resistance curve on type of copper used. 1. Special alloy copper. 2. Standard varistor copper from Chile. 3. Oxygen-free high-conductivity copper

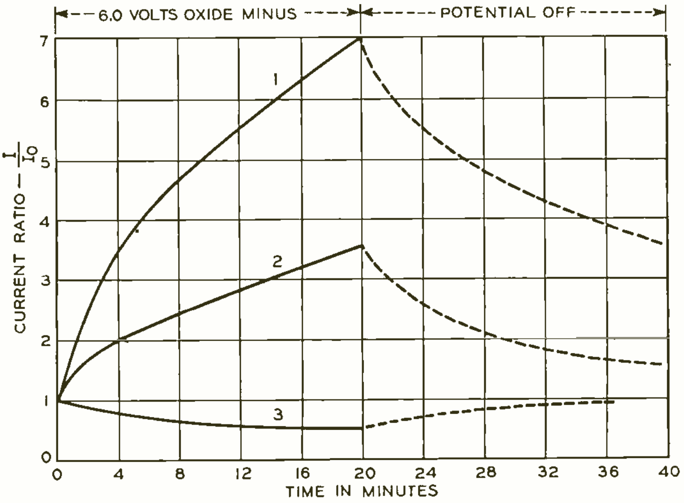


Fig. 9—Change of current with time for three samples

factors. To illustrate this we show first in Figure 10 the resistance curves for three types of varistors each made with the same heat treatment but from three different coppers, namely, (1) a special alloy copper (developed in these Laboratories), (2) the copper that is almost universally used to make copper oxide varistors and comes from Chile and (3) a commercial copper that is noted for its freedom from oxygen and its high electrical conductivity. The junction resistance is seen to be very sensitive in shape and magnitude to the type of copper used while the resistance of the oxide layer is less sensitive.

In Figure 11 are shown some of the effects of heat treatment. In this case the varistors were all made from Chile copper. It will be noticed that a change in heat treatment affects both the body resistance of the oxide and the junction resistance. Usually an increase in the body resistance is accompanied by an increase in the junction resistance, but one of these may change by larger factors than the other.

In conclusion it would, of course, be convenient to be able to interpret the electrical behavior of the copper oxide varistors in terms of fundamental physical and chemical laws. What this interpretation will be is still open to question. At present it appears that the structure-sensitive resistance of the oxide layer is due to very small amounts of certain impurities and that if these impurities were removed the cuprous oxide would have a resistivity of about 10^8 to 10^9 ohms per centimeter. As for the flow of current across the oxide-copper interface it is very similar in behavior to the flow of current between two thermionic cathodes, both at the same temperature but having different work functions. In this picture the oxide would correspond to the cathode having the higher work function. This analogy cannot be carried too far without special assumptions in regard to the nature of the oxide-copper interface.

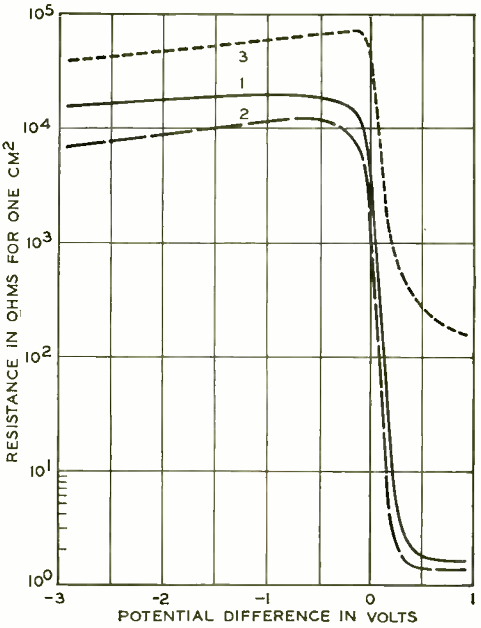


Fig. 11—*Resistance curves for three different heat treatments*

Repeaters for the C5 Carrier System

By E. H. PERKINS
Carrier Telephone Development

THE type-C carrier system* provides three two-way talking circuits within the frequency band between 5 and 30 kc. This system consists of a terminal at each end of the circuit, and repeaters spaced along the line between them. These repeaters provide amplification in both directions, and are located from 100 to 300 miles apart, depending on the transmission characteristics of the connecting line and the weather conditions likely to be encountered.

A new terminal and a new repeater have been designed for this system. The terminal† is designated the C5 and supplants the C4 terminal. The new repeater is designated C1, and replaces the A3 and B3 repeaters. By taking advantage of recent developments in repeater design, chiefly stabilized feedback, it has been possible to secure improved electrical performance and a considerable reduction in maintenance.

This repeater may be used with any of the frequency allocations provided by the C5 terminal without requiring changes except for the filters used to select the pilot frequencies. Although the frequency allocations provided by the C5 terminals extend only up to a little above 28 kc, the C1 repeater provides for a band up to 31 kc, and thus may be used with the early C systems which have one allocation extending to this frequency.

In general, the repeater functions the same as the previous repeaters. A block schematic is shown in Figure 1. The three channels from east to west comprise the lower group, and use the frequency range between 5 and 16 kc, while those from west to east comprise the upper group and use frequencies between 18 and 31 kc. At each end of the repeater circuit are the input and output directional filters that separate the two groups, those in the upper branch being high-

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*Record, *Aug.*, 1940, *p.* 354.

†Record, *Oct.*, 1940, *p.* 52.

pass filters and those in the lower being low-pass filters. In each branch of the repeater the major equipment consists of an input pad, equalizers, regulator, amplifier, and output pad. Besides these major circuit components, provision has been made in the design for certain other elements which may be needed at times. These include a high-pass filter in the input to the west-to-east branch, and auxiliary equalizers in both branches. These elements are required primarily because of the presence of other frequencies, such as those of the type-J carrier system, on the same open-wire line. A complete repeater including the regulating equipment now requires only eight feet of relay rack space as shown in the photograph on the opposite page.

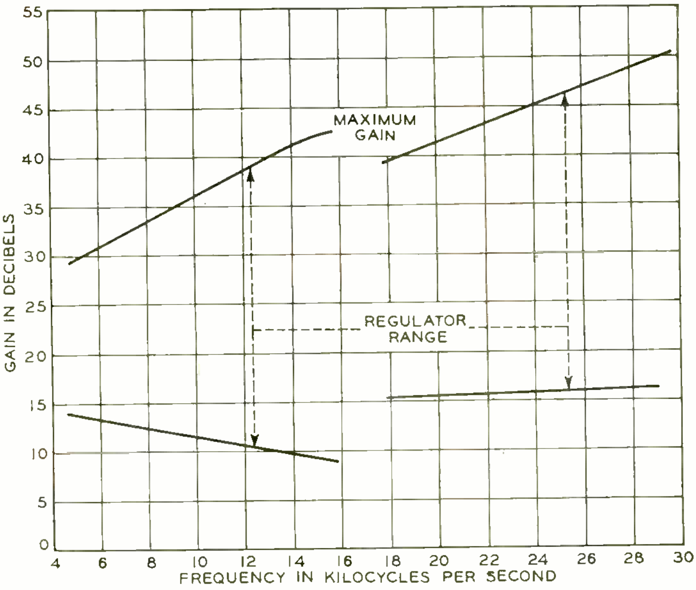

Fig. 2—Maximum gain characteristics of the C1 repeater

The repeater has maximum gain characteristics as shown by the upper curves of Figure 2. Such high gains are needed to provide margin for wet weather, ice, and sleet conditions. When less gain is required, the gain is reduced by adding artificial line having both slope and flat loss charac-

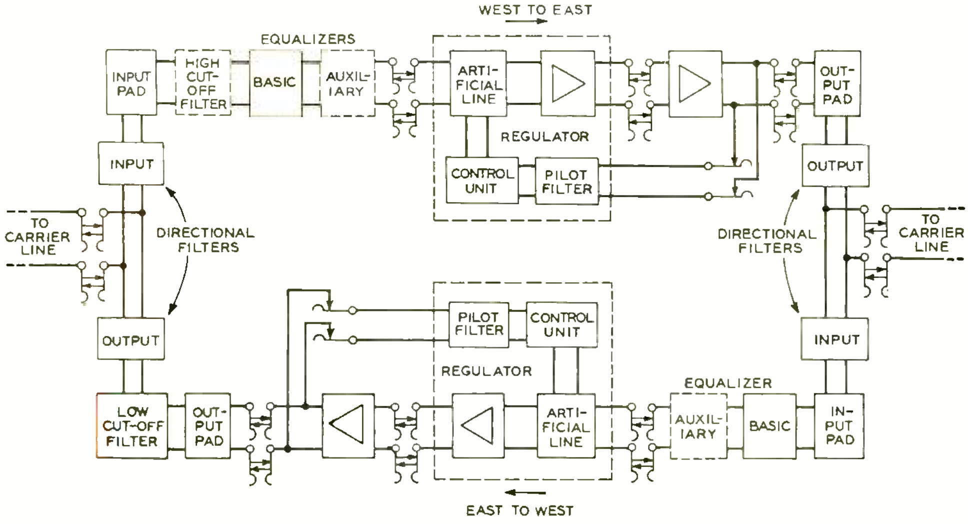

Fig. 1—Block schematic of the C1 repeater

teristics. This artificial line is under control of the regulator and is removed automatically as added gain is needed.

The method of regulating the repeater gain is entirely new, and forms one of the major differences between this and the repeaters used with preceding C carrier systems. The regulator is incorporated as a component part of all repeaters rather than being optional equipment as in the past. This regulator, guided by the level of the pilot frequency at the output of the line amplifier, automatically compensates for attenuation changes in the open-wire line due to varying weather conditions, so that the overall transmission of the system is maintained constant. The maximum range of this regulator is shown in Figure 2, which gives the maximum and minimum gain with the fixed adjustments all set for greatest gain.

This new repeater operates at the same signal level as have the previous repeaters, *i. e.*, at a normal output level 18 db above that at the transmitting toll test board. The impedance of the circuit has been maintained at a nominal value of 600 ohms.

An appreciable part of the improvement made in the new repeater is due to the new amplifier. The same type of amplifier is used in both branches of the repeater and in the terminals as well, while previously a different amplifier design was required for each direction of transmission. The amplifier employs only two tubes, both pentodes, and uses negative feedback. The circuit is shown in Figure 3. The feedback path, shown in the upper part of the diagram, is connected to the input and output of the amplifier through hybrid coils, and includes an equalizer that controls the gain characteristics of the amplifier.

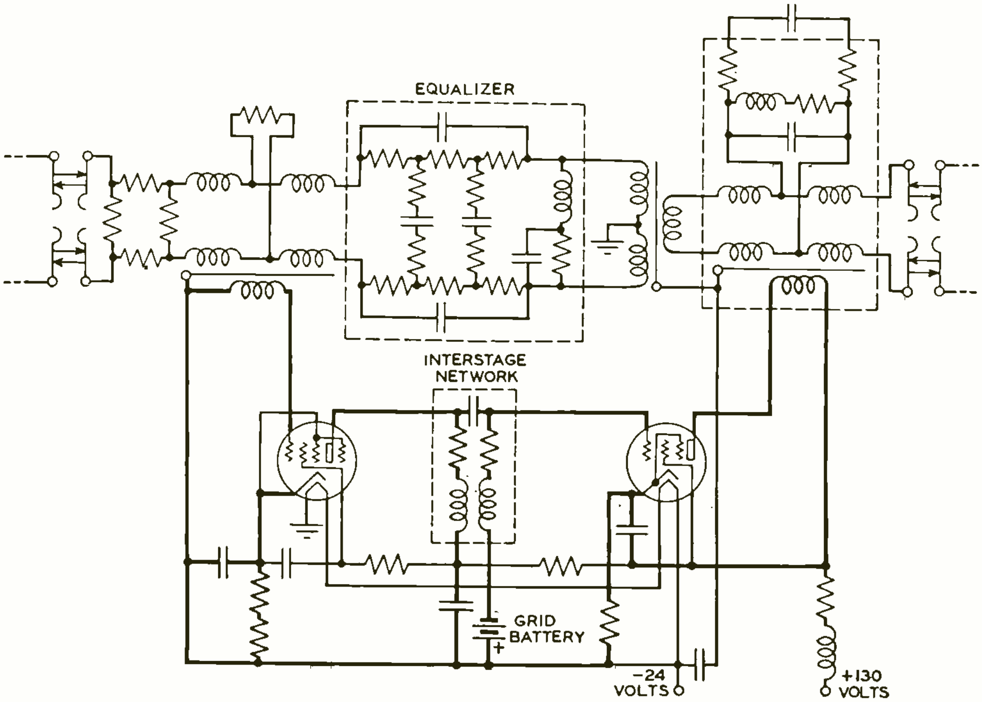

Fig. 3—Simplified schematic of the two-tube amplifier

Without feedback, the gain characteristics of the amplifier are affected by variations in the transformers, tubes, and interstage circuits, but, with feedback, these effects are all reduced to a negligible amount. As a result, a high degree of stability is secured with respect to tube and power variations. The extent to which the gain characteristic of the amplifier is flattened by feedback is shown in Figure 4, which shows the gain of the amplifier both with and without feedback. The difference between the two curves indicates the magnitude of the feedback.

To meet the modulation requirements in past designs of the type-C carrier amplifiers, it has been necessary to use push-pull circuits. In this new design the use of feedback provides sufficient suppression of modulation products to make it unnecessary to use a push-pull type of circuit. This change halves the number of tubes that would otherwise be required. It also eliminates the necessity for tube balancing, which had hitherto been required. This accounts for worthwhile savings in maintenance since tube-balancing consumes considerable time.

The use of pentodes in place of triodes further reduces the number of tubes required for two reasons. First, under these circuit conditions the pentode tube affords much more gain than the triode. Second, the pentode tube has considerably greater full-load operating efficiency than a triode tube. These advantages, coupled with the elimination of the push-pull circuit, permit the functions, which in the previous amplifier required eight tubes, to be performed by only two tubes. Along with the reduction in the number of tubes there is a corresponding reduction in the power required to operate them, which provides further operating savings. The reduction in the number of tubes required and the new mounting methods resulted in a much reduced size for the new amplifier. Figure 5

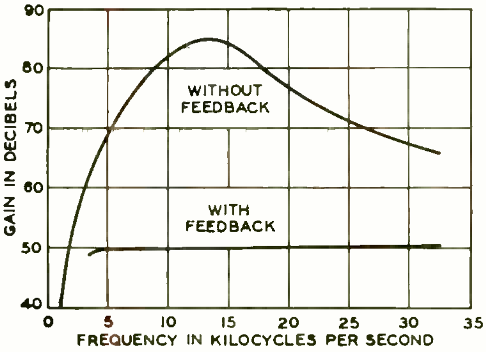

Fig. 4—Gain characteristics of amplifier with and without feedback

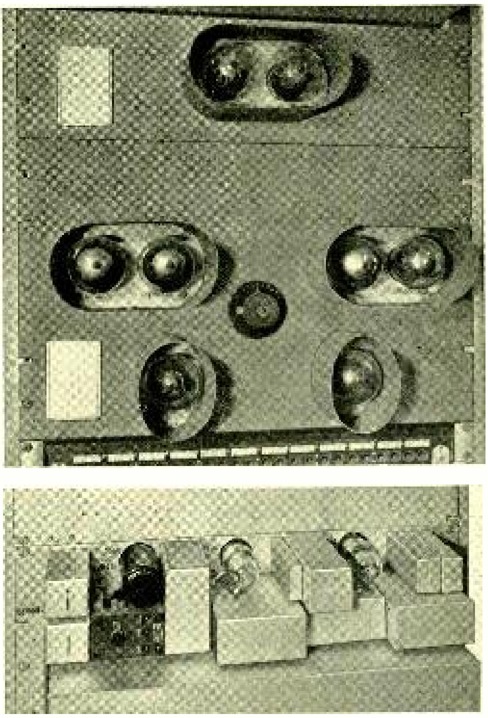

Fig. 5—The new amplifier, lower photograph, although giving better performance and having slightly greater gain than the previous one, requires appreciably less space than the earlier amplifier shown in the upper photograph

shows a comparison between the previous amplifier, which gave about 47-db gain, and the new two-tube amplifier, which provides 50-db gain. There is a further saving in space and wiring not shown here in that with the previous amplifiers the filament control equipment and power filtering circuits are located exterior to the amplifier panels whereas in the new amplifiers all of this equipment is mounted and wired on the amplifier panel itself. Thus the new amplifier while providing better performance and slightly more gain requires only one-fourth the number of tubes, one-fourth the operating power, and reduced operating maintenance.

This two-tube amplifier was designed primarily for new carrier systems. Since it offers operating and service advantages over the previous design and since both the new amplifier and the associated regulating equipment will mount in the space occupied by the previous amplifiers alone, the new design can also be used in the modification of existing systems.

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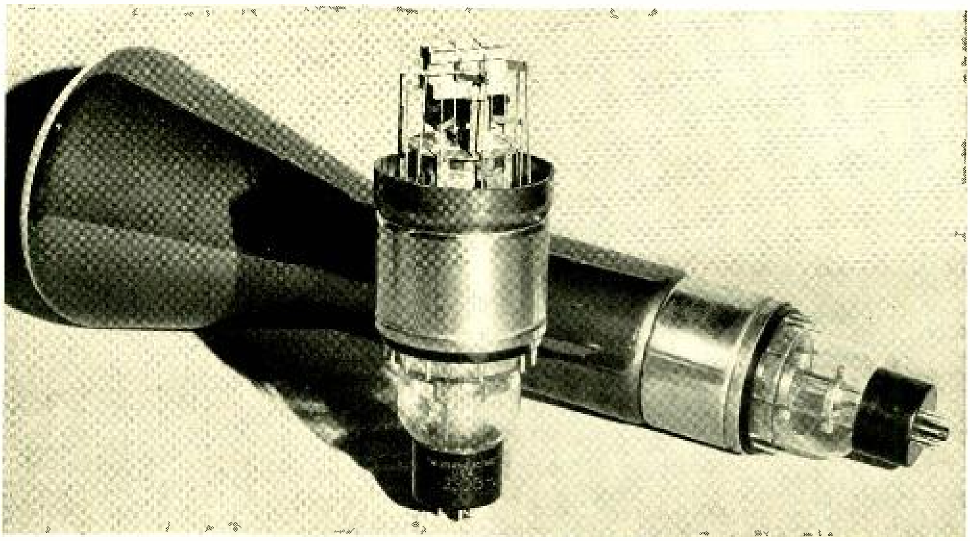

The Western Electric 330-type cathode-ray tube contains three separate electron guns and can be used to study three independent electrical phenomena simultaneously. The cutaway view shows the deflecting system. The three pairs of horizontal deflector plates which may be seen above the supporting insulator are separated by grounded plates to minimize interference or "crosstalk" between the three systems

Gopher-Protected Cables

By R. P. ASHBAUGH

Outside Plant Development

OVER the lead sheath of a telephone cable which is to be buried in the ground are layers of impregnated paper and jute, which are flooded with asphalt compounds to protect the lead against soil corrosion. These buried cables have been used extensively in rural areas for several years instead of aerial cables. However, in some localities cases are all too frequent where gophers have gnawed the cables, puncturing the sheath and so letting in moisture which ruins the insulation. A number of reasons have been advanced for this behavior of the little pests, but all of the theories suggested are highly speculative.

Two layers of substantial steel tape* have been sometimes added to protect the cable conductors against inductive interference from power lines, or for mechanical protection. These tapes afford sufficient protection against gophers but they are expensive and a cheaper construction was therefore sought. Several methods of using steel tape were investigated from the structural and economic standpoint and a design decided on which consists of: a single overlapping layer of impregnated paper; a single layer of thin steel tape applied helically with just sufficient gap to allow for normal bending; a second overlapping layer of impregnated paper; and one or two layers of impregnated jute roving. Floodings of asphalt compounds are applied over the sheath and over each protective layer of paper and jute.

This construction very closely resembles that of standard jute-covered cable with the addition of the steel tape. It is expected that it will give

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*Record, *June*, 1930, *p.* 465.

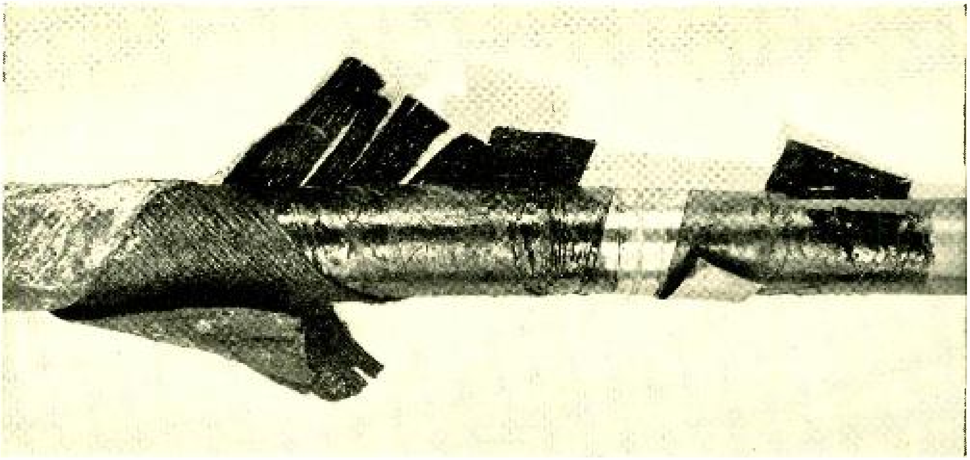

Fig. 1—Gopher-protected cable has over the lead sheath two layers of paper with a thin steel tape between them and one or two layers of jute, all flooded with asphalt

somewhat better protection to the lead sheath against soil corrosion and that the steel tape itself will be well protected. The cost is less than that of standard tape armoring for cables.

About 130 miles of this new construction has been furnished for the buried portion of the Stevens Point-Minneapolis cable and a considerable number of small orders for territories that are gopher infested have also been manufactured and installed.

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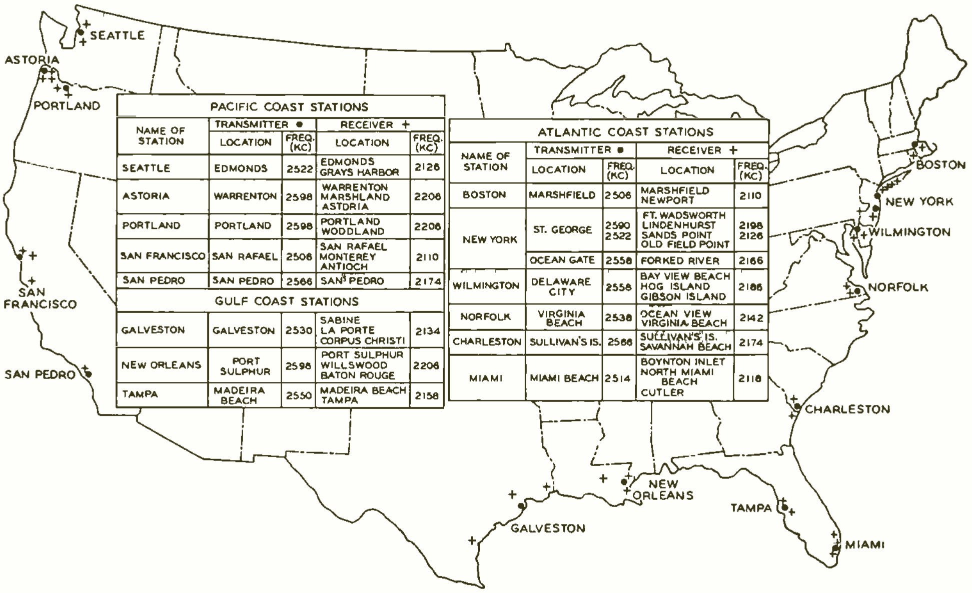

PACIFIC COAST STATIONS

NAME OF STATION	TRANSMITTER ●		RECEIVER +	
	LOCATION	FREQ. (KC)	LOCATION	FREQ. (KC)
SEATTLE	EDMONDS	2522	EDMONDS GRAYS HARBOR	2126
ASTORIA	WARRENTON	2598	WARRENTON MARSHLAND ASTORIA	2206
PORTLAND	PORTLAND	2598	PORTLAND WODDLAND	2206
SAN FRANCISCO	SAN RAFAEL	2506	SAN RAFAEL MONTEREY ANTIOCH	2110
SAN PEDRO	SAN PEDRO	2566	SAN PEDRO	2174

GULF COAST STATIONS

NAME OF STATION	TRANSMITTER ●		RECEIVER +	
	LOCATION	FREQ. (KC)	LOCATION	FREQ. (KC)
GALVESTON	GALVESTON	2530	SABINE LA PORTE CORPUS CHRISTI	2134
NEW ORLEANS	PORT SULPHUR	2598	PORT SULPHUR WILLSWOOD BATON ROUGE	2206
TAMPA	MADEIRA BEACH	2550	MADEIRA BEACH TAMPA	2158

ATLANTIC COAST STATIONS

NAME OF STATION	TRANSMITTER ●		RECEIVER +	
	LOCATION	FREQ. (KC)	LOCATION	FREQ. (KC)
BOSTON	MARSHFIELD	2506	MARSHFIELD NEWPORT	2110
NEW YORK	ST. GEORGE	2590 2522	FT. WADSWORTH LINDENHURST SANDS POINT OLD FIELD POINT	2198 2126
	OCEAN GATE	2558	FORKED RIVER	2166
WILMINGTON	DELAWARE CITY	2558	BAY VIEW BEACH HOG ISLAND GIBSON ISLAND	2186
NORFOLK	VIRGINIA BEACH	2538	OCEAN VIEW VIRGINIA BEACH	2142
CHARLESTON	SULLIVAN'S IS.	2566	SULLIVAN'S IS. SAVANNAH BEACH	2174
MIAMI	MIAMI BEACH	2514	BOYNTON INLET NORTH MIAMI BEACH CUTLER	2118

Coastal and harbor radio telephone stations of the Bell System. All of these stations connect with the Bell System network, and give service to and from over 2500 ships already equipped for radio telephone communication

Contributors to this Issue

O. J. Murphy joined the Laboratories in 1927 after receiving a B.S. degree in E.E. from the University of Texas that year. He has also done graduate work in physics at Columbia University. For several years Mr. Murphy engaged in research in the general field of voice-operated devices. Since 1937 he has been occupied by investigations in connection with the development of voice-frequency signalling systems. The study of pitch variations reported in this issue of the Record was undertaken by reason of Mr. Murphy's personal interest and the work was carried on in his own home.

G. A. Pullis joined the Laboratories in 1920 as a technical assistant, and with the transmission instruments group first engaged in transmitter and receiver studies. In 1928 he transferred to the toll systems development group, where he worked on the development of voice-frequency signalling for both ringdown and dialing circuits. More recently he has been occupied in developing line and balancing circuits, and composite signalling and dialing circuits for dialing and d-c signalling over trunks between toll offices or between operating offices and community dial offices.

Entering the Laboratories from the University of Minnesota where he had received his Ph.D. in 1929, Walter H. Brattain joined the Physical Research Department. Initially his work was on electronic emission from hot surfaces. The results of this work contributed to the knowledge of the effect of adsorbed films on electron emission and to a better understanding of the relation of the theoretical constants to the experimental results. Mr. Brattain then took up the study of electrical conductivity and rectification phenomena in semi-conductors. A major portion of this work was specifically concerned with the copper oxide varistor; the article in this issue is a résumé of some of that work. Mr. Brattain received the B.S. degree from Whitman College in 1924 and the M.A. from the University of Oregon in 1926.

R. P. Ashbaugh graduated in Electrical Engineering from Ohio University in 1910 and joined the Laboratories in

O. J. Murphy

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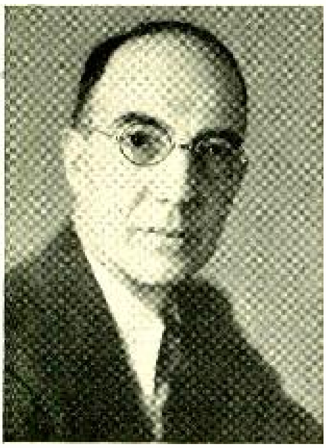

R. P. Ashbaugh

E. H. Perkins

O. S. Markuson

1911. Two years later he entered the lead-covered cable development group and has been in that work continuously since. He went to Japan in 1922 to supervise the placing and splicing of the first toll cable installed in that country and remained to work with the engineers of the Sumitomo Cable Works on problems of toll cable design. He returned to the United States in 1924 and was located at the Hawthorne Works of the Western Electric Company until 1938 and since then at their Kearny Works. During this entire period he has been mostly concerned with development problems and he has been actively connected with many of the refinements in quadded-cable design as well as the developments on fine-wire cables, such as pulp insulation and unit-type cables. He now has charge of the development work on exchange area cables.

E. H. PERKINS was graduated in 1930 from the Massachusetts Institute of Technology with a degree of M.S. in Electrical Engineering upon completion of the Co-operative Training Course with the Bell System. He joined the Systems Development Department of the Laboratories that summer, and since then has been associated with the development of carrier telephone repeaters. He has been particularly concerned with the development of the feedback amplifier and the application of this amplifier to carrier telephone systems.

After graduating with the degree of E.E. at the University of Minnesota in 1911, O. S. MARKUSON joined the student course of the Western Electric Company at Hawthorne. A year later, in the Engineering Department, he engaged in the design and development of lead-covered cables, becoming a supervisor in 1918. He transferred to the Inspection Engineering Department at West Street in 1925 and became concerned with cable and wire inspection engineering. In 1930, MR. MARKUSON went to the Kearny plant as a member of the Laboratories' Outside Plant Development Department and again entered the development of lead-covered cables. Later in the same year he transferred to the Point Breeze plant in charge of a group engaged in the same type of work. Since then he has been principally concerned with the development of various types of carrier cables, including the various coaxial cables.