WESTERN UNION
Technical Review

Teletape Facsimile

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Microwave
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Telegraph Signal
Analyzer

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Western Union Teletape Facsimile

LEON G. POLLARD

A paper presented before the Winter General Meeting of the American Institute of Electrical Engineers in Pittsburgh, Pa., January 30, 1948.

In the application of facsimile to the telegraph industry, development has primarily been directed toward the handling of regular telegraphic traffic in the form of messages on telegraph blanks. The introduction of Western Union's "Teledeltos"[1] recording paper some years ago provided a practical recording medium which was one of the principal things necessary to make facsimile telegraphy a success. Facsimile messages can be recorded directly on Teledeltos paper telegraph blanks, ready for delivery without any special processing or handling.

A number of articles[2] have been published describing the equipment which has been developed by Western Union engineers and is now used on Western Union, railroad and airline facsimile telegraph circuits. Some machines require the message to be manually placed in position on drums, while other machines are self-operating to the extent that it is necessary only to drop a message in a slot of the transmitter. The message is automatically wrapped around a revolving drum, scanned and transmitted to the receiving instrument, where the functions of recording and discharge of the message are again performed automatically.

In all machines of this class, the light-beam scanning and the photoelectric method of pickup are used and recording is accomplished by means of a metallic needle point on Teledeltos paper. During the war, civilian engineers at Camp Coles Signal Corps Laboratory made the discovery that pencil marks on Teledeltos paper provided a convenient medium for conductive pickup. While optical methods of pickup produce excellent copy and do not require special transmitting papers, the cost of the necessary equipment components somewhat restricts the field of application. With the disclosure that Teledeltos paper could be utilized for the purpose of transmitting as well as receiving facsimile messages, an entirely new field for this system of communication became available.

Western Union has subsequently developed facsimile equipment embodying this new type of pickup, specially designed for local intercommunication by means of hand-written messages. The machine used for this purpose is a transceiver which is called the "Teletape". It has been so named because Teledeltos paper in the form of tape provides a convenient and practical way of accomplishing the dual purpose of transmitting and receiving. Two of these small sized Teletape transceivers, located at the terminals of a two-wire circuit, will operate satisfactorily over a distance up to several miles. Messages written directly on Teledeltos tape are scanned, transmitted over the line and reproduced in facsimile form on the tape at the opposite end. Transmission can be carried out in either direction, as the machines automatically function as either transmitters or receivers.

As this is the first time that Teledeltos paper has been used as sending copy, several problems encountered in the development of the system may be of interest. When using Teledeltos for transmitting purposes, the intelligence is impressed on the surface of the paper either by means of a soft lead pencil or from a specially prepared carbon paper. In the Teletape system a pencil is used. As the message is written, the film on the surface of the paper is ruptured and graphite from the pencil forms a low-resistance

[1] Registered Trademark of The Western Union Telegraph Co.
[2] See References.

path through the paper. The paper, which has a conductive backing, rests on a metallic platen and scanning is accomplished by means of a fine metal stylus which is progressed across the surface. As the point of the stylus passes over the paper, the resistance between the stylus and the platen is reduced by several thousand ohms at the points where the film of the paper has been broken and graphite deposited. This resistance change is utilized to produce the actuating impulses for the electrical transmission. For satisfactory operation of this conductive pickup system, it is necessary to use a stylus having a small area of contact and yet of such design that the surface of the paper will not be damaged during scanning.

After the investigation and trial of a number of standard scanning systems, a simplified method was developed for the Teletape in which several of the difficulties encountered in other systems have been overcome. In all facsimile systems there are two fundamental requirements which must be fulfilled. First, the facsimile receiver must run in synchronism with the transmitter, and second, some method must be employed for phasing the machines to insure proper registration of the received message. When both ends of the circuit are powered from the same 60 cycle system, synchronism is automatically maintained; however, phasing is still required and is usually accomplished by means of a phasing pulse from one end of the circuit which, through a system of relays and commutators, orients the machine at the opposite end.

Figure 1 illustrates the principle of the Teletape scanning system. Teledeltos tape having a width of three-quarters of an inch is directed through a concave guide and passes by a rotating four-pointed stylus which brushes over the surface of the paper. This stylus is mounted on the shaft of a small synchronous motor running at 1800 rpm. The concave guide has a radius of exactly one-half inch about the axis of the stylus shaft, and the diameter across the tips of the stylus is slightly in excess of one inch. A narrow recess is machined in the concave guide directly behind the line of contact of the stylus with the tape. Because the radius of the stylus is somewhat greater than that of the concave guide, the tape is slightly depressed into the recess, as it passes by the stylus during scanning. This insures a positive rubbing contact of the stylus tips with the surface of the tape. Furthermore, as the tape passes over the recess in the guide, the edges are flattened just sufficiently to allow the tips of the stylus to miss contact at the extreme edge and prevent cutting the paper.

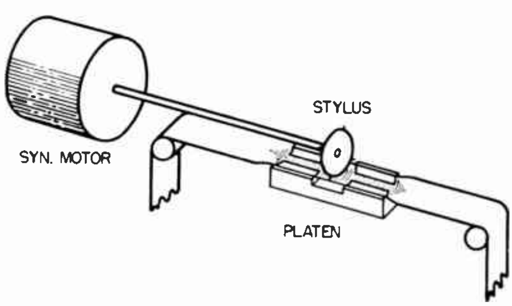

Figure 1. Method of scanning

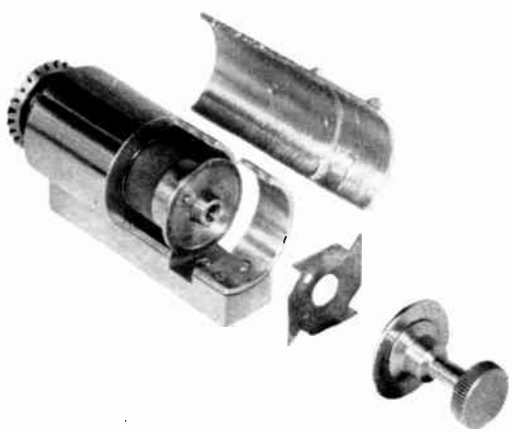

Figure 2. Exploded view of Teletape scanning head

Figure 2 shows an exploded view of the scanning head used in the Teletape machine. A polished cylindrical housing serves as a platen against which the tape is firmly pressed by a concave shoe as it is drawn through the machine. The stylus is a thin four-pointed metal wafer, so constructed that the tips are accurately spaced by 90 degrees and of equal radius. The narrow recess in the concave shoe aligns with a cut-out portion of the cylindrical housing and the stylus engages the tape at the center of this opening. The cylindrical housing also contains two precision type ball bearings supporting the rotating stylus shaft. On one end of this shaft is a small miter gear which, when assembled in the machine, engages a similar gear mounted directly on the shaft of the synchronous motor. The other end of this shaft carries an insulated stylus mounting, provided with a knurled thumbscrew to hold the stylus rigidly at right angles to the shaft. On the surface of this stylus mounting is a small pin which engages a hole punched in the stylus, thus orienting the stylus in a definite relationship with respect to the motor poles. It will be observed that with a four-pointed stylus, one point for each pole of the 1800-rpm motor, it is not necessary to phase the transmitter and receiver each time they are started. After initial phasing when the machines are installed, providing of course that both the transmitter and receiver are powered from the same 60-cycle system, no phasing is required.

Figure 3 shows a Type 5006-A Transceiver and its associated amplifier-power control unit Type 5046-A. These two units connected together through a twelve-conductor flexible cable comprise one terminal of a Teletape circuit. The transceiver unit consists of the scanning mechanism, a tape reel holding a five and one-half inch roll of Teledeltos tape, and a pull motor for feeding the tape through the

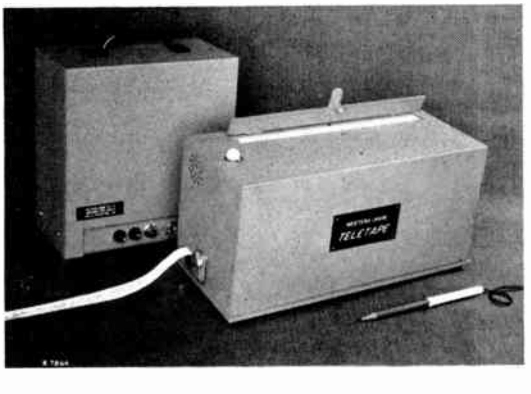

Figure 3. Teletape transceiver with amplifier-power control unit

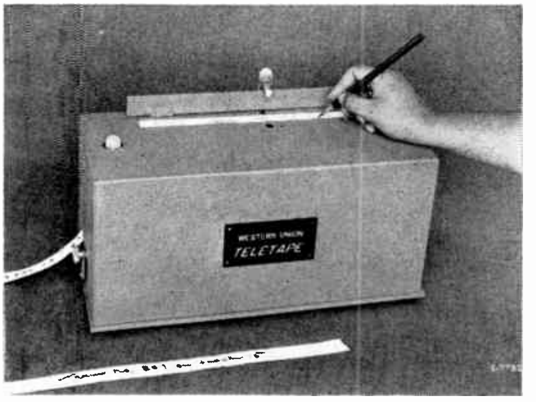

Figure 4. Preparing message for transmission

machine. The amplifier-power control unit contains the transmitting and receiving amplifiers and the necessary relays and power supply equipment. When installed in an office or other terminal position, the transceiver unit is placed in a convenient location for the user, and the power control unit is located in a more or less out-of-the-way place where it is accessible only for turning on and off once a day.

It will be noticed that in the top of the transceiver unit is a long narrow opening. In this opening and flush with the top of the case is a writing platform over which the Teledeltos tape from the storage reel is passed. A hinged cover with a short projecting handle covers this tape guide. In this particular model of the Teletape, the opening and closing of this cover actuates switches which in turn operate the circuit control relays. When not in use, the covers are always left in a closed position to maintain a normal stand-by condition.

To illustrate the operation of the machines, let us assume that station "A" desires to transmit a message to station "B". The operator at station "A" first opens the cover over the tape guide (Figure 4). This is necessary to expose the tape on which the message is to be written, but as the cover is opened, a circuit is made which lights indicating lamps at both stations "A" and "B". At the same time, cover locks at both stations are energized and the cover over the tape guide at station "B" is now locked in a closed position until the completion of the transmission. This prevents the operator at station "B" from attempting a simultaneous transmission. The operation of opening the cover at station "A" also energizes relays at both ends of the circuit, so that station "A" will function as a transmitter and station "B" as a receiver for this particular transmission. After the operator at station "A" has written his message on the tape, he closes the cover. This operation of closing the cover starts the motors and scanning mechanisms at both terminals and transmission is accomplished. At the end of the message both machines are automatically stopped and restored to a stand-by condition, ready for the initiation of another transmission from either end. When the cover at station "A" was closed, it also was latched to prevent further opening until this message had been completed.

Should station "B" desire to transmit to station "A", the same functions are carried out in a reverse direction. Opening the cover at either end of the circuit preempts the circuit for transmission from that end and at the same time prevents the operator at the opposite end from attempting to initiate a transmission.

Figure 5 is a view of the interior of the machine. It shows the relationship of the scanning head, tape reel and writing platform and the tape-pulling gear with its associated motor. The scanning head motor located behind the supporting bracket drives the scanner through a miter gear. It is mounted on a circular plate capable of rotation about the center of the motor shaft, by which means the relationship of the motor to the stylus may be conveniently changed for initial phasing purposes. It will be observed that as the tape leaves the writing guide, it passes over a roller and then assumes the concave form in passing through the scanning head. It thence passes over a second roller and through the draw-off mechanism.

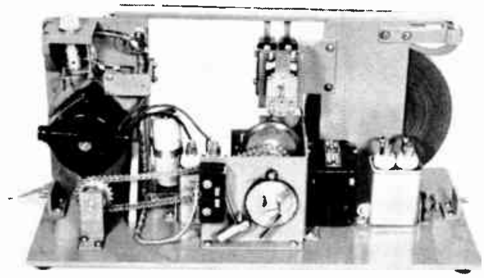

Figure 6. Inside view of transceiver showing tape pull-off mechanism and stop switch

Figure 6 shows the reverse side of the machine. The tape draw-off motor as well as the scanning motor is of the synchronous type. Connected through a reduction mechanism from this motor is a low-speed gear which makes one complete revolution during the transmission of a single message. A lever on this gear wheel actuates a trip switch just as the end of the written message is exposed out of the side of the machine. The motors of both machines are thereby stopped at the same instant at the end of each transmission.

As mentioned before, a-c power to the machines can be turned on at the beginning of the day and turned off at night. This insures that the amplifiers are in a warmed-up condition and ready for instantaneous operation. In order that the operator at one end of the circuit can be assured that the equipment at the opposite end is in an operating condition and ready to receive messages, a series line switch is incorporated with the power switch. The initiating circuit which is energized when either cover is opened, is a series circuit through both line switches. Therefore, if, when the operator at one end lifts the cover on his machine, the signal lamp at his end does not light, he knows that

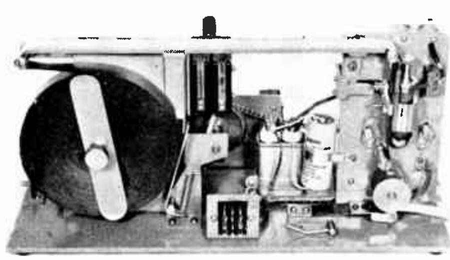

Figure 5. Inside view of transceiver showing scanning mechanism

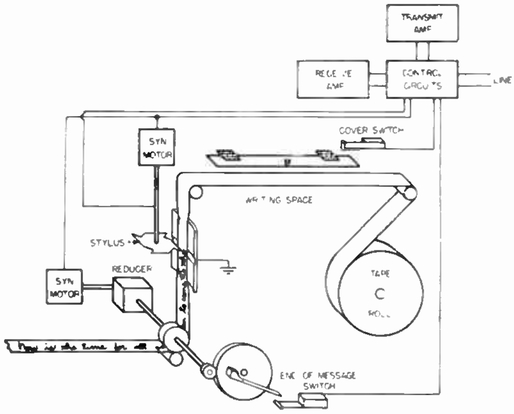

Figure 7. Functional diagram of Teletape terminal installation

power has not been applied to the distant end and no message can be transmitted.

Figure 7 is a functional diagram showing a Teletape terminal installation. In this particular model of the Teletape, the length of exposed tape in the tape guide on which a message may be written is eleven inches. The transmission time for each message is eighteen seconds. The tape reel holds a 600-foot roll of tape, sufficient for a total of about 325 messages. The styli used at present are hardened steel and each stylus has a life of between three and four hundred messages. A worn stylus may be easily replaced by the operator. Development work is still in progress to determine whether any other materials or forms would be more satisfactory for multi-pointed styli.

The interior of the amplifier-power control unit is shown in Figure 8. On the lower chassis are the signal control relays and the power supply. The upper chassis carries two amplifiers, one for transmitting and one for recording. The conversion of the written message to electrical impulses is somewhat unique in that the circuit from the stylus through the Teledeltos tape to ground forms one arm of a Wheatstone bridge, the output of which is fed to the transmitting amplifier. The signal frequency applied to the bridge is generated by a 5000-cycle local oscillator. This comparatively high frequency is dictated by the high scanning speed of 94 inches per second, employed in this system. If the bridge is balanced for background resistance, positive transmission results, because a pencil mark on the tape unbalances the bridge with consequent signal to amplifier. Conversely, if the bridge is balanced for a solid mark on the tape, negative transmission results. Practice limits line input levels to about zero dbm and one stage of amplification following the bridge is more than adequate to fulfill this requirement. The recording amplifier consists of a voltage-amplifier triode, and a power-amplifier pentode which has a high impedance output to the recording stylus. Adequate gain is provided so that this equipment may be operated over lines with as much as thirty db loss.

Another design of the Teletape transceiver is shown in Figures 9 and 10. In this model, both the transceiver unit and

Figure 8. Interior view of amplifier-power control unit

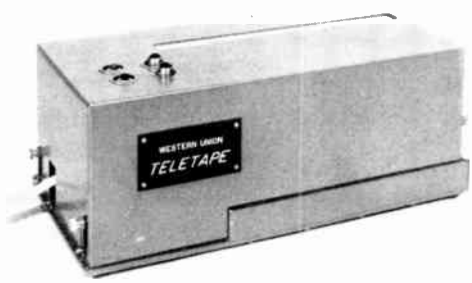

Figure 9. Transceiver with self-contained amplifier and control unit

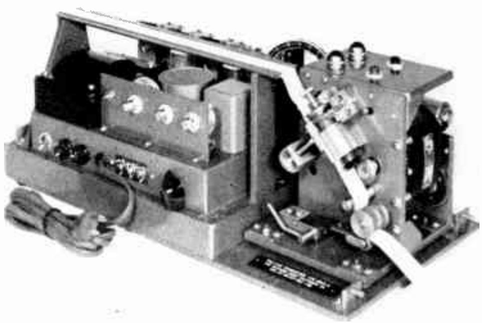

Figure 10. Interior view of transceiver with self-contained amplifier and control unit

the amplifier and control unit are mounted in one assembly. The tape reel is housed in a sliding drawer under the electronic equipment. The cover over the tape track has been eliminated in this model and circuit control and transmission are accomplished by means of two push buttons.

From the foregoing description it will be evident that Teletape, utilizing facsimile as a means of transmission, will have numerous applications in intercommunication systems. It provides a means for the speedy transfer of written intelligence from one point to another. It does not require the immediate attention of the recipient and it can be handled by anyone without the need for special training in its operation. There are many instances where such a system is desirable. A specific application is the linking of a teller in a branch bank with the bookkeeping department, located in another building. Another application is the connection between a ticket clerk and the reservation bureau, such as found in railroad stations and airline offices. Dispatching systems and quotation services also present possibilities for this type of communication. Teletape equipment is now undergoing tests in order to explore its field of usefulness and to determine operational requirements, with a view to its subsequent manufacture and distribution.

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THE AUTHOR: L. G. Pollard joined Western Union in 1922, after graduating from the University of Vermont, and for the next three years was engaged in research work under the Transmission Engineer. In 1925 he was transferred to Water Mill, to assist in the organization of the laboratory which is now the Electronics Division of the Development and Research Department. In this undertaking, his ability in every phase of the Laboratory's work was soon demonstrated. During the war, Mr. Pollard was put in charge of the model shop, where he was responsible for final designs and production of specialized devices for the Army and Navy. In 1943 he became Assistant Electronics Research Engineer, second in charge of the Laboratory. He has recently contributed many new developments to facsimile design and directed the construction of new facsimile equipment.

Western Union's Microwave Relay System

H. P. CORWITH and W. B. SULLINGER

The accelerated program of research during the war years resulted in the rapid advance of microwave techniques and opened a new and large portion of the radio frequency spectrum for use by communication engineers. Frequencies in the microwave region are attractive for communication purposes for many reasons. They are not affected by atmospheric disturbances such as lightning, static and many varieties of man-made interferences evident at lower frequencies, and reliable transmission is possible with low power and highly directional antenna systems. The concentration of the available power into a sharp directional beam makes it possible to use the same radio frequency channel over and over again without interference. At a given location, for example, one frequency may be used for transmitting or receiving up to eight times, provided the angle between beams is never less than 45 degrees. Frequencies above 1000 mc are particularly well suited to broad-band systems which will accommodate large numbers of circuits, because of the large amount of spectrum available and the ease with which the wide-band widths may be handled in this region.

Operating advantages are also evident, as the maintenance is concentrated at a few points as compared with wire lines, and the damage due to storms and other weather conditions will undoubtedly be less. These advantages, which tend to reduce cost as well as improve service, led Western Union to pioneer in the application of microwaves to telegraph services. It should be pointed out at this time that this type of radio transmission provides adequate secrecy for communications, as the area where a usable signal is available is limited by the directional characteristics of the antenna systems and further to line-of-sight locations between the transmitter and receiver. Also, the complex modulating and channelizing systems make the breakdown to individual telegraph circuits extremely difficult.

In 1945, Western Union and the Radio Corporation of America jointly established, between New York and Philadelphia, a microwave relay system to confirm theoretical work and laboratory tests, and to obtain propagation data on 4000-mc transmission. The results of the tests on this first experimental circuit were very encouraging. Certain design changes were indicated to improve the stability and reliability of the system. These changes were incorporated in model shop equipment, designed and constructed by the RCA Victor Division of RCA, and field tested on the original circuit between New York and Philadelphia.[1] The tests with this equipment proved the ability of this type of relay system to handle large volumes of telegraph traffic accurately and with continuity which exceeded that of open wire lines by several times. It is the purpose of this paper to discuss some of the features of this system, which is now being used on the recently completed microwave triangle connecting New York, Pittsburgh and Washington.[2]

The design of a modulation system capable of handling hundreds of telegraph channels through many repeaters without excessive noise, cross-modulation, or distortion presents many problems. Any such system should provide means for voice communication, called a service channel, between the terminals and relay stations, independent of the traffic channels, and means for checking the operating condition and failures at the normally unattended relay stations. Another requirement is that the over-all system must be capable of integration with the existing telegraph plant. The double-frequency modulation method, developed by Mr. L. E. Thompson of RCA, satisfies all of these conditions.[3] This system provides a signaling channel 150 kc wide which may be divided into 32 voice bands by frequency division techniques, and these voice bands may be further divided into telegraph channels, or used in full for facsimile or telephone service.

150,000-cycle frequency band is obtained by another discriminator.

When the section length is greater than approximately 15 miles, diversity reception is required to eliminate interruptions due to fading. Two identical receivers, spaced vertically by about 25 feet, are

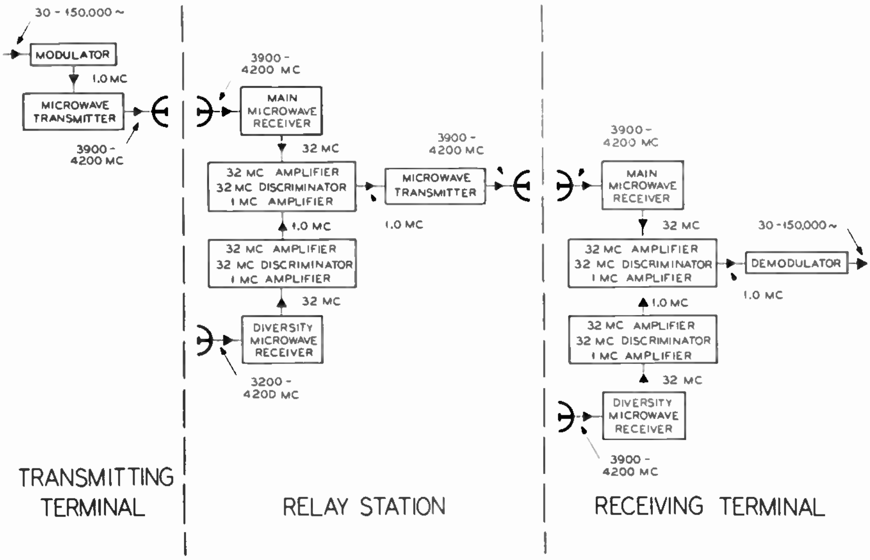

Figure 1. Double FM microwave relay system

A block diagram of the double FM system is shown in Figure 1. At the transmitting terminal, signals within the 30-cycle to 150,000-cycle band frequency-modulate a 1-mc subcarrier in the modulator unit. The output of this unit is fed by coaxial cable to the microwave transmitter, where the modulated 1-mc subcarrier frequency-modulates an RF carrier, in the 3900-4200 -mc band. At the relay station, the incoming RF signal is mixed with a local oscillator in the microwave receiver to produce a difference frequency of 32 mc. This signal is then passed through seven amplifier stages, the last ones of which act as limiters. A push-pull discriminator then demodulates the 32-mc signal to recover the 1-mc subcarrier. This subcarrier, of course, contains the 30-to-150,000-cycles modulation and is used to frequency-modulate the outgoing microwave transmitter. At the terminal receiver, the subcarrier is obtained by the same process and fed to the demodulator unit where the 30-to-

employed. The subcarrier output from the diversity IF amplifier is fed into the first 1-mc stage in the main IF amplifier. Thus, the subcarrier signals are combined before full limiting occurs, and the result is that the stronger signal provides practically all of the output voltage and the weaker signal introduces substantially no noise.

From the above discussion, it is seen that demodulation to the 30-to-150,000-cycle signaling band occurs only at the terminals, and hence the linearity of the modulating and demodulating circuits at the relay points is unimportant. For example, if we consider a signal through a relay station, it is found that the incoming signal is heterodyned down to an intermediate frequency of 32 mc and then amplified by conventional methods. Phase distortion of the modulating frequency (the subcarrier) may take place in the amplifier and also in the 32-mc discriminator. However, distortion is not introduced into the 30-to-150,000-cycle signaling band as the subcarrier, not the signaling band, is the modulating frequency. The 1-mc subcarrier may be distorted without affecting the signaling channel, as this channel depends upon the rate of change of the subcarrier and not upon the shape of its amplitude characteristic. The phase characteristic of the 1-mc amplifier circuits following the 32-mc discriminator is very important, as the modulating frequency in this case is the signaling channel. Therefore, it is desirable to place most of the tuned circuits and amplification ahead of the discriminator where the phase distortion is not critical. The linearity of the RF modulator is also unimportant, as here again the modulating frequency is not the signaling channel but the subcarrier. It is interesting to note that for the same RF band width, a single FM system is superior to double FM from the standpoint of signal-to-noise ratio, but that the double FM system is used because of its lower cross-modulation and distortion characteristics.

The service channel, for voice communication between the terminals and relay stations, and for fault locating purposes, is obtained by modulating the microwave transmitter directly and simultaneously with the subcarrier. The receiving side of this channel is available at each relay station at the output of the 32-mc discriminator, where it is amplified for local use and for modulating the outgoing transmitter. Microphones are provided at the relay stations for talking to the terminals and other stations. This channel has relatively high distortion due to non-linearity in the modulation characteristic of the RF oscillator tube and the 32-mc circuits; however, this is not objectionable as the channel is used only for maintenance purposes.

The fault locating circuits are also obtained on the service channel. Each relay station is assigned an audio frequency which is looped back over the service channel by means of a relatively narrow band-pass filter, to the transmitting terminal. By applying a series of tones, the terminal is able to locate a system failure by identifying the first station from which the tone fails to return. This procedure is carried out by both terminals and therefore an exact location of any trouble is assured.

Other indications are also obtained from this fault locating system. The test tone through the loop-back filter at the relay station is passed through a gate circuit which is normally kept open by a d-c voltage derived from the subcarrier frequency from the diversity IF amplifier, and from the combined subcarrier signal which modulates the outgoing transmitter. Should there be a failure of the diversity system, the gate circuit will be closed and there will be no return tone. This is true also if there is a fault in the 1-mc circuit between the main receiver and the transmitter. The operation of the main receiving system is checked by the terminal-to-terminal performance of the service channel, as this channel is not connected through the diversity receiver.

Another indication provided by the fault locating system is the condition of the automatic frequency control equipment on the outgoing transmitter. This is accomplished by modulating the return tone by either 60 cycles or 120 cycles derived from the automatic frequency control system of the outgoing transmitter. If the operation of this transmitter is normal, then the 120-cycle voltage is higher than the 60-cycle voltage; if the reverse is true, then tuning adjustments are required. If neither 60 nor 120 cycles is present there is a transmitter failure. Means for detecting the magnitude of the 60 and 120-cycle modulation on the return test tones is provided at the terminals in the Fault Tone Receiver Unit. This test may be made from each terminal, thereby checking all relay transmitters in each direction. Local oscillators, tuned to the identifying audio frequency assigned to each station, are provided at all relay points. This oscillator is connected to the service channel and is normally inoperative. When a station is working from the emergency power plant, or the building temperature is low, then the oscillator is energized and keyed according to a code to indicate to both terminals the condition of operation.

It may now be of interest to examine in detail some of the units which make up the foregoing system, and discuss their characteristics and operation.

The modulator unit, used only at the transmitting terminals, takes a band of frequencies between 30 and 150,000 cycles and delivers the frequency-modulated 1-mc subcarrier. The method by which this is accomplished is shown by the block

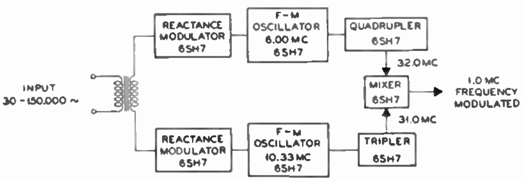

Figure 2. Block diagram of modulator

diagram in Figure 2. The signaling frequencies between 30 and 150,000 cycles are fed through suitable pre-emphasis networks to two reactance tubes operating in push-pull, which frequency-modulates two oscillators, whose normal frequencies are 8.0 mc and 10.33 mc. These frequencies are quadrupled and tripled, respectively, to deliver signals at 32.0 mc and 31.0 mc. Each of these signals is deviated to a peak value of ±200 kc and as the reactance tubes are push-pull, the deviations are in opposite directions. By mixing, the difference frequency of 1 mc is obtained with a peak deviation of ±400 kc. The linearity of this unit is very important as the modulating frequency is the signaling channel. The linearity is obtained by working the modulator tubes over a very small part of their characteristic and using multiplier stages to produce the required deviation. The pre-emphasis network is used to increase the deviation of the subcarrier by the higher frequencies, so the signal-to-noise ratio on all the derived voice bands will be approximately the same.

The demodulator, used only at the receiving terminals, takes the frequency-modulated 1-mc subcarrier and produces the original 30-to-150,000-cycle signaling channel, and is illustrated by the block diagram in Figure 3. The subcarrier with its modulation is first converted to 13 mc in a balanced mixer and then passed through three limiter stages. Demodulation takes place in a 13-mc discriminator,

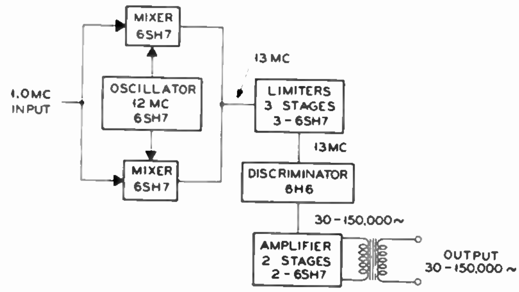

Figure 3. Block diagram of demodulator

to recover the 30-to-150,000-cycle signaling channel. This is followed by the de-emphasis network and a two-stage amplifier. The linearity of this unit is also extremely important, and for this reason the 1 mc is converted to 13 mc, as this makes it possible to design a linear discriminator over the 800-kc range required.

The microwave transmitter produces an RF carrier in the 3900-4200-mc range, frequency-modulated in accordance with subcarrier and service channel signals. A block diagram of the fundamental parts

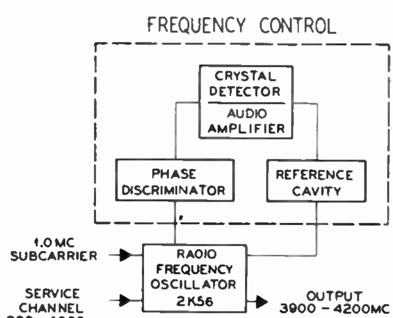

Figure 4. Block diagram of transmitter

of this unit is shown in Figure 4. The 1-mc subcarrier, from the modulator unit at the terminal and from the IF amplifier at the relay station, is fed through a transformer and gain-control to the repeller electrode of a W.E. 2K56 reflex klystron which serves as the microwave oscillator. Any change in the repeller voltage of this tube produces a change in frequency, and therefore the subcarrier voltage acts to frequency-modulate the microwave carrier. A frequency deviation of ±2 mc is used, which corresponds to between two and three volts on the repeller electrode. The service channel output is also applied to the repeller simultaneously with the subcarrier, at a voltage sufficient to deviate the RF carrier approximately ±100 kc. The output of the microwave oscillator is fed through a tapered line section, a double slug transformer, and a short length of coaxial cable to the dipole antenna. The power output of the 2K56 klystron is about 100 milliwatts. A four-foot parabolic reflector provides a power gain of about 28 db, with a beam width of approximately six degrees between half power points.

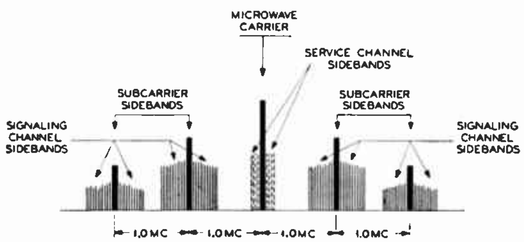

Figure 5. Frequency spectrum transmitted

The radio frequency spectrum at the transmitter output is shown in Figure 5. The first and second order sidebands produced by the modulation of the microwave carrier by the subcarrier are shown spaced 1 mc apart on either side of the carrier. The cluster of sidebands around the subcarrier sidebands is the result of the modulation of the subcarrier by the signals in the 30-to-150,000-cycle band. The sidebands shown by dashed lines, adjacent to the carrier, are produced by the service channel modulation of the RF carrier.

The frequency of the microwave oscillator is stabilized by an automatic frequency control (AFC) circuit which compares the radio frequency to the resonant point of an invar coaxial cavity. A reed on the inside of this cavity is magnetically driven by 60 cycles to vary the resonant frequency over a range of about two megacycles. The microwave oscillator is loosely coupled into this cavity and a Type 1N21B crystal serves to detect the currents produced. If the oscillator frequency is the same as mean resonant frequency of the cavity, the current produced at the output of the crystal detector is 120 cycles. If the oscillator frequency is higher or lower than the mean resonant frequency of the cavity, then the crystal detector output will contain a 60-cycle component, the phase of which, with respect to the 60-cycle reed driving voltage, will depend upon whether the oscillator frequency is higher or lower than the mean resonant frequency of the cavity. The output of the crystal detector is amplified and then fed to a phase discriminator. When 120 cycles is received, there is no d-c output from the phase discriminator; however, a 60-cycle signal produces a d-c potential, the polarity of which is determined by the phase of the 60 cycles, and which is applied through suitable circuits to the repeller electrode of the klystron to bring the tube back to the correct frequency. The reference cavity, klystron and other microwave components are maintained at a constant temperature of about 60 degrees C., and it is possible with this AFC system to hold the radio frequency to within ±.01 to ±.02 per cent. As mentioned previously, a comparison of the 60-to-120-cycle amplitudes is a measure of the AFC operation. A large 60-cycle component does not indicate that the transmitter has drifted off the assigned frequency, but rather that the AFC is supplying a large correction and adjustments are needed.

The microwave receiver and the intermediate frequency amplifiers will be considered together as they are closely related. The microwave receiver converts the incoming RF signal to an intermediate frequency, which is amplified and demodulated to the subcarrier level in the IF unit. This is illustrated by the block diagram

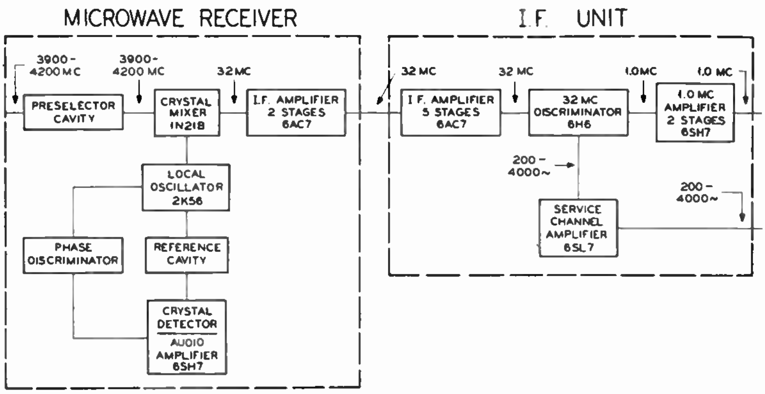

Figure 6. Block diagram of receiver and IF amplifier

in Figure 6. The received signal from the antenna is fed into the preselector cavity which is tuned, by adjusting the length of the center conductor, to the frequency of the incoming signal. This cavity reduces image response, and to some extent suppresses local oscillator radiation. The received signal is then mixed in a Type 1N21B crystal with the output of the local oscillator. This oscillator employs a Type 2K56 reflex klystron which is stabilized by an AFC circuit that is similar to the one used on the transmitter. The microwave components are all contained in a temperature controlled compartment that is maintained at about 60 degrees C. The

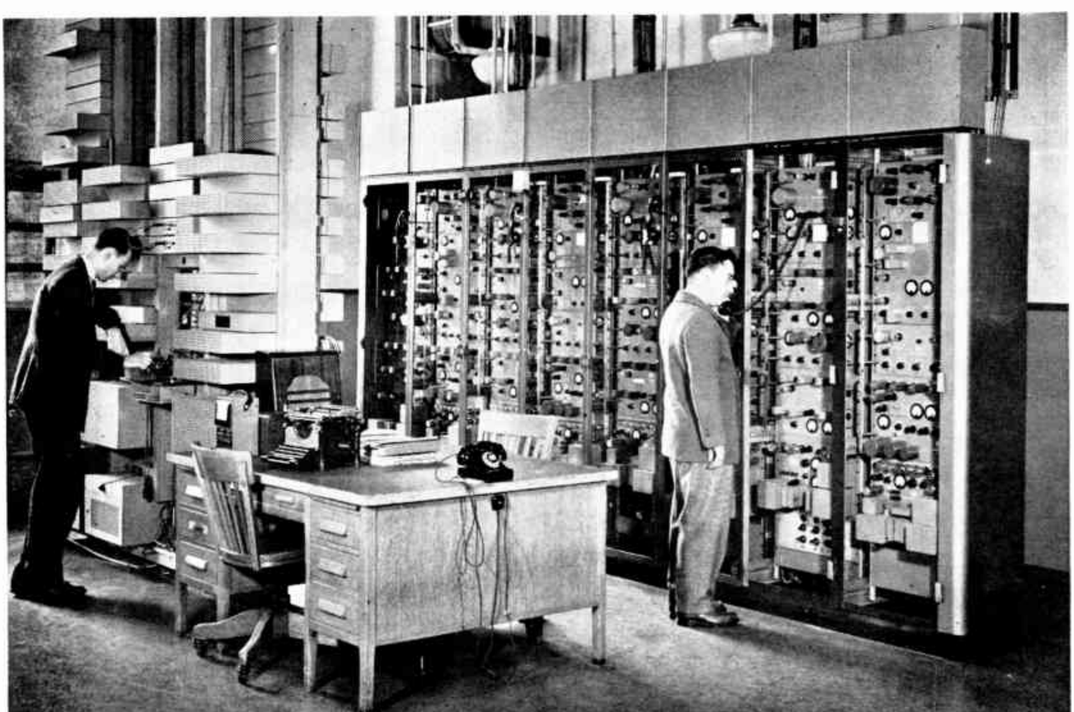

Figure 7. New York Terminal of the Washington, Pittsburgh and two Philadelphia microwave systems. A portion of the voice band equipment is shown on the left

Figure 8. Typical relay tower on the New York - Pittsburgh - Washington triangle. The transmitting and main receiving antennas are in the tower cabin behind the fibre glass windows; the diversity antenna is about twenty-five feet below

local oscillator is tuned 32 mc either above or below the incoming signal to produce an intermediate frequency of 32 mc which is pre-amplified and transmitted through a coaxial cable to the IF unit. Here the signals are further amplified and then limited before being fed to the 32-mc discriminator. There are a total of seven 32-mc stages, each having a gain of about eight times with an over-all frequency response of approximately 4.5 mc. The output of the discriminator contains the frequency-modulated 1-mc subcarrier and the service channel. The subcarrier is fed through a two-stage amplifier to the demodulator at the terminal, or to the outgoing microwave transmitter at the relay station. The service channel is also amplified for local use or for transmission to the next station.

The above description fits either the main or diversity receiving system. Automatic mixing of the subcarrier signals is obtained by connecting the output of the diversity IF amplifier across the cathode resistor in the first 1-mc stage of the main IF amplifier.

The microwave transmitter and receiver units are mounted within a few feet of the antennas. The remainder of the units may be located 100 feet or more away, and are connected by coaxial cables. Metering and control circuits are provided between the RF units and the rack equipment and are carried by ordinary cable conductors.

Any system which is designed to handle a large number of communication channels must prove its ability to perform reliably day after day under all types of operating conditions and without excessive attention. Therefore, a summary of the results obtained on the New York-Philadelphia circuit using the above equipment is of particular importance.

An analysis of about 11,000 hours of circuit operation, during most of which the circuit was given maintenance supervision only eight hours a day for five days a week, showed that the outage time due to all types of equipment failures was less than five per cent. This outage time comprehends the total period the circuit was out, including the time required for the maintenance man to reach the station from one of the terminals and correct the

Figure 9. Typical equipment building at relay stations, housing the rack equipment and power plant

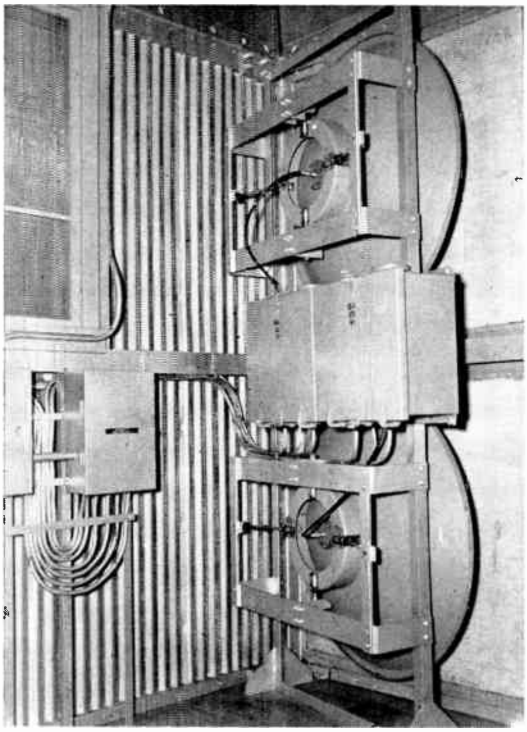

Figure 10. Interior of tower cabin, showing transmitting and receiving reflectors and head end boxes

trouble. With the normal maintenance which a regular operating circuit would receive, the total outage time can be expected to be not more than one per cent.

To insure traffic continuity, a second system has been installed between New York and Philadelphia to provide fallback protection during periods of interruptions to the regular circuit, and the systems interconnecting New York, Pittsburgh and Washington have been so arranged that any two legs of the triangle may be used as fallback protection for the third leg.

The ability of the radio system to work through severe weather conditions was forcibly demonstrated during the ice and sleet storm last January. At the conclusion of this storm, all open wire circuits, between New York and Philadelphia, had been interrupted due to the heavy ice loading on the wires. However, the radio systems continued to function all during this emergency, and provided reliable circuits for traffic service. Approximately one inch of ice formed on some of the unprotected reflectors, but this produced no noticeable effect on the over-all system performance. One relay station operated on emergency power continuously for about ten days as all the power lines in the vicinity were down due to the storm. This emergency plant is the type installed at each station and consists of a storage battery-vibrator combination which supplies the power until an engine-driven alternator is operating properly and takes over the load. All switching is automatic and is accomplished without any interruption to the telegraph channels.

Extensive measurements of distortion and cross-modulation have been made on the New York-Philadelphia system to check the calculated performance. With the 1-mc subcarrier looped at Philadelphia to form a 170-mile circuit with seven relay stations, the distortion, as measured with a single audio frequency, is normally 55 db to 60 db below the signal level. This is substantially the same value that is obtained when the modulator is connected directly to the demodulator.

Measurements have also been made with a 32-voice band load on the system, using experimental WN-2 multiplexing equipment developed by Western Union for use with the radio system.[4] Each of

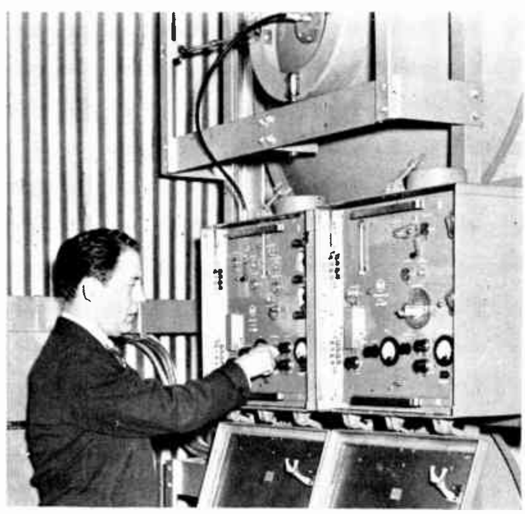

Figure 11. Transmitting and receiving head end units

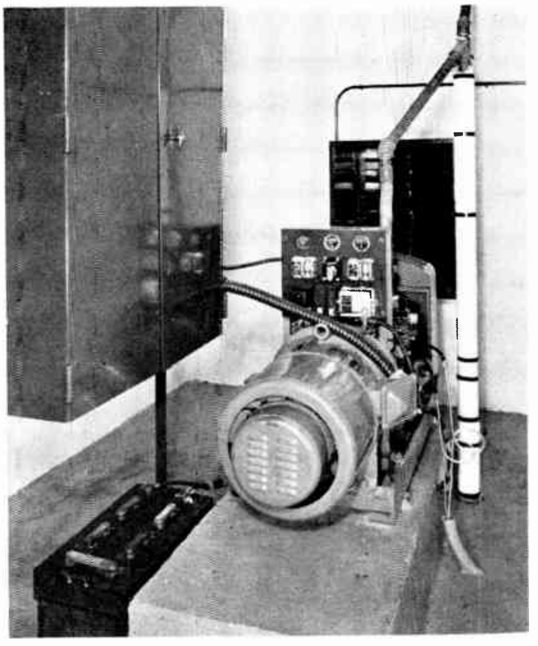

Figure 12. Emergency engine room at relay stations, showing the 5 KW engine-driven alternator and control cabinet

these voice bands, which are approximately 3000 cycles wide, was further divided into 9 or 16 telegraph circuits by Western Union Type 15 FM channel terminals.[5] The signal-to-noise ratio on each of the 3000-cycle bands under these conditions was approximately 40 db. Crosstalk was the limiting factor on the low-frequency bands and circuit noise on the high-frequency bands. Care must be exercised in setting the modulation level of the 1-mc subcarrier with a multi-channel load, as overmodulation by the signal peaks produces severe crosstalk in all channels. Experience has shown that peak voltage is about four times the RMS voltage at the combined output of a large number of independent frequency sources. Unfortunately, it was not possible to load each of the 32 voice bands for this test with a different group of telegraph channels, and so the load was obtained from only four groups of channels, each of which was connected to eight of the voice bands. This had the effect of increasing the normal peak-to-RMS ratio at the output of the WN-2 equipment and therefore the deviation of the subcarrier by each voice band had to be reduced to allow for the higher peak signals. Thus all of the anticipated FM improvement was not realized during this test, and it is expected that the signal-to-noise ratio under actual operating conditions will be somewhat greater.

The propagation of centimeter waves has been the subject of considerable study. The signal strength in each of the sections on the New York-Philadelphia experimental system has been recorded for over two years. The fading observed may be classified broadly into two general types. The first is a slow variation which takes place over a period which at times may be several hours; the second is a rapid variation during which the signal may change from a normal value to thermal noise in a matter of minutes.

The first type of fading may be considered to be the result of an abnormal refractive index of the atmosphere which causes bending of the radio waves. Such a condition may be due to temperature inversion as the result of warm air blowing in over cool land or water. Humidity conditions may also produce the same effect. In general, it may be said that when the air is agitated by wind, propagation conditions are normal. The slow fading, in most instances, occurs around the period of either sunrise or sunset and rarely exceeds 12 to 15 db. Also, experience indicates deep fading seldom takes place simultaneously over the entire length of a circuit. Space diversity reception does not overcome this type of fading, but the effect may be reduced by increased transmitter power.

The rapid type of fading usually occurs between midnight and dawn and is more prevalent during the summer months. These variations are considered to be the result of multipath transmission. The resultant field at a given receiver location is made up of two or more components which have traveled over two or more paths and may add in phase or in various degrees out of phase depending upon the difference in path lengths. At a wavelength of 7.5 centimeter, small differences in the length of the transmission path have a

Figure 13. Top of Neshanic, N. J. tower, showing tower house, television and diversity antennas, and wave guide antennas installed for 6000-mc experiments

large effect on the phase, and the indications are that almost complete cancellation takes place at times at a given receiver location. Vertical space diversity reception, with the antennas separated by about 25 feet, has been found to be a satisfactory method of overcoming this transmission condition. Increased transmitter power is not an answer to this type of fading. Since diversity reception was incorporated in this equipment, the outage time due to propagation on line-of-sight paths has totaled about 35 minutes over a period of more than two years.

Western Union has made extensive transmission measurements for almost two years over a path between New York and Neshanic, N. J., a distance of 42.5 miles, to determine the relative performance of frequencies at 1850 mc, 4150 mc, 6300 mc and 9500 mc. A large amount of statistical information has been accumulated and while the analysis is not yet complete, a few general conclusions may be drawn. As the wavelength is decreased, rain, snow and other atmospheric conditions affect the transmission to a greater extent and make these frequencies less reliable for communication purposes. Neglecting the effect of rain and snow on the higher frequencies, the general character of the fading is the same at all four frequencies, although the depth of fading tends to be greater with decreasing wavelengths, and the fading period coincides closely with the extreme variations occuring between midnight and sunrise during the summer months. This is also true during the winter months; however, the average variation is not generally as great.

Microwave relay systems are already playing an important part in Western Union's extensive modernization program. In addition to the New York-Pittsburgh-Washington triangle and the two circuits between New York and Philadelphia, relay sites have been selected as far west as Kansas City, and south to Atlanta, in anticipation of possible extension of the system to cities in the south and midwest. Terminal locations have also been secured in many of the larger cities.

Present engineering also contemplates sharing the towers and other physical plant along many of these routes with inter-city television circuits, should future circumstances make it desirable to furnish such facilities. A television circuit has already been installed between New York and Philadelphia, using existing telegraph relay stations at Neshanic and Mt. Laurel, N. J.

Thus it can be seen that microwave radio offers the promise of adequate facilities for Western Union's many services as well as the means for expanding its field of public communications.

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THE AUTHOR: H. P. Corwith became an Engineering Assistant in the Traffic Department of Western Union in 1916, after graduating from Cornell University. He gained wide experience in telegraph operations as operator, T. & R. attendant and multiplex supervisor in the New York office, and was head of the New York school for training multiplex operators. In 1925 he established the Water Mill Laboratory for radio experiments and observations, and in 1934 became head of the Electronics Division, Engineering Department, at Water Mill. Under his direction, cable plowing and depthometer equipment and cable leader gear were developed, as well as new artificial cable lines and cathode ray oscilloscope methods of cable balancing. The zirconium point source of light was also discovered and developed under his direction. In 1943, Mr. Corwith was appointed Assistant Chief Engineer of the Engineering Department, at New York, and in 1946 became Director of Research. He is a Member of the AIEE, a Senior Member of the IRE, and a Director of the New York Electrical Society.

THE AUTHOR: W. B. Sullinger joined the staff of the Research Division of Western Union after graduating from the Virginia Polytechnic Institute in 1930. During the next several years, he participated in studies involving d-c telegraph transmission, interference mitigation and carrier transmission. He later assisted in the design, development and field testing of the carrier systems now widely used by the Company. Since 1944, Mr. Sullinger has been concerned principally with the development of microwave relay systems for telegraph and television. He was appointed Assistant Radio Research Engineer in 1945.

The Western Union Varioplex Telegraph System

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The Western Union Varioplex is a type of automatic telegraph system in which a large number of individual variable-traffic-capacity lanes of communication are provided by means of a single high-traffic-capacity trunk circuit. These individual lanes or sub-channels are used primarily for furnishing telegraph facilities to patrons whose limited requirements do not justify the cost of a private leased wire. While the cost of this new type of service is relatively low, the service obtained compares favorably with that of a private wire lease. Development of the system was started some ten years ago and was made possible through the application of a unique method of dividing the total traffic capacity of a main line circuit —a method insuring efficient usage of the circuit facilities regardless of the number of components into which the total traffic load is divided or how the load is proportioned.

A varioplex circuit between two remotely located cities may be arranged to provide facilities for any number up to forty sub-channel connections. This maximum of forty sub-channels is not fixed by any theoretical limitations inherent in the method of operation, but merely through practical considerations. A business firm with offices in the two cities leasing one of these sub-channels is thereby provided with an effectively direct and private circuit between the two offices. Each office is furnished with two teleprinters, one for sending and the other for receiving. Communication may be carried on in either direction or in both directions at the same time.

Figure 1 shows a view of a familiar type of teleprinter. Messages are transmitted by operating the keyboard of the sending teleprinter in the same manner as that of a standard typewriter keyboard. Incoming messages are automatically printed by the receiving teleprinter. Teleprinters can be supplied either for page or tape copy and for table or console mounting, as desired. They are connected to the central office of Western Union by means of individual conductors. Similar pairs of conductors radiate from the central office to all patron offices having sub-channel leases over that circuit. Any patron may transmit at will, his signals, together with those from other patron lines, converging at the central office, whence, through appropriate apparatus located there, they are transmitted to the distant city over the single common circuit. At the distant point the central office apparatus automatically sorts out each received character and transmits it

Figure 1. Typical Western Union teleprinter.

Figure 2. Varioplex Central Office equipment.

over the local conductor to the office of the patron for whom it is intended. Charges for this type of service are computed on the basis of the actual amount of traffic sent. In order to furnish the necessary accounting information, each patron's sending line is provided with a character counter to record each character transmitted.

Figure 2 gives a view of a typical central office group of equipment for a Varioplex installation. An identical set of equipment is also installed at the distant city. The equipment may be divided into three groups or classifications: (1) that individual to each of the patron connections, (2) that common to all connections, and (3) that associated directly with the main line circuit. Figure 3 shows a close-up view of the major units of one set of the equipment in the first group. Three such sets of equipment are mounted on a metal frame or rack and provide facilities for three patron connections. A similar rack is provided for each three patron connections. At the top of the rack are six banks of multi-contact relays, two associated with each patron connection. This equipment, together with vacuum tubes, switches, signal lights, etc., also mounted on this rack, performs functions directly associated with the transfer of signals from the patron sending line to the main line circuit and from the main line circuit to the patron receiving line.

Figure 4 is a close-up view of a metal rack in which is mounted the equipment designated as group 2. It consists of banks of multi-contact relays, vacuum tube units, rotary stepping switches, signal lamps, manually-operated switches, and various monitorial facilities, all having functions common to all patron connections and providing control of operations in general. Figure 5 similarly shows the equipment of group 3 which, like that of group 2, is common to the whole circuit. It consists principally of two rotary distributors whose functions are the transmission of signals to the main line circuit and the distribution of the signals received from the distant end of the circuit. It includes also the line duplexing equipment and that used for testing and regulating the main line circuit. This group of equipment is practically the same as that used for

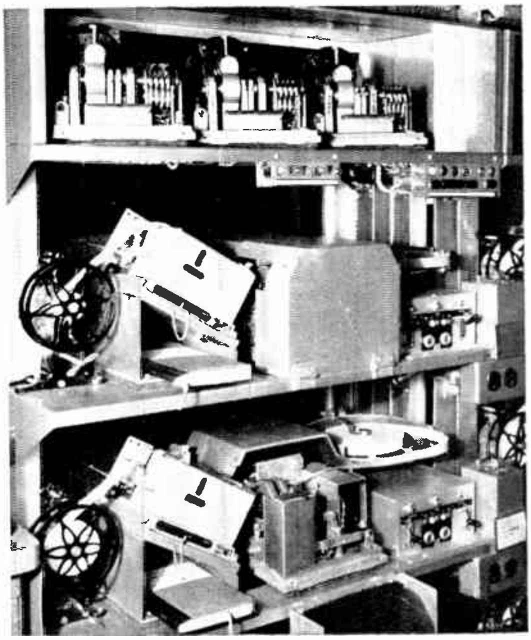


Figure 3. Varioplex Central Office equipment individual to patron connections.

ordinary automatic telegraph circuits. Figure 6 shows the mechanical details of the distributor. Copper brushes, attached to a rotating shaft, trail over pairs of stationary segmented and solid rings, each pair forming an independent commutating circuit. The rings are mounted on a removable plate, the whole assembly being designated as the distributor face plate.

Figure 7 illustrates in schematic form the essential features of a two-channel or "Double" type of Varioplex circuit. Stations X and Y represent the two remotely located cities between which the circuit operates. The terminal equipment is that used in transmitting from Station X to Y. In an actual installation an identical set of equipment is provided for transmitting in the opposite direction. The main line equipment comprises a segmented sending ring of the sending distributor, two banks of sending relays A and B at Station X, and a segmented receiving ring with corresponding banks of receiving relays at Station Y. The brushes of the two distributors rotate in exact synchronous relation, successively connecting each sending segment to the corresponding receiving segment for a short interval during each revolution. The segments are divided into two groups of five segments, each group constituting a channel.

The two channels are designated alphabetically as the A and the B channels. Five sending relays and five receiving relays are associated with the five respective segments of each channel and provide the means whereby a character is transmitted over each channel during each revolution of the brushes. The five sending relays apply positive and negative potentials to the respective sending segments and, as the brush traverses the five segments, a combination of positive and negative current impulses is transmitted to the line.

At the receiving end these impulses actuate the five respective receiving relays, causing them to assume operated and released positions in accordance with the signal combination. The five unit impulses provide 32 distinct combinations, each representing a character selection. Of

Figure 4. Varioplex Central Office equipment with control rack in foreground.

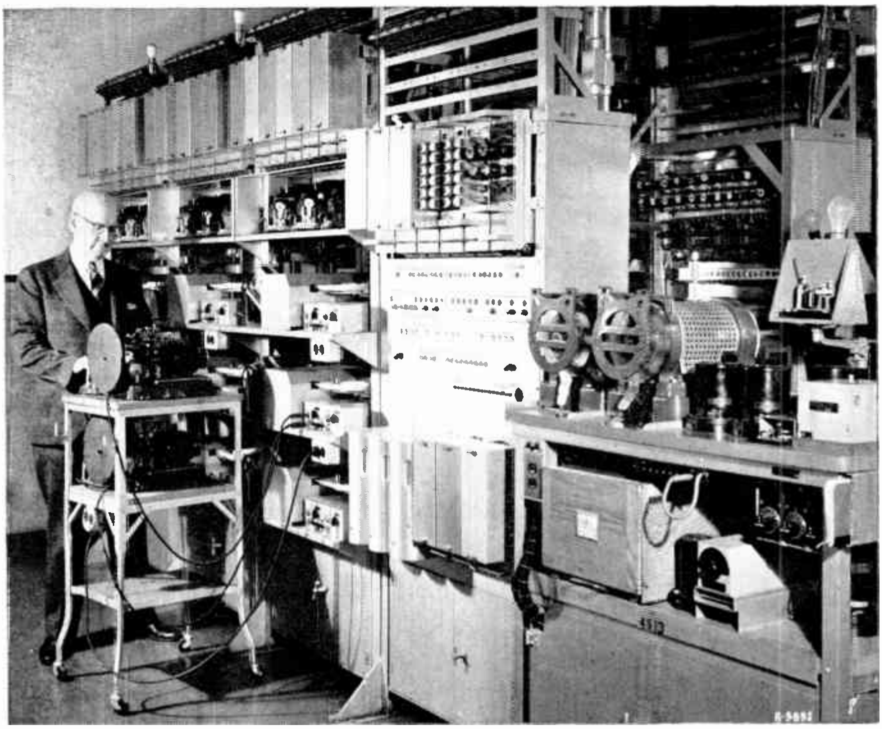


Figure 5. Varioplex Central Office equipment associated directly with the main line circuit

the 32 possible combinations, 31 are used for selective functions in the operation of the teleprinter, and are designated as "normal" characters. The remaining combination or "blank" has no selective function and, when received by a teleprinter, produces no evidence of its reception in the printed copy. It serves as a special signal, however, by which the operation of the central office equipment at the receiving end is controlled from the distant end of the circuit.

If the line connecting the Stations X and Y be one capable of conveying intelligible signals at a rate of 800 characters per minute, the two distributors are adjusted to a speed of 400 rpm. Each channel then transmits at the rate of 400 characters per minute. This is the method conventionally used on all high-speed automatic circuits for dividing the total traffic capacity of a circuit into smaller, but more practical components. Each channel functions as an independent traffic lane whose speed is equal to the quotient obtained by dividing the total circuit speed by the number of channels. For circuits with transmitting rates up to 1,600 characters per minute, segmented rings having three or four channel groups are used.

As indicated in Figure 7, the equipment associated with each sub-channel comprises a reperforator RPF, a transmitter XTR, two sending chain relays SA and SB, and a control relay SCO at the sending station, and corresponding relays RA, RB and RCO at the receiving station. The

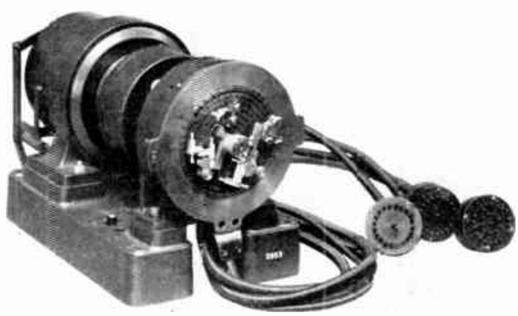


Figure 6. Varioplex distributor

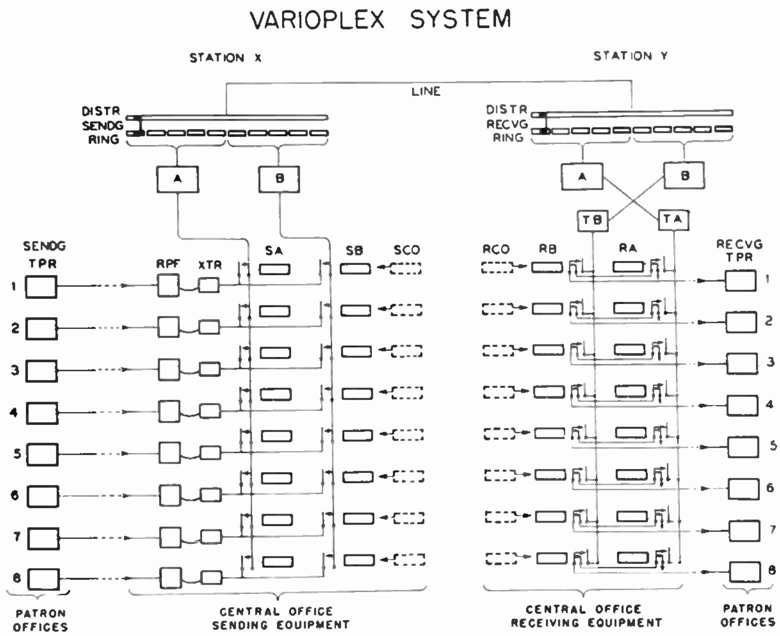


Figure 7. Schematic of two-channel or "double" type of Varioplex circuit.

reperforator is a mechanism arranged to respond to signals transmitted from a teleprinter and to record the transmitted characters in the form of perforations in a narrow paper tape. The nature of these perforations will be evident from Figure 8 which shows the transmitter through which the tape passes as it comes out of the reperforator. A magnetically-operated tape-feed mechanism steps the tape through the transmitter, causing it to advance one character per revolution of the distributor brushes. During the interval between steps, the tape remains at rest with a character perforation directly over five movable fingers or pins which press against the tape. Each pin engages the tape at a point where a hole may have been perforated and moves upward unless stopped by the tape. Five contacts controlled by the pins are thus positioned in accordance with the perforated combination of holes. The five contacts are multipled as indicated to five respective contact springs of the two chain relays SA and SB through which the circuits may be closed to the five sending relays of either of the two channels. Thus, if relay SA be operated during this interval the five relays of bank A assume operated and released positions corresponding to the character in the transmitter. As the sending brushes pass over the five segments of the A channel, the signal combination representing the character then is transmitted to the line.

A light contact lever, mounted between the reperforator and the transmitter, extends above the tape loop as it passes from the reperforator and into the transmitter. When the tape loop becomes too short to permit further transmitter stepping operations, this arm is lifted by the tape, causing the stepping circuit to become inactive. This automatically governs the stepping action of the transmitter, permitting it to step the tape whenever pos-

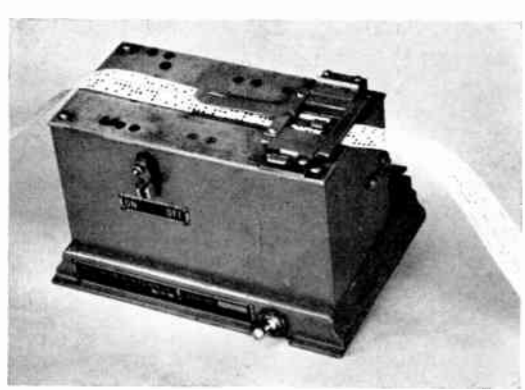


Figure 8. Tape transmitter.

sible, and stopping it when the tape loop becomes short — an arrangement commonly known as the auto-stop circuit.

At Station Y the signal combination is distributed by the five receiving segments of the A channel and causes the five receiving relays of bank A to assume corresponding operated and released positions. The relay RA of the sub-channel, whose character has just been transmitted, operates in unison with the distant SA relay so that, while the character is being selected, relay RA is operated and remains operated during the ensuing revolution of the distributor brushes. The two relays RA and RB of each sub-channel control the circuit of the line extending out to the receiving teleprinter in the patron office. The circuit passes through contacts of the two relays and is closed to a fixed potential when both relays are in their released positions. When either relay is operated, the patron receiving line is disconnected from the fixed potential and connected to a local transmitting device, which is associated with each channel. This transmitting device (TA and TB of Figure 7) consists of an arrangement of vacuum tubes whose operation is controlled by contacts on the five receiving relays of the respective banks A and B, and by a segmented ring of the receiving distributor known as the simplex ring.

With relay RA in its operated position, impulses furnished by the simplex ring segments actuate the input circuit of the vacuum tube unit TA in accordance with the selected character stored in receiving bank A, thereby causing a signal combination to be transmitted over the line to the patron office. This signal actuates the selecting mechanism of the receiving teleprinter, causing the character to be printed. The character could similarly have been sent over the B channel by means of relays SB and RB. No distinction is made with respect to channels in the transmission of characters from sub-channel transmitters. Successive characters are transmitted alternately over the two channels, one character being supplied by each sub-channel in turn. After all have transmitted one character the cycle is repeated. Successive characters from any particular sub-channel may be sent over either channel.

The relays SA and SB constitute the so-called "sending chain" and the relays RA and RB the "receiving chain." They operate in the cyclic manner characteristic of that type of relay circuit commonly known as a counting chain. As shown in Figure 7, the two groups of relays are associated with individual sub-channels in the horizontal rows and with individual channels in the vertical rows. For circuits having three channels a third vertical row of relays SC would be used while, for a four-channel circuit, there would similarly be a fourth row of relays SD. The sending and receiving chains are identical in their mode of operation and in the following description references to relays SA, SB and SCO apply likewise to the relays RA, RB and RCO. The relays SCO and RCO are necessarily included in the description, since they control the operation of the chain relays.

A local ring of the distributor furnishes two impulses per revolution for the operation of the chain relays. One operates relays SA and the other relays SB. Similarly, for three- and four-channel installations, a distinct impulse is used for each group of relays associated with a channel. Each chain relay is provided with a locking circuit and remains in the operated position after being actuated by the local impulse. The circuit is arranged so that, whenever any chain relay is actuated, any other previously operated relay in the same vertical row is released. Thus, there are never more than one SA and one SB relay in an operated position at the same time. The circuit is likewise arranged so that not more than one relay can be operated in the same horizontal row. If all eight sub-channels shown in Figure 7 were transmitting, chain relays would operate progressively upward, starting with No. 8 and its relay SB in the following order:

	Rev. No. 1	Rev. No. 2	Rev. No. 3	Rev. No. 4	Rev. No. 5
Channel A		SA-7	SA-5	SA-3	SA-1
Channel B	SB-8	SB-6	SB-4	SB-2	SB-8

In the four revolutions of the brushes each sub-channel would then have transmitted one character. The cycle of operations is then repeated and this sequence continues as long as perforated tape is supplied to each transmitter through the operation of the sending teleprinters at the patron offices.

As previously mentioned, the SCO relays control the operation of their associated chain relays. The manner of control is such that the pair of chain relays associated with an SCO relay may be removed from the chain operating cricuit, causing them to become inoperative. Such "removal" of a pair of chain relays does not affect the others. They continue to function as before. This action is effected by switching the chain impulse circuits at the contacts of the SCO relays, the chain relays being inoperative if the sending control relay SCO is in the released position, and operative if in the operated position. Thus, by controlling the SCO relay so that it remains operated if traffic is available at the transmitter, and released when traffic is not available, the use of the main line circuit is shared only by those sub-channels capable of usefully employing the circuit facilities.

The control of the SCO relay is obtained through a collating arrangement which "reads" the character in the transmitter, causing the sending control relay SCO to operate and release in accordance with the type of character. A sub-channel is said to be "cut out" when its SCO relay is released and "cut in" when its SCO is operated. Cut-in and cut-out operations occur in such manner that the chain continues its normal sequence, the only effect being to shorten or lengthen its operating cycle. Since each cut-in sub-channel sends one character in each of these cycles, it is evident that the transmitting rate of any sub-channel decreases as other sub-channels are cut in and increases as they are cut out. When all but two are cut out, the two chain relays remain in their operated positions and each sub-channel then transmits continuously over the same channel and at the maximum channel speed. This is also the case if only one sub-channel is cut in, one channel then becoming idle since it is not practicable to increase the sub-channel speed beyond that of the channel speed.

The continuous flow of characters arriving at the distant Station Y must be distributed to the patron receiving lines in the same order as they are transmitted at Station X. To insure this it is necessary that the receiving chain be made to operate in a cyclical manner identical to that of the sending chain. Since the two chains are alike in all operating respects, it is evident that this will occur if the receiving control relays RCO are operated and released in exact correspondence to that of the sending control relays SCO.

The control of RCO relays is effected through a circuit arrangement which automatically functions whenever an SCO relay is to be operated or released. This circuit, together with its associated apparatus, is called the cut-in system. It functions in response to information conveyed to it by the collating equipment associated with each transmitter. The latter determines when an operation or release of its associated control relay SCO is required and transmits this information to the cut-in mechanism. This causes the cut-in system to function and, upon the completion of its sequence of operations, the SCO and corresponding RCO control relays will have been placed in similar positions, i.e., both operated or both released, in accordance with the request signalled by the collating mechanism. The operation or release of the control relay SCO involves only local functions at Station X. The positioning of the distant control relay RCO involves the transmission of special signals over the line to Station Y. These signals must be distinguishable from those normally received at Station Y, they must indicate the particular RCO relay to be actuated and, finally, they must indicate whether the relay is to be operated or released.

The cut-in mechanism is arranged so that each operation positions four SCO and four RCO relays. These relays, therefore, are divided into groups of four, each group being assigned a distinct position at a set of contact studs of a magnetically-operated rotary switch. The rotary switch is provided with four contacting arms or wipers (in addition to those required for its control) and, as these wipers step from one position to the next, they successively engage the sets of contact studs associated with each group of relays. By means of similar switches at the two circuit terminals, each arranged to contact corresponding groups of SCO and RCO relays at simultaneous intervals of time, it is possible to indicate the particular group of relays to be acted upon by transmitting the special cut-in signal during the interval while the rotary switches are engaging the studs of the desired group of SCO and RCO relays.

The rotary switches are normally at rest at a starting or "home" position. A blank transmitted over the B channel furnishes the start signal for the distant RCO switch, causing it to start stepping at the same instant the SCO switch is started. The blank is transmitted by the cut-in mechanism by diverting the B channel from its normal use during that revolution. When the sending and receiving rotary switches reach the position at which a cut-in operation is to be performed, a second blank is transmitted over the B channel in the same manner as before. Following this a signal combination called the "pattern" character is transmitted over the A channel by the cut-in mechanism. Just prior to its transmission the four sending control relays SCO are positioned in accordance with the indications furnished by the collating circuits of the four sub-channels involved. While all four SCO relays are actuated by the cut-in mechanism and may actually be changed to their opposite positions (operated relays released, and released relays operated), generally only one of the four requires a change, the others remaining in their previous position. Immediately following this positioning operation the A channel sending bank is switched from its normal circuit and four of its relays are connected to contacts of the four SCO relays. This causes the four sending relays to assume positions corresponding to those of the SCO relays, thus transmitting a character in which the pattern of arrangement is displayed.

The B channel receiving bank at Station Y is provided with a collating arrangement which "reads" the incoming characters and determines when a blank is received. A blank received while the rotary switch is resting at the stud position of some group of four RCO relays informs the cut-in mechanism that the next character to be received on the A channel is a pattern character, and causes the mechanism to perform a positioning operation analogous to that performed at the sending end. The four receiving control relays RCO are thereby made to assume positions corresponding to the pattern displayed by the received character, thus placing them in exact agreement with the four distant SCO relays.

Following the pattern combination, a second character called the "confirmation" is transmitted over the A channel. This character is identical to the pattern character except that the four pattern-displaying impulses are sent with reversed polarities. Its function is to test the operations performed in response to the pattern character. It serves to check the line transmission as well as the local operations at the receiving end of the circuit. The four RCO relays must be in exact agreement with the positions indicated by the confirmation character at the time this test is made. Should they not be in agreement, a signal is immediately transmitted back to the sending station causing all further operation to stop. Audible and visible signals simultaneously inform the circuit attendants of the nature of the trouble, after which operation is restarted manually if inspection reveals no further evidence of the trouble. Such circuit stoppage causes all SCO and RCO relays to be released so that, when operation is subsequently started, pattern and confirmation signals are transmitted for all groups, thus insuring a proper positioning of all relays at the start.

The cut-in mechanism also provides means for operating or releasing relays other than SCO and RCO. These other relays are controlled from a certain group of studs on the rotary switches and provide special monitorial or circuit control features. One of these is the "home-stop" function which, when operated, causes transmission to stop from the station whence the signal is sent. Another, known as the "distant - stop," similarly causes transmission to stop from the opposite or distant terminal.

These signals permit manual stoppage of operation in either direction and from either terminal. They introduce no errors in the messages being received; hence they may be operated at any time desired. Stoppage of operation over the main line circuit does not necessitate stoppage of transmission from patron offices. Since most of these stoppages are of short duration, usually a matter of a few seconds, patrons are not in general aware of them at all. Any signals transmitted from patron offices during such stoppages are recorded in perforated tape in the normal manner. The tape, however, does not pass through the transmitter until the main line operation is again started. On occasions where a prolonged stoppage is necessary, a special signal is used to inform patrons that normal operation has been interrupted. This signal does not prevent the patron from transmitting should he so desire, but merely informs him that any subsequent transmission is subject to delay at the central office. All Varioplex circuits, however, are provided with spare main line facilities, spare units of equipment, etc., and extended delays or interruptions rarely occur.

The ten years that have passed since the first Varioplex circuit was installed have seen a substantial growth, both in the number of circuits installed, and in the total number of sub-channels. Today there are more than 50 Varioplex circuits of various types and more than 500 sub-channels. They form a network which extends over the entire U. S. A. Many improvements have been made during this period, both in design and in principles of operation. What the future may hold in the way of further improvements or further growth is difficult to predict.

THE AUTHOR: O. E. Pierson has been associated with Western Union since 1917, at which time he began work in the Traffic Department at Chicago where he held various positions from Testing and Regulating Attendant to Division Traffic Inspector. In 1930 he was transferred to the staff of the Engineer of Automatics in New York. Among his major assignments was the development of the Varioplex System in which he was actively engaged, together with other members of the staff, for some eight years. His other activities have been chiefly concerned with improvements in automatic telegraph circuits and repeaters. Since 1942, Mr. Pierson has been assigned to the Water Mill Laboratories, where he has assisted in the development of flight trainer equipment for the U. S. Navy.

Push-Button Switching

W. B. BLANTON and F. L. CURRIE

(Continued from The Development of Western Union Switching Systems, TECHNICAL REVIEW, April, 1948)

Push-button switching is a new method of setting up intra-office connections between line receiving positions and line sending positions in reperforator-switching offices. Switching turrets have "destination" push-buttons instead of jacks, and transmitters used for intra-office transmission have "initiate" push-buttons instead of the cord-and-plug formerly used. This new method was incorporated into the switching systems placed in service at Philadelphia and Cincinnati in 1947.

Push-button differs from plug-and-jack switching primarily in the manner in which it effects the intra-office connections. As shown in preceding articles, plug-and-jack connections were made by direct action through rings in the plug and contacts of the jack. Nine-conductor plugs and jacks were used. In push-button switching, connections are established through the rotor and stator contacts of rotary switches which operate under the control of "destination" push-buttons in switching turrets.

In the plug-and-jack method, messages are switched by a clerk who picks up a plug (thereby determining which transmitter is going to be switched) and inserting it into a selected jack in the turret (thereby determining the point to which it will be switched). In the push-button method, a clerk depresses an "initiate" push-button mounted adjacent to and on the same shelf with the transmitter (determining the transmitter to be switched), and then depresses a "destination" push-button in the switching turret, (determining the point to which it will be switched). These switching operations in either plug-and-jack, or push-button, merely establish "potential" connections between the intra-office transmitters and the selected intra-office circuits. A potential connection is electrically completed when the transmitter allotter tests a selected intra-office path and finds it idle.

Push-Button Switching Turrets

Heavily loaded receiving circuits are terminated at line receiving positions which have a push-button switching turret for each three receiving positions. Lightly loaded receiving circuits are terminated at line receiving positions which have a switching turret for each five receiving positions. As shown in Figure 27, a 5-position push-button turret arrangement consists of three double-deck tables, the switching turret being located on the upper shelf of the middle table. In a 3-position push-button turret arrangement, the left-hand double-deck table is omitted.

Each push-button turret has a push-button, a neon lamp, and a designation card for each of the sending destinations. The neon lamps serve the same purpose as the neon lamps associated with the jacks in plug-and-jack turrets. These push-buttons and lamps are arranged in the face of the switching turrets in nine rows having thirty buttons and lamps per row, thus providing facilities for switching to 270 destinations. This number was determined by operating factors. The system could serve more, or fewer, destinations if so desired.

Operation of Push-Button Switching Turrets

As indicated above, each switching turret serves three or five intra-office transmitters. The circuit arrangements are so interlocked that only one of the transmitters served by the same turret can be conditioned at a time for a switching operation prior to the act of depressing a

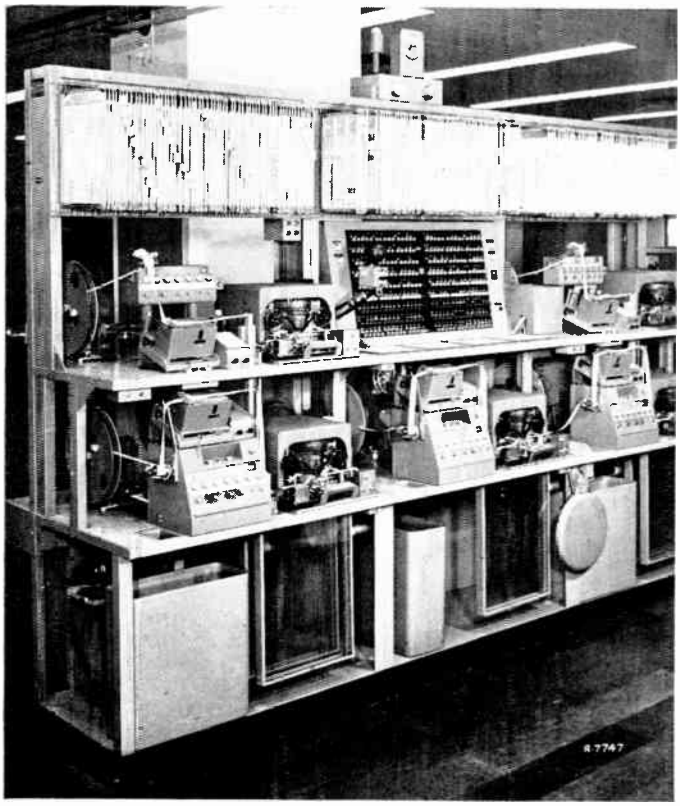


Figure 27. Five-position push-button switching turret

destination button in the turret. This prevents inadvertently conditioning two transmitters at the same time for a switching operation and then switching the first transmitter to the destination intended for the second transmitter.

An "initiate" push-button is associated with each intra-office transmitter. Momentarily depressing the initiate button of any one of the transmitters served by one turret will condition that particular transmitter circuit so that it will be switched to an intra-office circuit when one of the destination push-buttons in the turret is depressed. For example, assume that at a 3-position push-button turret one transmitter has a message for New York, another transmitter has a message for Dallas and the third transmitter a message for St. Louis. In order to switch these three messages, the switching clerk would momentarily depress the "initiate" push-button of one of the transmitters, for instance, the one associated with the transmitter having the Dallas message, and then she would momentarily depress the Dallas "destination" push-button in the turret. Next, she would depress the "initiate" push-button of one of the other transmitters, for instance, the transmitter having the St. Louis message, and follow this by depressing the St. Louis "destination" push-button. The message in the third transmitter would be switched similarly. The clerk would depress the "initiate" push-button associated with the third transmitter, and then the New York "destination" push-button.

In push-button turrets, only one push-button is provided for each destination. If two or more intra-office transmitters associated with one push-button turret have messages for the same destination, for example Chicago, the switching clerk would switch these messages in the following manner. First, she would depress the "initiate" push-button of one of the transmitters and then the Chicago "destination" push-button. Then she would push the "initiate" push-button of another transmitter and the same Chicago "destination" push-button. The same procedure would be followed for any other transmitters having Chicago messages. In each instance a potential connection to the Chicago intra-office circuit would be established. These potential connections would be converted to actual connections one at a time by the action of a transmitter allotter.

Signaling Lamps

Signaling lamps are provided to aid the switching clerks in performing the push-button switching operations. Associated with and adjacent to each transmitter initiate push-button is a white lamp. In each of the upper right-hand and left-hand borders of a switching turret are located a green "switching" lamp and a red "busy" lamp. When the switching clerk momentarily depresses an "initiate" push-button, the associated white lamp at the transmitter starts to flash and the two green "switching" lamps in the switching turret glow steadily. The flashing white lamp denotes that that particular transmitter has been conditioned to be the next one switched by the push-button turret. If the switching clerk should depress the initiate push-button of another transmitter prior to depressing a destination button in the turret, the white lamp of the second transmitter will remain unlighted while the white lamp of the first transmitter will continue flashing. Thus, a second transmitter cannot be conditioned to be switched until the switching operation for the transmitter that has the flashing white light has been completed. To complete the switching operation, the switching clerk depresses the proper "destination" push-button in the switching turret and holds her finger on it, generally for a fraction of a second, until the green "switching" lamps in the left and right-hand borders of the turret become extinguished. The extinguishing of these switching lamps indicates that the equipment has functioned to set up a potential connection from the intra-office transmitter to the desired intra-office circuit.

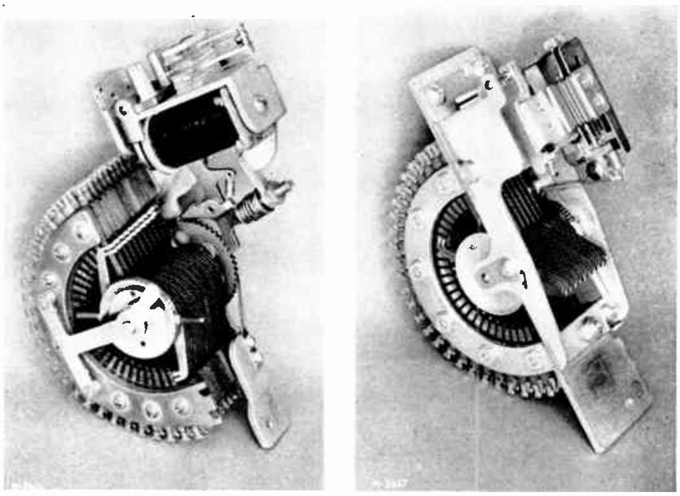


Figure 28. Two types of rotary switches

At the same time that the two green turret lamps become extinguished, the white lamp associated with the transmitter will cease flashing and glow steadily. The switching clerk may then depress another initiate push-button, thus causing its associated white lamp to flash, thereby denoting that the second transmitter is now conditioned to be switched. The green switching lamps in the turret will again glow. When the switching operation is completed for the second transmitter, the green lamps will become extinguished and the flashing white lamp will glow steadily.

If the switching clerk should deliberately or inadvertently depress the initiate push-button of a transmitter, thus causing the white lamp to flash and the green switching lamps in the turret to glow steadily, and then find that for some reason the switching operation for that transmitter should not be completed, she may, by depressing a "clear-out" button located in the lower right-hand border of the push-button turret, restore the transmitter circuit to its idle condition. The flashing white lamp and the green switching lamps will be extinguished, thus bringing all unconnected transmitter circuits at that turret to the idle condition where any one of the transmitters may be conditioned for switching the next message by depressing the proper transmitter initiate push-button.

Rotary Switches

The rotary switches which constitute the medium for making the connection between the intra-office transmitters and the selected intra-office circuits, are obtained from two different manufacturers and consequently two kinds of switches, as illustrated by Figure 28, are used. While these switches are different in construction details, they operate similarly. Both have a rotor, comprising a 10-arm wiper assembly, which can be stepped to any

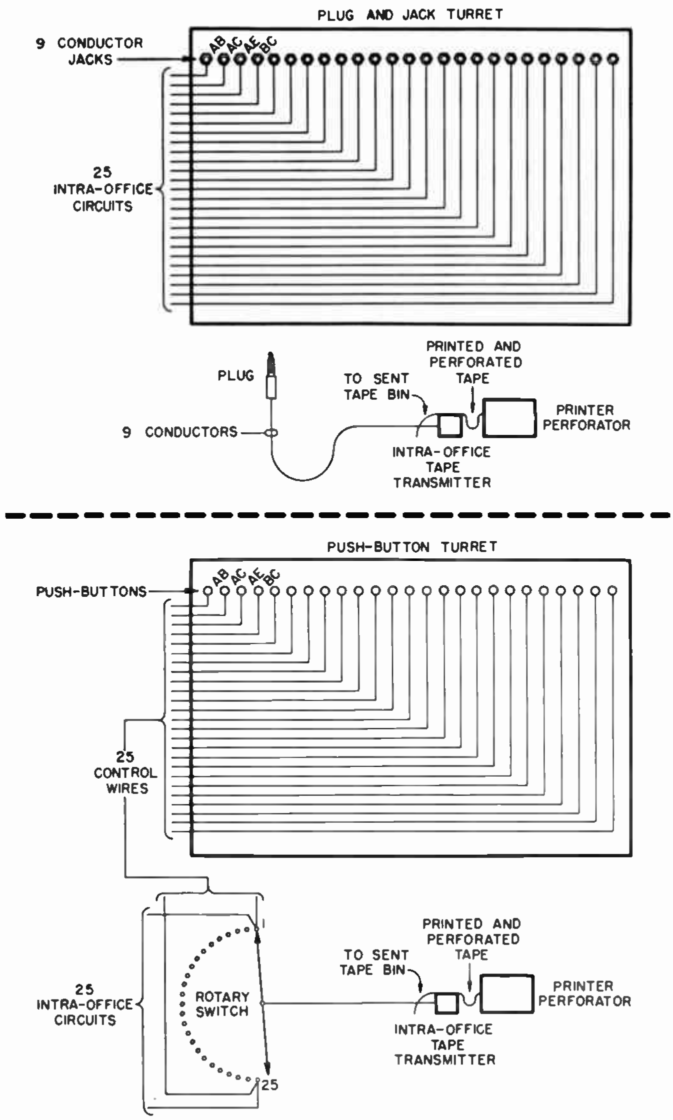


Figure 29. Diagrammatic comparison of plug-and-jack switching and push-button switching

one of 26 positions. The stator portion of these switches is equipped with ten contacts at each of 25 positions, while the 26th position has only one contact. This 26th position has no significance in push-button switching but is useful when the rotary switches are used in other types of circuits.

The rotary switches and the associated relay banks containing the relays for controlling the rotary switches are installed at racks located in a switch-room. The switch-room is kept closed and is provided with filtered air which is kept at a pressure somewhat higher than normal atmospheric pressure so that when a door is open, clean air rushes out instead of dirty air rushing in. Electrostatic dust precipitators are used to thoroughly clean the air. These precautions result in the equipment giving very reliable service with little maintenance effort.

Figure 29 illustrates diagrammatically a comparison of plug-and-jack switching and push-button switching. In the upper part of the sketch, an intra-office transmitter is shown connected to a 9-conductor plug. Twenty-five 9-conductor jacks are indicated in the switching turret for serving 25 destinations. By inserting the plug into any one of the jacks, the intra-office transmitter can be connected to the intra-office circuit of any one of the 25 destinations. In the lower part of the sketch, the intra-office transmitter is shown connected to the rotor, 10-wiper arm assembly, of a rotary switch. When the rotor is stepped to any one of 25 positions on the rotary switch, the 10-wiper arms make contact with the ten stator contacts at that position. The nine conductors of each of the intra-office circuits for 25 destinations are connected to nine stator contacts on the 25 positions of the rotary switch. The tenth contact of each of these positions is connected to the 25 push-buttons shown in the push-button switching turret.

Depressing any one of the 25 destination push-buttons in the switching turret will put a "marking condition" on the tenth contact at the position of the rotary switch on which the intra-office circuit for that destination is connected. By the action of

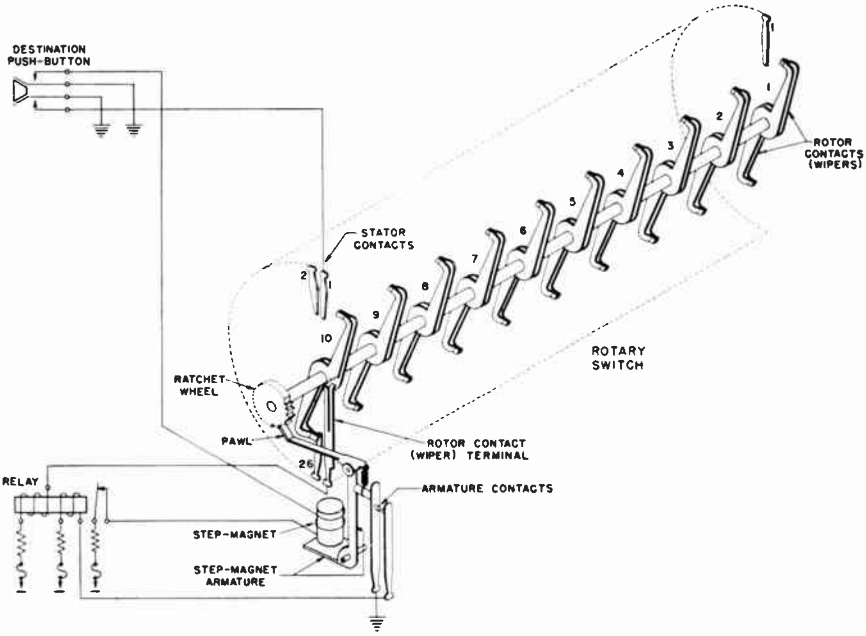


Figure 30. Theory of method used for stepping and stopping rotary switches

the electro-magnet, the stepping pawl and ratchet wheel, the rotor of the rotary switch will self-step until it finds this marked condition on the 10th contact. The rotor will then come to rest at that position on the switch. This connects the nine conductors of the intra-office transmitter circuit to the intra-office circuit of the desired destination in the same manner as inserting a 9-conductor plug into a 9-conductor jack.

Operation of Rotary Switch

A theoretical diagram illustrating the method used for marking the 10th contact of the desired intra-office circuit position on the rotary switch and the method used for self-stepping the rotary switch to that particular position is shown in Figure 30.

When the push-button is depressed, it prepares two circuits, one for actuating the step-magnet and one for marking the position of the rotary switch contact bank where the rotating contacts, termed "wipers", are to stop stepping. The circuit through the upper pair of contacts of the push-button extends through the rotary switch step-magnet, and back contacts of a relay to battery. That circuit actuates the step-magnet armature which causes the stepping pawl to engage the next tooth of the ratchet wheel and also causes a pair of contacts associated with the armature to close. The closure of the latter contacts completes a circuit for the operation of the relay which opens the circuit through the step-magnet and causes the armature to release. The release of the armature advances the wipers one step and reopens the armature contacts which release the relay. The release of the relay re-establishes the circuit condition which existed when the push-button was first depressed. Another operation will occur as just described and those operations will repeat until the marked position of the rotary switch is reached by the wipers. When that position is reached, a circuit will be completed to battery through the lower pair of contacts of the push-button, the stator and wiper contacts of the rotary switch, and a second winding of the relay. That circuit holds the relay operated and thereby prevents re-establishing the operate circuit through the rotary switch step-magnet. Thus, the rotary switch wipers are caused to be advanced over the switch positions and to be stopped when the marked position is reached.

Direct Switching

The diagram in Figure 31 shows a push-button switching arrangement whereby one transmitter can be switched to any one of 25 destinations. Figure 32 illustrates one method of expanding this arrangement so that a transmitter can be switched to any one of 265 destinations. In this arrangement, the transmitter is shown connected to the rotor of a 25-position rotary switch, designated No. 11. The first ten positions of this switch are connected to the rotors of ten other rotary switches. By stepping the 11th rotary switch to any one of its first ten positions, the transmitter can be connected to any one of the first ten rotary switches. For example, by stepping the 11th switch to its No. 5 position, the connections from the transmitter will be extended up to the No. 5 rotary switch. Then, by stepping the No. 5 rotary switch to any one of its 25 positions, the transmitter can be connected to any one of 25 intra-office circuits which are terminated on the 5th switch. This same procedure can be followed for any of the first ten rotary switches, thus providing facilities for connecting the transmitter to any one of 250 intra-office circuits. Stepping the 11th switch to any one of its positions from 11 to 25 would permit the transmitter to be connected to an additional 15 intra-cffice circuits. Thus, by the use of 11 rotary switches for each intra-office transmitter, facilities can be provided for switching a transmitter to any one of 265 destinations. This method of switching is termed "direct" switching since it permits a transmitter to be connected to any intra-office circuit directly through equipment individual to that transmitter.

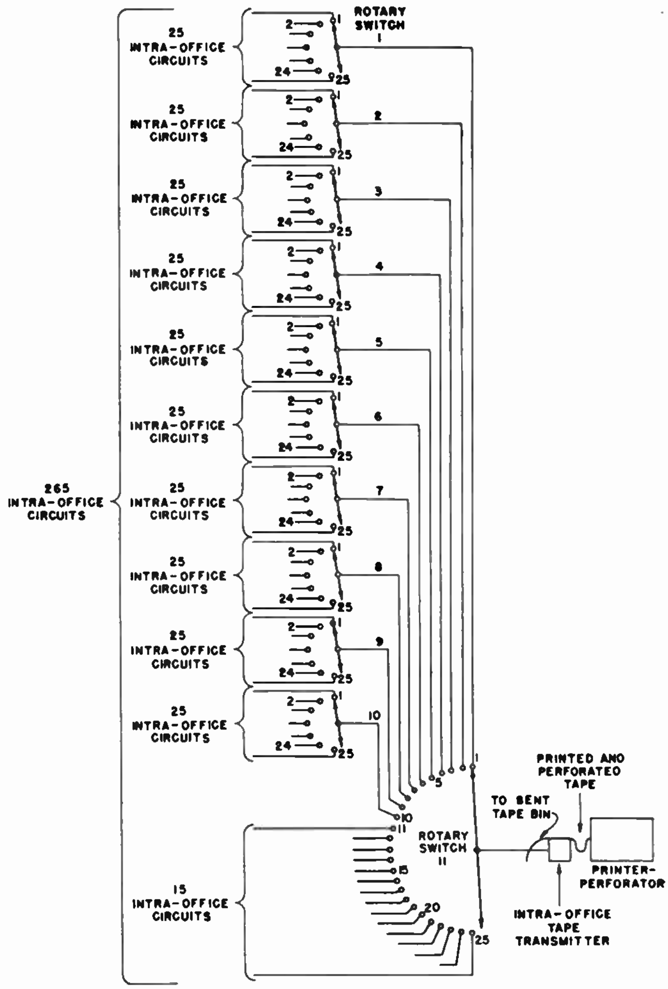


Figure 32. A push-button rotary switch arrangement for 265 destinations

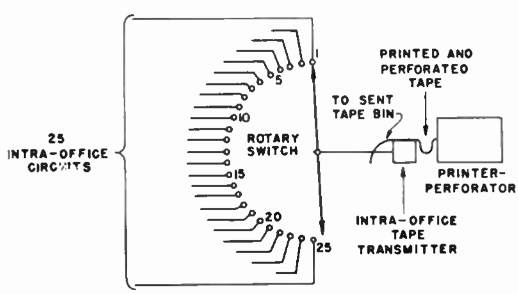


Figure 31. A push-button rotary switch arrangement for 25 destinations

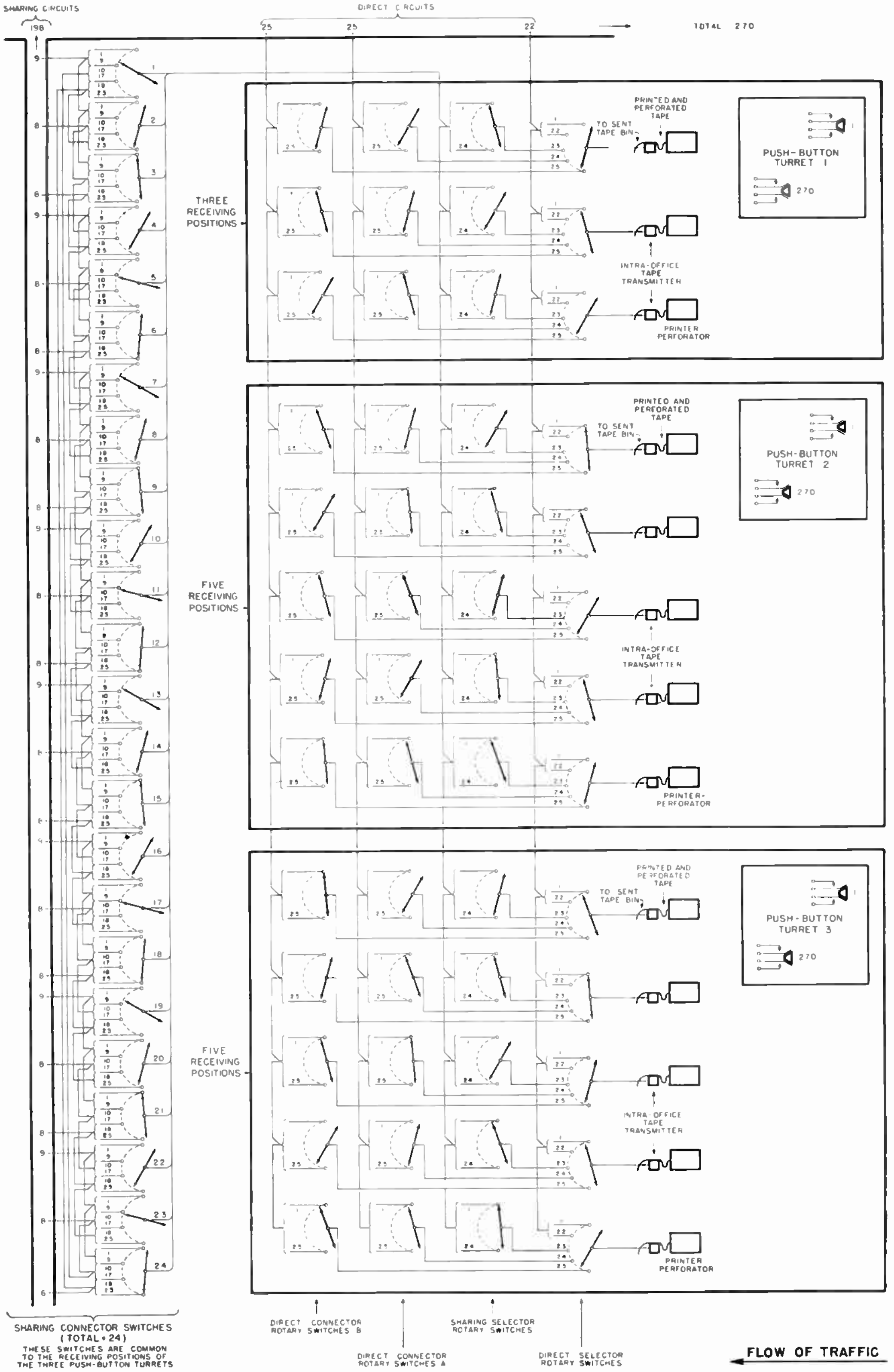


Figure 33. Direct and sharing rotary switch arrangement

Sharing Switching

Another method of providing switching facilities to a large number of destinations is to provide a group of rotary switches that are common to, or shared by, a group of transmitters. In this "sharing" switching arrangement, the number of common rotary switches provided for a group of transmitters is determined by the probability of simultaneous connections to various groups of destinations.

Economies were obtained in the push-button switching equipment used in the Philadelphia and Cincinnati offices by using a combination of "direct" and "sharing" switching arrangements. Each intra-office transmitter is provided with four rotary switches individual to that transmitter, by means of which it can be switched directly to 72 heavily loaded destinations, and can be switched to rotary switches, common to 11 or 13 transmitters, for reaching the other 198 destinations. The intra-office circuits for heavily loaded sending destinations are terminated on the stator positions of the rotary switches which are individual to the transmitters, while the intra-office circuits of the lightly loaded sending destinations are terminated on the stator positions of the sharing rotary switches. Figure 33 shows diagramatically the direct and sharing rotary switch arrangement for a group of 13 transmitters. This group of 13 transmitters would comprise two 5-position push-button switching turrets and one 3-position push-button turret. A similar arrangement is provided for groups of 11 transmitters which comprise two 3-position turrets and one 5-position turret.

The transmitter is connected to the rotor of the "direct selector" switch. The intra-office circuits of 22 destinations are connected to the first 22 positions of this switch. The 23rd position is connected to the "sharing selector" switch, the 24th position to the "A" direct connector switch and the 25th position to the "B" direct connector switch. Thus, through the direct selector switch and the direct connector switches "A" and "B", the intra-office transmitter can be switched to any one of 72 destinations through equipment which is individual to the transmitter. With these direct switching facilities, all 13 transmitters can be switched to the same destination or to 13 different destinations out of the 72. Sharing connector switches 1 to 24 are provided for the remaining 198 destinations, which gives a total of 270 destinations, the capacity of the push-button switching turrets.

The intra-office circuits of the destinations served by the sharing switches are connected to the stators of the sharing switches in the following manner. Starting at switch No. 1, nine destinations are connected to points 1 to 9 of the first three sharing switches. Then starting at switch No. 2, eight destinations are connected from points 10 to 17 of switches Nos. 2, 3 and 4. Starting at switch No. 3, eight more destinations are connected to points 18 to 25 of switches Nos. 3, 4 and 5. Starting at switch No. 4, nine more destinations are connected to points 1 to 9 of switches Nos. 4, 5 and 6. Starting at switch No. 5, eight more destinations are connected to points 10 to 17 of switches Nos. 5, 6 and 7. This pattern is continued throughout the 24 switches. This results in 200 destinations (only 198 are actually used) being connected to the 24 switches. It will be noted that each destination is connected to a point on three separate switches.

An intra-office transmitter is connected to one of the destinations terminated on the sharing switches by its associated "direct selector" switch advancing to the 23rd position, by its associated "sharing selector" switch advancing to the proper position to make connection with one of the "sharing connector" switches which serve that destination, and by that sharing connector switch advancing to the position to which the intra-office circuit of that destination is connected. All of these switches self-step simultaneously and their action is controlled by the destination push-button which is depressed in the push-button switching turret.

As has been previously stated, each destination is terminated on three separate sharing connector switches. If the first of these three sharing connector switches is busy with a connection from another intra-office transmitter, the "sharing selector" switch associated with the intra-office transmitter being switched at the moment will advance to the position to pick up the next sharing connector switch that serves that destination. If that sharing connector switch should also be busy at the moment, the sharing selector switch will advance to the position that picks up the third sharing connector switch. If all three sharing connector switches that serve that destination happen to be busy at that moment, the two red "busy" lamps in the switching turret will glow, thus indicating to the switching clerk that all of the sharing equipment that serves that destination is busy at that moment, and it will be necessary for her to wait an interval of time before she again tries to establish that connection.

Since a large portion of the messages are switched to the 72 destinations served by direct switching, and since there are many opportunities for the transmitters to be switched to the 198 destinations served by the sharing switching, it is seldom that the red busy lamps light.

The equipment savings resulting from the use of sharing switching facilities is readily evident. If direct switching facilities only were used, it is apparent from Figure 32 that 11 rotary switches per intra-office transmitter would be required for switching to 265 destinations. The combination of direct and sharing switching as illustrated by Figure 33 results in slightly less than six rotary switches per intra-office transmitter being required for switching to 270 destinations for 13-transmitter groups, and slightly more than six rotary switches per transmitter for 11-transmitter groups.

THE AUTHOR: W. B. Blanton: For photograph and biography, see the January 1948 issue of the TECHNICAL REVIEW.

THE AUTHOR: F. L. Currie began work for the Western Union in Mississippi in 1917, and held various positions in the Commercial and Traffic Departments. In 1924, after graduating from the Milwaukee School of Engineering, he was transferred to the Engineering Department in New York. Since that time, he has been engaged in the development and design of both apparatus and circuits, the latter including circuits now used in subcenter switching systems, facsimile concentrators and reperforator switching systems. Mr. Currie is a member of the Equipment Research Division of the Development and Research Department.

Courtesy of United Air Lines

A modern reperforator switching installation for patron telegraph service. This is typical of the private wire systems to be described in the October issue of TECHNICAL REVIEW

A Telegraph Signal Analyzer

G. L. ERICKSON

A paper presented before the Winter General Meeting of the American Institute of Electrical Engineers in Pittsburgh, Pa., January 30, 1948.

The maintenance of accurate and reliable service over modern automatic telegraph circuits has necessitated the development of testing equipment capable of measuring transmission quality and detecting the causes for transmission irregularities. The telegraph signal analyzer described herein is a small, portable test set designed for this purpose and intended for field use on start-stop telegraph systems. It can be employed for straightaway testing with any form of transmitted text, and hence permits observations of distortion on working circuits carrying miscellaneous signals. The signal analyzer has also proved very useful in measuring the transmission capabilities of telegraph circuits and investigating the relative importance of the various components that make up the total distortion. Other applications include measurements to determine the condition of signals delivered by transmitting keyboards or regenerative repeaters, and tests to check the operation of receiving printers. Measurements are made conveniently, rapidly, and with a degree of accuracy which is ample for all field purposes.

When compared with other test equipment similar in purpose*, the outstanding feature of this telegraph signal analyzer is that it has been made very simple and very compact. The complete set is much smaller and lighter than a printer, and is also very much cheaper. As shown in the photograph of Figure 1, it is contained in a small metal box measuring 6 by 9 by 8 inches and weighing only 18 pounds. Two cords are provided for making connections to a source of 110-volt a-c power and to the circuit being tested. On the face of the panel there is a jack and a power outlet which permit a printer to be inserted in the same circuit. The panel also carries the analyzer unit, a power switch, and a second switch for starting and stopping the test. During the test period an observation is made of the distortion on every individual signal pulse as it is received. This has the distinct advantage of indicating the effect of occasional peaks, as well as the average distortion, and also makes it easy to identify troubles that occur systemmatically. The test results are presented in the form of a permanent record on a paper chart which may be analyzed in detail, measured quantitatively, and retained for future reference.

The printers most commonly used on start-stop telegraph circuits are the 65 word per minute teleprinters employing a 7-unit code, and the 60-speed teletypewriter with a 7.4-unit code. The signal analyzer can be used with either of these codes. It will be recalled that the basis of transmission in these systems is a set of seven pulses which are transmitted for each

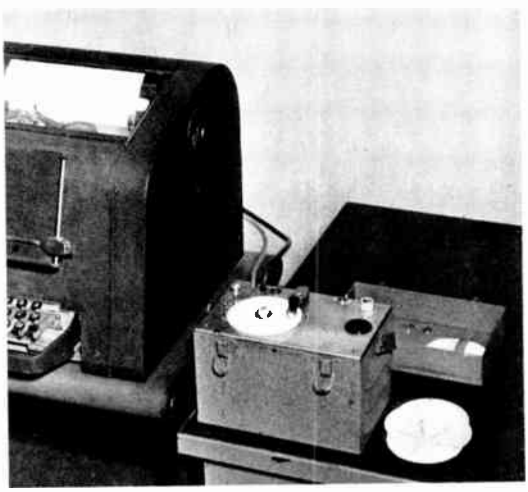


Figure 1. Signal analyzer

* See References.

character. A marking signal is used for the stop pulse transmitted during the idle condition. The first pulse of each character consists of a spacing signal, the start pulse, which is followed by five intelligence pulses. Each of the intelligence pulses may be either spacing or marking. The seventh pulse is the marking stop pulse again, which is transmitted until the start of the next character. From the signal diagram shown in Figure 2, it is evident that the only difference between the 7-unit code and the 7.4-unit code is found in the duration of the stop pulse. In the 7-unit code equal-length pulses are used, and each is of 22 milliseconds (.022 seconds) duration. The pulse lengths are exactly the same for the 7.4-unit system except that the stop pulse is somewhat longer and lasts for 31 milliseconds (.031 seconds). Of course, the distinction between the two codes exists only if signals are transmitted at top speed by some form of automatic machine. When a keyboard is operated manually, the stop pulses are seldom as short as this and they may be very much longer.

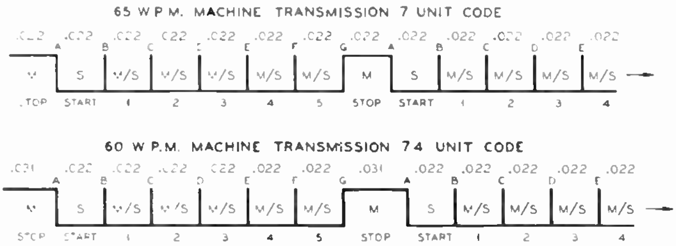


Figure 2. Telegraph signal codes

Signals are considered as perfect whenever they are timed as shown in the above diagram to the extent that each of the first six pulses is exactly 22 milliseconds long. The seven points marked A, B, C, D, E, F and G represent the instants at which signal transitions may be made from marking to spacing or vice versa for distortionless operation. The effect of signal distortion is to advance or retard one or more of the transition points so that it no longer occurs in its proper position with respect to transition A, the beginning of the start pulse.

To measure the distortion it is necessary to determine the amount that any transition has been shifted, remembering that time intervals must be measured from instant of the start transition. In the signal analyzer this has been done by establishing reference points 22 milliseconds apart beginning with the arrival of the start pulse, and by then recording with respect to these reference points all transitions as they occur. A circular paper chart is rotated through one complete revolution whenever a printer character is received, and each signal transition in the code is caused to make a mark on the paper. The departure of these marks from radial lines printed on the chart at 22-millisecond intervals is a measure of the distortion.

The operating principle of the analyzer mechanism will be explained with the aid of Figure 3. A start-stop shaft is driven through a slip clutch by a 60-cycle synchronous motor geared down to 420 rpm.

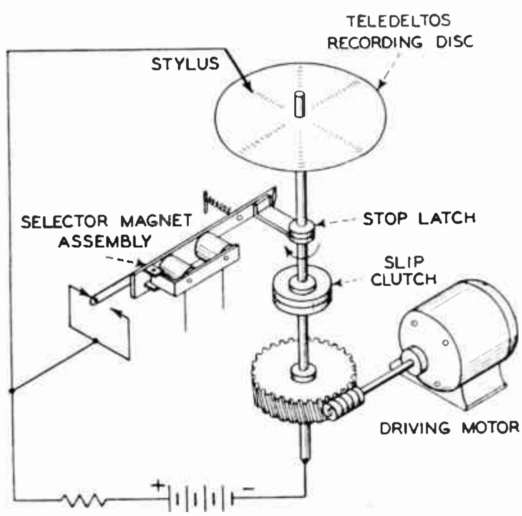


Figure 3. Simplified sketch of mechanism

The chart is a four-inch disc of Teledeltos recording paper fastened to a small hub at the end of this shaft. When the selector magnet is energized by a marking stop pulse, the stop latch is engaged to prevent the shaft from turning. As soon as a spacing start pulse arrives, the magnet releases the latch and the shaft is free to rotate while the code pulses for one character are being received. The stop pulse at the end of the character brings the shaft to rest again after the chart has made one revolution.

Meanwhile a stylus in contact with the surface of the disc has been energized by the signals and has recorded a series of black marks on the paper. Because it is desired to record only the transitions between pulses, the recording voltage does not appear on the stylus as long as the tongue of the selector magnet is on either its spacing or its marking contact. But while the tongue is moving through the gap between contacts, the stylus receives a short impulse which lasts as long as the tongue is not touching either contact. As a result, current flows from the stylus to the Teledeltos paper during each signal transition and causes a small black mark to be recorded on its electrically-sensitive surface. The recording voltage, represented as a battery in the sketch, is supplied by a rectifier contained within the set.

The recording stylus is moved radially across the paper from the center of the disc to its outer edge by means of a mechanism not shown in the illustration. When it reaches the outer edge of the chart, the stylus returns to the center again and then continues to move slowly back and forth in this manner as long as the test is continued. In each trip across the chart, the signal transitions for approximately 190 characters are recorded. Signals may be recorded on one chart for a period of a half hour or longer.

When the signals received by the analyzer are of perfect quality, free from bias or other distortion, the alignment of the marks recorded on the chart will appear as shown in Figure 4. The seven radial lines printed on the chart at A, B, C, D,

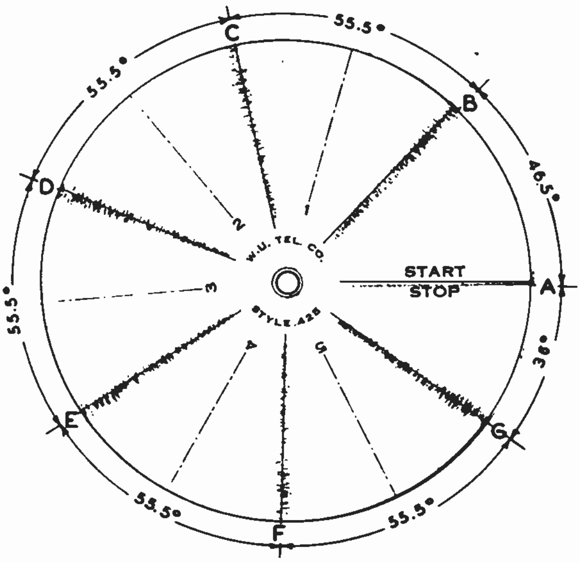


Figure 4. Analyzer chart with perfect signals

E, F and G are reference marks 22 milliseconds apart, corresponding to the signal transition points similarly labeled in Figure 2. Undistorted signals cause all of the marks made by the stylus to fall on these lines. With distortion present the transitions will occur earlier or later than their normal times, and will appear on the chart displaced to an extent determined by the amount of distortion. The dotted lines 1 to 5 represent the centers of the intelligence pulses and are helpful in estimating the amount of distortion loss.

The speed of the start-stop shaft in the analyzer is 420 rpm, which means that the chart is rotated through an angle of 55.5 degrees in 22 milliseconds when running freely without clutch slip. In Figure 4, it will be noted that this is the angle subtended by each of the five intelligence pulses on the chart. When the shaft has been stopped and then released again, a small amount of slip occurs in the clutch before the chart is accelerated to its free speed. The inertia of the rotating parts has been minimized by supporting the paper disc only at the center, but nevertheless the angle for the start pulse is necessarily reduced slightly. The clutch is so adjusted that the chart rotates 46.5 degrees during the start pulse. With a start pulse and five intelligence pulses totaling 324 degrees, an angle of 36 degrees remains for the stop pulse. This is sufficient to insure that the shaft is stopped at the end of each complete revolution even though the stop pulse occurs as much as 14.3 milliseconds late, corresponding to a signal distortion of 65 per cent.

In discussing the effects of signal distortion, it will be of interest to consider the case of bias. Bias is a systemmatic distortion that displaces every signal transition with respect to its position in undistorted signals. All of the mark-to-space transitions are uniformly shifted in one direction and all of the space-to-mark transitions in the opposite direction. With spacing bias, the directions are such as to lengthen the spacing pulses and shorten the marking pulses. With marking bias, the marking pulses are lengthened at the expense of the spacing. In either case, the net effect of bias in a start-stop system shows up only on the space-to-mark transitions and never on the mark-to-space transitions. The reason for this is made evident by Figure 5, which shows the signal code combination for the letter "Y" with either (A) spacing or (B) marking bias. It will be noted that transitions C and E are always properly timed with respect to transition A, the beginning of the start pulse. This is because A, C and E are all mark-to-space transitions and consequently they have all been displaced by the bias exactly the same amount. Hence the effective displacement of C and E is zero. On the other hand, the space-to-mark transitions at B, D and F are uniformly retarded from their proper times of occurrence by spacing bias, and advanced by marking bias.

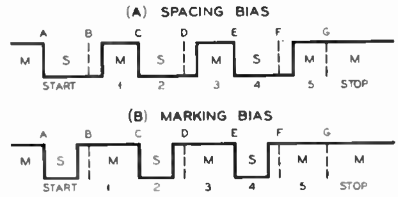
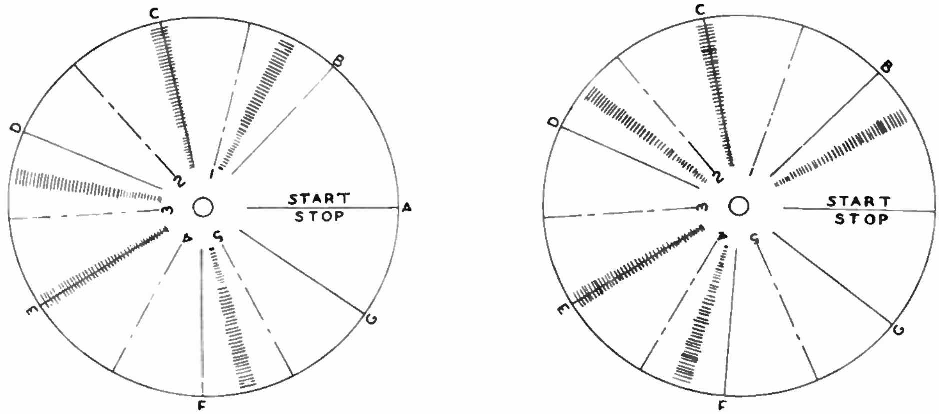


Figure 5. Biased signals, letter "Y"

The appearance of the analyzer charts for the signals described above is shown in Figure 6. The marks recorded at C and E fall on the reference lines in both charts. Those at B, D and F are late in (A) and early in (B). Since the marks fall midway between the reference lines and the pulse center lines, they indicate a bias loss of about 25 percent. Note that there is no transition recorded at G because the fifth intelligence pulse is marking, the same as the stop pulse, for this particular signal.

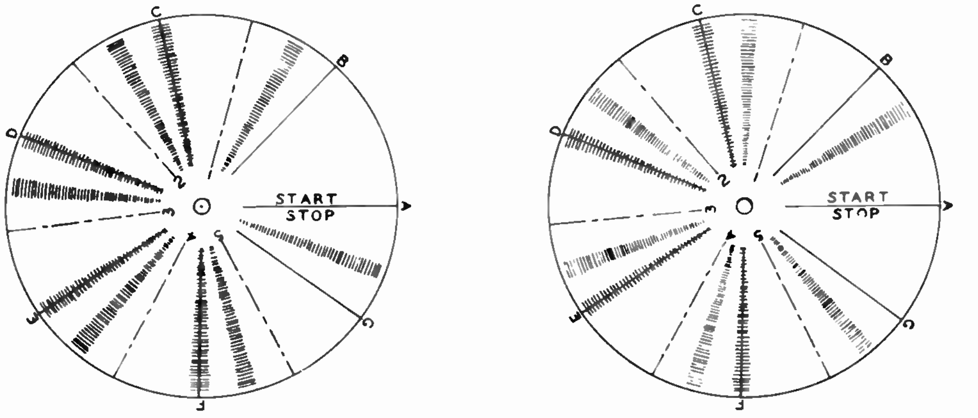
Figure 7 shows charts obtained with the same amount of bias when transmitting miscellaneous signals. At each of the reference points, transitions occur in some of the code combinations and are absent from others. Whenever transitions do occur at B and G, they must always be from



(A) 25% Spacing Bias

(B) 25% Marking Bias

Figure 6. Bias charts, letter "Y"



(A) 25% Spacing Bias

(B) 25% Marking Bias

Figure 7. Bias charts, miscellaneous signals

spacing to marking and hence they are all shifted by the amount of the bias. At C, D, E and F, transitions can occur in either direction between spacing and marking, and therefore some appear correctly timed while others are displaced by the bias.

Fortuitous distortion causes the signal transitions to be shifted about in a random fashion so that some transitions are advanced and others are retarded in varying degrees. This causes the marks recorded on the chart to be dispersed in the manner shown by Figure 8. Usually the distortion experienced on a telegraph circuit is due to a combination of bias and fortuitous effects. Then the chart resembles one of those in Figure 7, but includes also the erratic characteristics of Figure 8. The two components are easily separated because the dispersal of the marks at C, D, E and F is caused by both effects, while that at B and G is due to fortuitous distortion alone. When characteristic distortion is also present, it can be detected by comparing the results of measurements using different recurring test signals.

Examples of charts obtained when using the signal analyzer to check the output of transmitting equipment are given in Figures 9, 10, and 11. In general when there is some irregularity in a sending mechanism, whether it be a printer keyboard, tape transmitter or regenerative repeater, the defect will be manifest as a systematic displacement of certain transitions. The analyzer provides a convenient means for determining the cause of the trouble and following the effect of steps taken to correct it.

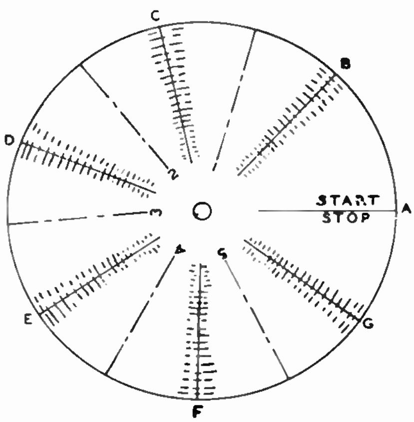


Figure 8. Fortuitous distortion

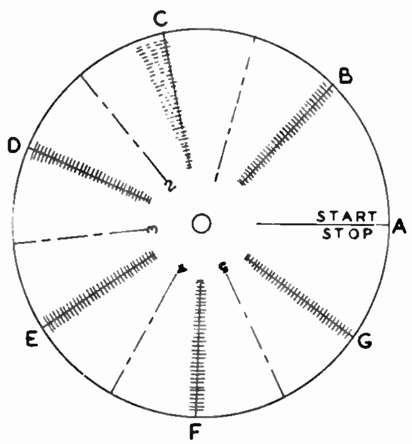
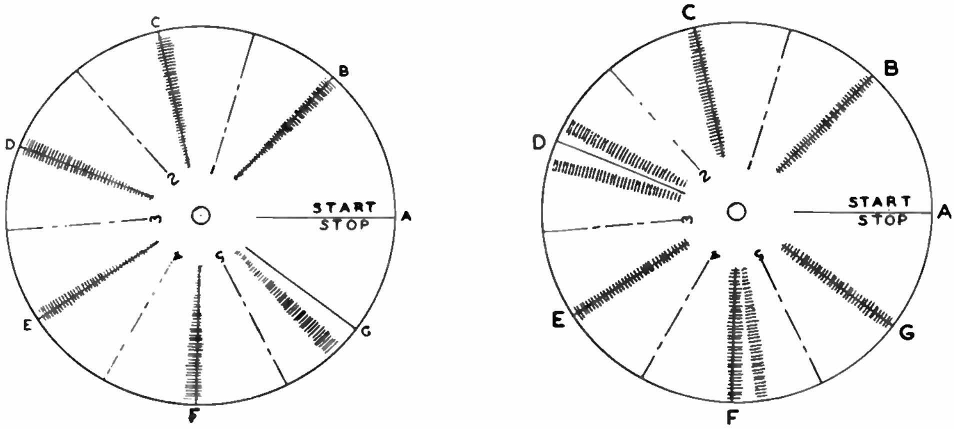


Figure 9. Defective commutator segment



(A) Defective Stop Contact

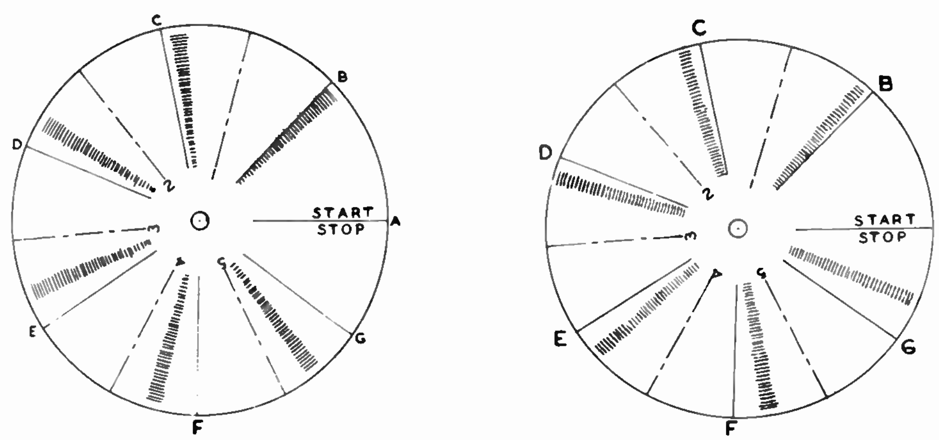
(B) Contact Overlap

Figure 10. Tests of cam transmitters

In a commutator type transmitter, the signal pulses are sent from a segmented distributor by a rotating brush arm. If one segment becomes worn or dirty, the sending brush will fail to make a positive contact and the signal will be mutilated every time a marking pulse is applied to that segment. Figure 9 shows an example in which the erratic behavior of transition C indicates that the segment for pulse No. 2 is defective.

In a cam type transmitter, the pulses are sent from a set of contacts which are operated in sequence by rotating cams. The signal transitions will be improperly timed if a cam is defective or if a contact spring is out of adjustment. One example of this is illustrated in Figure 10 (A), where the displacement of transition G shows that the start-stop contact always closes earlier than normal. If the start-stop contact opens incorrectly, it will advance or retard the start transition and cause all subsequent transitions to be out of place by a fixed amount.

When irregularities are present in the cams or contacts that transmit the intelligence pulses, the marks recorded on the chart by miscellaneous signals will usually overlap in the manner shown by Figure 10 (B). The double line of marks at D indicates that transitions produced by the opening of contact No. 2 are shifted in one direction, while transitions due to the closing of contact No. 3 are shifted in the opposite direction. The marks at F consist



(A) Sender Too Fast

(B) Sender Too Slow

Figure 11. Tests of transmitter speed

of one group perfectly aligned and a second group occurring later than normal. Obviously, contact No. 4 is opening too late or contact No. 5 is closing too late. The exact nature of the trouble is readily determined by observing recurring signals, such as the letter "Y" as compared with the letter "R".

If the speed of a transmitter is too fast or too slow, the displacement of transitions will be as shown in Figures 11 (A) and 11 (B) respectively. When the speed is too fast the transitions occur early and the marks are advanced by an amount which becomes progressively greater around the chart. When the speed is too slow the marks are retarded similarly.

The operation of a receiving printer can be checked with the signal analyzer by comparing the signal quality revealed by a test chart with the printing range actually obtainable. A defective printing mechanism is indicated whenever the printer fails to yield the expected range. A printer in good condition gives a range of about 80 points with perfect signals. The loss of range due to signal distortion is estimated by observing the transition displacement angle on the chart and comparing it with the 55.5-degree angle between reference lines, which represents one pulse or 100 points of range. It has been found possible to predict the loss within five points by visual inspection alone. Greater accuracy can be secured if a protractor or specially graduated scale is employed to measure the displacement angle.

Of course, the analyzer mechanism itself must be properly adjusted if a high degree of accuracy in the distortion measurements is required. However, the device is exceptionally rugged and dependable and requires little maintenance attention once the necessary adjustments have been correctly made. Since the analyzer will always reveal its own imperfections, it is only necessary to check its performance from time to time by driving it with a source of perfect signals.

Only a few of the more common circuit and equipment troubles have been illustrated by the chart records presented in the foregoing discussion. The telegraph signal analyzer can be relied upon to disclose any type of signal impairment experienced on start-stop telegraph circuits. In some cases, careful study and analysis may be required to diagnose obscure troubles and determine the cause of transmission irregularities revealed by a test chart. Nevertheless, it has been found that operating personnel quickly learn to recognize troubles of the types that are frequently encountered. By comparing test results with sample charts illustrating typical examples, they are soon able to use the signal analyzer to good advantage. When the analyzer is employed to check circuit operation periodically, incipient troubles can be detected and corrected before printing failure occurs, thus assuring a high standard of transmission quality and continuity.

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