A New Telephotograph System *

By F. W. REYNOLDS

Transmission of photographs over telephone wires was begun commercially several years ago, but recent improvements have increased to 11 by 17 inches the size of photograph that could be transmitted and have made it possible for the picture to give much more information. The new machines used for sending and receiving photographs are described in this paper, and the requirements and control of the wire system necessary to prevent imperfections in the picture and to permit switching of sending and receiving stations are discussed.

A TELEPHOTOGRAPH message service between New York, Chicago, and San Francisco was initiated in April 1925 by the Bell System, and was extended during the following two years to five additional cities. Experience in the operation of this service, using equipment previously described,[1] indicated that a number of improvements were desirable in order to meet more satisfactorily the apparent requirements of this form of communication. Development work was undertaken to effect these improvements, and this paper describes the new equipment and some of the features involved in establishing a leased wire telephotograph network connecting 26 cities as shown in Fig. 1.

During the eight years of operation of the first Bell System telephotograph service the performance of the system was observed, analyses made of the material transmitted, and opinions formulated regarding the acceptability of the received pictures. The early equipment required the preparation of the material for transmission as a film transparency in an area not exceeding $4\frac{1}{4}$ inches by $6\frac{1}{2}$ inches. This relatively small image field combined with the use of 100 scanning lines per inch and the added photographic operations to prepare the material for transmission were considered as limiting the usefulness of this new service. For example, in transmitting many of the forms of printed matter it was necessary to divide the copy into overlapping sections, to transmit each piece separately and to assemble the sections as a composite picture at the receiving point. Obviously this procedure could not be applied advantageously to a photograph or news picture and therefore the maximum information content of such transmissions was limited by the small size of image field and the

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[1] For all numbered references see list at end of paper.

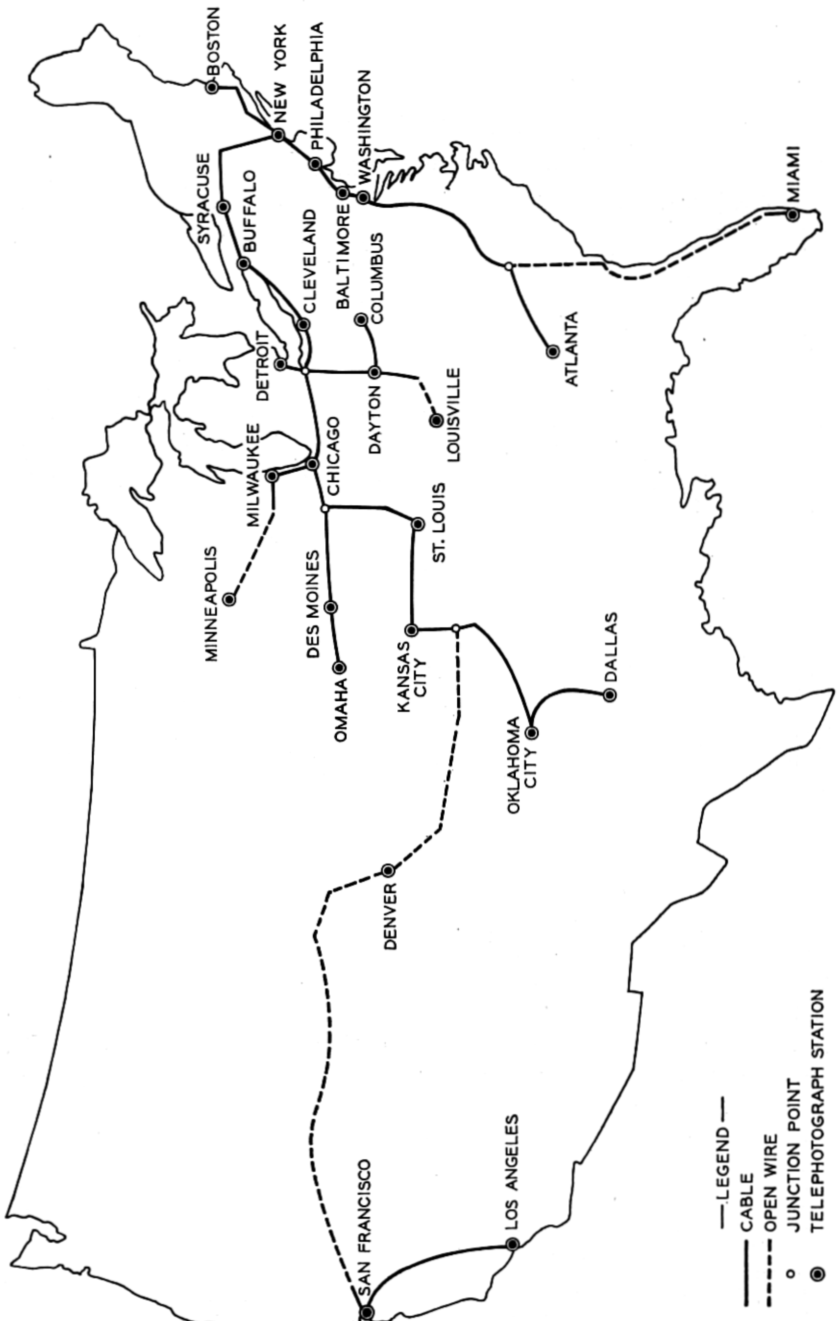

Fig. 1—A leased wire telephotograph network in the United States.

number of scanning lines employed. Certain types of pictures such as portraits, small groups, and others of a rather limited information content were transmitted satisfactorily with this early equipment, but transmissions of those pictures containing much greater amounts of information frequently were regarded as inadequate.

In formulating specific requirements for the new telephotograph system consideration also was given to the increasing interest in news pictures and to the trend in this country toward improvement of newspaper halftone reproduction. The former public demand for pictures of the occasional catastrophe or outstanding news event is today apparently being supplemented by an interest in the pictorial reporting of even minor news items. These factors are reacting to elevate the standards for acceptable telephotographs to a plane where newspaper halftone reproduction of original and transmitted pictures may soon be comparable in quality and information content. The requirements met by the new telephotograph system are summarized briefly in the following paragraphs.

Scanning

Pictures are scanned by reflected light at 100 lines per inch. This permits direct transmission from original subject matter in the majority of cases without recourse to special preparation such as photographic copying.

Size of Image Field

A useful image field is provided for scanning and reproducing pictures of various sizes up to and including 11 inches by 17 inches. This area is sufficient to accommodate most sizes of subject matter likely to be encountered in telephotography and is well adapted to transmission of black and white information such as financial statements, advertising layouts, and the like. Furthermore, it provides a practical method of varying the information content of received pictures by using original prints of appropriate sizes. This point is illustrated in Figs. 9 and 10, which are reproductions from transmissions made from prints of the same subject which were respectively $4\frac{1}{4}$ by $6\frac{1}{8}$ inches and 10 by $14\frac{1}{2}$ inches. The useful circumference of the picture cylinder employed is 11 inches. In the case of news pictures, which are ordinarily distributed as 8 by 10 inch photographic prints, the remaining one-inch space on the circumference of the cylinder may be utilized for transmitting the caption as part of the picture.

Speed of Transmission

The image field in the new equipment is scanned at 100 lines per inch with a velocity of 20 inches per second, which results in the transmission of one inch of picture per minute, measured along the axis of the picture cylinder. This rate of scanning produces essential signal frequencies extending approximately from zero to 1,000 cycles per second and is more than double the speed of transmission used in the earlier equipment. However, by employing the single-side-band method of transmission it has been possible to use this speed of transmission over telephone circuit facilities of normal band width but specially modified as described in a later section.

Synchronism

Operation of the earlier Bell System telephotograph equipment over long telephone circuits indicated the desirability of providing improved means for synchronizing the sending and receiving equipment. Accordingly, development work was undertaken, and local frequency sources of the required stability were made available to permit independent speed control without transmitting synchronizing signals. Experimental oscillator units were installed for tests at three telephotograph stations about two years after the opening of the public telephotograph service in 1925. Experience gained from the use of these oscillators, which were vacuum tube driven tuning forks maintained within close temperature limits, indicated that this method was practicable, although the particular arrangements employed at that time could be advantageously improved.

A new design of tuning fork controlled oscillator has been provided in the new equipment whose frequency can readily be adjusted and maintained constant to within a few parts in a million. This difference in speed between sending and receiving machines is so slight that skewing of the received picture is not noticeable.

Starting and Phasing

The simultaneous starting of all machines participating in the transmission and reception of a picture is effected by means of a signal sent over the line by the transmitting machine. Phasing of the machines is automatic, since all are started simultaneously from the same angular position by a positive action clutch. This requirement is similar to that met by the earlier equipment, but more difficult to fulfill because of the use of a much larger picture cylinder. It required the development of a new type of clutch which would permit a gradual increase in velocity of the cylinder and yet be positive in action. The fulfillment of this requirement is important as it assures accurate phasing without consuming valuable circuit time, irrespective of the number of machines involved in a transmission.

Design

In addition to meeting the above general requirements the new design includes arrangements for daylight operation, a new type of driving motor, and scanning with a pulsating beam of light whereby the photoelectric current can be amplified by a-c. methods.

Description of the New Telephotograph Equipment

The general specifications outlined in the preceding paragraphs are embodied in the new telephotograph equipment now being manufactured. Telephotograph equipment of this type for a station arranged to send and receive pictures consists of a sending machine and a receiving machine mounted on separate tables (see Figs. 2 and 3),

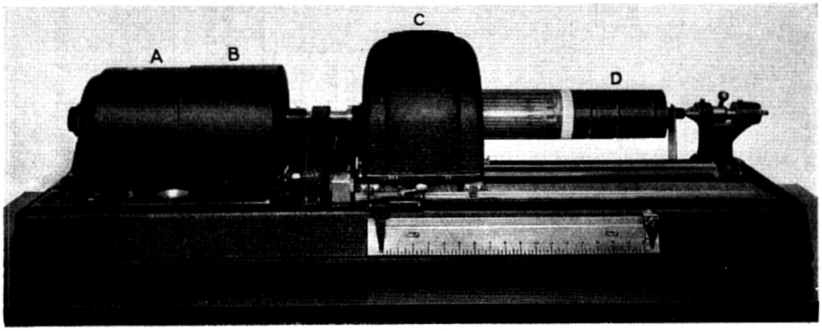

Fig. 2—Telephotograph sending machine.

A—Motor.
B—Clutch.
C—Optical system.
D—Picture cylinder.

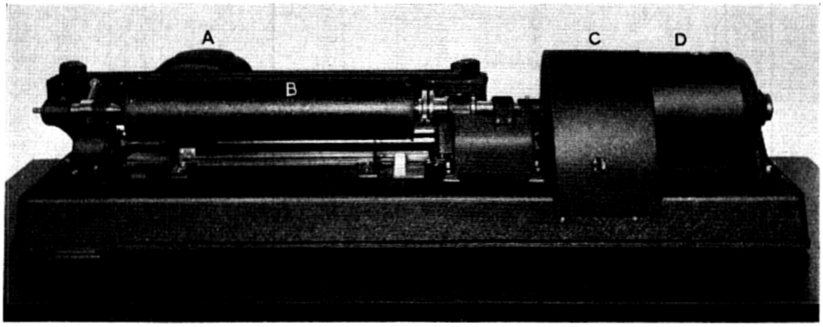

Fig. 3—Telephotograph receiving machine.

A—Optical system.
B—Cylinder housing.
C—Clutch.
D—Motor.

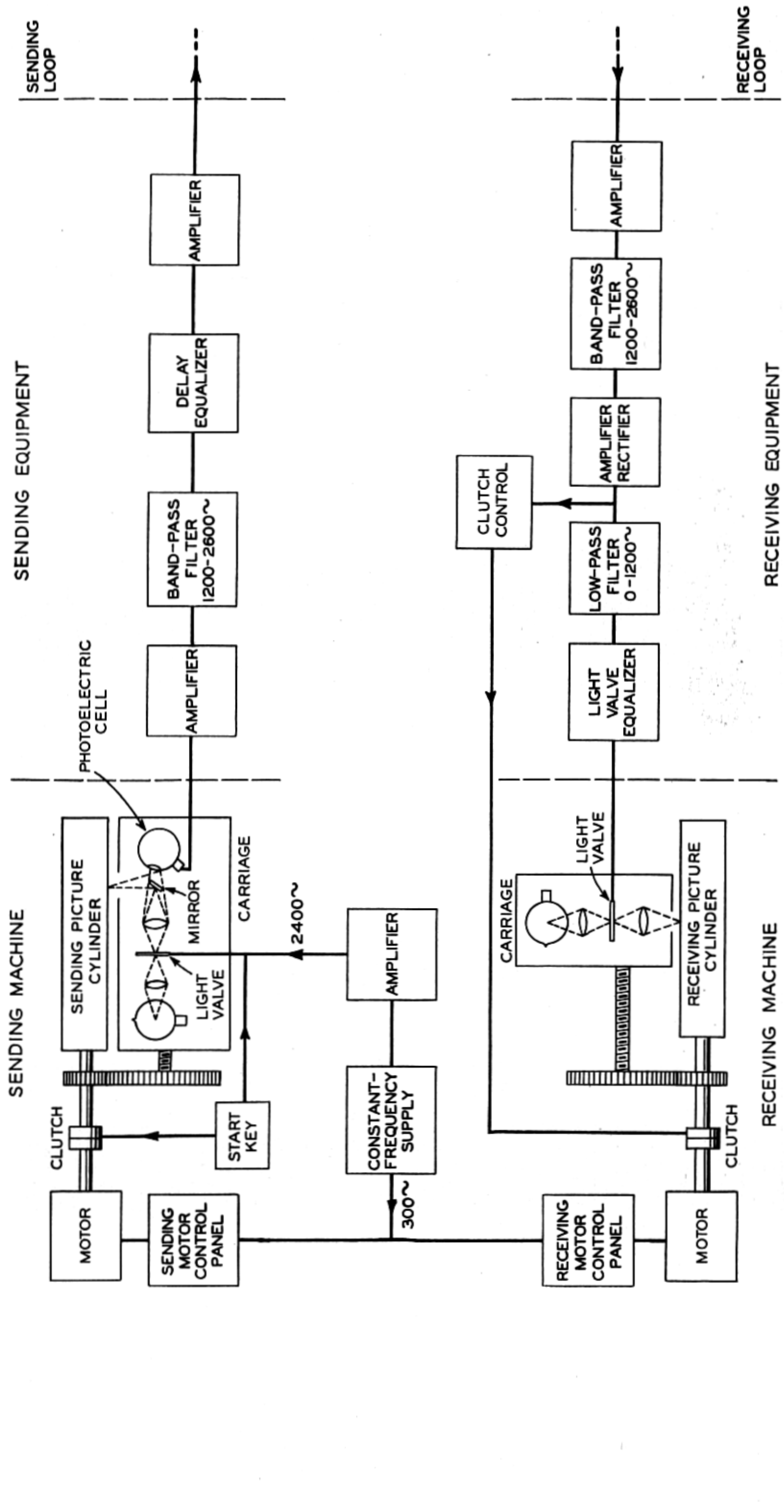

Fig. 4—Schematic diagram of sending and receiving equipment for one station.

two bays of relay-rack-mounted apparatus, and a cabinet of power supply equipment. A third bay comprising loop terminating arrangements, telephone, and loud speaker equipment may be furnished by the telephone company if ordered by the customer. This telephotograph equipment connected by suitable circuits will transmit pictures and other forms of graphic information from point to point or from one to a number of points simultaneously.

Figure 4 is a schematic diagram illustrating the functional relationships of the various units of this equipment. Certain features of these units that may be of special interest have been selected for description in the following.

Motor and Associated Speed Control Circuit

Although the driving motor for the telephotograph machine is essentially of the d-c. shunt type, it functions in combination with its associated speed control equipment as a synchronous unit and upon starting locks automatically in synchronism with the frequency generated by the local carrier and motor control oscillator. This is accomplished in a manner similar to that previously used in television equipment demonstrated by the Bell System.[2, 3] An inductor type generator built into the frame of the motor delivers an a-c. output of 300 cycles per second at the normal speed of the motor, 100 r.p.m. The output of the generator is impressed upon the plates of two vacuum tubes the grids of which are energized by the 300-cycle output of the carrier and motor control oscillator as shown in Fig. 5.

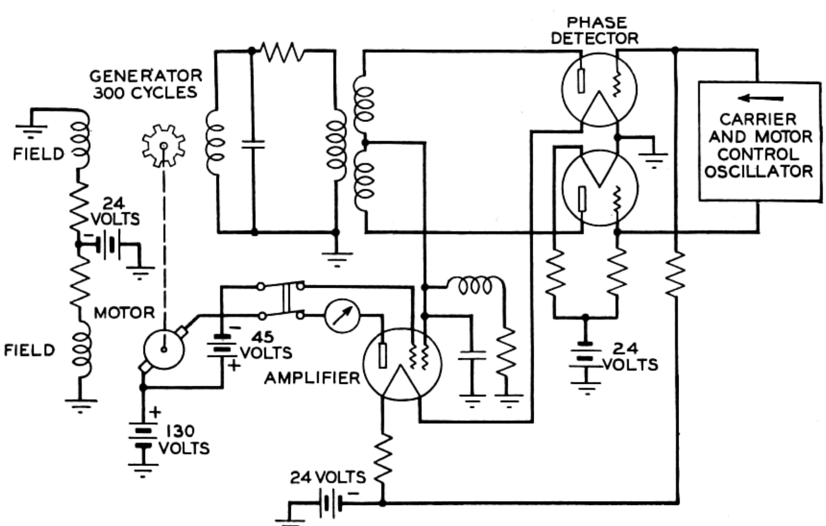

Fig. 5—Telephotograph machine motor control circuit.

These tubes act as a phase detector and vary the input voltage across an amplifier which supplies the total armature current of the motor. Armature rather than field control is employed to obtain faster and more complete regulation. The capacitor across the terminals of the generator armature, tuning the circuit to a frequency slightly in excess of 300 cycles per second, and the coupling impedance between phase detector and amplifier acting as a low-pass filter, assist in preventing hunting of the motor.

Clutch

Connection between driving motor and picture machine is made through a positive action clutch electrically operated. This clutch gradually applies the driving torque to the picture machine during the starting interval. It operates on the principle of storing energy in a coiled spring during the first part of the starting interval while the velocity of the machine is increasing and then allowing this energy to be released gradually by an escapement mechanism while the parts of the clutch are assuming their normal operating position. The time interval required for complete operation of the clutch corresponds to three or four revolutions of the picture cylinder but variations in the length of this interval do not affect the accuracy of phasing, inasmuch as the latter is determined by the time of operation of the clutch trip magnet and each receiving machine may be readily adjusted to compensate for this variation.

Circuit arrangements associated with the clutch of the receiving machine permit its operation from a starting signal received over the line from the transmitting machine.

Sending Optical System

The optical system of the sending machine is arranged to direct a scanning light beam upon the surface of the picture which is mounted on a cylinder. This scanning beam, attenuated by reflection from the various shades of the picture, is directed to a photoelectric cell. The illumination is obtained from a small incandescent lamp and is interrupted in passing through the aperture of a double ribbon light valve. This double ribbon light valve, which is a modification of a type previously described,[4] is actuated by the picture carrier frequency, 2,400 cycles per second, and its interruption of the scanning light beam permits the use of a-c. methods of amplification of the photoelectric currents. Aside from its general simplicity and freedom from the usual difficulties experienced with rotating light choppers, this type of interrupter readily effects a sinusoidal variation in illumination.

It is obvious that, since the illumination incident upon the picture is pulsating at the carrier frequency, the currents present in the output of the photoelectric cell will consist of the picture signal currents and the carrier frequency modulated by these currents, the picture itself acting as a simple direct product modulator.

Filters and Delay Equalizer

The application of single-side-band transmission methods to the present telephotograph equipment has resulted in the design of electrical filters of rather unusual phase shift and attenuation-frequency characteristics. It has previously been pointed out in connection with a discussion of telegraph transmission theory [5] that three conditions should be fulfilled for single-side-band transmission:

1. The system should have a linear phase shift-frequency characteristic.
2. The sluggish in-phase component of the signal resulting from a displacement of the carrier from the middle of the transmitted band should be eliminated.
3. The received quadrature component resulting from the loss of the component of the side band suppressed, equal in magnitude but opposite in sign, should also be eliminated.

The first two conditions are met by the careful design of a delay equalizer network and a special filter giving a suitably shaped admittance characteristic for the system. This characteristic exhibits a type of symmetry about the carrier frequency which would result in a superposition of the regions adjacent to the carrier if rotated about this point. Consequently the attenuation of the filters and associated delay equalizer should be 6 decibels greater at the carrier frequency than at the middle of the band of the transmitted frequencies, in addition to meeting the requirement of a linear phase shift-frequency characteristic. Over-all attenuation and phase shift-frequency characteristics of the filters and equalizer of the sending and receiving equipment of the present design are shown in Fig. 6.

In regard to the third condition for single-side-band transmission, experiments have shown that the effect in received pictures of the quadrature component is not of practical importance in the present equipment. The quadrature component is determined essentially by the slope of the signal envelope which is in turn restricted by the equivalent transfer admittance characteristic [6] of the scanning aperture, and by the slope of the filter characteristic to meet condition 2.

Receiving Optical System

The receiving optical system of the new telephotograph equipment is similar in its general aspects to that employed in the earlier Bell System equipment. Illumination from an incandescent lamp is directed to the receiving photographic emulsion through the aperture of a single ribbon light valve. The latter, however, is operated by the rectified picture currents instead of by the modulated picture carrier current as used in the earlier equipment. This change results in very simple yet efficient optical arrangements for receiving a

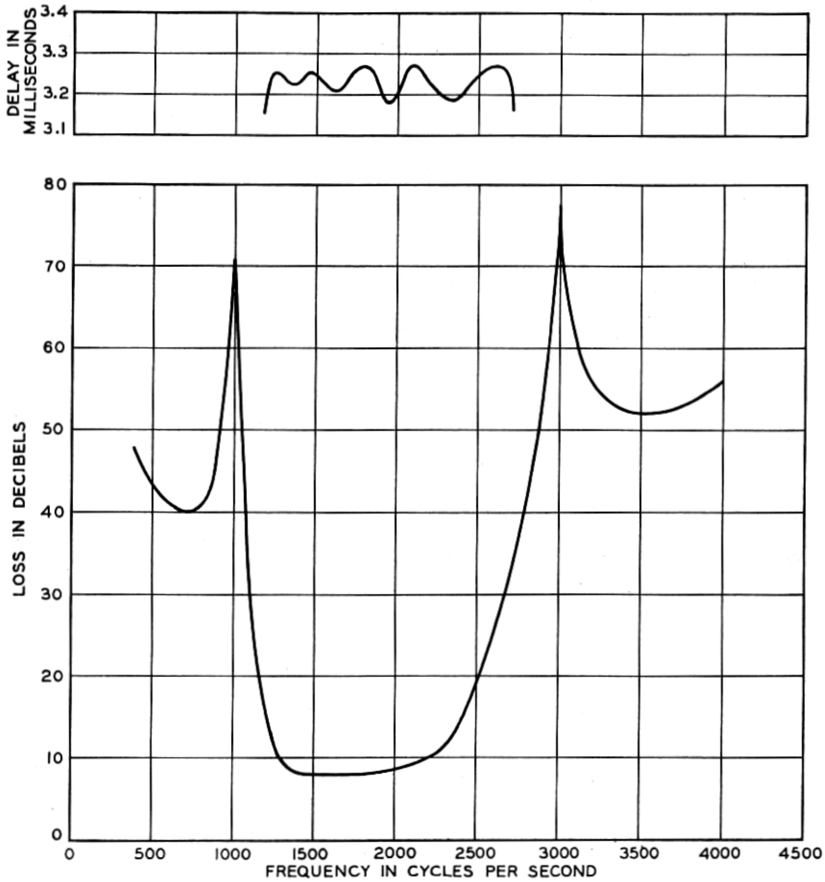

Fig. 6—Over-all characteristics of filters and delay equalizer.

variable density constant line width picture with no apparent structure. The aperture of the light valve, which is uniformly illuminated by the incandescent lamp, is adjusted so that the width of its image on the receiving emulsion is 0.01 inch. The height of the aperture, which determines the exposure, is regulated by the instantaneous position of the light valve ribbon and this is proportional to the received picture currents. A uniformly illuminated field is obtained at the light valve aperture with a minimum loss of light by using a sphero-cylindrical condenser lens which focuses the diameter of the helical filament of the lamp without imaging individual turns of the helix at the plane of the aperture. Imaging of the lamp filament with the usual type of spherical condenser lens would result in non-uniformity of illumination not only because interstices between individual turns of the helix have an intrinsic brilliancy much greater than the outer surface of the filament but also because of the angular variation of the masking effect of the turns of the helix upon the illumination emerging from the interstices. The ribbon of the light valve is tuned mechanically to resonance at 1,200 cycles per second, and is shunted by an equalizer [7] consisting of inductance, capacitance, and resistance in series which is tuned to the resonant frequency of the ribbon, thereby producing a flat response-frequency characteristic over the useful range of signal frequencies.

Carrier and Motor Control Oscillator

This portion of the equipment furnishes the carrier frequency of 2,400 cycles per second and the motor control frequency of 300 cycles per second accurate to within a few parts in a million. The arrangements used consist of a 300-cycle tuning fork within a temperature regulated container, a vacuum tube amplifier circuit designed to provide controlled regenerative operation of the fork, and a vacuum tube harmonic generator for supplying the carrier frequency.

Although this general method for obtaining a constant frequency is old and has been described previously,[8, 9, 10] in view of its importance in the operation of the present telephotograph equipment it may be of interest to indicate briefly the specific arrangements employed.

The tuning fork is made of a heat treated nickel chromium steel alloy to obtain a small frequency-temperature coefficient and is mounted in a thermostatically controlled metal cylinder wound with a heating coil over which are wrapped alternate layers of copper and felt to provide attenuation of heat transfer.[11] The pick-up and drive coils associated with the fork are connected to the vacuum tube amplifier circuit as shown in Fig. 7. The frequency of a fork is affected by a number of factors including temperature, amplitude of vibration, and aging of the material. Since it is impracticable to maintain constant all of the factors involved, it is necessary to provide means for occasional adjustment to meet the requirements for constancy desired in picture transmission. In the present equipment the temperature of the fork is maintained within $\pm$ 0.1 degree of its nominal value of 50 degrees centigrade; two adjustments are provided for changing the amplitude, one of which varies the grid potential of a vacuum tube which acts to limit the current supplied the driving coil, and the other, a variable capacitor in the circuit containing the

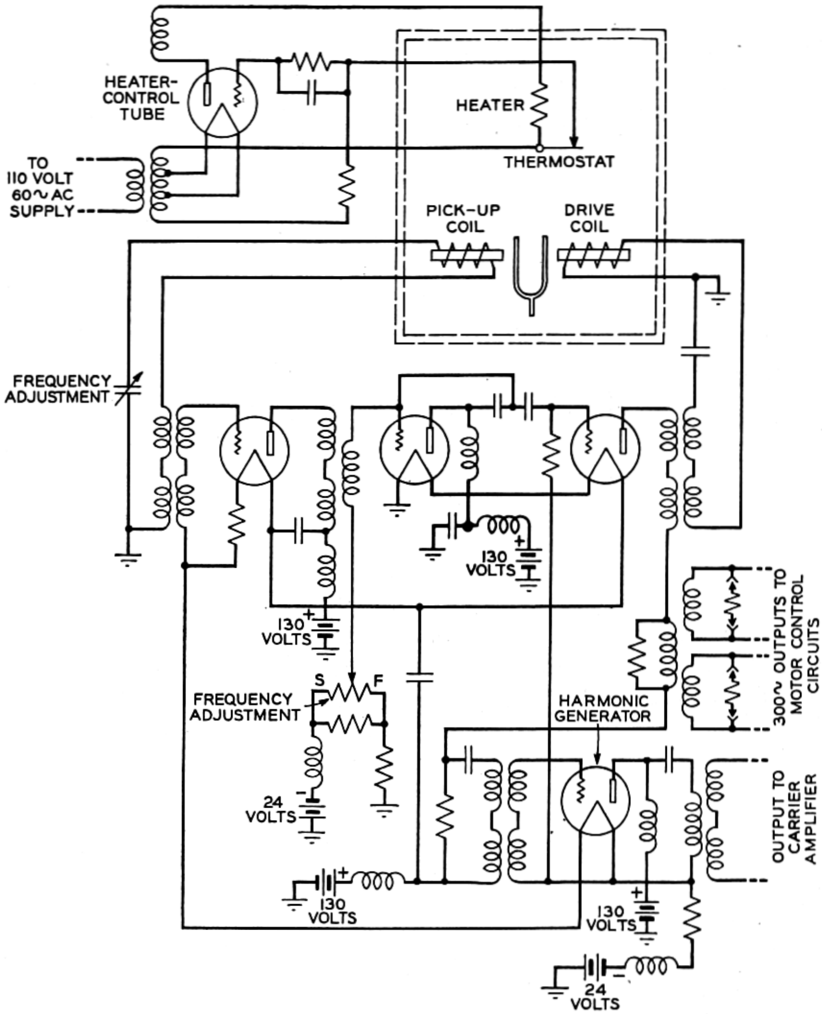

Fig. 7—Carrier and motor control oscillator.

pick-up coil varies the phase relation between the currents in the drive and pick-up coils. Three outputs are provided from the oscillator, two for the sending and receiving motor control circuits and the third for the carrier frequency supplied the sending light valve.

All of these outputs terminate in high impedance circuits and have no appreciable reaction upon the constancy of operation of the fork.

Line Facilities Used with the New Telephotograph Equipment

Requirements for the communication channel used in the transmission of pictures are obviously dependent upon the characteristics of the telephotograph equipment employed and the amount of degradation resulting from transmission which can be tolerated. In general, telephotograph equipment capable of recording the transmitted signals with a degree of fidelity of the order required for good pictures may also record certain extraneous disturbances in the transmission channel which will appear as blemishes on the received picture. The more important of these disturbances are abrupt variations in line net loss, delay distortion, certain types of noise, echoes, and crosstalk. With the exception of delay distortion which is more pronounced for the new equipment because of its higher speed of transmission, the requirements relating to the other disturbances are comparable to those applying to the earlier Bell System equipment. Experience over a period of years with the earlier equipment indicated that selected telephone circuits, specially conditioned to adapt them to picture transmission and established as a regular network, could be relied upon to give consistently good results. This general procedure has been followed in establishing wire networks for use with the new telephotograph equipment and unretouched reproductions of typical news pictures received over such circuits are shown in Figs. 8 and 11.

The circuit facilities employed with the new telephotograph system are 4-wire H-44-25 side circuits in cable [12] where available and elsewhere 2-wire open-wire [13] side and physical circuits.* These facilities are provided with delay equalizer networks for the frequency range from 1,200 to 2,600 cycles per second and precautions are taken to minimize various transmission disturbances. Means are provided, controlled by the sending telephotograph equipment, to prevent operation of the transmission regulating network relays on cable circuits during the transmission of a picture, and to obtain one-way transmission over 2-wire circuits. A wire network of nearly 8,000 miles established as outlined above and connecting 26 stations of the new telephotograph equipment has been in operation for more than a year, giving reliable and technically satisfactory service.

* A side circuit is a physical circuit that is used for one of the paths of a phantom circuit; the notation H-44-25 indicates a loading coil spacing of 6,000 feet, inductance of physical or side circuit loading coils 44 millihenries, and inductance of phantom circuit loading coils 25 millihenries.

Transmission Requirements

The effects of extraneous line disturbances may or may not be particularly objectionable in a specific case, depending upon their magnitude and form and also on the nature and use of the received picture. Furthermore, the predominance of the recorded disturbance may also be affected by normal variations in the adjustments of the telephotograph equipment. It is not practicable, therefore, to establish precise limits for the transmission requirements. The following values are mentioned as illustrative of the order of magnitude for some of the more important requirements applying to circuits used with the new telephotograph equipment, and which experience has shown will give generally satisfactory results.

(*a*) *Line Net Loss*

Abrupt variations in line net loss of 0.2 decibel or greater usually will produce a noticeable change in shade of the received picture. However, a gradual variation in net loss occurring over a period of minutes is less objectionable and in many instances a change of as much as 2 or 3 decibels during a transmission can be tolerated.

(*b*) *Noise*

Noise of a single-frequency type is likely to be recorded in the received picture as an objectionable *moiré* pattern if the difference between the maximum signal and interference energy is less than 50 decibels. However, if the interference energy is distributed over a relatively wide frequency band an energy difference of about 35 decibels usually can be tolerated.

(*c*) *Delay Distortion*

Delay distortion introduced by the circuit, if of sufficient magnitude, may produce multiple outlines along the edges of objects or lines in the received picture and result in a loss or general masking of picture detail. In order that this effect may be inappreciable in pictures received with the new telephotograph equipment it is desirable that the maximum deviation in envelope delay throughout the useful frequency band (1,200 to 2,600 cycles per second) be less than $\pm$ 300 microseconds.

D–C. Control Circuit

Sudden small variations in line net loss are normal on toll cable circuits in the United States as the result of the stepping of the regulating network relays, which, under control of a pilot wire regulator, compensate for the effect of temperature changes on the attenuation

Fig. 8—Telephotograph received at New York from Miami. Size of received picture was $7\frac{3}{4}$ by $13\frac{1}{2}$ inches. Reproduced by courtesy of the Associated Press.

Fig. 9—Telephotograph. Received $4\frac{1}{4}$ by $6\frac{1}{8}$ inches with 100 lines per inch. Reproduced by courtesy of the Associated Press.

Fig. 10—Telephotograph. Received 10 by $14\frac{1}{2}$ inches with 100 lines per inch. Reproduced by courtesy of the Associated Press.

Fig. 11—Telephotograph received at New York from Baltimore. Size of received picture was $8\frac{3}{4}$ by $14\frac{1}{2}$ inches. Reproduced by courtesy of the Associated Press.

of the circuit. Since these sudden variations in net loss produce noticeable changes in shade of the received picture, means similar to those employed with the earlier Bell System telephotograph equipment have been made available to prevent these relays from operating while a picture is being transmitted. Simple types of control units actuated by signals transmitted over a control circuit are connected to each regulating repeater associated with the picture circuit. This control circuit consists of two one-way d-c. channels obtained by compositing the telephotograph circuit and extended to each telephotograph station over simplexed loop arrangements. The control circuit is also arranged to perform other functions such as effecting one-way transmission of the 2-wire circuits during a picture transmission. The operation of the control circuit normally is performed automatically at the sending telephotograph station.

Inasmuch as the transmission requirements for this control circuit are very lenient compared with those for telegraphy, it has been possible to employ simple types of d-c. repeaters as illustrated in Fig. 12. A signal from the subscriber's sending equipment operates the receiving relay of the station repeater, which in turn places a ground on the *M* lead and thus transmits the signal to all line repeaters which may be associated with this junction. Only one direction of operation at a time is possible so that when a sending telephotograph station takes control at the beginning of a picture transmission the control circuit is operated and remains in this condition until released automatically at the end of the transmission. A slow release circuit is provided in the d-c. repeater used at regulating network points on the cable circuits and also in another type of repeater, not shown but used on open-wire circuits to obviate false operation of the repeaters as the result of interruptions of less than two seconds duration.

Delay Equalization

Delay equalization [14] of telephotograph circuits is not new, but was applied in 1925–26 to certain medium-heavy loaded toll cable circuits between New York and Boston which were used in the early Bell System telephotograph service. (This application was discussed in reference 14 relative to delay distortion, and examples of transmitted printed matter were reproduced.) However, because of the increased speed of transmission of the new telephotograph equipment and the demand for longer circuits for picture transmission it has been necessary to make further application of delay equalization to some of the more common types of circuits used for this purpose.

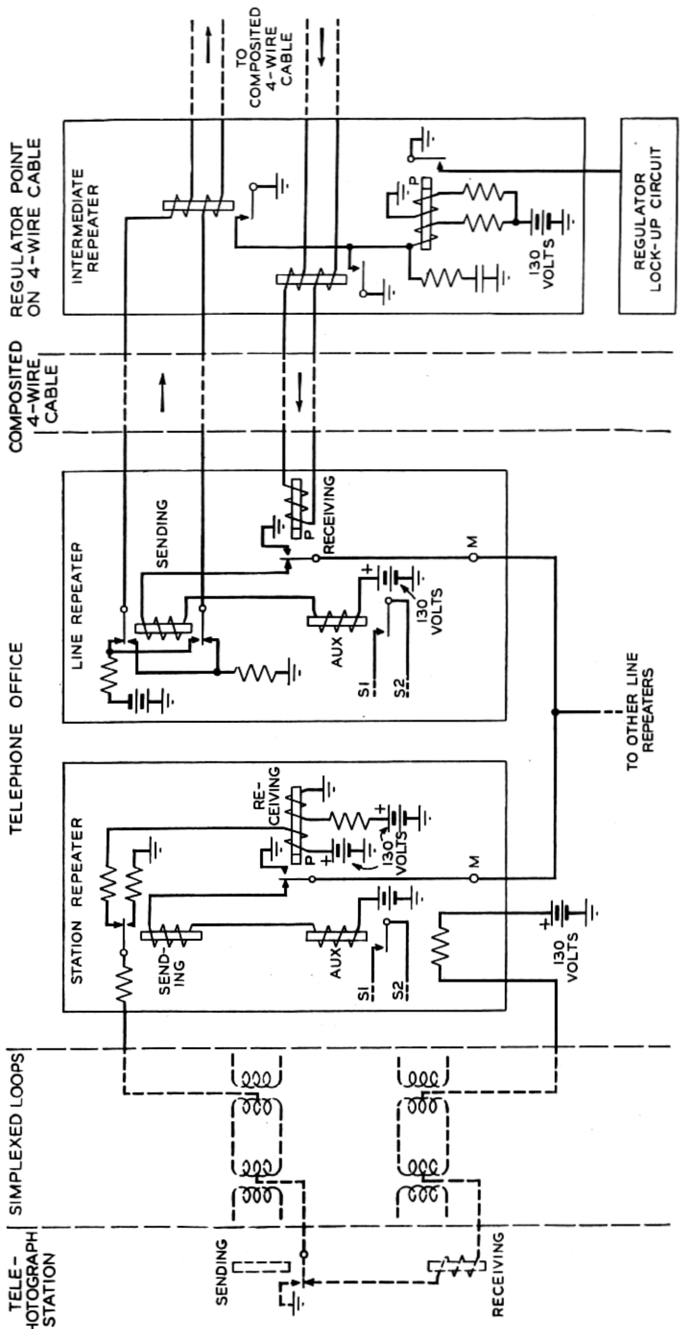

Fig. 12—D-c. control circuit repeaters.

Delay distortion in H-44-25 cable circuits, which is largely the result of the loading, has been compensated by delay networks consisting of a basic unit correcting for 150 miles of composited 19-gauge side circuit, adjustable in 10-mile steps, and a "mop-up" unit of four sections for more complete compensation. A balanced lattice type of structure was used in the design of these equalizers. Figure 13

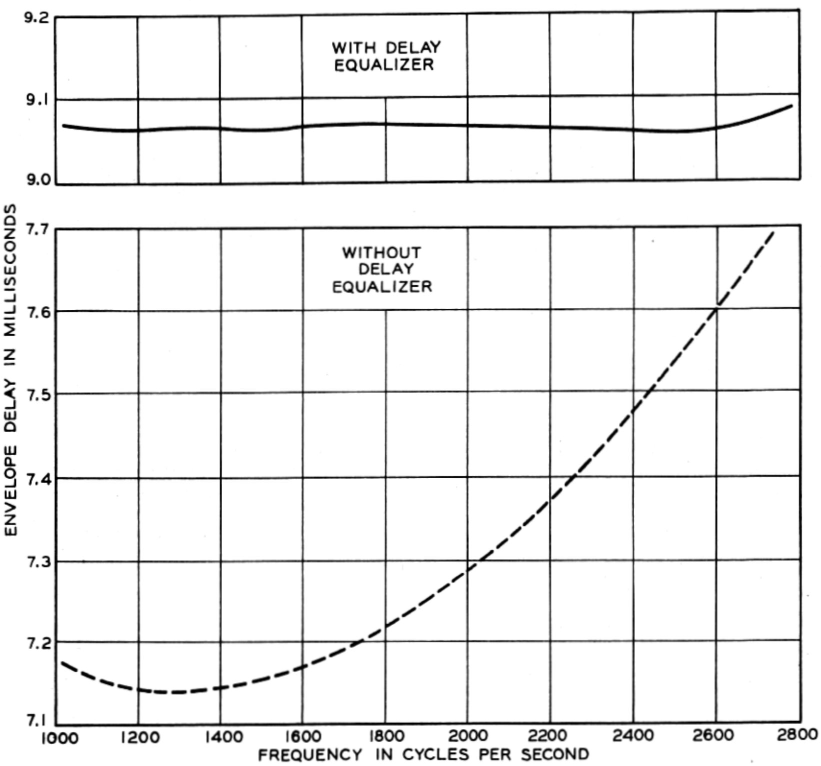

Fig. 13—Delay characteristic of 135 miles of H–44 repeatered and composited side circuit before and after equalization.

illustrates the application of equalizer units to cable circuits and shows the delay characteristics before and after equalization. Similar types of delay equalizers have been applied to open-wire circuits, in which case it is the equipment located at the repeater stations rather than the line itself which is responsible for delay distortion. The delay equalizers are normally located at terminal and bridging points on the telephotograph network and at some intermediate points such as junctions of open-wire and cable circuits.

Telephotograph Networks

One of the obvious advantages of network operation of telephotograph stations is that it offers a means for rapid and simultaneous distribution of facsimile information and pictures to a large number of receiving points. This method of operation appears to be particularly advantageous for use by the large news-picture gathering and distributing agencies giving a nation-wide service. Such network operation of a number of telephotograph stations presents additional requirements, not mentioned in the preceding paragraphs, which may be of general interest.

Requirements encountered in connecting a large number of sending and receiving stations were that any sending station should be able to transmit a picture simultaneously to all receiving stations, and that any one station could be selected as the transmitting point, establishing a new direction of transmission with a minimum loss of time. The situation has been met by permanently bridging each telephotograph station, consisting of separate sending and receiving equipment, to the wire network on a 4-wire basis using separate sending and receiving station loops and performing automatically such switching operations as may be involved in altering the direction of transmission.

Typical arrangements which have been used at a bridging point on a telephotograph network are illustrated in Fig. 14. Suppose, for example, that the telephotograph station at this point wishes to transmit a picture to the network. Operation of a key associated with the subscriber's telephotograph transmitting equipment sends out a d-c. signal over the simplexed loop to the control circuit station repeater at the local telephone office. Since this repeater is multipled with the d-c. repeaters associated with each of the telephotograph circuits connected at this point, the signal is transmitted over the entire network and the switching operations performed to place the circuits in condition to send a picture from this point. The d-c. repeaters at the local telephone office also cause short circuits to be applied to the incoming transmission paths which are connected to the bridging networks, thus preventing the temporarily inactive parts of the circuit from contributing possible disturbances to the outgoing paths being used. This figure also indicates the switching operations performed on the 4-wire terminating set. At the conclusion of the transmission the d-c. control circuit is automatically released by the transmitting machine and the circuits returned to the initial two-way condition permitting any station on the network to seize control of the circuits for picture transmission. Signal lamps are provided at all d-c. repeater points and are actuated by the d-c. control circuit to indicate when pictures are being transmitted over the network and also the direction of transmission.

The problems involved at junction points in connecting a number of circuits, particularly of the 4-wire type, have been simplified

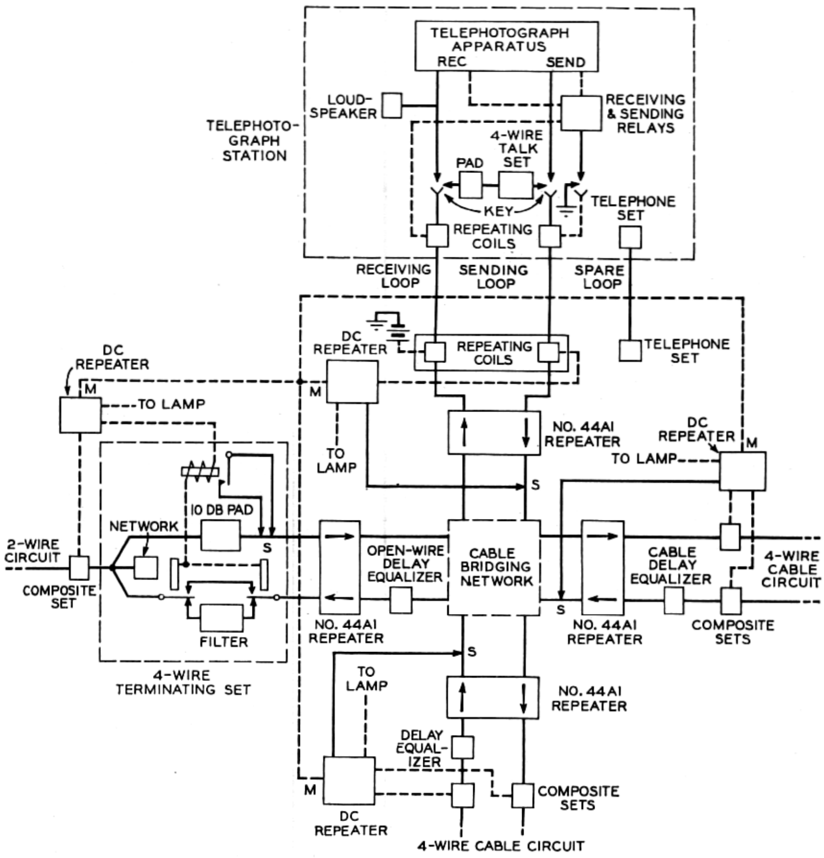

Fig. 14—Schematic diagram of arrangements at a typical bridging point.

through the use of a new form of bridging network. Although this situation could be met by employing unilateral devices such as vacuum tube amplifiers, it was found that comparable results could be obtained simply and at less expense with interconnected resistance type pads. Two designs of such networks, essentially alike except for the values of attenuation provided, are in use, one for cable and the other for open-wire circuits. These bridges are used not only at junctions of circuits forming the network but also at all points at which telephotograph stations are connected.

A single line schematic of the type of bridging network employed is shown in Fig. 15 (upper left), and a more complete representation of a portion of the network used on cable circuits is shown in Fig. 15 (lower right). Current entering the bridge, for example at the West input, traverses three direct paths of equal attenuation and leaves at East output and branch A and branch B outputs. There are, of course, numerous indirect paths between the West input and each of the bridge

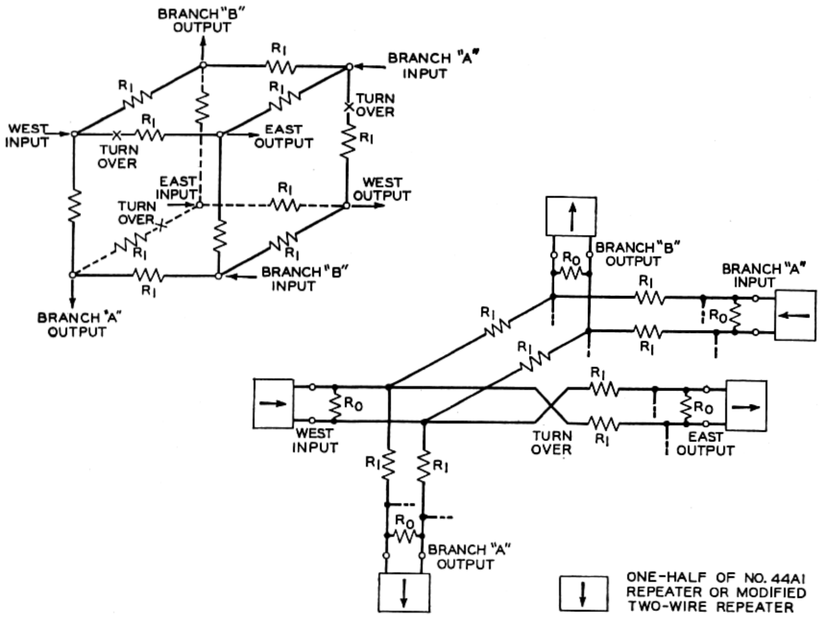

Fig. 15—Single line diagram of cable and open-wire bridging networks (upper left) and portion of cable bridge showing arrangement of resistances (lower right).

outputs; for example, there are two parallel paths to each output. Each of these two paths has three times the attenuation of a direct path and the current through it is 180 degrees out of phase with that through a direct path because of the reversals shown in the wiring. However, the aggregate of all of the indirect paths does not appreciably alter the loss between input and output of this bridge as calculated by neglecting them. It may be noted that the two directions of transmission for the same circuit are connected by six parallel paths each of which has three times the attenuation of a direct path between an input and output of the bridge. The currents through three of these paths are 180 degrees out of phase with the currents in the others, and hence would result in infinite attenuation of the echo were it not for small unbalance currents. Measured crosstalk losses for the echo paths in excess of 70 decibels have been obtained for these bridging networks manufactured with ordinary tolerances.

Certain auxiliary features may also be incorporated in telephotograph networks to assist in their operation and perform other related functions. For example, telephotograph methods are not efficient in their present form for the rapid exchange of operating instructions; therefore telephone facilities may be associated with a telephotograph network for use by the customer in coordinating the operation of this system. Arrangements may be used whereby such voice communication may be carried on over the telephotograph circuit between picture transmissions, and loud speakers may be bridged on the circuit for monitoring purposes.

Acknowledgment

The attainment of this objective in telephotograph development and the establishment of the present leased wire network has engaged the initiative and resourcefulness of several score of individuals at the Bell Telephone Laboratories, Inc., the Western Electric Company, and the American Telephone and Telegraph Company. In reviewing the advances which have been made, the practical limitation of space has made it impossible to discuss in greater detail the various phases of the work and to render individual recognition to all who have contributed to the solution of the problems involved. Among those most intimately concerned and through whose efforts the many details have been worked out and correlated are W. A. Phelps and P. Mertz of the Bell Telephone Laboratories, Inc., and I. E. Lattimer of the American Telephone and Telegraph Company.

References

1. "The Transmission of Pictures Over Telephone Lines," H. E. Ives, J. W. Horton, R. D. Parker, and A. B. Clark, *Bell System Technical Journal*, v. 4, April 1925, pp. 187–214.
2. "Synchronization of Television," H. M. Stoller and E. R. Morton, *Bell System Technical Journal*, v. 6, Oct. 1927, pp. 604–15.
3. "Synchronization System for Two-Way Television," H. M. Stoller, *Bell System Technical Journal*, v. 9, July 1930, pp. 470–6, and discussion, p. 477.
4. "A Permanent Magnet Light Valve," G. E. Perreault, *Bell Laboratories Record*, v. 10, Aug. 1932, pp. 412–16.
5. "Certain Topics in Telegraph Transmission Theory," H. Nyquist, *A. I. E. E. Transactions*, v. 47, April 1928, pp. 617–44.
6. "A Theory of Scanning and Its Relation to the Characteristics of the Transmitted Signal in Telephotography and Television," Pierre Mertz and Frank Gray, *Bell System Technical Journal*, v. 13, July 1934, pp. 464–515.
7. "An Oscillograph for Ten Thousand Cycles," A. M. Curtis, *Bell System Technical Journal*, v. 12, Jan. 1933, pp. 76–90.

8. "The Use of the Triode Valve in Maintaining the Vibration of a Tuning Fork," W. H. Eccles, *Physical Society* (*London*) *Proceedings*, v. 31, 1918–19, pp. 269.
9. "Frequency Measurement in Electrical Communication," J. W. Horton, N. H. Ricker, and W. A. Marrison, *A. I. E. E. Transactions*, v. 42, June 1923, pp. 730–41.
10. "Precision Determination of Frequency," J. W. Horton and W. A. Marrison, *I.R.E. Proceedings*, v. 16, Feb. 1928, pp. 137–54.
11. "Thermostat Design for Frequency Standards," W. A. Marrison, *I. R. E. Proceedings*, v. 16, July 1928, pp. 976–80.
12. "Long Distance Telephone Circuits in Cable," A. B. Clark and H. S. Osborne, *Bell System Technical Journal*, v. 11, Oct. 1932, pp. 520–45.
13. "The Transmission Characteristics of Open Wire Telephone Lines," E. I. Green, *Bell System Technical Journal*, v. 9, Oct. 1930, pp. 730–59.
14. "Phase Distortion and Phase Distortion Correction," Sallie P. Mead, *Bell System Technical Journal*, v. 7, April 1928, pp. 195–224.