BELL LABORATORIES RECORD

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LUBRICATION
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In this Issue

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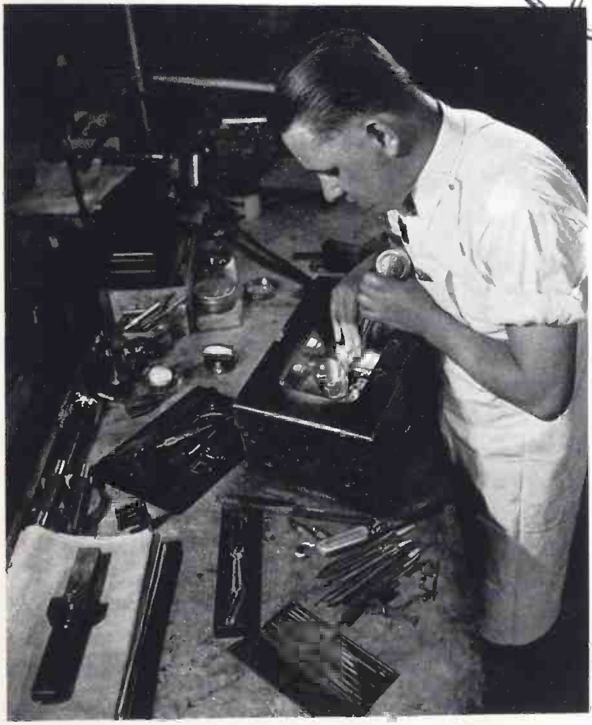

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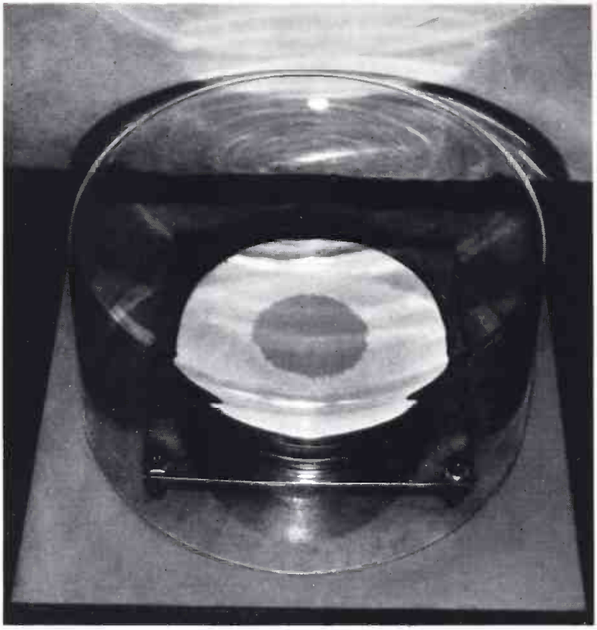


Boundary Lubrication

By W. E. CAMPBELL
Chemical Laboratories

WHEN a wire is drawn through a die, or when a journal is rotated in a bearing, lubricating the relatively moving surfaces reduces the friction between them. But there is a great difference between the two sorts of lubrication which these instances represent. Between the surfaces of journal and bearing, operating at ideal speed and load, the lubricating film is of appreciable thickness. But the pressures developed by the wire-drawing operation will not admit a lubricating film between wire and die of much more than molecular thickness. As might be expected, the corresponding mechanisms of lubrication are entirely different in nature.

The coefficient of friction between two rubbing surfaces is influenced by such a large number of variables that it is impossible to predict the effect of changing any one without reference to extended data. If we restrict the number of variables by considering only geometrically similar bearings, it can be shown by reasoning based on dimensional analysis that the coefficient of friction, μ, may be written as a function of zn/p where z is the absolute viscosity of the oil at the bearing temperature, n is the speed of the journal, and p is the pressure per unit projected area of the bearing. Thus, by plotting μ against zn/p, a picture of the relations between the important variables in journal-bearing lubrication can be represented in one diagram, such as that of Figure 1.

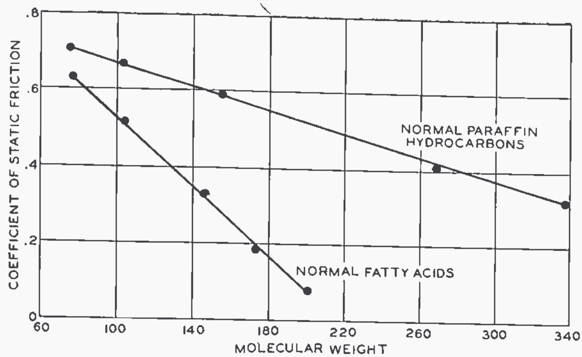


Fig. 2—There are simple linear relationships between the coefficient of static friction and the molecular weight for some of the normal paraffin hydrocarbons and some of the normal fatty acids used as lubricants

The portion, BC, of the curve lying in the region to the right of the minimum point, B, gives the relation between μ and zn/p which obtains when the bearing is operating under normal conditions of speed and load. In this case, a fluid film of finite thickness separates the bearing surfaces, and the friction is due to the forces tending to prevent slip between the molecules of the lubricant. In other words, the coefficient of friction is directly proportional to the absolute viscosity of the lubricant for constant speed and load.

In the region to the left of the minimum point, known as the region of boundary lubrication, the coefficient of friction is no longer directly proportional to the absolute viscosity for constant speed and load, and a new set of conditions of which little as yet is known enters into the problem. The total effect of these conditions is covered by the term "oiliness." When two oils, having the same viscosity at atmospheric pressure and at the temperature of the film, are tested under identical conditions, the oil giving the least friction is said to have the greater oiliness.

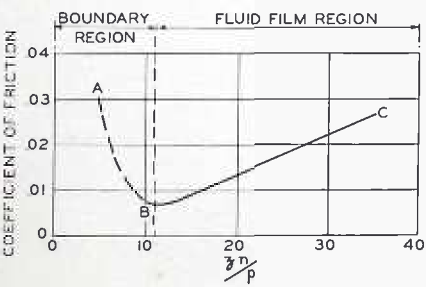


Fig. 1—When for a particular bearing the coefficient of friction, a dimensionless quantity, is plotted against a function of viscosity, speed and load, which is also dimensionless, a point of minimum friction can be found, corresponding to the point at which the fluid film breaks down

The importance of oiliness studies for general engineering purposes has been much debated. For a properly designed mechanism, running continuously, the only lubricating requirement of importance is the selection of a stable oil whose minimum viscosity under the conditions in question will insure operation well to the right of the minimum point B in Figure 1, where rupture of the film occurs. But under conditions where machinery has frequently to be stopped and started again as in the case of automobile operation in city traffic, or when loads are very high and speeds very low as in the case of the gears operating the rolls in rubber mills,

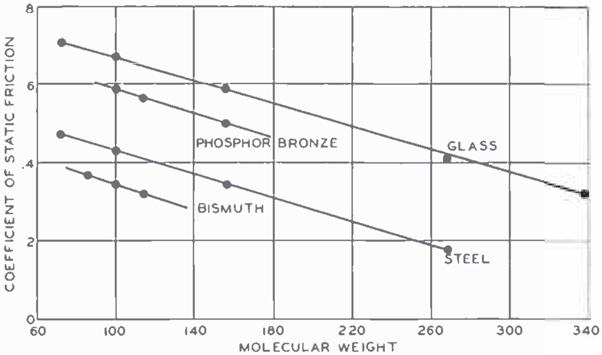


Fig. 3—Experiments with the widely differing bearing surfaces represented by glass on glass, bronze on bronze, steel on steel, and bismuth on bismuth, lubricated by normal paraffin hydrocarbons, shows that the chemical nature of the surfaces modifies the friction

reference to Figure 1 will show that operation under boundary conditions becomes a factor which must be considered. For operations such as wire drawing, cutting, and deep-drawing, a study of boundary lubrication seems to be of paramount importance.

Problems in boundary lubrication have been studied by various workers with the aid of four main classes of apparatus. One class measures static friction under high loads. Another measures dynamic friction under high loads and small speeds. Still another measures the load, at a given speed, which will cause the lubricated parts to seize each other. Finally measurements have been made on the change in the viscosity of lubricants when subjected to high pressures.

Progress in the theory of boundary lubrication has been considerably delayed by the difficulty which has been experienced in controlling the variables so as to give results which can be reproduced by different observers, and in finding one apparatus by means of which all the factors can be investigated. The evidence at present is that no one method of attack can be used, but that comparison and combinations of the results of two or three methods will be necessary to a clearer understanding of the problem.

Perhaps the most interesting data from a fundamental standpoint have been obtained from static friction measurements using chemically pure substances as lubricants. Measurements of this nature have been carried out by W. B. Hardy and his collaborators, and these Laboratories are now working on the verification and extension of his theories with the aid of apparatus such as that shown in the tailpiece. For members of the normal paraffin series of hydrocarbons and for their related acids and alcohols, the measurements under boundary conditions reveal astonishingly simple linear relationships between the coefficient of static friction and the molecular weight of the lubricant.

It had first been demonstrated that the coefficient of friction between two surfaces lubricated by a chemically pure lubricant was independent of the load above a certain pressure. The measurements represented in Figures 2 and 3 were taken under conditions which gave a pressure above this limiting value.

The curves in Figure 2 show the relation existing between the coefficient of friction and molecular weight for some of the members of each of two chemical series, the upper curve giving the relation for the normal paraffins and the lower that for the fatty acids.

Similar relations have been found to hold for the normal alcohols and for members of the benzene series. The fact that the coefficients for the heavier fatty acids are considerably lower than those for the paraffins of the same weight, is in accord with the fact that fatty oils are more satisfactory as cutting lubricants than mineral oils. Figure 3 gives similar curves obtained for one chemical series, the normal paraffins, using different kinds of bearing surfaces.

Analysis of the curves in Figures 2 and 3 leads to the relationship $\mu = b_0 - d - c\,[N-2]$. N is the number of carbon atoms in the chain. Of the remaining parameters, b_0 is the friction between the clean solid surfaces and is a function only of the properties of the solid; c is the decrement in friction due to any single atom in the carbon chain other than those in the end groups; and d is the decrement due to the end groups.

These phenomena have been interpreted as indicating that the lubricant acts in the boundary state as a sort of buffer which separates the solid surfaces and reduces the attractive forces between them. Although this work has by no means cleared up the problem completely, expression of the parameters c and d in terms of other known physical properties of the lubricant, and extension of the measurements to more complex compounds, should go a long way towards identification of the variables which are grouped under the term "oiliness."

It has been shown recently that static and dynamic friction measurements do not explain all the phenomena of lubrication, but that other properties of the oil must be considered. Oils giving the highest oiliness coefficients do not always rate first from the point of view of their ability to prevent seizure under high loads. Experiment indicates that valuable contributions to the theory of boundary lubrication may be made from a study of the viscosity of lubricants under pressure. Both mineral and fatty oils increase greatly in viscosity at high pressures, and certain oils, notably lard oil, show indications of abrupt solidification at room temperature under pressures in the neighborhood of 1500 kilograms per square centimeter. The work on static friction has proved of great importance, however, particularly from the point of view of theories regarding the structure of adsorbed films.

In terms of these theories the experimental data illustrated in Figures

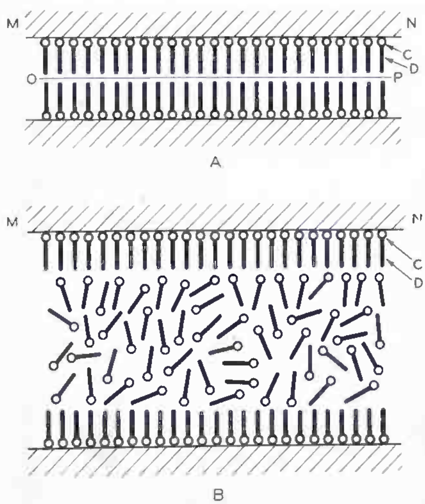


Fig. 4—When polar substances are used as lubricants, the condition of affairs can be represented as in A for boundary lubrication and as in B for fluid-film lubrication. MN is the metal-lubricant interface; OP is the plane of slip between non-polar ends of molecules; C is the polar end of a molecule (·OH, ·COOH, or the like); and D is the non-polar hydrocarbon chain $(CH_3 \cdot CH_2 \cdots CH_2 \cdot)$

Fig. 5—In the same span of time a drop of mineral oil (shown in the headpiece) has spread far more than a drop of fatty oil of the same size and about the same viscosity

2 and 3 have received a physico-chemical explanation. It is assumed that one or more layers of molecules are oriented at the surface. The polar group*, in the case of substances such as fatty acids or alcohols, is turned in towards the metal surface, and the rest of the molecule sticks out in a direction approximately normal to the surface. Slip is assumed to take place between the non-polar ends of the oriented layers, between which attractive forces are comparatively low. The difference between boundary friction and fluid friction may thus be represented as in Figure 4.

In Figure 4 only one layer of oriented molecules is shown. It is probable that the effect of the surface forces extends further into the liquid, thus giving several such oriented layers. Experiments on the flow of liquids in very fine capillaries have shown that this effect extends to a distance less than two or three hundredths of a micron, and it is fairly generally believed that the oriented layer is only a few molecules thick.

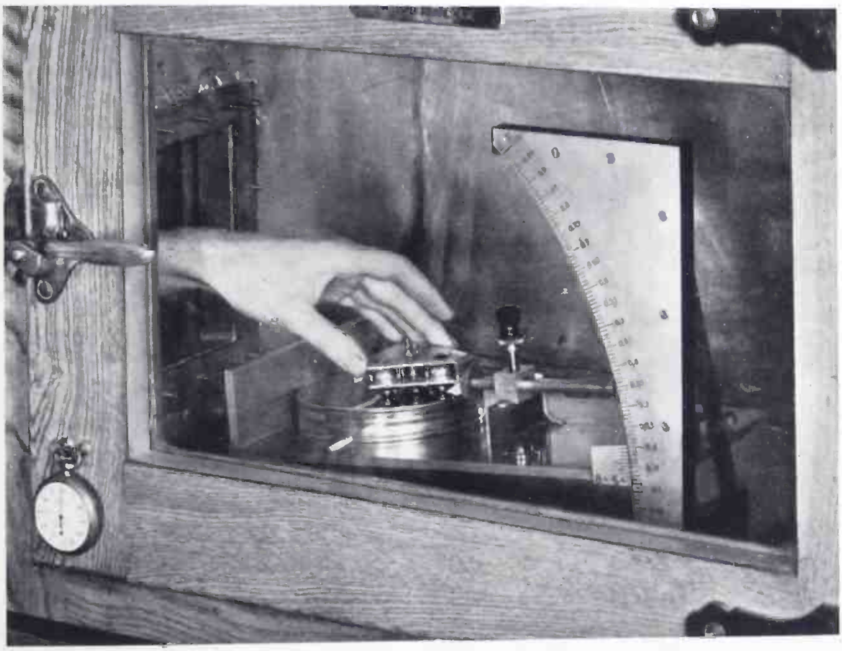
Many effects which have been noticed in the practical operation of machinery may be explained by the theory given above. For example, it is generally conceded that animal oils and vegetable oils are better lubricants in the boundary region than mineral oils. This would be expected from the theory since the molecules of fats are polar and would be adsorbed more strongly at the surface, thus neutralizing a larger proportion of the attractive forces between the solids.

Another well-known phenomenon which is explicable by this theory is the difference between the spreading tendencies of fatty oils and mineral oils on metal surfaces (Figure 5). It is convenient to think of such a tendency thermodynamically: as measured by the decrease in free surface energy when a drop spreads on a metal surface. This decrease would be given by $\Delta F = \gamma_1 - \gamma_{12} - \gamma_2$ where γ_1 is the surface tension of the solid phase, and γ_{12} is the liquid-solid interfacial tension. The surface tension, γ_2, of the liquid will be practically the same for both fatty and mineral oils, since the surface layers are composed of identical chemical groups. This is because the greater attraction of the liquid for the polar ends of the surface molecules will orient the non-polar ends toward the surface, and these ends have the same chemical structure in both fatty and mineral oils. Since for a given solid γ_1 is also constant, the tendency to spread will be governed by the value of γ_{12}. The fatty oils, by virtue of the stronger attraction between the polar group and the metal surface, would be expected to give a high value for γ_{12} and consequently a lower change in free surface energy of spreading than

*Bell Laboratories Record, *June*, 1931, *p.* 462.

the mineral oils, which consist for the most part of mixtures of relatively non-polar compounds.

Unfortunately, fatty oils are chemically considerably less stable than mineral oils. Moreover, their supply is limited and the cost of the more stable types is consequently prohibitive. It has been found recently, however, that the advantages of both types of oil may be combined by blending them in various proportions or by addition to mineral oils of free fatty acids obtained from fatty oils. The static and dynamic friction between two metal surfaces which are lubricated under boundary conditions can be reduced by as much as 40% by the addition of 1% of oleic acid. The so-called "germ process" for automobile oils depends on this fact and many of the problems met with in the lubrication of fine mechanisms are being solved in the same manner.



A Permanent-Magnet Light Valve

By G. E. PERREAULT
Sound Picture Development

THE light valve is the heart of the Western Electric system of recording sound on film. Its function is to transform a modulated current of electricity into a similarly modulated beam of light, which, falling on a moving film, produces a record of the original sound. In a form employing an electromagnet for excitation, it has long been used successfully, but because of the high degree of accuracy necessary in its adjustment, and of its comparatively large size and weight, it has been somewhat unsatisfactory for portable apparatus. Advantage has been taken therefore of a new type of light valve developed by E. C. Wente, and a commercial design—both for it and for its associated apparatus—has been made.

Permanent magnets to supply the exciting field, its chief distinguishing element, make possible a valve of only about a tenth the size and weight of the electromagnetic type and give an efficiency appreciably higher. The relative size and appearance of the two types are shown in Figure 1. The principle of light-valve action requires that two non-magnetic conducting ribbons of very low mass be strung parallel to each other in a single plane with their adjacent edges only a thousandth of an inch apart, and that a strong magnetic field pass through them at right angles to their common plane. The modulated cur-

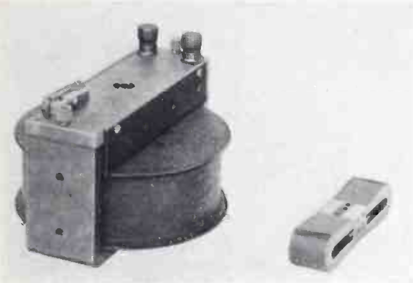


Fig. 1—The permanent-magnet light valve is only one-tenth the size and weight of the electromagnetic type

rent passing through the ribbons reacts with the magnetic field to widen and narrow the slit between them and thus correspondingly vary the amount of light falling on the film.

The construction of the new valve may be seen from the partially assembled unit of Figure 2. The ribbons are connected together electrically at one end, and at the other end two terminals are provided for the leads from the modulated current supply. The magnetic field is supplied by two horseshoe magnets of cobalt steel, and is directed through the ribbons by projections from two rectangular pole pieces. The ribbons, of duralumin, are mounted on a duralumin supporting structure fastened between the two pole pieces.

This supporting structure is a rectangular plate with a slit cut in the middle at right angles to the longer axis. Along two edges of one of its faces are fastened copper strips with a thin plate of special contact metal on their upper surfaces. The strip along one edge is continuous, but that on the other is split at the center line of the slot in the duralumin plate, and the two parts are separated by a piece of cellophane insulation .002 inch thick. Strips of cellophane of the same thickness are also used to insulate the metal strips from the duralumin plate to which they are fastened. The single strip along one side connects the ribbons together at one end, and the two strips along the other side serve as terminals for the other two ends. The ribbons are held to these contact surfaces by insulating strips of glyptol.

The duralumin plate is milled out on one surface along all four edges, which leaves space along two sides for fastening the mounting strips for the ribbons, and at the two ends leaves a projecting tongue which is used in locating the valve in its associated apparatus. Duralumin was selected for the material of this plate because its expansion coefficient was the same as that of the ribbons, and thus would cause no changes in adjustment with variations in temperature. The two pole pieces, which span the gaps between the poles of the horseshoe magnets, have V-shaped projections which form a narrow air gap through which the ribbons pass. The bottom of the duralumin plate is cut out to receive the projection of the bottom

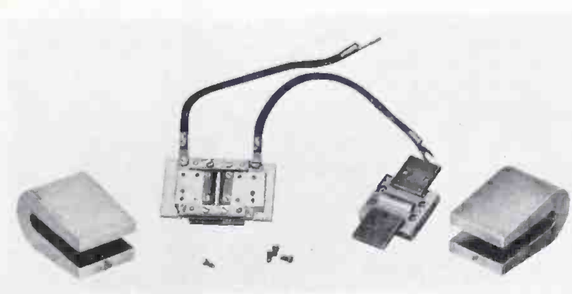


Fig. 2—The free length of the ribbons of the present valve is only half an inch

pole piece, and two brass pieces are fastened to the top pole piece to raise it far enough above the aluminum plate to allow the V projection just to clear the ribbons. A cross section through the center line of the magnets, shown in Figure 3, illustrates the construction.

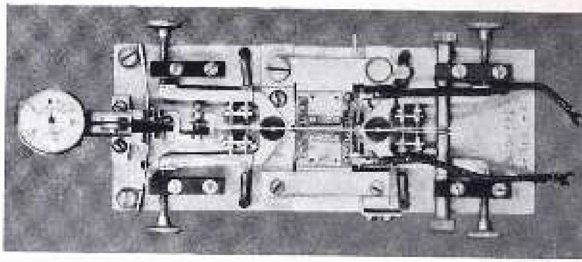


Fig. 4—Assembly jig for permanent-magnet light valve. The ribbons are strung with a tension that will cause resonance to occur at some frequency between 9,000 *and* 13,000 *cycles*

In service these valves sometimes burn out or become inoperative, usually because of accidental overloads or of mechanical shocks to the microphone. Since this may happen in the middle of a recording, it is highly desirable that a replacement be made with a minimum of time. This requires that the valves be made so exactly alike that no adjustment is needed when a new valve is inserted. To make this possible all parts must be accurately made so that the dimensions of all valves will be alike, and the ribbons must be strung in exactly the same positions. Provision must also be made so that a valve can be inserted in its associated apparatus in only one way. This latter feature is accomplished by means of the grooves at each end of the string element formed by the bottom edge of the duralumin plate and the two brass pieces fastened to the upper pole pieces as already described. These grooves are of different depths so that the valve can be inserted in only one way, and the bottom surfaces of the brass pieces, which are in the plane of the ribbons, serve as surfaces of reference for locating the valves in their associated apparatus.

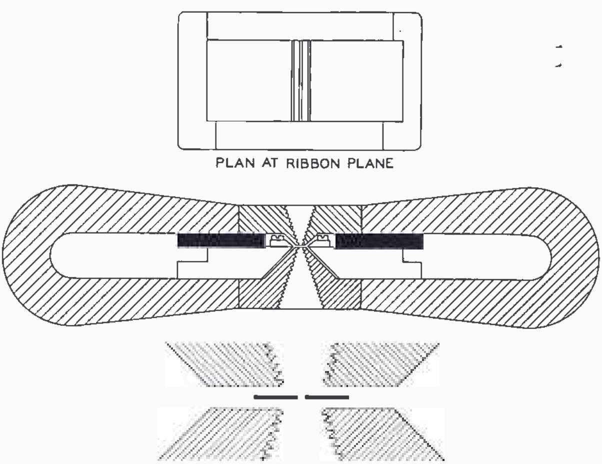


Fig. 3—Cross section of permanent-magnet light valve. The duralumin ribbons are .006 *inch wide and* .0005 *inch thick*

The accuracy required in the construction of this valve is of a very high order. When the valve is located in a machine, it is essential both that the plane of the ribbons be at the focal plane of the condenser lens and in the proper position, and that the image of the slit falling on the film be at right angles to the center line of the sound track. This latter requirement

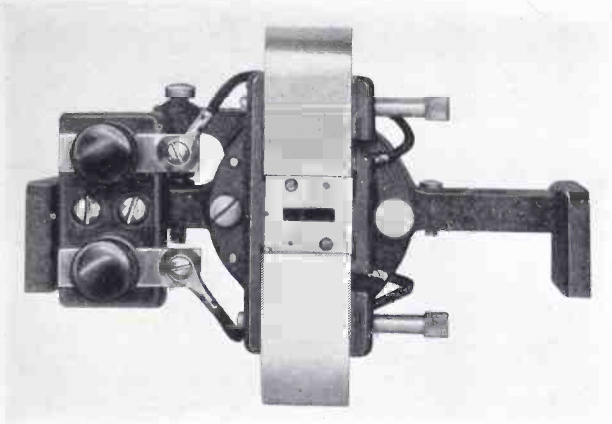


Fig. 5—Mounting employed for permanent-magnet light valve in studio recording machine

time, but perpendicular cross hairs in the eye-piece form a fixed point which traces a straight line as the jig is slid back and forth along the ways of the frame.

To insure that all valves be strung alike it is necessary both that the ribbons be centered over the cellophane insulation separating the contact strips at one end of the valve, and that they be accurately perpendicular to the lapped edge. Since this lapped edge of the valve rests against the lapped locating surface of the jig, and since the ribbons are strung along the line of the intersection of the cross hairs of the eyepiece of the microscope as the jig is slid back and forth, it is necessary, as a preliminary adjustment, to make the locating surface of the jig perpendicular to the line traced by the intersection of the cross hairs. For this purpose all jigs are adjusted

is called being in correct azimuth, and to secure it the ribbons of all valves must be strung exactly at right angles to one edge of the valve, which is accurately lapped and used as a reference surface.

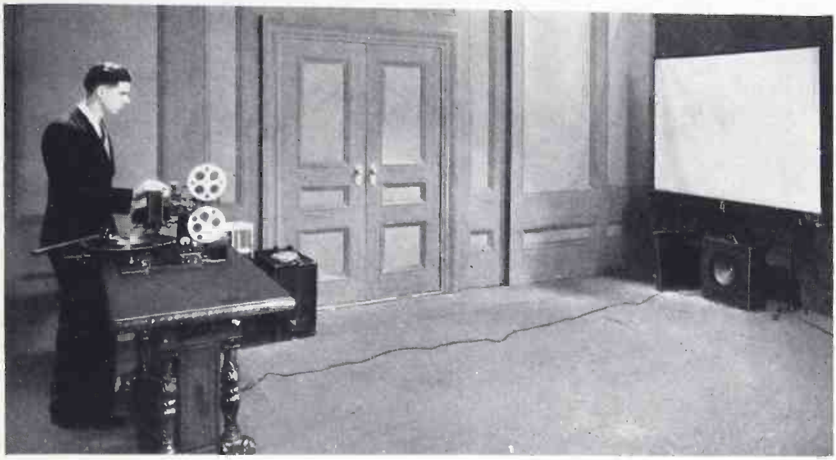
The valves are assembled and strung on a special jig, shown in Figure 4, which has one locating surface against which the lapped edge of the valve is held; point contacts only are made against the three other sides. This surface of the valve is also used in positioning the valve in the apparatus with which it is used. When a valve is to be assembled it is placed in a jig which rests on accurately machined ways of a frame carrying a microscope, as shown in the photograph at the head of this article. Only a small part of the valve may be seen through the microscope at a

Fig. 6—Modulator unit for portable recording unit employing the permanent-magnet light valve

with a test block which has a lapped edge and a line on its surface accurately perpendicular to this edge. This test block is first placed in the jig and the position of the locating surface adjusted until the intersection of the cross hairs follows the line on the test block as the jig is slid back and forth. With this adjustment made all valves strung on the jig will have their ribbons also perpendicular to their reference edge.

In the actual stringing process the valve is placed in the jig with its lapped surface against the adjusted locating surfaces of the jig and clamped in place. The ribbon is then looped over the tension pulley and the two ends brought back over the spacing pulleys and fingers, and fastened to the two take-up screws. The proper amount of tension, as indicated by the gauge, is then put on the ribbons by means of these screws, and then the spacing screws are adjusted until the ribbons, as watched through the microscope, are centered over the insulation between the contact strip and in line with the intersection of the cross hairs in the microscope. After they have been correctly located, the insulating clamps of glyptol are screwed down to hold them in place. With the valve still in the jig, the top pole piece and the magnets are put in place, and the resonance frequency of the ribbons is checked by an oscillator. If it is correct, the ends of the ribbons are broken off at the edge of the valve, and the valve is ready for service.

This permanent-magnet light valve, which is still undergoing field trials and may possibly be subject to further modifications, was first employed in a studio recording machine. The mounting used for it is shown in Figure 5. An azimuth adjusting screw, in the left background, allows the ribbons to be made perpendicular to the sound track, and because the valves are all strung exactly alike no change in adjustment is needed when a new valve is inserted. Another adaptation of the new light valve was in the special modulator unit used for portable recording machines, shown in Figure 6. This entire unit is lighter and smaller than the old type of light valve alone, and is a striking illustration of the merits of the new valve.



Portable Sound-Picture System for Sixteen Millimeter Film

FOR a number of years portable motion picture projectors, using a film narrower than the commercial theatre size, have been employed for advertising purposes and for educational work in schools. To enhance the usefulness of this class of apparatus, the Laboratories have recently developed a projector which incorporates a turntable driven in synchronism with the film so as to provide the many advantages of sound accompaniment. Exclusive of the screen, all the necessary apparatus is contained in two carrying cases, one of which contains a complete projector-turntable unit and the other, the amplifier and loud-speaker unit. In the design of the apparatus, high quality of reproduction, long life, and simplicity of operation and maintenance have been held paramount, with the result that the apparatus should have application to a wide variety of uses.

The projector-turntable unit consists of a common base on which is mounted the projector unit, near the center, the turntable at one end, and the drive motor at the other end. The projector head which overhangs the turntable and motor, is pivoted to its supporting pedestal so that it may be tipped from about 15° above to 5° below the horizontal. The switch for the drive motor is in the upper part of the projector head and is part of the light-dowser mechanism. Loss of either the upper or lower film loop causes the dowser to drop in front of the light beam and shuts off the motor to prevent injuring the film.

In addition to the main drive motor there is a small fan motor used for

This is an abstract of a paper presented by R. A. Miller and H. Pfannenstiehl before the Society of Motion Picture Engineers.

ventilating the lamp housing. Because of the comparatively large size of the lamp, 250 watts, and the small size of the housing, ventilation is essential to maintain permissible operating temperatures. To insure, therefore, that the lamp is never burning without ventilation, both lamp and ventilating motor are controlled by the same switch. This switch, together with a four point transformer tap switch, which is set to impress the proper voltage on the lamp, is mounted at the base of the projector pedestal.

Since the apparatus will usually be operated in the room in which the audience is seated, every effort has been made to keep machine noises to a very low level. The drive motor is dynamically balanced and very quiet in operation, and all driving elements and mechanisms have been made to run as smoothly and quietly as possible. Completed machines are tested for noise by a special noise measuring set, and the noise level must be below a value which is established as being satisfactory.

Not only must the machine be quiet but no vibrations should be present that might react on the sound pick-up and result in disturbances in the output of the loud speaker. Vibration absorbing mountings have been provided for both motor and turntable, and the drive of the turntable has been designed to act as a mechanical filter to absorb small changes in rotational speeds such as might be caused by irregularities in the gear teeth.

The drive motor is mounted on four adjustable springs which absorb possible vertical vibrations, and its hold-down bolts pass through rubber sleeves which damp out horizontal vibration. By properly designing these elements practically no motor vibrations are transmitted to the base. The motor is connected to the machine drive through a slip coupling which allows the machine to be brought up to speed without shock, and which also prevents damage to any part of the mechanism should an excessive load be placed on the drive. The armature of the motor is connected to this coupling through a short length of flexible shafting which prevents vibrations being transmitted to the main drive and also permits a slight misalignment between the motor and main drive shafts.

The platform that supports the turntable also carries the bracket holding the reproducer, and is mounted on rubber cushions which prevent vibrations being transmitted to it from the base. The end of the drive shaft from the motor carries a worm which meshes with a worm wheel connected to the vertical shaft of the turntable through a cylindrical felt coupling.

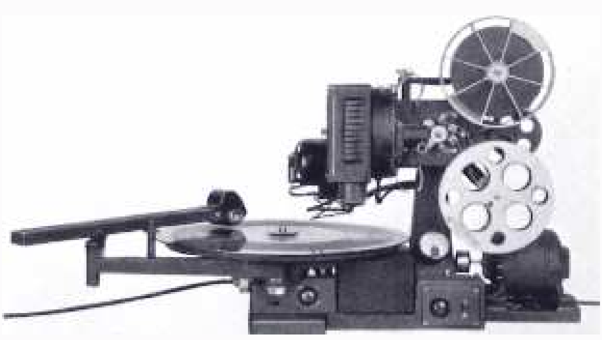


Fig. 1—The projector-turntable unit is compactly arranged and mounts all the controls necessary for the operation of the set

The resiliency of this felt cylinder and the mass of the turntable platen are designed to produce the filter action already referred to.

The amplifier and loud speaker unit, shown in Figure 2, is permanently mounted in its carrying case, but the front and rear covers are removed when the unit is in use. Removal of the front cover exposes the opening to the dynamic type loud speaker, and of the rear cover provides ventilation for the amplifier. Space in the top of the case is provided for carrying the two cords required, and also for spare vacuum tubes.

Sufficient amplification is provided by the amplifier to raise the output of the reproducer on the turntable to an energy level that will permit the loud speaker to deliver sufficient acoustic energy for an audience of several hundred persons. The amplifier is arranged for operation on the ordinary alternating current house-lighting service at any voltage from 102 to 127 and at any frequency from 50 to 65 cycles per second. Only 90 watts of power are required. A line voltage selector switch is furnished to permit the tube filaments to be operated at the lowest brilliancy consistent with satisfactory operation, and under ordinary conditions a continuous service of several thousand hours may be expected—the equivalent of several years for the average system.

The amplifier tubes are of newly developed types, designed for their most effective operation at the audio frequencies. Those in the input stages have been especially constructed to be free from microphonic response, and are thus unaffected either by mechanical vibration or by acoustic shock from the loud speaker, which may be required at times to deliver rather high acoustic pressures.

Fig. 2—Amplifier and loud speaker are combined in a single unit. The rear cover is removed as shown while the set is in operation to provide ventilation

A schematic diagram of the amplifier circuit is given in Figure 3. Three stages of amplification are provided, and a full-wave rectifier. The first two stages, employing Western Electric unipotential or heater-type cathode tubes, are resistance coupled, and the second stage is transformer coupled to the power stage, which is in push-pull arrangement. The gain is approximately 71 db and practically uniform amplification is secured over the range of frequencies necessary to high quality reproduction. Between 70 and 7000 cycles the variation is only of the order of $\pm$ 1 db.

High quality of reproduction and long life have been held paramount in the design of this amplifier, and all apparatus has been held to the rigid requirements necessary for such service. Except for the vacuum tubes, no elements have been employed that are expected to deteriorate either with age or prolonged use, nor are the various component parts called upon to perform other than normal duties in the interest of economy or compactness. The amplifier will operate indefinitely at all temperatures up to 100° Fahrenheit, thereby making possible reliable operation under a wide range of climatic conditions.

All parts of the system have been carefully shielded, and hence in so far as reasonable are free from the effects of stray electrical interference. Although noise introduced into the output by operation on alternating current may be audible at a distance of as much as three feet from the loud speaker under static conditions in a quiet room, it is 75 db, on a loudness basis, below the output level of the amplifier, and so imposes no limitations on the playing of commercial records. The amount of noise just referred to is that under the worst possible conditions and no noise balancing or compensating devices, which might detract from the quality of reproduction when used by an unskilled person, have been employed.

No gain control is provided in the amplifier unit, since it is desirable to have control of the entire system at the projector-turntable unit which may be at some distance from the loud speaker. A potentiometer for controlling the input to the amplifier, with a range of about 45 db, is located on the projector unit just below the turntable, as may be seen in Figure 1.

Portable folding screens with suitable carrying cases are available for use with this system, with the result that a complete and portable system for sound picture projection is provided in three moderate size carrying cases. Although employing the small 16 millimeter film and not designed for commercial theatrical purposes, this new portable system is comparable with the best commercial grades in quality of reproduction.

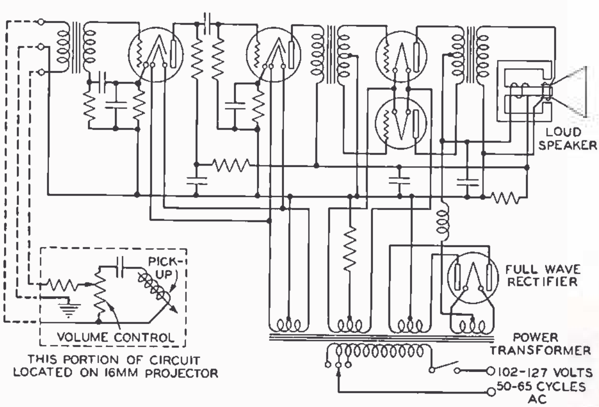


Fig. 3—All tube filaments of the amplifier are operated on alternating current, but a full-wave rectifier is provided to supply direct current voltages for the plates and grids, and for the field of the loud speaker

Wires for Subscribers' Premises

By J. B. DIXON
Outside Plant Development

TO connect a subscriber's station to the terminating point of an outside line offers peculiar problems which have long justified the use of special wire known as "inside wire." Growth in the use of the telephone, developments in building construction and interior decorating, and improvements in the wire art have all led to periodic changes in the design of this wire, and recently to the additional development of "inside wiring cable," affording many conductors in a small space. Intended solely for interior use, where they are not exposed to excessive moisture, the newest wire and cable have been particularly adapted to the installation facilities and service conditions which modern buildings afford.

In general, inside wire consists of an annealed copper conductor insulated with rubber and covered with a braid of hard glazed cotton yarn. It is available as a single wire, and in twisted form in pair, triple and quad wires. All these forms of inside wire except the quad have been familiar in the plant for many years, and have met plant needs eminently satisfactorily. Continued development has resulted in a number of improvements.

Inside wiring cable has been developed recently for use in the installation of P.B.X. boards, monitors, wiring plans, and other equipment where groups of inside wire, or lead-covered textile-insulated cable, have been employed heretofore. In forming the new inside cable, annealed copper conductors are continuously coated with a varnish-type enamel. The enameled conductors are covered with washed cotton yarn, closely served twice in reverse directions, and this covering is coated with cellulose acetate lacquer. The insulated wires are twisted into pairs and formed into cables of 4, 6, 11, 12, 16 and 26 pairs. After stranding, the cable is bound with two spaced servings of cotton yarn and served with a layer of rubber-frictioned cotton tape. An outer covering, of closely braided unglazed cotton yarn, is finally applied.

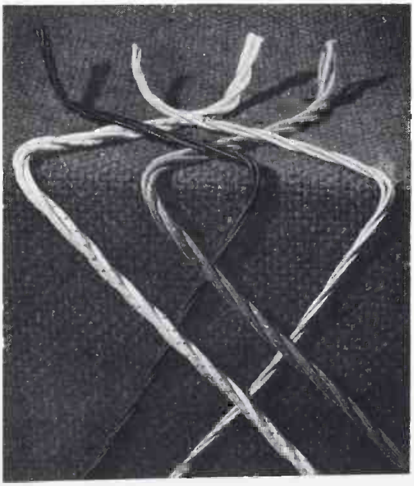


Fig. 1—The colored identification threads in the new inside wire are less conspicuous than in the old

The softness of the annealed copper used for the conductors in both wire and cable gives them maximum flexibility in handling. For many years it was necessary to employ conductors of No. 19 gauge in inside wire to secure adequate tensile strength and transmission efficiency. Improvements in installation methods, in braid strength, and in the efficiency of associated apparatus, have permitted a reduction in the size of the conductors to No. 22 gauge.

For insulating inside wire, rubber compounds are most satisfactory in both performance and cost. Recent advances in rubber chemistry, leading to the use of antioxidants and accelerators, have greatly improved the initial characteristics and increased the useful life of these compounds.

By adopting these more serviceable substances for the new wire, the nominal thickness of the rubber insulation has been reduced from 1/32 inch to 1/64 inch, with attendant savings in space and materials. The reduced cross-sectional area is particularly valuable in congested wiring spaces, where the problem of providing additional wiring facilities is often serious.

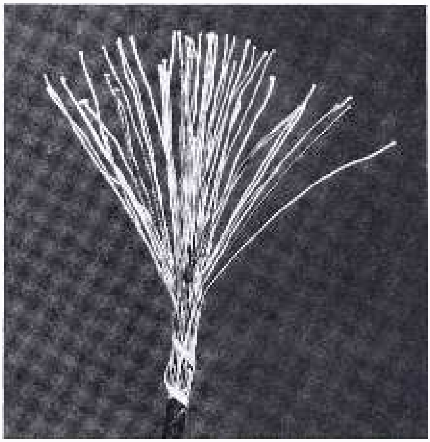


Fig. 2—Inside wiring cable affords many conductors in a small space

New methods of rating rubber compounds have also materially aided this development. Samples of the compounds used in the wire are given an accelerated aging test by exposure to oxygen under high pressure. The insulation is rated before and after aging by tests in a machine which records compression characteristics of the samples.*

In the development of the insulation for inside wiring cable, space considerations were of primary importance. The use of enamel, washed textiles†, and cellulose acetate, provides a cable whose diameter is only about half that of an equivalent number of braided, rubber-insulated wires. Conductors insulated in this newly developed way have shown adequate insulation even when immersed in water for long periods.

The braid is an important factor in obtaining tensile strength in these wires and cables. In average installations, where attachments are provided at frequent intervals, the requirements on tensile strength are not severe.

Interesting considerations in the development of the braiding were those of appearance. On inside wire, which must sometimes be placed where it is exposed to view, hard glazed yarn is used. It affords economically a surface which is less subject to discoloration during installation and to the accumulation of dust and dirt than that of the less expensive soft yarns. Since inside wiring cable is more frequently concealed, and its appearance is therefore somewhat less critical, unglazed yarn is used for its outer covering. To select shades which would harmonize

*Record, *January*, 1928, *p.* 153.
†Record, *April*, 1929.

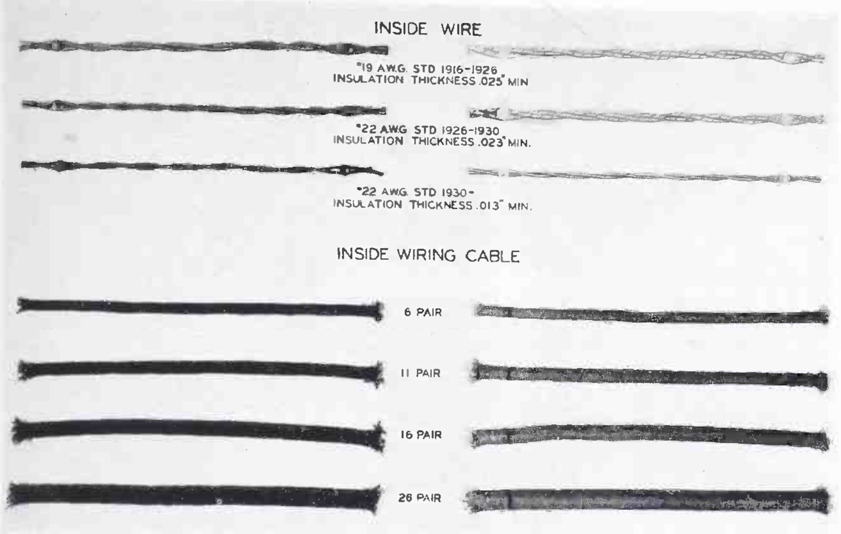
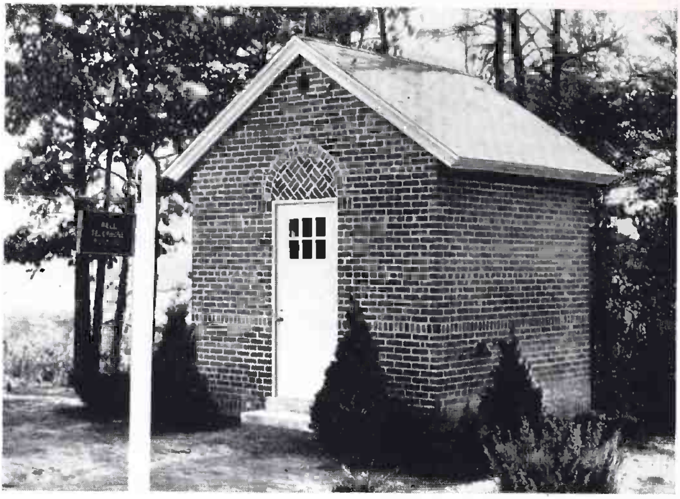


Fig. 3—Inside wire has been considerably reduced in thickness over a period of years, and the new inside wiring cable occupies far less space than an equivalent number of conductors in the form of inside wire

well with modern interior decorations, a number of trial installations were made. Ivory and brown were found to meet the field requirements best, and in the new wire and cable these tints have replaced the olive green and white previously employed.

Each of the conductors of inside wire and inside wiring cable is distinctively marked to permit ready identification by plant forces during installation. In inside wire, the marker is a strand of yellow, red, green or black thread woven into the braid about the individual conductors. The selection of the tracer shades is such that they are readily discernible at short distances, yet do not produce contrasts which are evident when the wire is observed at a distance of several feet. In the cable, the identification is obtained by coloring the second serving of yarn around each wire, in accordance with a standard code employed in other types of cable.

For appearance's sake, it is essential that the braid retain its original color as long as possible. Since the wires and cables are frequently installed in locations exposed directly to sunlight, fading requirements have been placed upon the dyed yarn. It has been found that exposure to light with the spectrum of sunlight affords a more satisfactory accelerated method of rating dyes for this purpose than exposures to the shorter wave-lengths which are not characteristic of service conditions. Although inside wiring is intended primarily for use in locations where it is not likely to be immersed in water, it may nevertheless be wetted in the course of household cleaning. The dyed yarns are therefore tested for reasonable insolubility of the dyes in water.



Dial Service for Small Communities

By C. A. COLLINS
Equipment Development

A NEW dial office, the smallest in the Bell System, has recently been developed for service in the villages and small towns of rural areas. The central-office building in which it will be housed may be smaller than a one-car garage. This new office—called the 370—comes in two sizes: the 370-A with an upper limit of ninety lines, and the 370-B, for forty lines or less.

The typical community that will utilize the 370 is at present served mainly by magneto telephones with a number of stations on each line. Such party lines, with from one to ten stations, are also provided for by the 370, but the code ringing, instead of being done by a hand crank, will be automatically controlled, and the set of dry cells at each station will be replaced by a central-office battery.

Practically all village central offices are manually operated at the present time, but the expense of providing first-class 24-hour manual service tends to favor the introduction of the dial into a number of villages. Inexpensive housing, with little or no heat, and low operating charges tend to offset the higher first cost of dial equipment.

Another possible use for the new office will be at crossroads where at the present time a number of lines radiate to serve the farmers in a rural neighborhood. All these lines are carried for miles from this crossroads point to the central office in the nearest town. By placing a 370 type office at the crossroads it will be possible to furnish interconnecting dial service to the farmers in the neighborhood and to replace a number of lines to the village central office by a few trunks. Connections for other than local calls will then be made at the village office.

Step-by-step switching equipment is employed for No. 370 type offices, and consists of selector-connectors and line finders. The selector-connector, one form of which has already been described in the RECORD*, is the heart of the system, and performs functions usually requiring several switches. In addition to possessing the ordinary selector and connector functions, it controls the code ringing for party lines, hunts over PBX groups, and handles reverting calls—connections between subscribers on the same line. This latter feature is designed to economize equipment by avoiding the use of important switching units when they are not necessary.

By using two-way trunks with incoming selector-connectors, the 370 office may be used as a tandem point. These trunks will be connected to the banks of all selector-connectors and may thus be reached with tandem calls. Such two-way trunks to various offices in other communities will give subscribers direct dialing service to telephones connected to these remoter switchboards. The more common cases of equipment and line trouble will be referred automatically to a "master-office operator" in the market town.

A visit to almost any 370-A or 370-B dial office will show practically the same arrangement of equipment. There will be a small frame carrying the switching equipment on the right as one enters the door, and a power plant on the left. These will have been shipped from the factory virtually as they stand on the floor, and the work of connecting them is simple. A small distributing frame, at one end of the switch frame, provides means of connecting lines with the switching equipment. Additional small units, mounted on swinging gates hinged to the main switch frame, are required for two-way trunks, post payment coin lines, and for unusually long lines.

The ideal office for a small community would contain only the equipment required for the existing number of lines, and still be able to provide economically for growth. As the number of telephones increases, it should be possible to adjust the extra equipment necessary so as to keep the cost per telephone as low as is consistent with satisfactory service. The 370

Fig. 1—Interior of 370-B office in Manakin, Virginia

*RECORD—*January, 1931, p. 219.*

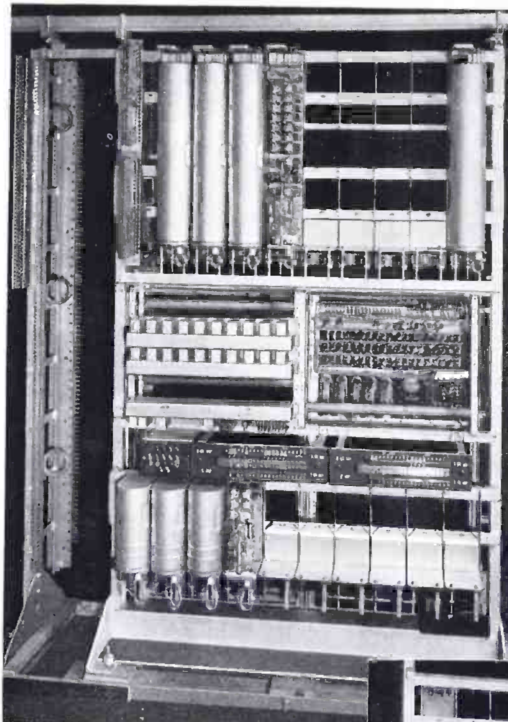


Fig. 2—On the upper part of the switch frames are the selector-connectors, and at the bottom the line finders. The distributing frame is at the left

type offices approach this ideal by offering a marked flexibility in the amount of equipment included in any installation. Generally one switch frame is sufficient for each 370-A or 370-B office. A 370-B office, when the number of lines grows unexpectedly beyond forty, may readily be modified to accommodate fifty lines, or it may be supplemented by a similar switch frame to increase the capacity to ninety lines. For the largest and busiest 370-A offices, a supplementary frame, carrying additional line finders and selector-connectors, may be included originally or added at a later date without interrupting service. For both offices, lines or switches may be added one at a time as required.

In such an office, where a small extra cost, because of the relatively small number of lines, increases quite appreciably investment per line, engineering and installing methods must be made as economical as possible. Without limiting the choice of equipment, the simplest practicable methods have been set up for No. 370 offices. To obtain such an office, the engineer of the telephone company

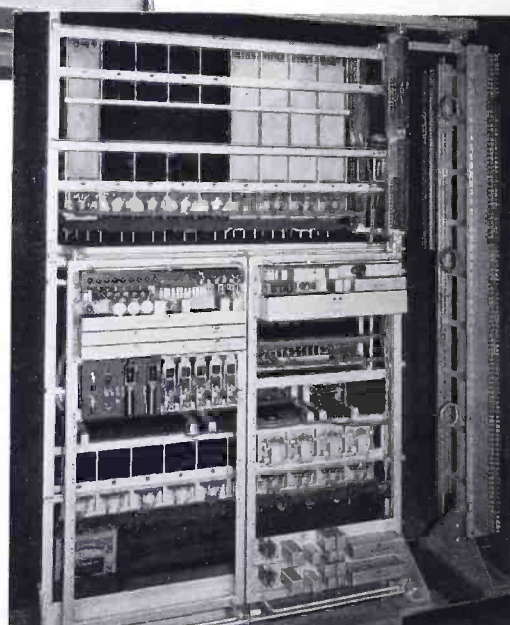


Fig. 3—On the rear of the frame are relays and miscellaneous equipment

fills in the blanks of an order form specifying the particular combination

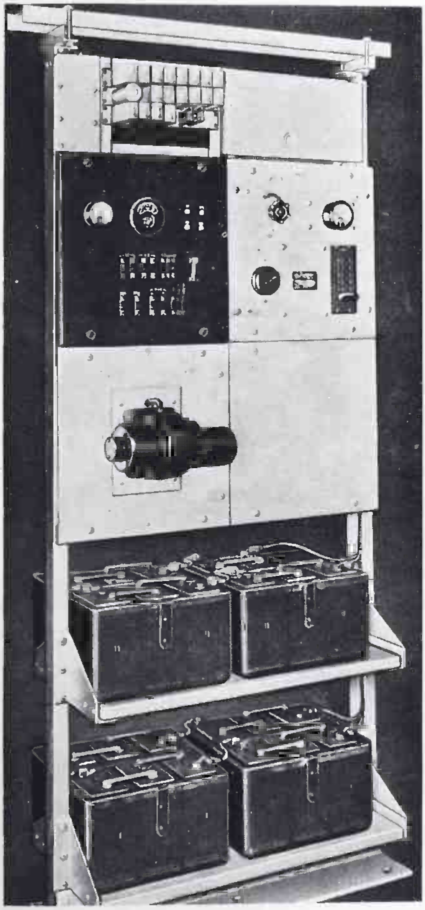


Fig. 4—The power plant bay includes batteries, a hot cathode type battery charger, a small battery-driven ringing machine, and certain accessory equipment

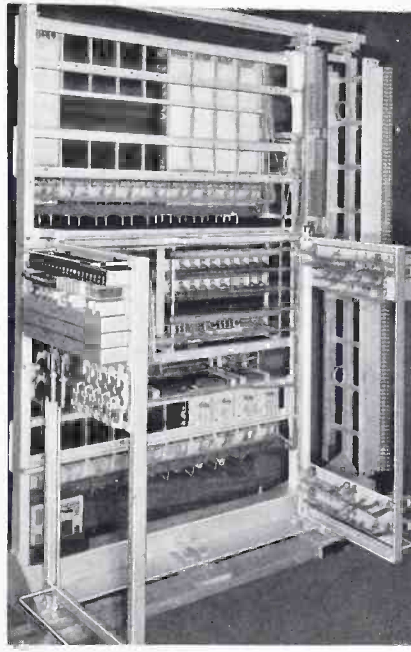
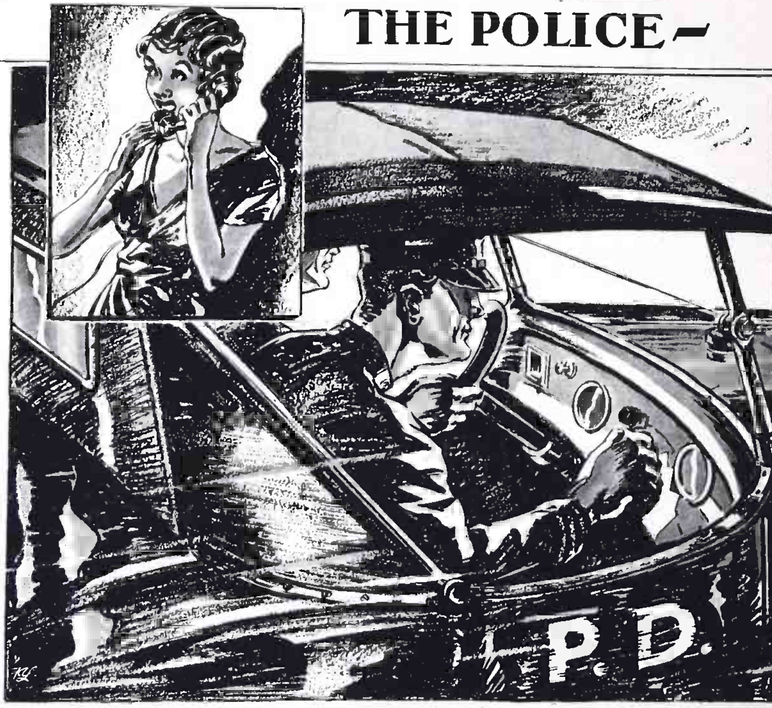


Fig. 5—Hinged gates are provided on the rear of the frame so that equipment mounted on them may be swung out to give access to the wiring of equipment on the front

of lines, trunks, and switches he needs. The switch frame and power plant will be built directly from this order with practically no sacrifice of mass-production methods. Since the frames are completely assembled and tested before leaving the shop, the simplest installing and testing practices consistent with the insurance of Bell System service standards have been adopted.

'PHONE
THE POLICE –



- IF YOU SEE A CRIME COMMITTED
- IF SUSPICIOUS PERSONS LOITER ABOUT YOUR PREMISES
- IF DANGER THREATENS IN ANY WAY

TELEPHONE AND THE NEW

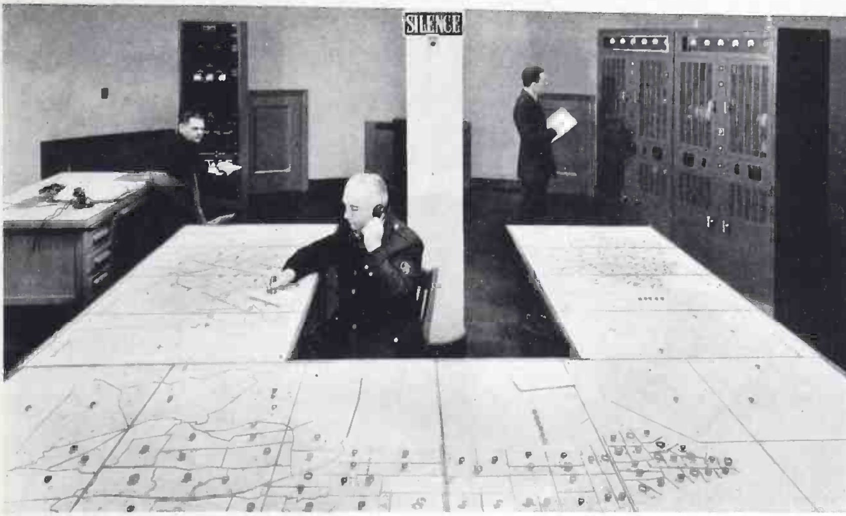
POLICE RADIO SYSTEM

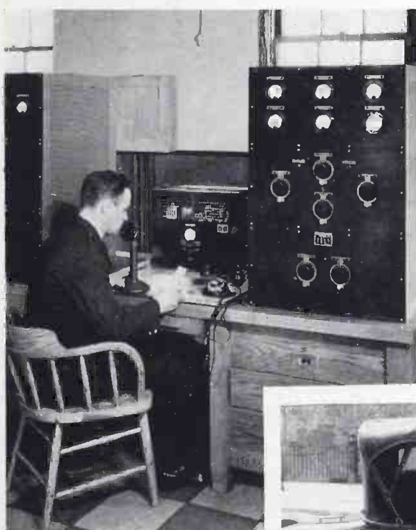
WILL BRING YOU HELP IN A HURRY

HELP FIGHT CRIME

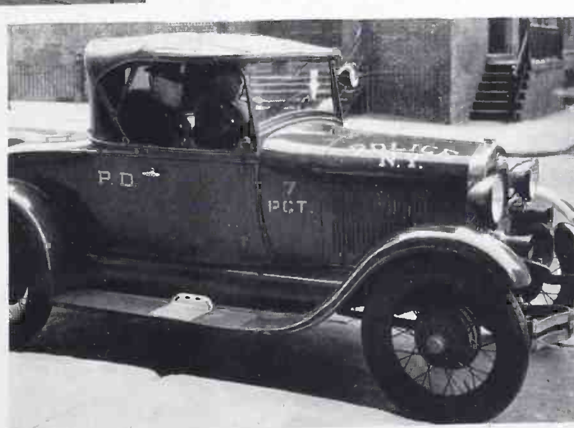
EDWARD P. MULROONEY
POLICE COMMISSIONER

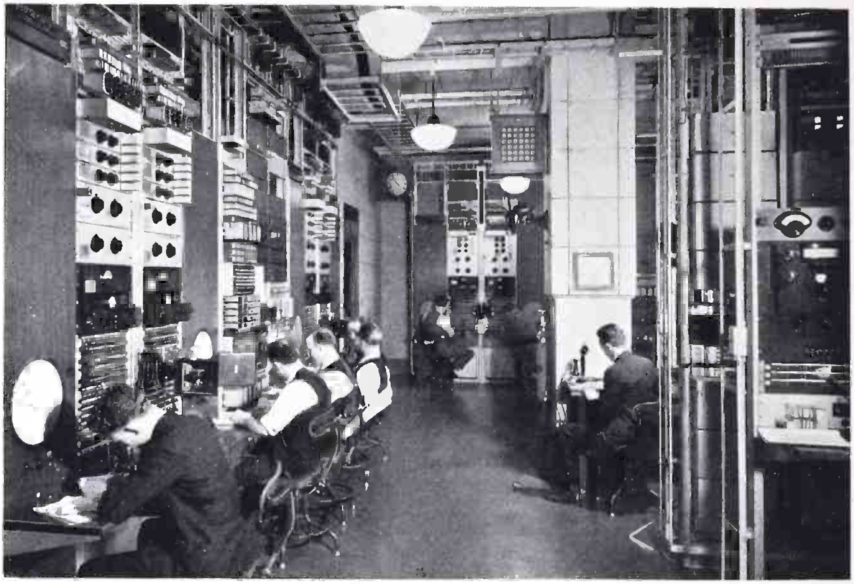
240 CENTRE STREET
MANHATTAN





From beginning to end of the New York Police Department's war on crime, the telephone plays a prominent part. Telephone wire facilities have now been supplemented by radio telephone equipment. Transmission is from sets engineered by these Laboratories and manufactured by the Western Electric Company. Police headquarters can communicate at all times with a swarm of the Department's automobiles, whose locations it can direct and follow by reference to the large map shown above.





A New Switching Unit for Program Circuits

By F. S. ENTZ
Toll Development

BROADCASTING methods have changed radically during the past decade. Instead of single stations all operating independently of each other, groups of stations, tied together by telephone lines, are now operated as a single unit. Practically all programs of the big national advertisers originate in a studio, perhaps in New York or Chicago, whence they are transmitted over high grade telephone lines to stations scattered all over the country. From these stations the programs received by wire are broadcast for the radio public in their vicinity. The telephone lines used for this purpose are known as program networks. Each is designated by a color. There are seven of them in permanent use, usually sixteen hours a day, called the Red, Blue, Gold, Orange, Amber, Brown, and Purple networks. 175 broadcasting stations and over 35,000 miles of line are included in these networks, and in five others, used only recurringly, are 5000 miles of line and thirty additional stations.

On the larger networks there are certain stations permanently connected to the circuit and others associated with it for only certain programs. These latter stations are grouped on branch circuits which are connected by lines to distributing centers where the circuits are monitored continuously. At such centers, known as network key points, operators are on constant duty to monitor the circuits and to perform any switching required at changes of program. Until recently this switching has been done by plugs and jacks, but with the growth of the number of stations and the increasing tendency to shorten the period allowed for switching, the burden on the operators at the larger centers was becoming too great.

To provide, therefore, for more rapid rearrangement of the stations associated with a network, with less strain on the operators, the Laboratories have recently developed a system by which all connections for a program are set up while the preceding program is in progress. When the change from one program to the next is to be made, all that is ordinarily required of the operator is the operation of the transfer switches, which modifies the arrangement of the network from that required for the preceding program to that for the following. An installation has recently been made in the Chicago Toll office for switching the stations on two of the largest networks, the Red and the Blue. The photograph at the head of this article shows this installation as well as other network units, and the photograph of Figure 2 shows a close-up of the switching equipment.

The new system provides for five main networks and sixteen connections to them. As used in the Chicago office the networks involved are the Red, which has separate circuits for transmitting east and west, the Blue which also has separate east and west circuits, and a spare which is used for special purposes. The main networks are referred to as incoming circuits, and the sixteen connections running to optional broadcasting stations are known as the outgoing circuits.

The underlying plan of the arrangement is quite simple and for two incoming and two outgoing circuits is illustrated by the simplified schematic of Figure 1. Two groups of keys, each containing a row of buttons for each incoming circuit, and each row containing a button for each outgoing circuit, are mounted on the frame of a relay rack facing the operator. The two groups are separated by five transfer switches, and above and below the groups are mounted the accessory relays and equipment. The buttons in the various rows for the same outgoing circuit are mounted vertically above each other to form columns. This gives an arrangement of intersecting columns and rows, and pushing any one button connects the outgoing circuit corresponding to that column to the incoming circuit corresponding to that row. The outgoing circuits terminate at the springs of a set of sixteen relays, and the back and front contacts of these relays are connected to the upper and lower sets of keys respectively.

Each incoming circuit is provided with a monitoring position which is connected to the switching position by a two-way signalling circuit. When a prearranged cue is received on an incoming channel, such as some readily distinguished series of musical tones or certain words, the monitoring operator presses a key that lights a lamp signal at one end of the transfer switch for that particular incoming circuit. The switching operator then turns the switch to transfer the incoming circuit to the outgoing lines with which it is to be associated for the next program. He then presses a switch at the side of the signal which extinguishes both the lamp at his position and a guard lamp at the monitoring position as an indication that the transfer has been made. After this he is free to set up the next program on the row of keys that has just been switched out of service.

While all incoming circuits are connected through one group of keys, a red lamp at the side of the bank is lighted to show that that bank is in use, and that the other bank is free for setting up the next group of programs. When one incoming circuit is switched to the other bank, the red lamp is extinguished and a green lamp opposite each bank is lighted to indicate that a transition from one bank to another is in progress.

Programs at the various studios are carefully rehearsed in an effort to terminate them all within a very few seconds of each other so that all circuits may be transferred at the same time. This is not always possible, however, and not infrequently one or more programs may hold over a minute or two after the others have been transferred. This condition brings in one of the many complications that must be provided for in the new system. Incoming circuit No. 1, for example, may be holding over, while incoming circuit No. 2 has already been switched for its next program. This causes no inconven-

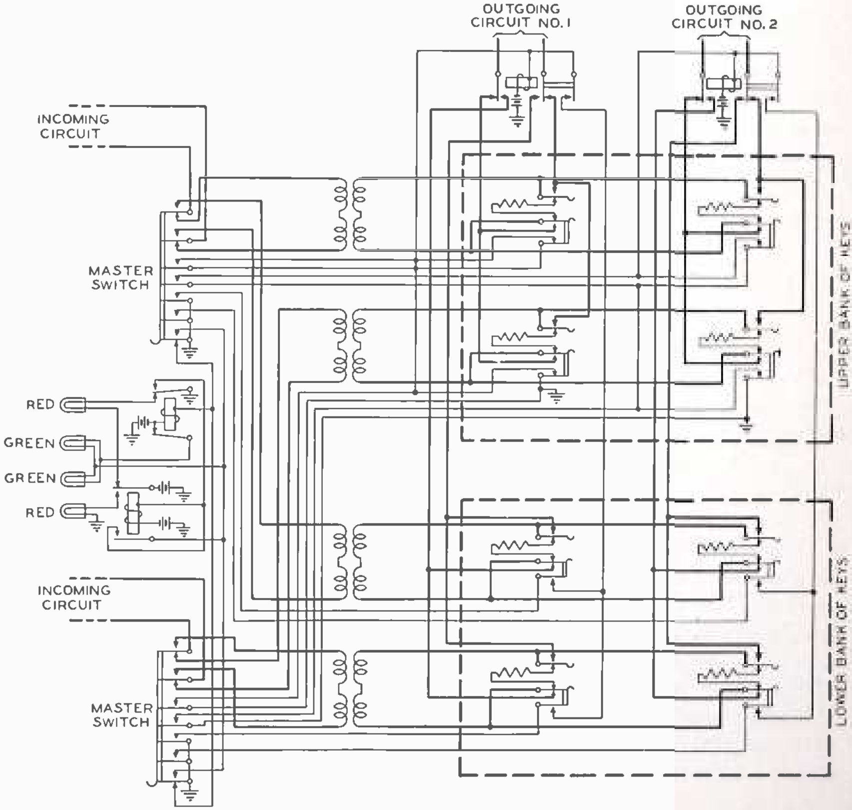


Fig. 1—Simplified schematic for the outgoing and the incoming circuits, showing the division into two banks of key-operated switches

ience if none of the outgoing stations required for the new set-up on circuit No. 2 is in use on circuit No. 1. Should there be one or more circuits required for the new set-up on circuit No. 2 that are in use at the time on circuit No. 1, means must be provided for holding them on circuit No. 1 until that program is completed. This is very important in a commercial program since it is generally in the last few minutes that the advertiser's name and product are mentioned. Provision has been made in the new system, therefore, to hold over such stations until their program is over and then to transfer them to their new connection. Occasionally it is desirable not to hold over an outgoing circuit because of some special importance of the next program, and this is made possible by the row of "cut" keys at the bottom of each of the groups.

Another special feature incorporated in the new system is the disabling switches at the end of each transfer switch (hidden by the lamp and signal button in the photograph). The operation of one of these switches opposite an incoming circuit that is not in use, permits the proper action of the red and green pilot lamps on each bank without throwing the unused transfer switch.

Still another special feature permits the connection of a number of special incoming lines to a network, one after another at short intervals of time. The row of keys just below the five transfer switches is used for this purpose and is employed on such occasions as nation-wide banquets where speakers talk successively from one point after another at short intervals.

In addition to these various operating features to take care of all likely conditions, other provisions must be

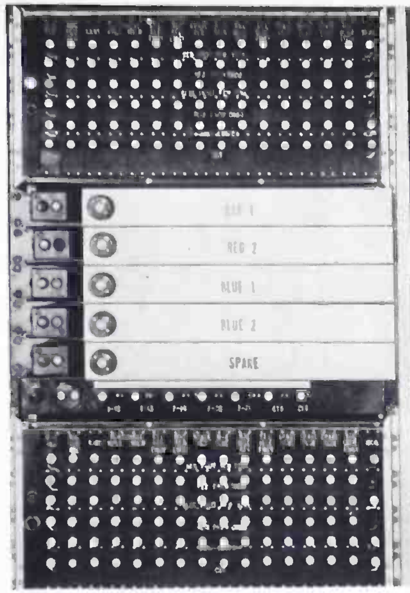
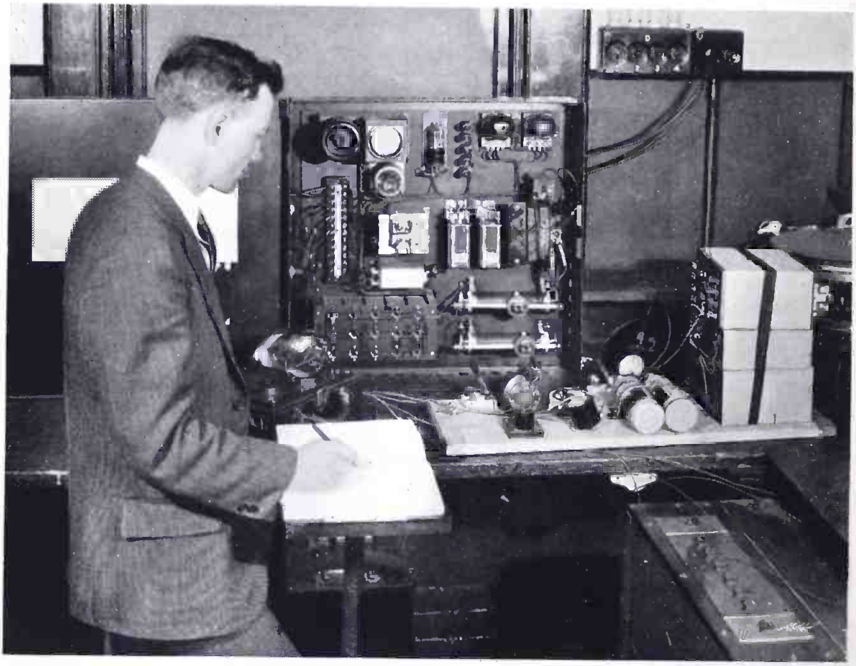


Fig. 2—Two banks of keys are used for setting up network connections

made to maintain the proper impedance conditions on the circuits at all times. Resistance networks are associated with each incoming circuit, and they are adjusted to provide the same impedance regardless of the number of outgoing circuits that are connected at any one time. Each key for all outgoing circuits has a 600 ohm resistance connected to it so that when an outgoing circuit is not connected, the incoming circuit will be terminated by the proper impedance.

Each morning the operators at the switching and monitoring positions are given detailed schedules of the various "switches" required for the day's program. These give them all the necessary information as to duration of programs and the various set-ups of circuits that are to be made. Every possible effort is made to avoid errors, and after each bank of keys has been set up for a new program it is checked, first by the switching operator himself and then by a supervisor. The system has proven very satisfactory in service, and its use will probably be extended in the future. At smaller or less important key points, it has been found possible to employ a somewhat similar system but with only one bank of keys.



J. R. Power with a very high precision voltage regulator to be used chiefly on direct current test circuits

Contributors to This Issue

W. E. Campbell was graduated from the University of Witwatersrand, South Africa, in 1923. After three years teaching chemistry, he entered the Chemical Research Department of these Laboratories. Until 1929 he conducted research in electroplating and corrosion, in the course of which he developed a method of accurately measuring the corrosiveness of the fumes from wooden cable duct on the lead sheath of the cable. Meanwhile he continued his studies of chemistry at Columbia, receiving the A.M. degree in 1929. Recently he has been investigating the properties of materials in relation to their behavior as lubricants, in the attempt to lay a groundwork for the solution of the lubricating problems which are becoming of ever increasing importance in telephone operation.

In 1916 J. B. Dixon was graduated in Electrical Engineering from Pratt Institute and entered the employ of the Westinghouse Company at Pittsburgh where he worked in the Railway Department on the design of equipment for electric locomotives. Five years later he joined the Public Service Corporation of New Jersey, in whose Operating Department he worked on the distribution of electric light and power. In 1923 Mr. Dixon came to the New York Telephone Company for outside plant engineering work on lead-covered cables, cable testing and splicing, and the like. His transfer in 1926 to the Development and Research Department of the American Telephone and Telegraph Company brought him into development work on cables and methods of cable testing. A year later Mr. Dixon transferred to these Laboratories to develop wires and wire products for outside plant purposes.

G. E. Perreault received a B.S. degree in Mechanical Engineering from Worcester Polytechnic Institute in 1930 and immediately after joined the technical staff of Bell Telephone Laboratories. Since coming here he has been occupied with machine design in the Special Products Department. Most of his time has been spent on the development of light valves for sound recording and picture transmission on film.

C. A. Collins was graduated from the University of Washington, with a degree of B.S. in electrical engineering, in 1925.

W. E. Campbell

J. B. Dixon

G. E. Perreault

He then took the student training course with the Pacific Telephone and Telegraph Company, and during the next four years served in various capacities in the San Francisco area. He was successively switchboard repairman, methods engineer, line and station repairman, switchboard repairman, panel dial switchman, and transmission engineer. Early in 1930 he transferred to the Laboratories where, with the Systems Department, he has been engaged in the development of small dial offices.

F. S. Entz was graduated from Yale (Sheffield) in 1919, and after two years with the American Bridge Company, joined the Engineering Department of the Western Electric Company—now Bell Telephone Laboratories. Following a short period during which he was engaged in relay design, he transferred to the switchboard group where he took part in developing the No. 3 Toll Switchboard. After a number of years at switchboard design, he turned to the development of repeaters until, in 1929, he was placed in charge of a group formed to handle toll signalling and switching circuits, with which work he is still associated.

C. A. Collins

F. S. Entz