WESTERN UNION Technical Review

Electronic Regenerator

•

Switching to Canada

•

Foot-Operated Printer

•

Radio Relay Maintenance

•

Inventory System

•

Vacuum Tube Reliability

VOL. 5 NO. 4
OCTOBER 1951

WESTERN UNION

Technical Review

VOLUME 5
NUMBER 4

Presenting Developments in Record Communications and Published Primarily for Western Union's Supervisory, Maintenance and Engineering Personnel.

OCTOBER
1951

CONTENTS

Published Quarterly by

THE WESTERN UNION TELEGRAPH COMPANY

COMMITTEE ON TECHNICAL PUBLICATION

Address all communications to THE WESTERN UNION TELEGRAPH CO., COMMITTEE ON TECHNICAL PUBLICATION, 60 HUDSON ST., NEW YORK 13, N. Y.

Subscriptions $1.50 per year — Printed in U.S.A.

Electronic Regeneration of Teleprinter Signals

H. F. WILDER

An understanding of the operation of the electronic signal regenerator will be facilitated by a review of the principles of start-stop signaling and of one electromechanical device now used to decrease the fortuitous distortion on long circuits. Start-stop signals are semisynchronous; sufficiently good exactness of phase between the sending and receiving machines is maintained only for the time of duration of a single character after which a rest period must be provided to permit the entire system to come to a stop in preparation for the next character. Teleprinter signaling is thus differentiated from the synchronous systems, such as the multiplex, where each signal transition contributes to the continuous maintenance of exact phase.

The code containing the intelligence to be transmitted is common to both systems and consists of the various combinations of five unit length impulses of either spacing or marking polarity of the sending battery. In a synchronous system these arrive without interruption and are separated into groups of five units by a synchronized commutator. In an asynchronous system it is insufficient to transmit the five unit groups in isolated bursts

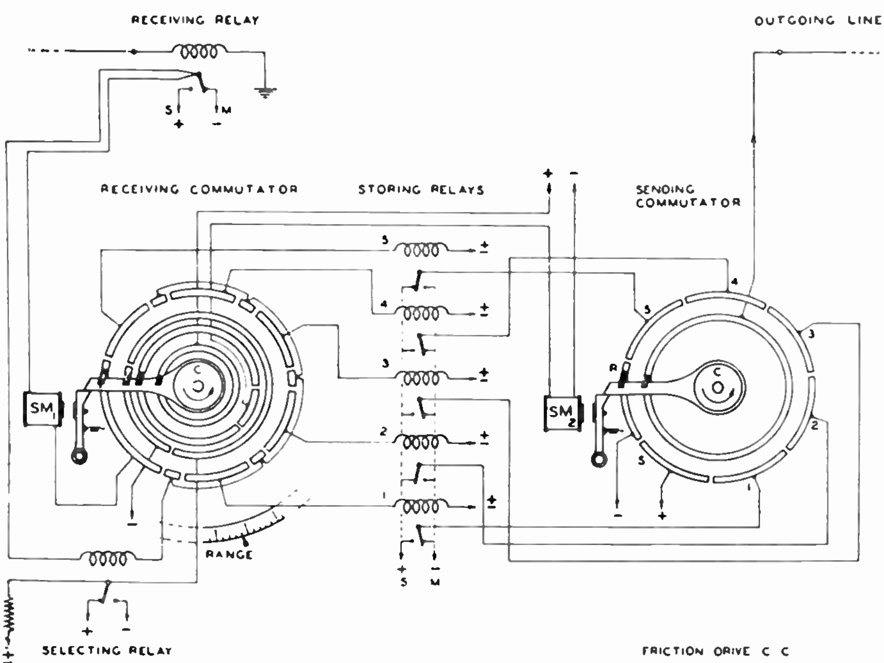

Figure 1. Theory of the mechanical teleprinter signal regenerator

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followed by a rest period, for in some characters the first intelligence impulse is of the same polarity as the rest interval. The additional impulse required to initiate operation of the receiving device is created by a signal transition from the rest condition potential to the opposite pole and precedes the five intelligence impulses. Neither the rest nor this start impulse can be made shorter than unit length, if transmission on long lines is not to be impaired.

Though the start or synchronizing transition of the polar teleprinter signal is not inherently susceptible to the influence of random interfering line currents, phase shift of this transition is doubly damaging on a teleprinter circuit, as the selecting mechanism of the receiving printer is set in motion by the start signal and not by the phase of the average signal as in the synchronous systems. A transient disturbing current that advances the start-signal transition in time may well have its counterpart appear in the intelligence group and there delay a signal impulse by an equal amount to cause selection to be made close to the edge of the impulse. Therefore, when the interference level is the limiting factor in circuit operation, the teleprinter system requires just as careful engineering attention as a synchronous system of twice the transmission speed.

If fortuitous distortion is present in each of the separate lines of a long teleprinter circuit, the effects are accumulative when the lines are coupled by simple relays. Before the shifting in time of the signal transitions becomes sufficient to impair accuracy of service, signal regenerators are inserted at one or more of the repeater points. The basis of regeneration is a process of signal scanning by accurately timed impulses that are independent of the variations in arrival time of the signal impulses. From these observations made in the vicinity of the center of each impulse a new signal is created and retransmitted free of fortuitous distortion.

Mechanical Regeneration

The theory of a mechanical start-stop signal regenerator is shown in Figure 1. The system is at rest having completed the regeneration of the letter *F*. When released by their latches, the brush arms are rotated by the friction drives *CC* on the continuously rotating constant-speed shafts. Upon reception of a start-signal transition, the receiving-relay armature moves to the spacing contact *S*, energizing the start magnet *SM*-1 through the outer pair of brushes and releasing the brush arm on the receiving commutator shaft. As this arm moves counterclockwise, the signal polarity appearing on the tongue of the receiving relay is set up periodically on the selecting relay through connection to the shorter pickup segments. Immediately following signal selection the longer segments successively connect the selecting relay armature to the coils of the five storing relays. These relays firmly bank in the selection position. Only the intelligence impulses are scanned. If the speed of rotation of the brush arm is approximately that of the distant transmitter, the receiving relay will be on its marking contact, corresponding to the rest polarity, when the arm reaches the latch at the end of one revolution, and it will again come to rest.

At some time before the brush arm completes its revolution, a second pair of brushes is arranged to complete the energizing circuit of the unlatching magnet *SM*-2 to release the sending commutator brush arm. The latter continues to send the rest polarity momentarily until it passes over the segment *S* permanently connected to spacing telegraph battery to inject the start-signal impulse that must always precede the intelligence group. Further rotation of the arm connects the storing relays to the outgoing line in correct sequence and time of duration and entirely removed from the influence of the receiving relay. In circuit regulating a teleprinter is connected to the output of the sending commutator while a prearranged test signal is being received and the receiving commutator oriented until limits on the range scale are found within which the retransmitted signals are correct. The center of this angle or range is the center of the average of all the intelligence impulses; correct signal selection is most probable with this angular position of the scanning segments. This adjustment also compensates for the time interval required to accelerate the brush to shaft speed and for any change in clutch operation that may have previously occurred.

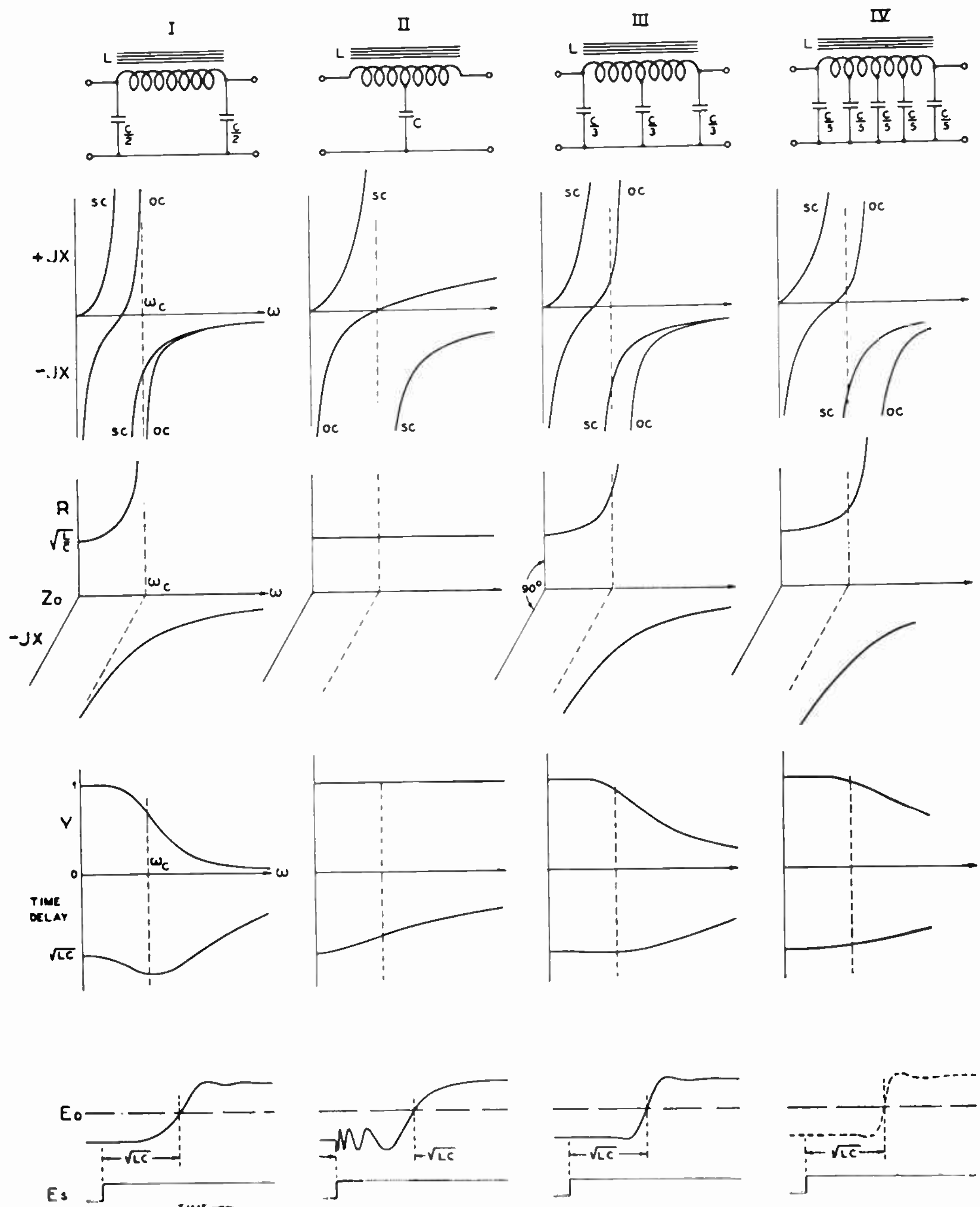


Figure 2. Frequency characteristics of delay network sections

The Timing Network

Perhaps the most interesting problem in the development of the electronic regenerator was the choice of a scanning-impulse generator. Two rather incompatible requirements are presented. To insure good signal quality it is desirable that the timing of these impulses be of such an order that the last scanning impulse in any train shall not deviate from a standard time taken with the start-signal transition as the origin by more than one-half of one percent. Following the production of a single train of impulses, the generator must come to rest immediately if a retardation in the generation of a second train is not to result. And, being part of a start-stop system, the generator always must come up to speed, as it were, regardless of the time that it may have been at rest. Simple oscillators of the specified frequency stability do not lend themselves to this purpose because of the transients which cushion the change from rest to steady state and vice versa. However, the resonance phenomena that give the oscillator frequency stability may be retained in certain reactive filter networks, and in particular the uniform recurrent ladder structure, without the troublesome transient effects. With correct configuration these structures will provide time of delay between the mesh junctions dependent upon the choice of the network parameters, and, if a connection is effected between the junctions and electronic relays arranged to scan the received signal impulses, the rate of transmission of the regenerated signal will be a function of these time intervals.

For this application the network should not exhibit frequency discrimination. It should pass all frequency components in the driving force with a constant time of delay. Then the arrival curve will possess infinite slope (zero time of build-up), and the triggering of the vacuum-tube relays connected to the network junctions will occur precisely at times determined only by the reactive components of the network and independent of the regulation of the power supply voltage.

In general the attenuation and time of delay of reactive networks are not invariant with frequency. The midshunt or pi section of the familiar low-pass filter composed of a series inductance and shunt capacities will discriminate somewhat against frequencies even below cutoff, and the phase characteristic is so concave that frequencies near the cutoff are delayed considerably more than components approaching zero. Either frequency or delay distortion in the filter will act to decrease the slope of the transient response or arrival curve, and experiment soon confirmed the necessity for correcting the natural behavior of the network. Equalization with additional network components was objectionable because of the increased cost and space requirements, so attention was given to improving the inherent frequency characteristics of the delay-network sections. The steps leading to a section having a satisfactory transient response are shown in Figure 2.

Transient Response Shown

The actual coils had ferromagnetic cores and a Q of 20 at 45 cycles per second. With this Q the effects of dissipation are not excessive, and the output voltage at the terminating resistance is more than half that of the driving force. For comparison the total inductance and total capacity in each of the four cases calculated were held constant. The loci of the short- and open-circuit reactances were first computed and the square root of their product, the characteristic impedance Z_0 plotted immediately below. In the determination of the frequency response only one section of each type was considered. The section was assumed to be driven by a harmonic generator having an internal resistance equal in ohms to the nominal value of the characteristic impedance of the network and to be similarly terminated. This is the situation in the regenerator, except that several sections are in cascade. The frequency response Y is the locus of the IR drop across the terminating resistance versus frequency and is an admittance function.

The time of delay has been plotted directly below the transfer admittance, and at the origin this time in seconds is the square root of the oscillation constant, *LC*. With each increase in frequency the delay was obtained as the quotient of the angle of current lag in radians and the angular frequency *w*. In all the loci having the angular frequency as abscissas the ordinate *wc*, the theoretical cutoff frequency of section I has been drawn in for reference.

The transient response at the resistive termination of a cascade of six sections is shown at bottom of Figure 2. These are reproductions of oscillograms. The rectangular driving voltage is E_s. There has been no opportunity to confirm experimentally the transient response of section IV, and the dotted curve is only a prediction of its form.

Returning to the first filter studied. section I, an inspection shows that as long as the short- and open-circuit reactances are of opposite sign, the characteristic impedance, the impedance that would be seen looking into an infinite number of such sections in cascade, is a pure real quantity and has the appearance of a rapidly increasing resistance with frequency up to the cutoff point. In this range the network will absorb power from the generator and transfer this power to the resistance termination. Beyond the cutoff frequency the reactances are of like sign, the impedance becomes an imaginary quantity decreasing with frequency, and the power transmitted by the filter falls off rapidly. In the transmission range between zero and the cutoff frequency where the attenuation is low, the delay distortion is of particular interest, for in this region it has the major effect on the transient response. As the frequency of the driving force is increased, the delay is not constant but increases to a maximum at the cutoff frequency. In a section having a nominal time of delay of 22 milliseconds. for example, the cutoff frequency is 14.3 cycles, and components in this vicinity will be so delayed as to arrive nearly 180 degrees out of phase with respect to the components of the wave near zero. Beyond the cutoff frequency the delay time is of less interest, for the components beyond this point are so attenuated as to contribute very little to the slope of the arrival curve anyway. Because of this variation in transmission time the slope of the transient response continuously changes, being initially low as the low-frequency groups arrive first and only attaining maximum steepness after crossing the zero axis as the frequencies in the vicinity of cutoff finally make their appearance. This form of response is not ideal for the operation of devices responsive to the magnitude of the driving voltage, and it was recognized as similar to the arrival curve of a loaded submarine telegraph cable. Here in the receiving network a midseries or T section with mutual coupling between the coil arms is used as a distortion equalizer, and so similar sections as in section II at first were alternated with the pi sections with considerable success.

Because the characteristic impedance of section II is real and constant, the filter transmits power without discrimination at all frequencies from zero to infinity. Its phase characteristic. however. is convex and opposite to the concave characteristic of its alternate, the pi section. The slope of the phase characteristic, the delay time, is a decreasing function of frequency. A network composed of these sections alone is just as unsatisfactory as the midshunt section, because now the low frequencies are the last to contribute to the arrival curve, and the higher frequencies arrive early, with those approaching infinity having no delay at all. Alternation of the two types doubled the number of coils in the complete delay network.

If a center tap on the coil of the pi section is connected to a portion of the total shunt capacity, the new filter, section III, will be found to have a response equivalent to the alternate arrangement of sections I and II. From an inspection of the characteristics we find that the pole of the characteristic impedance has moved to a somewhat higher frequency and that the impedance locus is more nearly constant over a wider range of frequencies prior to the cutoff frequency. Consequently there is less loss in the transmission range because of increased coincidence with the terminating resistances. Of equal importance is the less rapid decline in the transfer admittance beyond the cutoff frequency of the pi section. The improvement in the locus of time delay is most prominent. Up to the new critical frequency the delay is constant, as the opposite characteristics of the combined filters mutually compensate, and the ultimate decrease is at a lower rate than either alone. This region beyond the cutoff is now of real importance, as the less attenuated higher frequencies are present in the transient response in more nearly correct phase with the lows and can contribute to its steepness. The transient response is the result of the synthesis of a wider band of frequencies of nearly simultaneous arrival time, so that its time of build-up is a minimum, and it is symmetrically located about the zero-voltage axis. This is the configuration used in the timing network of the electronic regenerator.

The network contains a minimum number of coils, and the timing of the individual sections may be adjusted easily in a step-by-step refinement of the nominal capacity values without disturbing the timing of the preceding sections. With trigger tubes that will operate on a voltage swing one-third that available at the terminating resistance, the variation in their operating time is well within the prescribed limits for a ten-percent change in the power-supply voltage and the ambient-temperature range ordinarily encountered. The precision of operation is comparable to that of a well-machined commutator with a synchronous motor-driven brush arm. The actual network consisted of six sections, each having a coil of 72 henrys and a total shunt capacity of 6.7 microfarads, preceded by a seventh section of half the delay. The time of delay of each larger section is 22 milliseconds; very closely the time length of a single teleprinter signal impulse. As measured at the terminating resistance, the time of build-up was 40 milliseconds, which becomes less at junctions nearer the input terminals. The network occupies a space of approximately one cubic foot.

One might theorize as to the response of a section similar to III in which the total shunt capacity is still further subdivided into a not impractical number of paths. Improvement would be evidenced by an increase in the steepness of the transient response. To confirm this speculation the frequency characteristics of such a filter, section IV, in Figure 2, were calculated. In the locus of the characteristic impedance Z_0 the critical frequency has moved still further to the right, and the real part of the impedance is more flat for a wider range of frequencies. Consequently both frequency characteristics are improved. Although the time of delay is somewhat more constant than that of section III the greater improvement appears in the frequency response Y, which is noticeably more constant.

Build-Up of Transient Response

In this article the time of build-up of the transient response has been assumed to be the time interval between the intersection of the timing wave with a prolongation of the steady-state levels before and after its occurrence. In filter sections having nearly constant time of delay, so that all components arrive in correct phase, the time of build-up will be inversely proportional to the bandwidth. Neither section III, nor particularly section IV, can be said to have definite frequencies of cutoff limiting the bandwidth. However, when it is recalled that after all the low frequencies furnish the bulk of the wave, it is interesting to establish arbitrarily such a limit for the three sections at a frequency 2.5 times the cutoff frequency of section I and then to compare the relation between the areas under the admittance loci and the times of build-up. The inverse ratio of the areas of section III and section I is 0.74, a rather close agreement with the experimentally determined times of build-up of 40 and 55 milliseconds respectively for timing networks composed of such sections alone. In like manner the inverse ratio of the areas under the Y loci of sections IV and III is 0.85, so that the predicted time of build-up for section IV becomes 85 percent of 40, or 34 milliseconds.

It seems, therefore, that continued subdivision of the shunt capacity will not increase the steepness of the timing wave reversal sufficiently to justify more numerous coil taps and capacitors. For timing purposes section IV is an adequate approach to the ideal section of constant attenuation and constant time of delay.

The Electronic Regenerator

The theory of the electronic teleprinter signal regenerator with a timing network of type-III delay sections is shown in Figure 3. The relays and regenerative circuits are in the rest condition. A series of voltages occurring in the system for the regeneration of the letter *F* is shown in the lower part of the figure. While the times t_0, t_1, and so on, represent instants

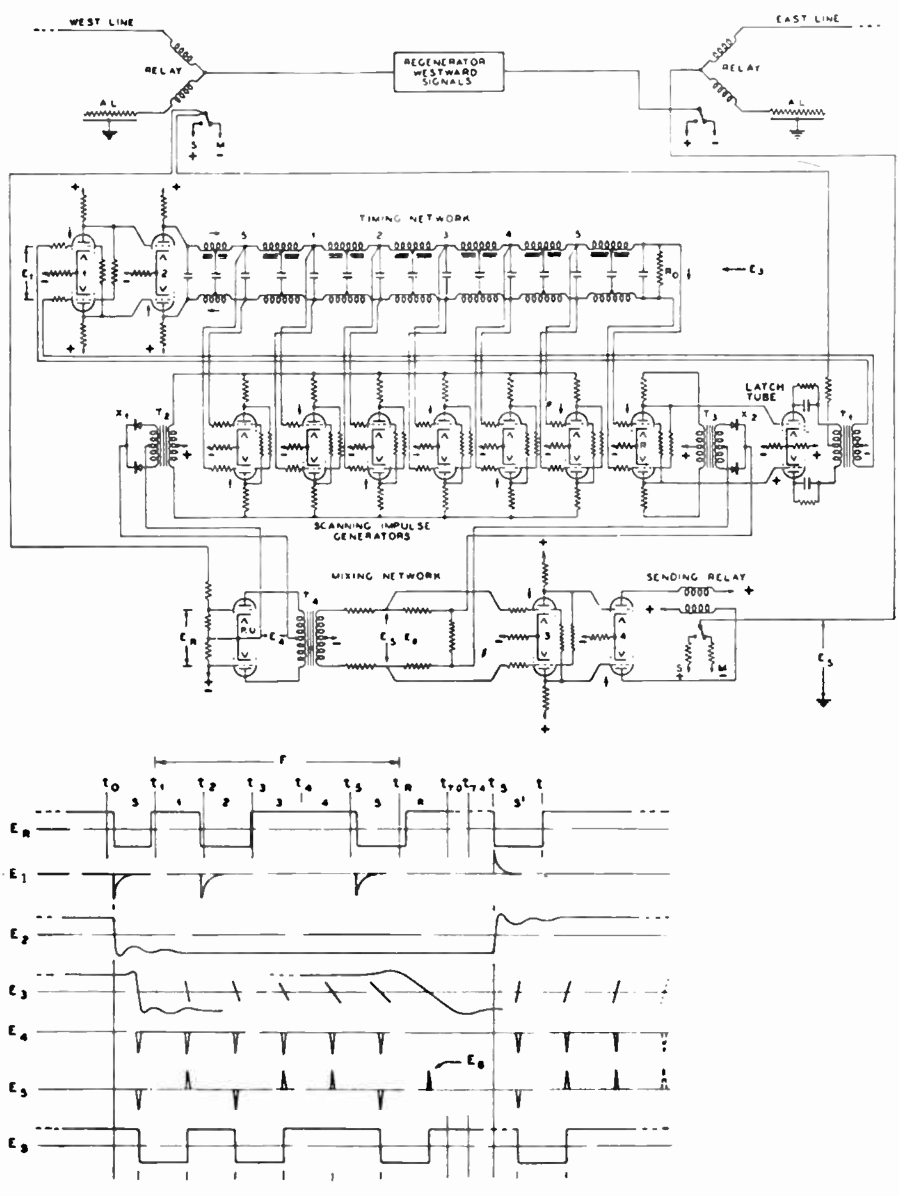


Figure 3. Theory of the electronic teleprinter signal regenerator

of signal transition in the absence of distortion, the existence of extraneous line currents has been assumed, and the signal transitions have been delayed or advanced to an extent not greatly different from that actually encountered in operation. In any event the theoretical limit is one-fourth the period of a single impulse.

In the regenerator twin-triode vacuum tubes are arranged in symmetrical push-pull circuits to eliminate polarity distortion. Pair 2 and their external plate resistors form a bridge circuit the diagonal of which is the impedance presented by the input terminals of the timing network. The plate circuits of the other low-power tube, pair 4, are the differentially wound coils of the sending relay. Telegraph battery potential is connected to the contacts of this relay, and from its armature the regenerated signal is applied to the apex of the duplexed east line. The remaining tubes are characterized by relatively low transfer conductance and high amplification factor. The pickup and latch tubes are simply electronic switches. Dependent upon the polarity of the control-grid voltage, these tubes present either an extremely high-plate-cathode resistance or a resistance comparable to the impedance of the circuits to which they are transformer coupled. The remaining nine tube pairs are connected in a balanced Eccles-Jordan trigger or flip-flop circuit. This circuit displays negative resistance between plate elements over a portion of the characteristic between the stable states, and, if a momentary displacement of the grid voltage occurs, the potential from plate to plate will instantly reverse. This relay characteristic will convert any general input waveform in the grid circuit above a definite minimum to a rectangular output wave of constant amplitude.

The nominal characteristic impedance of the timing network is equal to the resistance looking back into the bridge circuit of tube 2. Except for the first section of the network, which has half the delay of any one of the following six, each section has a time delay ($t_d = \sqrt{LC}$) equal to the time of duration of an undistorted signal impulse, or 21.98 milliseconds. Each inductor consists of two identical windings on a single silicon steel core so disposed that the cathode returns of the six scanning-impulse generators and the rest-interpolating tube are equipotential with a horizontal plane bisecting the network. A reversal of the network input potential appears across the junction S eleven milliseconds later and at the termination R_0 in a total elapsed time of 143 milliseconds.

Regeneration is begun by movement of the receiving-relay armature to the relay-spacing contact in response to the start impulse of a teleprinter character. As directed by the latch tube, a single reversal of potential is applied to the timing network by its driving tubes. With progression of the timing wave from junction to junction a series of six pickup impulses are generated successively activating the pickup tube scanning the incoming signal. The observed polarity of each signal impulse is at once transferred to the sending-relay drive tubes through the mixing network. Twenty-two milliseconds after the selection of the fifth intelligence impulse the timing-wave reversal appears across the resistance termination and triggers the R tube to interpolate an impulse of the rest polarity in the mixing network and simultaneously to make the latch tube again receptive to any future start signal.

A more detailed description must begin with an examination of the circuit conditions with the regenerator at rest. Now the receiving-relay armature is held on its negative contact by the marking line current received, and negative battery is applied to the center tap of the transformer T-1. A second circuit from the receiving-relay armature develops the incoming signal voltage Er in the grid circuit of the deenergized pickup tubes. As indicated by the small arrows adjacent to the tube elements, all trigger tubes are banked in the direction last operated; a condition that will be reversed after the regeneration of a complete character.

Constant Current from Battery

A constant current from positive battery flows through the external plate resistor associated with the upper tube of the driving pair to the right and along the upper windings of the inductors to the terminating resistance R_0. This current returns to negative battery through the lower windings and the lower and conducting drive tube. By reversing every other pair of wires connecting the scanning-impulse generators to the network junctions, these tubes are banked in alternate directions, and the sum of their plate currents entering the center tap of the primary of *T*-2 is divided equally between the winding halves. Consequently as the scanning-impulse generators are triggered successively, the differential primary current never exceeds unit amplitude, and hysteresis effects in the core material are minimized.

Just as a similarity will be recognized in the function of the latch tube and the brush-arm release mechanism of the mechanical distributor, so are the *R*-tube functions equivalent to the *R* segment on the sending commutator and the two paired segments on the outer rings of the receiving commutator which permit the start magnet circuit to be energized only after a complete revolution of the brush arm. If the upper *R* tube is conductive, the plate of the nonconducting lower tube will be at a very high positive potential and will by direct connection correspondingly elevate the grid of the lower latch tube. Upon reception of a teleprinter signal the center tap of *T*-1 is at once made positive as the receiving-relay armature contacts its spacing stop. Under the conditions established, however, a charging current to only the lower-resistance shunted condenser flows in the lower half of the primary winding of *T*-1. The transient secondary voltage is E_1. In the course of reception of the incoming signals negative potential is at times applied to the center of *T*-1, and in these intervals the condenser charge is dissipated in the shunting resistance. If correctly poled the transient E_1 causes tube 1 to trigger, reversing tube 2 and the potential across the timing network. Subsequent impulses of like polarity in E_1 may occur in the reception, two more are present in the letter *F*, but the initial impulse alone is of importance.

Although the continuity of the description perhaps is interrupted, an interesting operating condition now may be described. This occurs when either the west line is opened, or, if in circuit, regulating, the west transmitter sends steady spacing battery. In either case the marking battery applied to the apex of the west duplex line at the regenerator station causes a current to flow in the artificial line winding of the receiving relay, which holds the armature on the spacing contact and so applies positive battery to the midpoint of *T*-1. Now upon the arrival of the first timing wave at R_0 the conductivity of the latch tubes is interchanged while their plate circuits are energized positively and a starting impulse of local origin is created at E_1. A second timing wave is set up, and the process becomes continuous. A characteristic recurrent signal of six unit length impulses of spacing polarity followed by a half unit length marking impulse is transmitted to the east line; a signal that is easily interpreted by the distant east receiver as an open line west of a regenerative repeater.

Returning to the description, the *R* tube is also the circuit element that restores the sending relay to its marking contact after the transmission of the intelligence impulses. A reversal of the *R* tube in either direction produces a transient voltage in the secondary of *T*-3. These are introduced at the right of the mixing network after being made unidirectional by the rectifier X_2. The solid triangular impulse E_6 in the time diagram is of this origin. Consequently the regenerator cannot fail to send a rest signal.

Form of Timing-Wave Reversal

The waveform of the timing-wave reversal across the network input terminals is shown in E_2. Until this reversal has reached the termination R_0 and operated the *R* tube, another reversal cannot occur, and then only with reception of a second character of which S' is the start impulse. Although a gradual decrease in slope of the wave is apparent as successive meshes attenuate the higher-frequency components, symmetry is retained as depicted in E_3. The scanning-impulse generators are triggered at intervals of at first 11, and then 22 milliseconds. The sum of their plate currents in the differentially connected primary windings of T-2 is either zero or unit amplitude, depending upon whether an even or odd number of impulse generators are at any instant banked in like electrical position, and a change in net primary current occurs six times with the passage of a single timing wave. The resultant series of six alternately poled derived impulses of extremely short duration in the transformer secondary is rectified by X-1 and introduced, as E_4, between the cathode and plates of the pickup tubes.

Any one of these scanning impulses can produce current flow only in that half of the primary of T-4 associated with a pickup tube whose grid is positively displaced with respect to the common cathode connection. The polarity of the transformer secondary voltage is therefore dependent upon the polarity of the incoming signal Er at the instant of scanning. A proportion of the polarized pickup voltage appears as E_5 at the midpoints of the mixing network to position the sending-relay drive tubes and the sending relay. Es is a plot of the telegraph battery potential transmitted by the sending relay to the east line. It is a reproduction of the perfect signal originally transmitted, being composed of unit length impulses as determined by the timing network and independent of variation in received-signal transition time.

If signals are transmitted from a slowly operated keyboard, the rest impulse is considerably longer than unit length. Frequently, however, intelligence groups contained in a perforated tape are passed through a transmitter that automatically inserts a rest-and-start impulse between groups. In this case the rest impulse may be considerably shortened, if, under the most adverse effect of signal distortion, the preceding start impulse suffered delay in arrival and the start transition of the following character is advanced in time. Then the rest signal is not regenerated but must absorb the total phase shift of the two start impulses. In some systems a 42-percent extension in length of all rest impulses is made to absorb these phase shifts, but a reduction in the number of letters per minute transmitted must be accepted if the same maximum line frequency is retained.

Performance

To measure the telegraphic efficiency of the regenerator a chemically recording transmission testing machine was used. Transmission was continuous from a prepared tape, unless to simulate keyboard sending the transmitter was sporadically autostopped. To permit the time relation between any regenerated signal impulse of a character and its start impulse to be observed, the sending ring could be rotated through increments of one segment.

With this arrangement the timing of the network sections was adjusted successively until the maximum departure from normal of any regenerated impulse was less than two percent. By moving the segment sending the start impulse with respect to the segments sending the intelligence group, the minimum time of duration of an impulse required to insure correct selection by the pickup tubes was found to be 0.5 millisecond. The response of the latch tubes to the start signal was instantaneous, irrespective of how long the regenerator had been at rest.

Physical Aspects

The electronic regenerator has been developed as an adjunct to direct-point repeaters. Any one of a group of rack-mounted unidirectional units may be inserted quickly in a teleprinter circuit at a repeater station. Experience has shown that the regenerator will operate continuously for six months without attention.

H. F. Wilder's biography and picture appeared in the July 1951 Technical Review.

Switching to Canada at Gateway Cities

G. G. LIGHT

APPROXIMATELY 7,000 of the telegraph messages originating daily throughout the country are destined for Canada. Such messages are transmitted to designated Western Union "Gateway" offices where they are relayed over trunk circuits to either Canadian Pacific or Canadian National telegraph offices in Canadian gateway cities. The Canadian telegraph companies relay the messages to their destinations. Likewise, messages originating in Canada for points throughout this country are transmitted through Canadian gateway cities to Western Union gateway offices, whence they are relayed to their destinations.

In accordance with a negotiated agreement, the Western Union maintains a definite ratio in transmitting messages to the two Canadian telegraph companies. At the present time the ratio is 1 to 3, one message being transmitted to Canadian Pacific for each three transmitted to Canadian National.

Messages whose destinations are served by only one of the Canadian companies are classified as exclusive, since they must be handled by that company. Also, messages that contain check-line instructions to route to one of the companies are considered exclusive messages. Messages whose destinations are served by both of the companies, and therefore may be handled by either of them, are classified as nonexclusive. Since both exclusive and nonexclusive messages are included in the ratio agreement, it is obvious that the fixed ratio can be maintained only by appropriate routing of the nonexclusive messages. RQ's, BQ's, service notes, etc., are not included in the message quota for either company.

Prior to the introduction of reperforator switching, when all messages were manually relayed, quotas at gateway offices on messages transmitted to Canada were maintained manually through the use of tally sheets at a routing position. As each Canadian message passed through this position, reference was made to route charts and the tally sheet to determine over which Canadian circuit it should be transmitted. The routing was then marked on the message and entered on the tally sheet.

The conversion to reperforator switching at gateway offices presented no problem in handling incoming messages from Canada. The receiving sides of Canadian circuits could be terminated at printer-perforator receiving positions in the same manner as the receiving sides of other trunk circuits, thereby permitting the messages to be push-button switched to their proper destinations.

However, in handling messages for Canada, it was impractical, because of the complex routing problem and the necessity of maintaining the fixed ratio of messages transmitted to each of the two Canadian telegraph companies, to switch either automatically or by push-button means from the various domestic receiving positions directly into line sending positions terminating the sending sides of Canadian circuits. It would have been necessary to maintain at each push-button switching position voluminous Canadian routing information. While only a few trunks emanate from each Western Union gateway office to Canadian gateway cities, the route charts for Canadian switching are extensive due to the fact that a large number of destinations have to be listed, many of which must appear in French as well as in English. Besides the route charts, it would also have been necessary to provide at each push-button switching position an arrangement, preferably an electromechanical one, to enable the switching clerks to maintain the fixed message ratio.

In order to concentrate the routing functions and facilitate maintaining the fixed ratio by automatic means, secondary switching positions are provided for handling messages destined for Canada. Figure 1 is a block diagram showing the

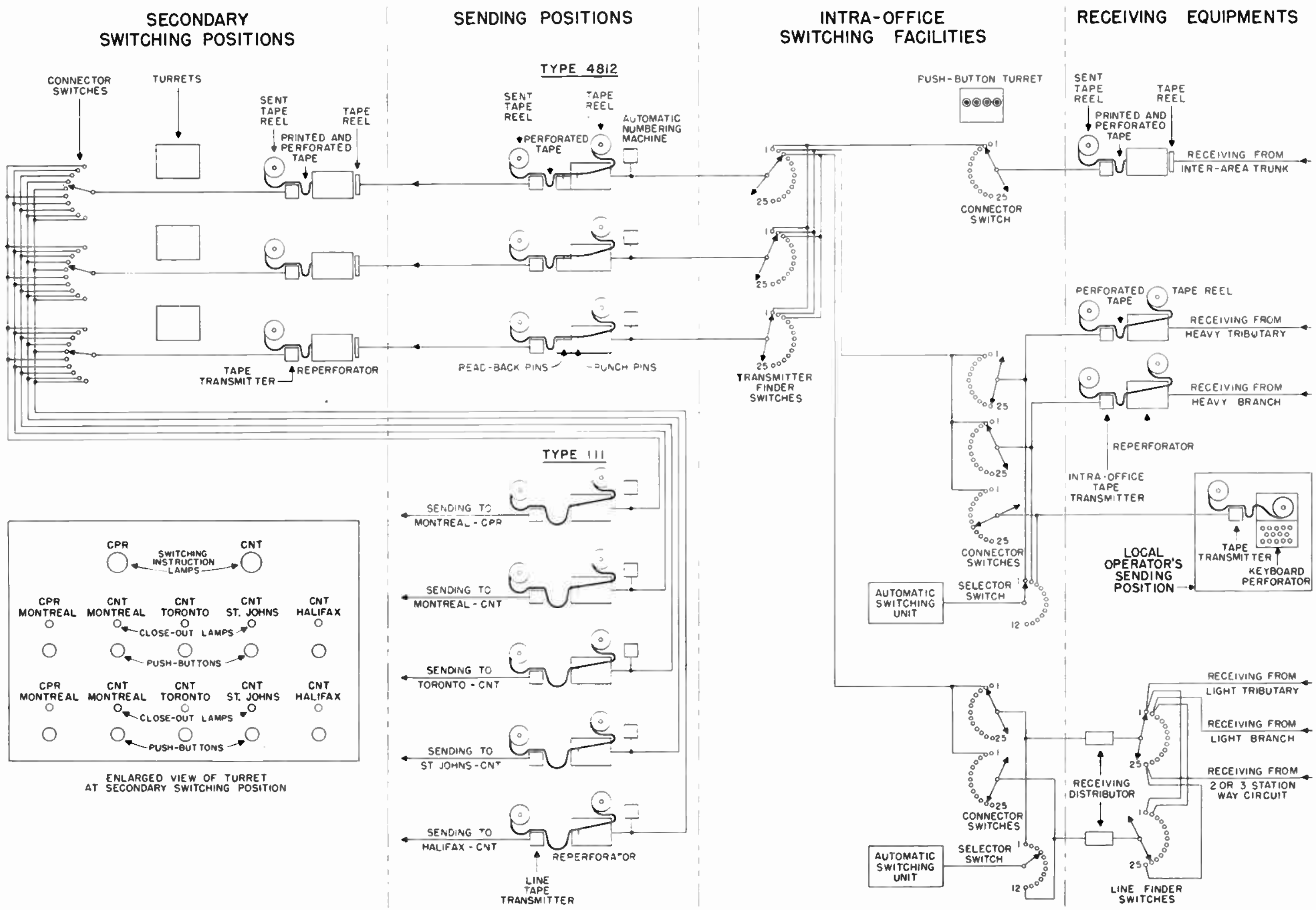


Figure 1. Secondary switching positions and their relation to the reperforator switching system of a Plan 21 office

secondary switching positions and their relation to the principal reperforator equipments in the Boston office, which is also typical of the Syracuse, Detroit, and Portland, Oregon gateway reperforator offices. Messages for Canada received in Boston over trunk circuits are switched cross-office into three Type 4812 Sending Positions by depressing a push button labeled CP (Canadian points) in the switching turrets of the main switching aisle. Messages for Canada that originate at branch offices and local operators' positions in Boston and at tributary offices within the Boston area are prefixed with the selection characters CP which cause them to be switched automatically into the Type 4812 Sending Positions. Each Canadian message switched into a Type 4812 Sending Position is prefixed with an intra-office sequence number by the automatic numbering machine at that position.

The Canadian messages flow from each of these sending positions to printer-perforators at the secondary switching positions. The successive messages, as received on the printer-perforators at the secondary switching positions are separated by eleven or twelve "blank" characters. These characters are automatically punched in the tape at the sending positions following the double-period termination of each message.

The printed-perforated tapes at the secondary switching positions feed into associated transmitters, each of which is controlled by a small individual switching turret. The layout and assignment of lamps and push buttons in these turrets are shown at the lower left of Figure 1. The top row of push buttons is utilized for switching all messages that are counted in the message quotas into Type 111 Sending Positions, the line sides of which terminate the sending legs of circuits to five Canadian gateway cities. The bottom row of push buttons is used for switching RQ's, BQ's, notes, etc., which are not included in the message quotas, into the same sending positions. Each message, including RQ's, BQ's and notes, switched into each of the Type 111 Sending Positions is prefixed with a channel sequence number by the automatic numbering machine at the sending position.

The two lamps designated CPR and CNT, at the top of each turret, are controlled automatically by a quota ratio indicator. One or the other of these lamps is lighted at all times, the lighted lamp indicating the appropriate route (CPR or CNT) to be selected for the next nonexclusive message. As each message (exclusive or nonexclusive) is switched, it is registered by the quota ratio indicator, which functions to alternate the condition of the two switching instruction lamps in such a manner as to maintain the desired ratio of messages switched to the two companies.

Operation

The transmitters at the secondary switching positions (Figure 2) step the blank characters separating messages until the first character of the next message appears over the pins of the transmitter. When this occurs, the transmitter stops stepping and the associated turret is conditioned for a switching operation. The switching clerk observes the destination of the message and notes whether the check line contains information to route specifically to one or the other of the Canadian telegraph companies, thus making it an exclusive message. Should CPR be indicated, the top left push button in the turret is depressed since the only outlet to CPR is the Montreal circuit. Should CNT be indicated, the switching clerk may have to refer to the route charts to determine over which of the four CNT circuits the message should be transmitted, after which she depresses the appropriate push button in the top row. In either event, the switching instruction lamps at the top of the turret are disregarded.

If the check line of the message does not contain specific routing information, the switching clerk refers to the route chart to determine whether the destination is served exclusively by one of the Canadian companies. Should this be the case, the message is an exclusive one and is switched to the appropriate circuit with no regard to the condition of the switching instruction lamps.

Messages for destinations served by both of the companies, and not containing specific routing information, are considered nonexclusive and are switched in accordance with the switching instruction lamps, each message being directed to the Canadian company whose switching instruction lamp is lighted at that time.

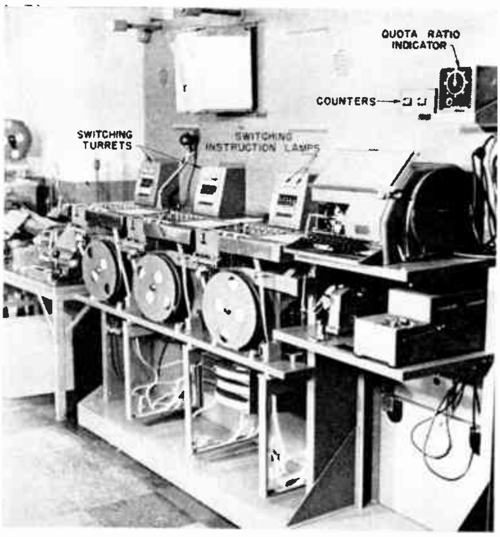


Figure 2. Secondary switching positions and auxiliary table

RQ's, BQ's, notes, etc., are switched to the appropriate Canadian circuits by means of the bottom row of push buttons, independently of the condition of the switching instruction lamps. Connections established by this row of push buttons are not registered by the quota ratio indicator, and consequently do not affect the condition of the switching instruction lamps.

A number sheet is provided at each of the secondary switching positions on which the switching clerk marks off the intra-office sequence number of each message switched and adds the call letters of the Canadian office to which it is switched.

Auxiliary Operations

Occasionally a message is received at the secondary switching positions which, for one of various reasons, requires rerouting to a destination other than those served by the secondary switching positions. It may also be necessary at times to produce a "hard copy" (tape gummed on a blank) of a message. An auxiliary table, shown to the right of the secondary switching positions in Figure 2, is provided for these purposes. The auxiliary table is equipped with a 2-B Teleprinter, a distributor-transmitter with an associated plug, and two jacks, one for reroutes and one for hard copies.

The series of "blank" characters separating each message received at the secondary switching positions permits messages requiring rerouting and those requiring a hard copy to be extracted from the tape. Such messages are placed in the distributor-transmitter at the auxiliary table and the associated plug then inserted in the reroute or hard copy jack. The reroute jack establishes connection to a circuit over which messages may be retransmitted to a receiving position in the main switching aisle from whence they are push-button switched to their proper destinations. This circuit includes an automatic numbering machine in order that a sequence number record may be maintained of such messages. The hard copy jack establishes connection to a tape teleprinter at a gumming position. This circuit also includes an automatic numbering machine.

The 2-B Teleprinter at the auxiliary table provides a copy of all transmissions from the table and also records the sequence number that is automatically prefixed to each message transmitted from there. The keyboard is used for transmitting any special instructions that may be necessary in connection with the handling of such messages.

Quota Ratio Indicator

Figure 3 shows the quota ratio indicator and the principal elements involved in switching messages at one of the secondary positions. The top five push buttons in the turret mark points 1 to 5 respectively on the 10th level of the connector switch. The bottom five push buttons mark points 6 to 10 respectively on the 10th level of the switch. Depressing any push button in the turret actuates the *switch initiate* relay. The operation of this relay causes the connector switch to step to its marked point and thereby establish through its levels 1 to 8 a potential connection from the transmitter at the secondary switching position to the appropriate sending position. The conversion from a potential connection to an actual connection is under the control of an allotter, which is utilized to assure that the transmitter at only one of the secondary switching positions may

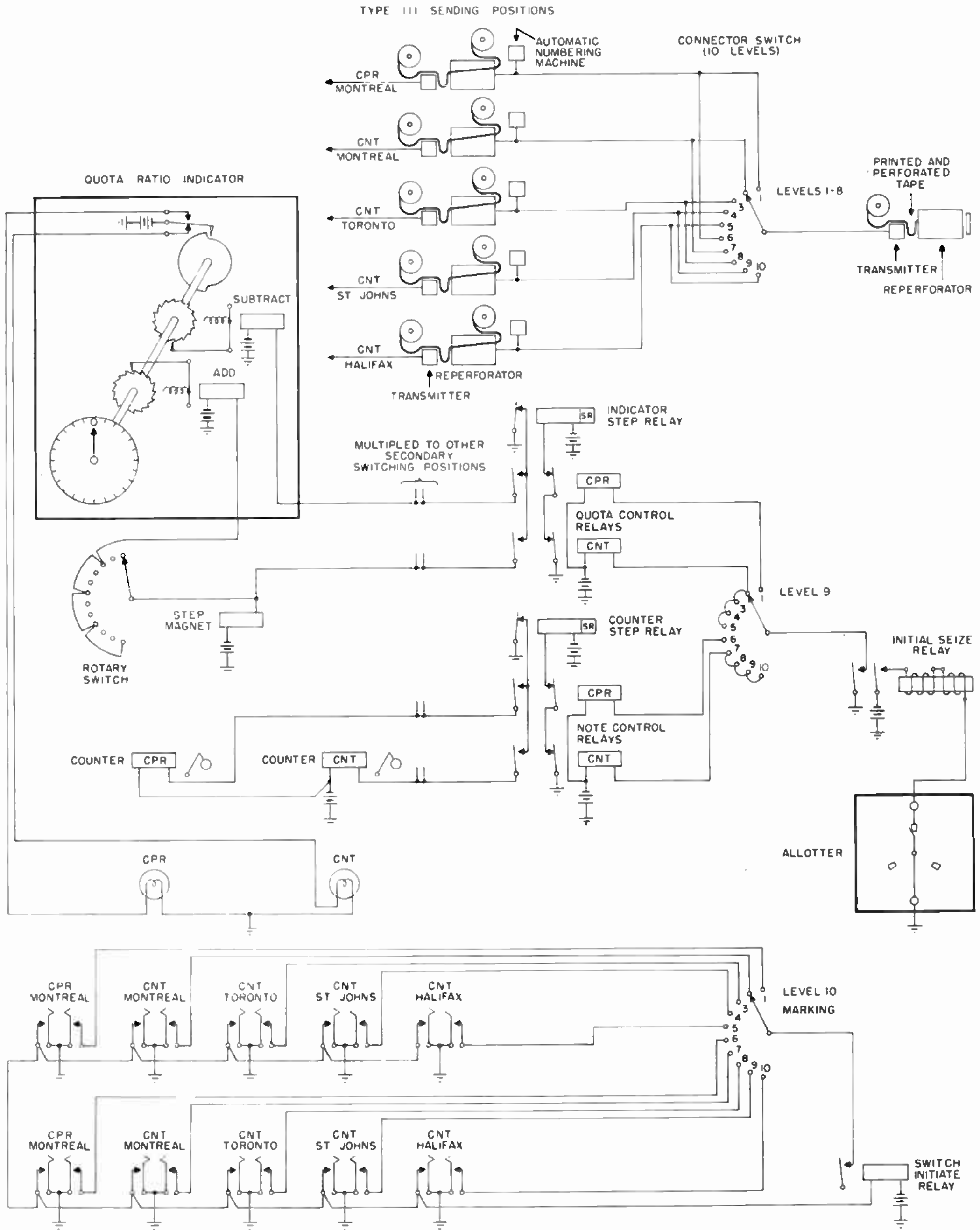


Figure 3. Partial circuit diagram of a secondary switching position

be connected to any particular sending position at any one time. When an actual connection is made, as indicated by the operation of the *initial seize* relay, a ground is applied to the rotor of the 9th level of the connector switch. The 9th level is used for controlling the quota ratio indicator when a message is switched by means of the top row of push buttons, and for controlling electromagnet operated counters when an RQ, BQ or note is switched by means of the bottom row of push buttons.

The quota ratio indicator consists of a dial with pointer, an add magnet, a subtract magnet and a main shaft on which are mounted two ratchets and a cam. Each time the add magnet is operated, one of the ratchets is engaged to cause the indicator to advance one step in a clockwise direction. Each time the subtract magnet is operated, the other ratchet is engaged to cause the indicator to move one step in a counterclockwise direction. The cam, which controls a set of contacts, is so cut that the CNT switching instruction lamp is lighted when the indicator is on zero or any point to the left of zero and the CPR lamp is lighted when the indicator is on any point to the right of zero.

Each time the top left push button in the turret is depressed to switch a message to CPR-Montreal, causing the connector switch to step to point 1, the ground subsequently applied to the 9th rotor of the switch by the *initial seize* relay is extended to the CPR *quota control* relay. The operation of this relay applies a short pulse, controlled by the release time of the slow-to-release *indicator step* relay, to the subtract magnet of the indicator. Each time any one of the other push buttons in the top row is depressed to switch a message to one of the four CNT circuits, causing the connector switch to step to point 2, 3, 4 or 5, the ground applied by the *initial seize* relay is extended to the CNT *quota control* relay. The operation of this relay does not apply a pulse directly to the add magnet of the indicator since three messages should be switched to CNT for each one switched to CPR. Instead, the short pulse is applied to the step magnet of a rotary switch, causing the switch to take one step and thereby register one message switched to CNT. As a second message is switched to CNT the rotary switch advances another step. When a third message is switched to CNT, the short pulse applied to the step magnet of the rotary switch is also extended through its rotor and stator to the add magnet of the indicator.

Thus, the quota ratio indicator is backstepped once each time a message is switched to CPR and is advanced one step on every third message switched to CNT. If all messages were nonexclusive and were switched in accordance with the switching instruction lamps, the indicator would move back and forth only from zero to the first position right of zero. Although the switching of exclusive messages via their indicated routes, with no regard to the switching instruction lamps, at times may cause the quota ratio indicator to be stepped several positions to the left or right of zero, it is soon returned to the zero position through the switching of nonexclusive messages in accordance with the switching instruction lamps.

Counting RQ's, BQ's and Notes

As previously stated, RQ's, BQ's, notes, etc., switched to the two Canadian companies by means of the bottom row of push buttons are not registered on the quota ratio indicator. They do, however, receive a sequence number from the automatic numbering machines at the Type 111 sending positions the same as messages switched into these positions by means of the top row of push buttons. The RQ's, BQ's, notes, etc., switched to each company are therefore counted in order that these readings may be subtracted from the totaled numbering machine readings on the circuits to each Canadian company to give the number of actual messages switched to each.

Each time the bottom left push button in the turret is depressed to switch an RQ, BQ or note to CPR-Montreal, causing the connector switch to step to point 6, the ground applied to the 9th rotor of the switch by the *initial seize* relay is extended to the CPR *note control* relay. The operation of this relay applies a short pulse, controlled by the release time of the slow-to-release *counter step* relay, to the CPR counter, thereby causing it to advance one digit. Each time any one of the other push buttons in the bottom row is depressed to switch an RQ, BQ or note to one of the four CNT circuits, causing the connector switch to step to point 7, 8, 9 or 10, the ground applied by the *initial seize* relay is extended to the CNT *note control* relay. The operation of this relay applies a short pulse to the CNT counter, thereby causing that counter to advance one digit.

The above described arrangement for switching to Canada, now being utilized in four gateway reperforator offices, has provided a marked improvement in operating efficiency and speed of service.

G. G. Light, Assistant Switching Development Engineer, joined the Equipment Research Division of Western Union in 1927 following his graduation from Virginia Polytechnic Institute. Except for some time spent in the development of repeaters and terminal sets, he has been engaged exclusively in the design of manual, semi-automatic and automatic switching systems. He did circuit development for all of the major leased reperforator switching systems prior to 1942, at which time he entered upon active military duty. He attained the rank of Major in the Signal Corps while discharging important responsibilities in connection with its research and development program for wire facilities. Since his return in 1946 he has been active in the post-war mechanization program, doing circuit development work for the nation-wide network of interconnected reperforator switching centers.

Foot-Operated Printer

R. STEENECK

USUALLY when a new product is developed, the engineer hopes that the demand for it will equal or even exceed that allegedly created by the "better mousetrap." In the case of the foot-operated printer, however, it is earnestly hoped that the demand will be very small indeed.

This printer was developed at the request of, and later presented to a patient at the Lyons, N. J., Veterans' Hospital, who is suffering from amytrophic lateral sclerosis, the same disease that crippled Lou Gehrig some years ago. This disease has left the patient unable to speak or use his hands, but fortunately he still possesses some slight control of the movement of his feet. Furthermore, his mind has obviously become even keener, as is often nature's way of compensating for a weakened physique. His interest along radio and electronic lines led him to visualize a printer that could be worked by the slight motion still possible with his feet. It took him some five hours to make clear his original idea to a devoted and patient sister, whose painstaking method of communicating with him was to recite the alphabet until he indicated by a sign that the required letter had been reached, then start from the beginning and repeat the alphabet until the next required letter was reached, and so on until a word had been put together laboriously, letter by letter.

The search for a company that could supply the desired equipment was long, but it ended at Western Union when the research engineers heard what was wanted. The Western Union Universal Ticker seemed to fill the bill. Here was a machine that printed on a tape from a typewheel that could be stepped, character by character, around the alphabet until the character required was in position to be printed. The stepping function could be halted and a separate magnet energized to print the letter or figure on the paper tape. Power could be supplied from a 6-volt rectifier and appropriate foot-switch circuits incorporated to control the letter selection and printing functions.

It was as simple as that, but there was one thing wrong; the patient, Mr. Frank Bamford, could not tell what letter was in position to be printed. Mr. Bamford of course was aware of this shortcoming, for in his original request he had asked that the machine be connected to an alphabet electric light sign he was having built at the hospital. This was not impossible to do, but would have necessitated a somewhat elaborate system for distributing the

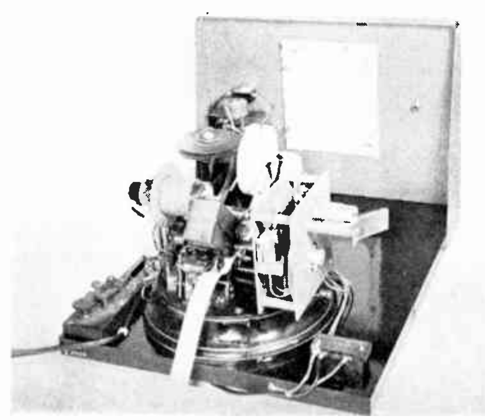


Figure 1. Arrangement of ticker, projector and control apparatus in cabinet

light circuits involved. It was decided to try a system by which each character, as it came into printing position, would be projected upon a screen. This was not too difficult a task; while the projection had to be accomplished in a short distance from lens to screen, on the other hand only one letter at a time needed to appear, hence much more distortion could be tolerated than in most projection systems. As it turned out, two rather inexpensive double convex lenses served very well as a projector lens assembly, and by projecting the letters in white, the problem of masking not only was eliminated but the area to be projected was held to a minimum. This made intense illumination possible with a standard automobile headlight bulb and a single condensing lens.

The projection transparency was made by photographing a dial drawn four times normal size in black on a white background. The resulting negative was then sandwiched between two sheets of lucite and attached to an extension of the typewheel shaft. The image was projected upon the rear surface of a small Translux screen after being once reflected from a front surfaced mirror. The mirror reflection was necessary to enable the ticker projector and control apparatus to be housed in a cabinet about the size of a small television receiver. In Figure 1 the cabinet cover is removed showing how the ticker, projector, and control apparatus were arranged.

It might be of interest to mention here that while Mr. Bamford was waiting for the printer to be assembled, another rather simple device was evolved to help him "talk" with his sister and the hospital staff. A chart similar to an office organization sheet was made, dividing the alphabet into three groups three times, as shown in Figure 2. The

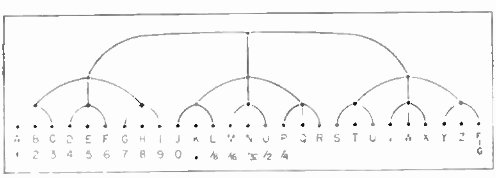


Figure 2. Alphabet chart. (When figures are desired, the path to "FIG" is first indicated)

patient was able to make different sounds indicating that the letter he wanted was in the left, the right, or the middle group. Three such group selections led directly to the desired letter, thus it was possible for the patient to spell out words using only three sounds per letter. The alphabet chart was made on soft copper in which selection lines were actually indented tracks, so that whoever was using the chart could make a letter selection by following the indented lines with the point of a pencil, without looking away from the patient. Since it was not possible for the latter clearly to discern the alphabet characters on the copper chart while it was being used, a large code chart was fastened on the wall to show coded directions for indicating the path to each letter, as follows:

A—l, l, l.	J—m, l, l.	S—r, l, l.
B—l, l, m.	K—m, l, m.	T—r, l, m.
C—l, l, r.	L—m, l, r.	U—r, l, r.
D—l, m, l.	M—m, m, l.	V—r, m, l.
E—l, m, m.	N—m, m, m.	W—r, m, m.
F—l, m, r.	O—m, m, r.	X—r, m, r.
G—l, r, l.	P—m, r, l.	Y—r, r, l.
H—l, r, m.	Q—m, r, m.	Z—r, r, m.
I—l, r, r.	R—m, r, r.	FIG—r, r, r.

The chart soon became superfluous, however, since Mr. Bamford had completely memorized it after the first week's use.

This simple system was used extensively by nurses, doctors, red cross workers, and others who visited the patient throughout the day, and although it produced no written record, the device resulted in a much faster method of communication than had been possible previously.

The entire printing operation of the communication device was controlled from a single microswitch built into the foot pedal of the wheel chair. Depressing the foot pedal started a motor-driven commutator stepping the typewheel at the rate of about two steps per second. As each character stepped into printing position, it was projected upon the screen, and when the desired letter or figure appeared the foot pedal was released. This instantly stopped the stepping motor and energized the print magnet, thus printing the character upon the tape. A second foot pedal is now being considered, which will be used to repeat characters and step out tape at the end of each message.

The ticker typewheel has two positions for shifting from letters to figures and back to letters, which function was left in the ticker. The shift of projection from letters to figures was accomplished by a magnetically operated shutter actuated from contacts attached to the ticker shift mechanisms. Figure 3 shows the printer in use and the first message to be transmitted by the patient. The speed of operation is slow, but it fits the time response of the patient. Most important, he can now personally and without assistance write any messages he may desire.

As there was no thought of putting this device into production, the development was not handled as routine, consequently no detailed drawings or specifications were made. An added deterrent to further production is the fact that the Universal Ticker used as a nucleus of the mechanism is an obsolete type that is out of production.

This problem in the field of personal communication was a departure from ordinary research projects, but the engineers tackled it with sympathy and enthusiasm, and the pleasure of solving the problem successfully has been their reward.

Figure 3. Foot-operated printer in use, and first message sent by the patient— "Now watch my smoke"

R. Steeneck, after graduating from Stevens Institute of Technology in 1926, joined the Telegraph Company on the staff of the Apparatus Engineer. In 1928 he transferred to the Engineer of Automatics to assist the Ticker group in the development of the newly established Teleregister service. In addition to his accomplishments in the Ticker field, he was responsible for the development of Western Union's line of Sport Timers. Before World War II he assisted in the development of the varioplex system; during the war he worked on the Navy Radar Contact Trainer project at the Company's Electronics Research Laboratory at Water Mill, L. I. Now associated with the Equipment Research Division, Mr. Steeneck is engaged in a phase of Western Union's facsimile developments. Producing the equipment described in this article was done during odd moments and is indicative of his versatility and readiness to be helpful. He is a member of the New York Electrical Society.

Maintenance of a Radio Relay System

G. B. WOODMAN

THE TECHNICAL ASPECTS of applying carrier current and microwave techniques to the transmission of telegrams over Western Union's experimental radio relay system have been covered in previous issues of TECHNICAL REVIEW.[1, 2] Problems of propagation and fading have been explored,[3] and other engineering features such as special power supplies[4] and factors affecting location of radio relay towers[5] have been described.

It is thought that the reader's interest in this subject may have been sufficiently aroused by those articles to cause him to wonder how such a system is maintained after it has been placed in service, as its towers are located from 17.3 to 54.5 miles apart, and are situated in generally remote areas at elevations of from 90 to 2900 feet. With that thought in mind, this paper has been prepared to deal with some of the problems encountered and the methods used in maintaining the Company's present radio relay system.

Training and Assignments

During the construction period it is necessary to plan for a force of maintainers that will be able to take over as soon as the system is ready for traffic. Each of these men must qualify for a Federal Communications Commission second-class radio telephone license. They must also be trained in general radio theory, as well as on the specific equipment used in the microwave system. Applicants for the position of maintainer are given a simple screening test; the required number of those who pass are then schooled for several weeks to prepare them in the above subjects. Upon successfully completing the theory courses, field training or "on the job" training is given.

An FCC requirement calls for continuous coverage at the radio beam terminals which in the system under discussion are located at New York, Philadelphia, Washington and Pittsburgh. This coverage is provided by detailing four men to each terminal on a 3-tour day, 7-day week basis.

Relay stations can be handled in a different manner as continuous coverage is not a requirement. Geographical locations and accessibility are major considerations in grouping the relay towers to be assigned to a single maintainer. At present two or three stations per man is the rule. For example, a glance at Figure 1 reveals a natural grouping of Allegheny, Jennerstown and Bakersville and these are actually assigned to one man. On the other hand, Mt. Holly and Blue Mountain are two of the most nearly inaccessible towers and are, therefore, the only ones assigned to another maintainer.

It is also necessary to consider the overall distances between towers and the driving time required to go from the tower at one end of the section to the tower at the other. This is illustrated by considering Little Savage, Sideling Hill and Gambrill Park, where the beam route is 79.9 miles but the driving distance is over 90 miles and involves passing through two small cities. The maintainer may be doing routine work at one end of his section when called upon to restore service, because of a failure, at the tower at the far end. Delay in getting to the station is reflected in the beam outage time, thus a more extended section would be impractical.

Transportation

Transportation for the maintainer to use in getting to his several stations is an important consideration. The type of vehicle which may be suitable under certain conditions is not necessarily the best for others, so here again consideration has to be given to the geographical locations and accessibility of the towers.

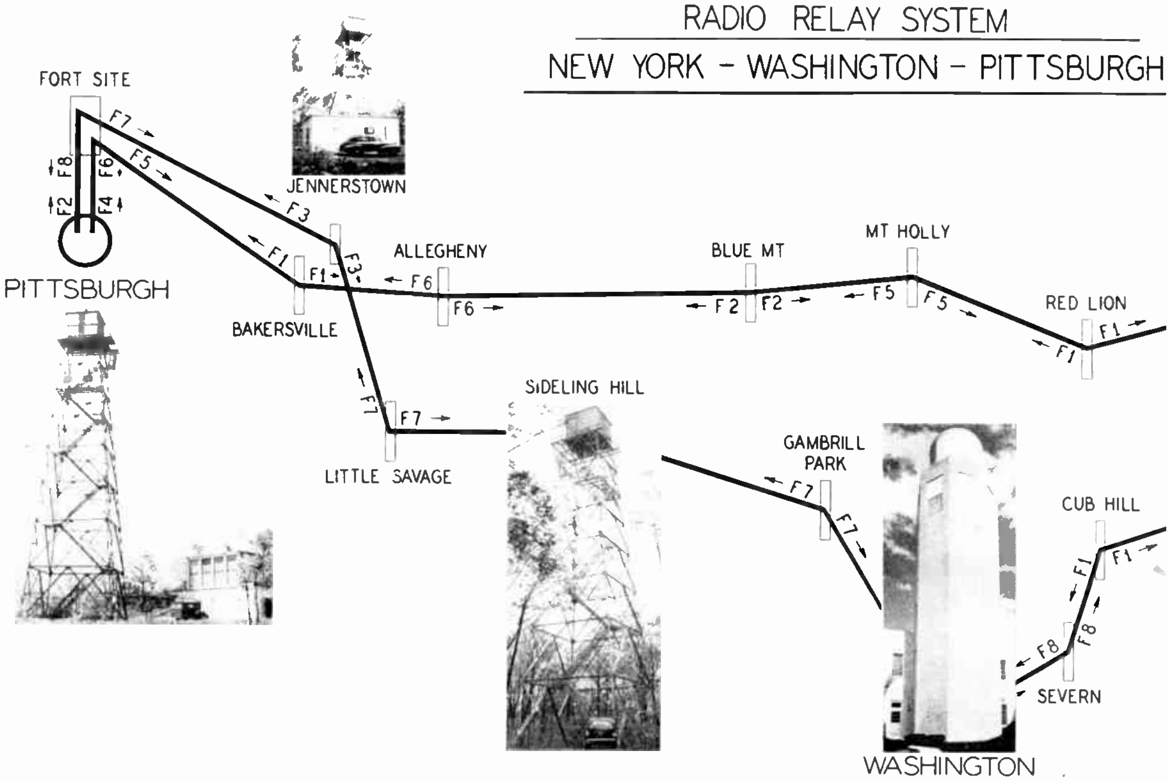


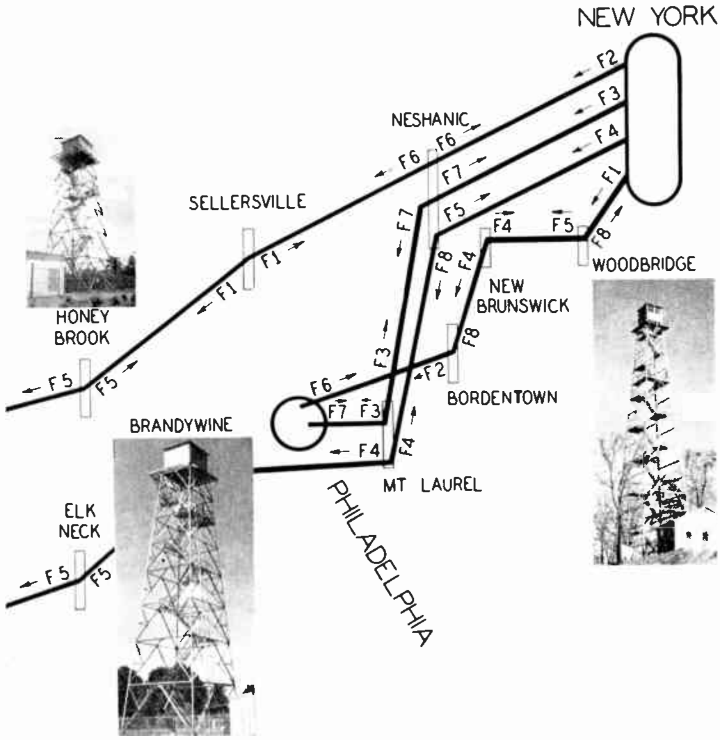
Figure 1. Chart of terminal and repeater locations showing some of the towers between New York, Washington and Pittsburgh

Several models of cars were tried to determine by actual experience the value of various types under different conditions. Initially three types were assigned, consisting of a standard sedan delivery and two kinds of commercially available vehicles having 4-wheel drive. Figure 2 shows one of the latter with a specially constructed enclosed body.

One of the 4-wheel drive models soon proved to be unsatisfactory while the other has been quite satisfactory, in general. The discarded model was actually a light truck and possessed undesirable characteristics for the work, such as high operating costs, excessive weight, rough riding and difficult handling. The 4-wheel drive feature is a valuable adjunct where towers are reached via steep unpaved mountain roads. Snow tires provide additional traction during the ice and snow of winter or mud of spring. Provisions have been made for clearing snow from entrance roads that are not maintained by public agencies. The winch and cable which have been provided on the front of each of these cars are shown in Figure 2. This cable can be used to assist in pulling the car back onto the road if necessary, or for other purposes. Where towers are generally accessible and driving is mostly confined to improved roads, the sedan delivery type has shown considerable worth.

Maintenance

Under normal conditions the maintainer visits each of his assigned stations at least once a week when a number of routine checks and tests are made. Similar routines are followed by the maintainer at each of the terminals on a weekly basis. Meter readings are taken which indicate



FREQUENCY ASSIGNMENTS

F1 - 4,030 - 4,040	F5 - 4,160 - 4,170
F2 - 4,040 - 4,050	F6 - 4,170 - 4,180
F3 - 4,050 - 4,060	F7 - 4,180 - 4,190
F4 - 4,060 - 4,070	F8 - 4,190 - 4,200

the conditions at various points in the radio equipment. These records permit comparisons to be made from week to week which may show the need for adjustments or replacements. A typical form used for recording the readings is shown in Figure 3.

One of the more important checks is that made on the condition of the super-high-frequency reflex oscillator (Klystron) used in the transmitter and receiver units. In the WU system the Klystron operates in the 3900-megacycle to 4200-megacycle range. The meter readings may show that it is in need of remoding, is in danger of failing, or needs replacing. Corrective action is of course necessary in such cases.

Normally the Klystron frequency is held to that of a fixed frequency cavity through the operation of an automatic frequency control circuit. For minor corrections a simple mechanical adjustment of the Klystron is sufficient to bring the peak of the power output characteristic (mode pattern) in line with the cavity frequency. Impending failure is generally apparent to the experienced maintainer and the Klystron is changed before the occurrence of an interruption to a working circuit. When a change is made the new tube must be permitted to become acclimated to the temperature of the thermostatically controlled oven in which it is mounted, before final tuning. In general the characteristics of the new oscillator will be such that adjustments of both the Klystron and cavity are required before the tube is properly moded at the designated operating frequency. While in theory changing the cavity should not be necessary, field experience indicates that it must be done. A suitable probe inserted into the output path permits the attachment of a wave meter for a check of the frequency. Preamplifiers in the receivers and slotted line tuning in the transmitter permit refinement of response. The wave meter is also used by the maintainer for semi-annual checks of transmitter frequencies which are required by the Federal Communications Commission.

Figure 2. One type of vehicle with special body used by maintainers

If a receiver is involved, the use of diversity reception permits the removal from service of either of the two receivers for servicing, during periods of no fading. Work on a transmitter will generally interrupt the circuit and therefore must be avoided until traffic is switched to the fall-back route. Switches during the heavy load period of the day are postponed unless emergency maintenance is indicated. Normally, arrangements are made with the Dispatcher to reroute traffic, during the early hours, to the fall-back route. The following paragraph is a brief explanation of the above reference to fading, and is taken from a "Discussion of

RADIO RELAY SYSTEM

Periodic Inspection Record From______ 19__ to______ 19__

STATION CALL__________ LOCATION __________

CIRCUIT __________ MAIN____ DIVERSITY____ MAINTAINER __________

DIRECTION __________ **RECEIVER** TERMINAL____ RELAY____

DATE									
INITIALS									

ACTUAL INDICATION

OSC. FREQ.									
AF C COUPLING									
OVEN TEMP.									
OSC. COUPLING									
MIXER COUPLING									
AF C FREQ.									
PRE-SELECTOR									
ANT. COUPLING									
A F C GAIN									
V_1—I_c									
V_2—I_c									
V_3—I_c									
V_1—I_p									
V_1—E_r									
Y_2—I_x									
Y_1—I_x									
120— ≈ —E									
IF—E_1									
AFC ZERO									
DISCRIM. I.F									
M2 AF C									

Figure 3. Sample of typical form used for recording meter readings

Meteorological Factors" which appeared in conjunction with the article on propagation tests:[3]

"Variations in transmission at microwave frequencies for an unobstructed overland path are caused primarily by variations in the distribution of the dielectric property, or dielectric constant, of the lower atmosphere. The manner in which this property is distributed in a region of space at any instant of time depends almost wholly upon the manner in which the air pressure, temperature and water vapor content, enclosed in this region of space, are distributed with respect to height above the earth's surface at that instant. Ground reflections and diffraction effects also influence microwave transmission, but to a lesser degree. This last statement is far from true, of course, for transmission paths that lie partially or wholly over water and for paths that are obstructed."

Deep fading is generally apparent only during the night hours, although severe conditions have been experienced during the day. It is also more prevalent during the summer and autumn months than at other times during the year. If a recording meter chart of received signal strength is made it will show continuous fluctuations not of sufficient intensity to affect transmission of a strong signal.

Figure 4 is reproduced from the detailed description of the emergency power plants previously mentioned[1] to indicate the equipment which must be maintained. A no-load and full-load test run of the engine generator is made during the

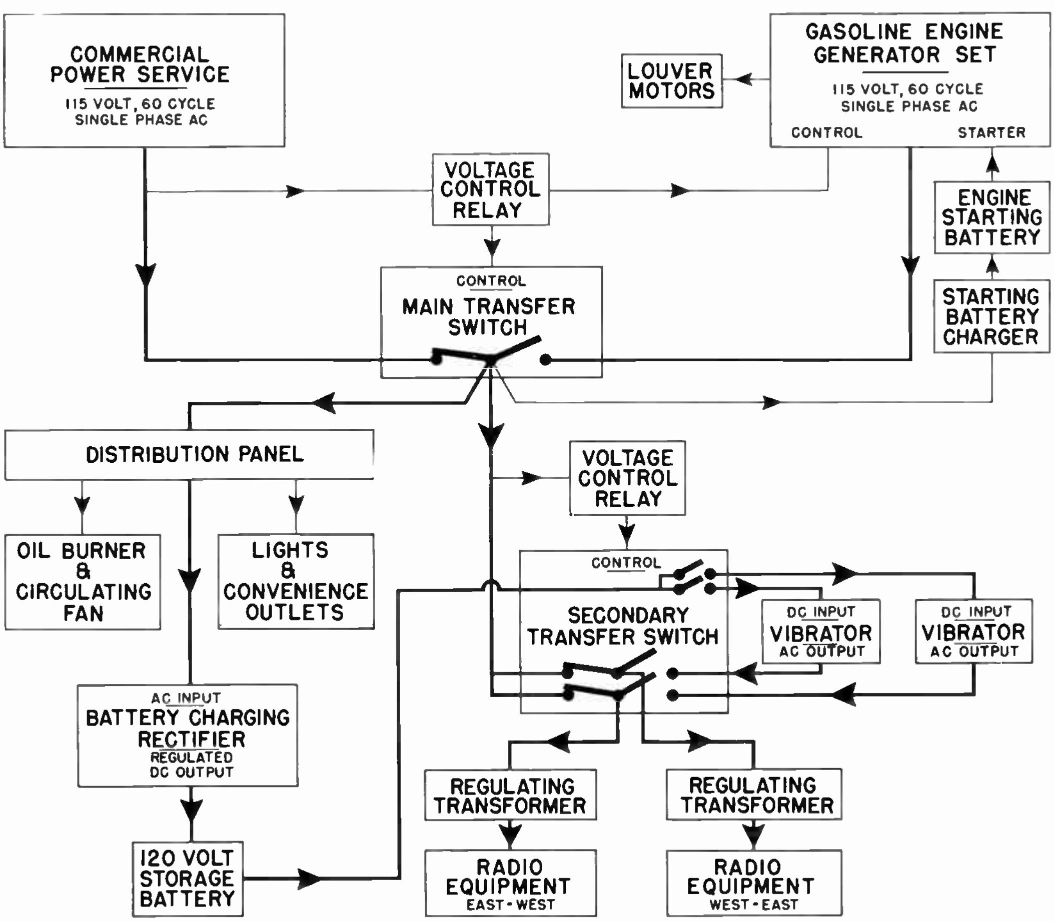


Figure 4. Block diagram of relay station power plant

weekly visit to the station. Batteries are checked and water added when necessary. Adjustments and cleaning of the various pieces of equipment is done as required. Other work associated with proper maintenance of an emergency power plant is done at less frequent intervals during special trips to the stations.

Each maintainer whether covering relay stations or assigned to a terminal station is furnished with a kit of tools. This kit consists of the usual complement of small tools normally used for radio maintenance and repair, contained in a standard WU leather tool kit such as the maintainer in Figure 2 is carrying. Each terminal and relay station is provided with a tube tester, a Voltohmyst and multimeter. A small flat-top work table is located at each tower and each terminal has a large work bench equipped with convenience outlets and an instrument shelf. Maintainers are also furnished with crystal test sets and a wave meter. A relay test set 4814-A is provided at each tower to check the 41-C relays used in the voltage control units of the automatic emergency power panel.

It is not planned to do major repair work on the radio equipment at the towers. The field man is not provided with sufficient test apparatus for complete checks of all units, but instead is provided with spare panels which are used on a change-out basis where the fault is not readily recognizable. If the trouble proves to be one which can be found by the field man, he makes the necessary repairs or adjustments; otherwise, the unit is sent to one of the terminals. Test apparatus at the terminals consists of signal and sweep generators, microvolters, oscilloscopes, communication receivers, vacuum tube voltmeters, audio frequency generators, distortion meters, and attenuator panels, which permit a thorough analysis by the terminal attendant. The unit is restored to a first-class working condition and returned to the maintainer who sent it in.

Another function at the terminals is the preaging of all maintenance spare vacuum tubes. A special panel has been provided on the work bench so that all tubes can be aged for several hundred hours before being distributed as spares. Tubes passing this aging test will then generally have a normal service life. A few of the tubes fail during the test and thus potential troubles are eliminated. Periodic tests of tubes in service are scheduled every six months.

One of the responsibilities which falls on the terminal men is to recognize the difference between a fading condition and actual trouble with the equipment at some relay station. The maintainers' ability to do so is sharpened by experience so that they now have little difficulty in recognizing trouble due to fading. This faculty, which is assisted by use of the fault tones and collaboration with the distant terminal, is important in that it prevents maintainers being called out unnecessarily.

A brief description of the function and maintenance use of the fault locating tone may be of interest at this point. Primarily that part of the system consists of a fault tone generator and fault tone receiver located at each terminal, and a fault locating unit at each of the relay towers. The fault tone generator is a unit for electronically generating a number of fixed audio frequencies which are fed by selection onto the repeller of the transmitter Klystron by the terminal attendant. The fault locating unit at each relay station is equipped with band-pass filters individual to that station's assigned fault tone; it also has a frequency generator of the same tone. The fault tone receiver is equipped with visual and audio means of identifying received fault tones. When the system is operating normally, a tone sent from a terminal will be received at the distant terminal on the fault tone receiver and will also pass through only one locating unit, at the station associated with that tone, to be transmitted back to the terminal of origin where it is received on the fault tone receiver. Failure of the fault tones to pass through the system in a normal manner indicates the failure of some unit at a station. Cooperative tests by both terminals, and proper analysis of the results will show what station is inoperative and possibly indicate the particular unit at fault.

The frequency generator in the fault locating unit is used in conjunction with a coding device to transmit the station characteristic tone to the terminals, indicating such information as illegal entry, operation of the emergency power plant, or low temperature at the station.

Emergencies

When a failure occurs on one leg of the New York—Pittsburgh—Washington triangle, service is immediately restored by switching between terminals to the fall-back block of frequency spectrum on the other two legs. Similarly traffic can be switched to a fall-back route between New York and Philadelphia. After location of a fault as described above, the maintainer is notified of the trouble via the beam service channel if he is on duty at one of his assigned towers, or at his home by other means. Of course, if the trouble is at the terminal, it is located and cleared by the local attendants.

Conclusion

Over a period of three years invaluable experience has been gained in maintenance techniques. Western Union field forces have attained a competence which has been reflected in a continuous reduction in the number of interruptions to traffic. With the adoption of certain engineering modifications which are now planned, it will be possible to maintain a microwave system so that practically one hundred percent reliability is achieved regardless of weather, aurora borealis, or conditions which affect other types of facilities.

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G. B. Woodman graduated from the University of New Hampshire in 1925 with a B.S. degree in Electrical Engineering and immediately joined Western Union. Following a training period at Red Bank, N. J., he was assigned to the former Eastern Division of the Plant Department. Here his work involved the inductive and physical coordination of electric power and Western Union lines. With the advent of the company into the use of carrier, he was associated with field developments in both equipment and lines. Mitigation of extraneous interference and transmission problems of various types were also handled. In 1947 he became a Plant Supervisor on the staff of the Director of Maintenance, the position he now holds. Present duties embrace maintenance supervision of radio relay, carrier, Telecar radio, and Marine News reporting by radio.

Inventory System Using Digital Computer Techniques

E. L. SCHMIDT and J. J. CONNOLLY

THE IMPACT of new techniques on the communications industry is of vital concern to most readers of the TECHNICAL REVIEW. The highly complex economy of our modern industrial age has created heavy demands for efficient, high-speed transmission of information over our communications facilities. The industry has kept pace with these demands through technical advances in the electronics art and the development of more and more high-speed automatic equipment to replace time-consuming manual operations.

A closely allied field encompasses the automatic high-speed processing and storage of large quantities of information, with input and output communications links providing selective access to the stored information. These requirements are pertinent to many inventory systems now burdened by manual operations which introduce excessive delays in the rapid flow of information. In recent years, the phenomenal growth of industry has created a serious problem in that it is becoming increasingly difficult to provide a fast, accurate inventory service. Card records and display boards used to show whether or not items are in stock introduce access and visibility problems. Furthermore, the manual computations, plus the delays in transfer of indications to records or to the display board, create serious time lags in the system. The need for an automatic inventory system, geared to handle constantly expanding volume has been recognized for some time, and one experimental system, developed by The Teleregister Corporation, an associated company in the Western Union system, has been in successful operation for over four years. This paper outlines some interesting features of another application of digital computer techniques to the solution of inventory problems, developed by Teleregister.

Designing for Dependability

Inasmuch as the complete inventory system in duplicate involves the use of over 1500 vacuum tubes, it became apparent very early in design that a high degree of dependability was necessary here in order to insure continuous operation. A trouble must be measured not only by its frequency of incidence, but also by its complexity (difficulty of finding and correcting). With this in mind, a survey was made of all major computing programs which might contribute statistical data for determination of the various causes of failure and their relative importance. From an evaluation of these data, many principles of design philosophy were determined. For example:

1. Exclusive use of 60 percent tin, 40 percent lead, low impurity solder.
2. Use of high quality tubes.
3. Physical chassis arrangement to make all solder joints visible and accessible.
4. Use of functional (logical) plug-in subassemblies in order to:
   - (a) Render functional understanding of the equipment easier.
   - (b) Allow location of trouble through rapid substitution of subassemblies.
   - (c) Allow the rapid correction of trouble and hence return of equipment to service by replacement of subassemblies. (The defective component can be corrected at leisure).
5. Alteration of the functional design of the equipment, at some sacrifice of operational efficiencies in such matters as time or equipment, in order to provide a simpler functional behavior and hence render corrective as well as preventive maintenance procedures more understandable to the personnel assigned to this work.

6. Circuit design to minimize the effect of variation in vacuum tube characteristics on the dependable operation of the circuit.
7. The use of error detecting means which in itself contains a very low error probability. Intelligence represented (1) parallel in time would require considerable equipment, (2) serial in time, less equipment, and (3) by a single pulse whose time is intelligence, still less equipment. Hence (3) was chosen as the error detecting means.
8. The use of a conservative pulse repetition rate of 20 kc.

A working model of this equipment has been in operation in the Teleregister Laboratory for over seven months and all indications are that commercial dependability has been achieved.

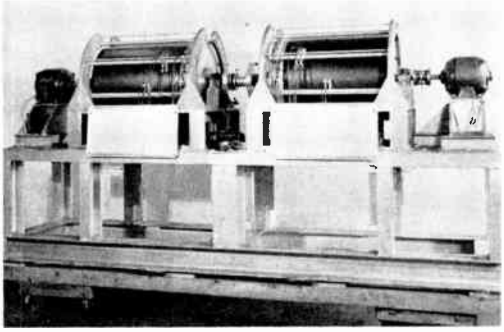


Figure 1. Rotary magnetic storage drums showing read-record heads partially installed

Inventory Data Storage

The fundamental problem of any inventory system is the provision of an adequate and reliable means of storing data. The minimum initial requirements for Teleregister's newest system involve the provision for storing data on 10,000 units, with each unit storage containing means for recording from 0 to 100 items. This, in turn, required the use of at least a 7-element binary number for each unit, providing a means of recording up to 127 items. Since a total of 70,000 storage elements were necessary, a comparatively inexpensive storage medium was a "must". It was apparent that any form of storage in which a component of equipment (such as a relay or static magnetic memory unit) is used for each elementary signal would have been far too bulky and expensive. This applied as well to systems employing rotary switches, counters, and the like, since at least 10,000 of any of these would have been needed. Other factors controlling the choice of storage means were as follows:

1. Rapid access
2. Non-volatile (permanent until changed)
3. Readily changeable

The requirements of rapid access eliminated the use of spools of magnetic wire or tape, and the requirement of permanence eliminated such devices as acoustic delay lines or electrostatic mosaics where a power interruption would destroy the inventory record. The last requirement, that the data be readily changeable, eliminated all forms of printed or perforated records. The solution to the storage problem was found to be the use of cyclic magnetic storage in the form of a continuously rotating drum.

This type of storage involves the use of a cast aluminum drum which has a coating of magnetizable material, such as an iron oxide, applied to its surface. Read-record heads are mounted in close proximity to the rotating surface so that each head controls a channel, or track, of the drum surface. Application of a pulse of current to a head produces a magnetized spot on the drum surface beneath the head. Teleregister's new inventory apparatus employs both positive and negative pulses in recording, with a positive pulse corresponding to a "mark", or binary 1, signal and a negative pulse to a "space", or binary 0, signal. Magnetized spots on the drum are never erased, but are altered by the application of an opposite polarity pulse when the signal indicates a change from binary 1 to binary 0, or vice versa. In reading, voltage pulses of reversed polarity are generated in the head by positive and negative magnetized spots. Selection of a specific head or drum channel is accomplished by relay techniques, whereas selection of specific spots or cells within a channel is under control of synchronizing channels and appropriate electronic counter and gating circuits.

Figure 1 is a photograph of the drum storage unit showing a few of the read-record heads in position. In order to provide a high order of reliability, the electronic and magnetic storage equipment would be installed in duplicate, with suitable cross-checking circuit to detect malfunctioning in either group. Each of the two groups is capable of functioning independently to maintain system operation and the out-of-service drum may be loaded from the other in a matter of seconds when it is put back into service. Using a very conservative packing factor in the interests of dependability, each drum has a total storage capacity of approximately 250,000 cells or code elements.

Data Selection

It has been explained that access to the stored information was a determining factor in selecting magnetic drum storage. In order to provide selective access to the storage in the most useful form, it was necessary to devise a flexible system of grouping. For example, the equipment might be required to check three units of storage for a complete answer. A similar requirement might exist if a number of alternative choices must be selected by a single keyset operation. To this end, the system was designed so that each operation initiated by a keyset results in the selection and read-out from the drum of a group of from one to eight units of storage, which in turn control the selection of inventories in the drum. Furthermore, the combination of specific units of storage in any one group selection may be altered at will by supervisory personnel.

It is interesting to note that the magnetic drum, in addition to its data storage function, also serves to act as a very efficient and flexible translator in performing this multiple encoding. To illustrate, a group selection code, originating from a keyset position, is routed to a unit section of the drum where eight unit codes assigned to the specific group are stored. These unit storage codes are read from the drum and, by means of suitable programming equipment, serve to initiate a secondary selection into the "inventory" section of the drum where the item count on the eight codes in question is stored. Alteration of the storage code assignments within group selections is accomplished by merely writing into the drum new codes from a master control position at the central office.

Figure 2. Inventory system keyset

Computer Functions

In order to maintain an accurate inventory of the item count on all units in the storage, it is obvious that the data must be operated upon in accordance with the orders originating from the various keyset positions. These orders are of four types and are controlled by lever key operations at keysets such as the one shown in Figure 2. They are:

1. Check availability
2. Issued
3. Received—Restricted
4. Received

When checking availability, a tentative subtraction of the requested number of items from the stored inventory count is made, but the actual inventory is not changed. When an issued order is initiated, a tentative subtraction is first made to determine if the required number of items on all of the storages involved are available and, if the answer is affirmative, the number of items issued are subtracted from the total. In the case of a received-restricted order, the stored inventory is examined to determine if any of the storages involved show zero inventory. If such is the case, the order is rejected. This procedure is to assure that the incoming items are first checked against any possible back order list which must receive priority. In the event the items in question are not subject to back order action, a received order (which can be initiated only by certain designated keysets) will be accepted by the computer, even though the inventory is at zero, and the count is added to storage, where it becomes available for issue by calling keysets. Received-restricted orders involving inventories which are not at zero, and all received orders, cause the computer to add the item to the quantity stored in the inventory.

The type of answer sent back to the keyset in response to an order is the lighting of a confirmation lamp indicating that the order has been carried out, or in the event an issued order has been attempted on a storage having an insufficient number of available items, the lighting of a reject lamp. In the case of a check availability order, a group of eight lights shows those storages on which no stock is available for the quantity of items requested.

In order to achieve the necessary speed of operation the inventory system uses electronic equipment to serve as the data handling link between input-output line terminations and the magnetic storage. It is used for the computer functions, programming, and for the input-output functions of the magnetic drum storage. Figures 3 and 4 show front and rear views of the Teleregister Arithmetic Unit chassis (less subassemblies) which is used to perform the computer functions. This is an add-subtract unit capable of handling the 7-place binary numbers stored in the inventory. Figure 5 is a view of a typical electronic subassembly. All electronic and relay components in the system are mounted on similar plug-in subassemblies.

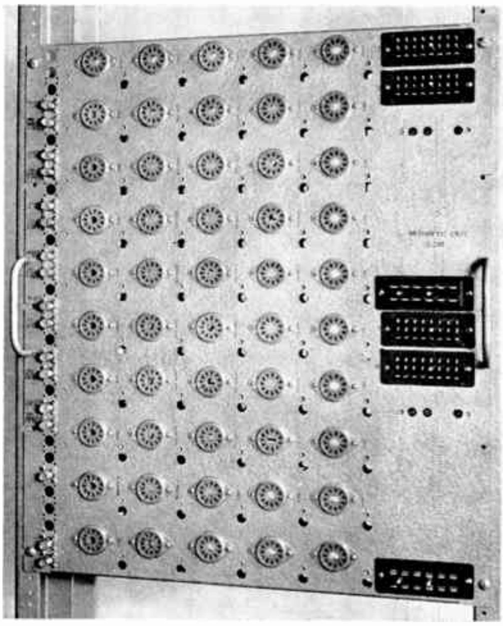


Figure 3. Arithmetic unit chassis showing plug-in arrangement

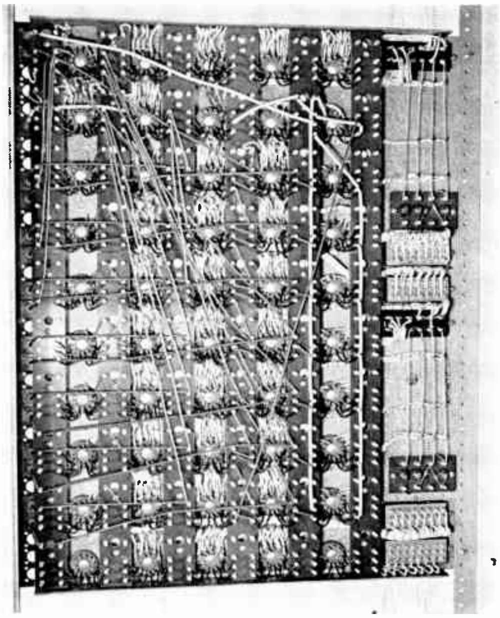


Figure 4. Arithmetic unit chassis, rear, showing wiring

Input-Output Functions

All operations from the home office and remote office locations are made by means of keysets. As noted previously, selection into the stored inventory is made by "groups" or combinations of eight storage units. A group selection may, therefore, comprise eight units of storage, or it may be made up of combinations of single and multiple storages, or entirely of multiple storages. In order to minimize the possibility of human error in the selection and interpretation of the designations on the many storage units, it was necessary to devise a very simple selection and designation mechanism. This requirement is met by the use of combination coding and designation plates which are inserted by the keyset clerk, one at a time in a slot in the keyset. By means of a shutter arrangement which exposes either the lowermost or next to the lowermost line of information on the plate and simultaneously changes the selection coding, and four possible ways in which the plate may be inserted, eight groups of eight units each, or a total of 64 storage units may be selected with each plate. Inasmuch as slots on the plate serve to initiate the selection coding, and the storage designation is an integral part of the selection means, it is an impossibility for the keyset clerk to err in associating storage designations with the selection made.

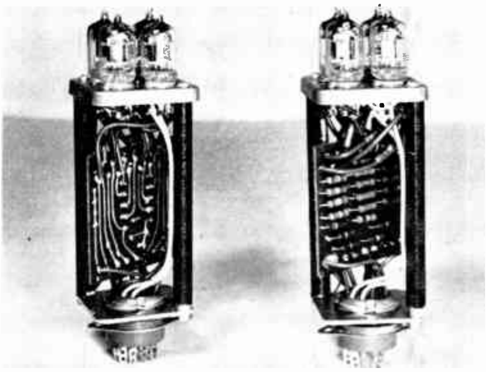


Figure 5. Typical plug-in electronic subassembly

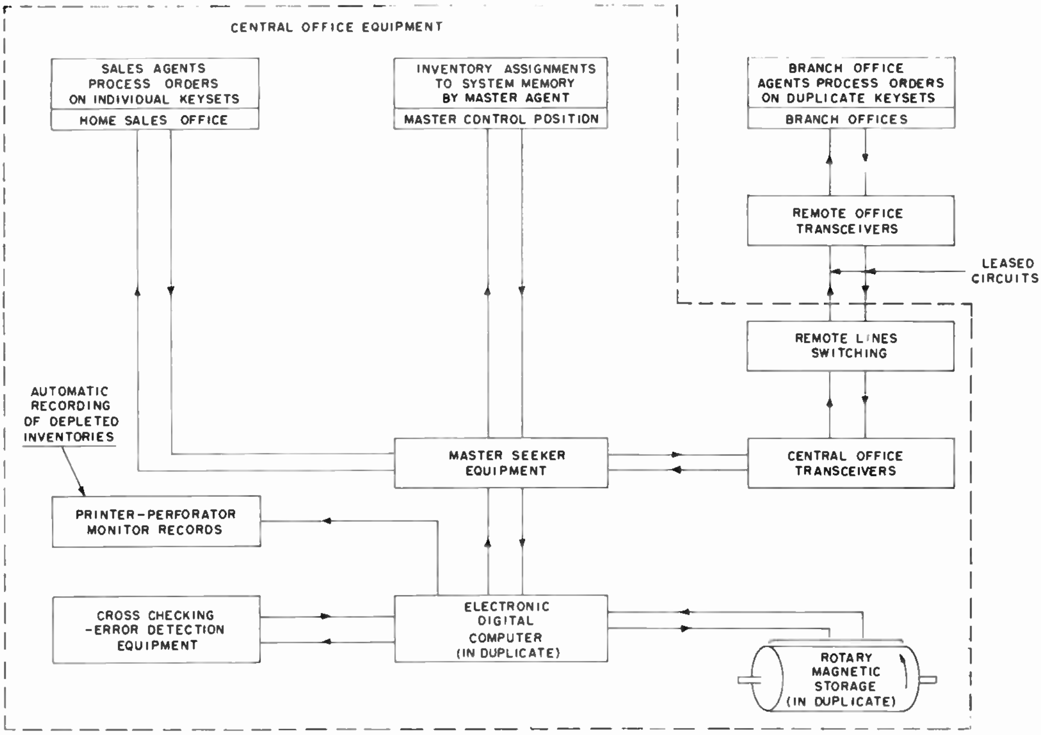


Figure 6. Inventory system block diagram

Directly beneath the eight storage designations on the selection plate are eight combination lamp and push-button assemblies. The lamp function is used to indicate whether or not the required item is available on each storage when a "check availability" order is initiated. The push-button function is utilized by the clerk in connection with an "issued" or "received" order on specific units of storage within a group.

Quantities are inserted by means of conventional interlocking keystrips and all orders are initiated by means of two lever key assemblies. A "clear" lever key position does not initiate an order to the computer, but is merely a local operation which serves to release any depressed storage unit button in the event the clerk wishes to correct an erroneous selection of storages before initiating an "issued" or "received" order.

Keysets at remote offices operate into the home office equipment by means of coded pulse transmissions from transceiver equipment over leased circuits. Local and remote keyset positions time share connections to the computer and magnetic storage under control of seeker equipment. Access time varies from 0.100 to 2.0 seconds dependent on the number of storage units involved and the type of order received from the keyset.

Changes in inventory code assignments are under control of a Master Keyset located in a supervisory position at the central office. This Master Keyset also has the ability to read out the actual count of items on any unit in the storage. This count is displayed on lamp units at the master position where it may be used by supervisory personnel to check the status of any storage element in the system.

It is felt that this inventory system using specialized electronic computer and magnetic memory techniques will find many applications in a field where there is a need for the high-speed processing and compact permanent storage of large quantities of information.

E. L. Schmidt, Assistant Director Teleregister Laboratories, is a graduate in Electrical Engineering of Pratt Institute of Technology. He started work with the maintenance department of The Teleregister Corporation's quotation division in 1929, and was City Manager in Cleveland from 1934 until he was transferred to the Engineering Department at New York in 1942. There, as Chief—Production and Field Engineering Section, and as Project Engineer, Mr. Schmidt has been engaged in active system development of various data-handling and display projects. He is a member of the New York Electrical Society.

J. J. Connolly, Project Engineer in Charge of Electronic Research of The Teleregister Corporation, was educated at Carnegie Tech and Yale University, graduating from the latter in 1944. During the war he was engaged in radar work both at M.I.T. and with the U. S. Naval Research Laboratory. He joined Teleregister in 1947 as a junior engineer, and his work with that organization has been primarily concerned with digital computers and magnetic storage, and their application to industrial and military problems. Mr. Connolly is a member of IRE, ACM and Tau Beta Pi, honorary engineering fraternity.

Vacuum Tube Reliability

F. H. CUSACK

For some time now the obvious trend in electronics has been toward smaller and smaller vacuum tubes, and the remarkable results achieved have attracted so much attention that it often seems as though all other objectives have been forgotten. The bantam tube gave way to the miniature type which was quickly followed by the subminiature, and a point has been reached where the "peanut tube" of bygone days looks gigantic beside its truly goober-style descendant. Throughout these exciting developments, the designer has kept an eye on tube quality and has attempted at least to preserve the customary degree of reliability. Satisfactory results have been obtained despite wattage dissipations and bulb temperatures greatly exceeding the bounds of what had formerly been considered as safe limits. The smaller tubes have been a resounding success and have been produced in very large quantities. Miniaturization is seen as a basic way toward lower costs because of the economic value of savings in material and space.

Reliability—A Reverse Trend

Quite recently there have been signs of a reverse trend in electronic research—a trend toward emphasis on reliability as an ultimate goal, with the cost factor relegated to a subordinate position. This has come about because of a growing demand for tubes of improved quality to be used in military and industrial equipment. Industrial users have long felt that electronic apparatus is not as dependable as it should be, largely because commercial tubes are not sufficiently reliable for many applications. They have sometimes asked what could be done to make tubes as rugged and unchanging as a crowbar.

Tube manufacturers were understandably slow in accepting the challenge. Electronic research and development work was always supported by the extensive market for low-cost tubes manufactured by mass production methods. There was little incentive to invest heavily in the design and production of special types for a very limited demand. Today the application of the electron tube in industrial uses is still in its infancy with a tremendous future ahead. Realization of this fact has resulted in the first steps toward tubes developed with a shift in emphasis from reducing costs to improving performance. American manufacturers are gradually introducing tubes designed for stability, uniformity, mechanical strength and long life. Evidently the new trend is also being felt abroad for a British manufacturer has announced a "range of trustworthy valves of robust construction with a high expectancy of life under arduous conditions".

A very high degree of reliability in electronics can eventually be attained through the best efforts of the tube designer working in close cooperation with the equipment designer. Studies must be made of all the many factors that contribute to service failures, and means must be found for improving performance regardless of the innovations needed. The requirements of various users must be classified, recognizing that different applications necessitate different interpretations of the general term reliability. Sometimes long life will be the primary consideration, sometimes uniformity or stability of electrical characteristics, or resistance to shock and vibration, or any combination of these and other features which assume importance in a particular specialized field. Clearly the job is not an easy one, nor can revolutionary advances be expected overnight.

Reliability Today

In the meantime, large numbers of electron tubes are already serving industry reliably and well—performing functions better than could be done by other methods, and sometimes making possible things that could not otherwise be achieved. Today a vacuum tube repeater lies on the bed of the ocean, some 200 miles from the shore, where it enables a Western Union transatlantic cable to be operated at three times its normal message capacity. A number of other instances can be cited of tube applications where dependability of a high order is regularly experienced. If available tubes are considered adequate by those who sink their hopes in submerged repeaters, then certainly such tubes can be used with satisfaction for all manner of less daring schemes.

The equipment designer can do much to utilize better the capabilities of present tubes and improve the reliability of electronic devices. It is his duty to see that operating conditions and performance requirements are properly related to the tube ratings. The selection of the best tube for the job is important, and the extent to which characteristics vary from tube to tube and with age must be taken into account. Probably the greatest threat to reliability in electron tube operation is the temptation to exceed the tube ratings, or at least to exploit fully the rated capacity and neglect the need for a factor of safety. Tube life may be as dependent on circuit conditions as on the design or quality of the tube. Wherever a high degree of dependability in electrical performance is being obtained with existing tube types, conservative designs and favorable operating conditions are largely responsible.

The user of electronic apparatus usually has little or no control over the design of the circuits or the tubes involved. Nevertheless, he can do much to improve reliability by following maintenance procedures designed to prevent service interruptions caused by tube failures. A systematic program of tube surveillance employing periodic testing routines will make it possible to replace tubes which are likely to become service hazards. Such a plan is not entirely incompatible with tube longevity and can be successfully applied while at the same time realizing as long a life as is safely possible. In considering ways of accomplishing this, it will be of interest to review some of the known facts regarding the life expectancy of vacuum tubes.

Studies of Tube Life

Detailed studies which have been made of tube life have usually been of a statistical nature. This approach recognizes that very little can be said with certainty about the life of an individual tube except that it will end sometime. But when life tests are made on a large group of tubes, a statistical analysis of the data will yield important practical information regarding their performance. The results of many studies of this kind have shown that the life curve for a group of tubes tends to follow an exponential law. Tube failures occur pretty much at random, and the rate of failure expressed as a percentage of the tubes still in operation tends to become a constant. The dotted line of Figure 1 shows such a survival curve. At the end of a certain interval of time, 10 percent of the tubes had failed leaving 90 percent still serviceable. Then at the end of another equal time interval, 10 percent of the survivors (9 percent of the original group) had also failed leaving 81 percent in operation. The exponential curve becomes a straight line on semi-logarithmic coordinate paper. The solid line of Figure 1 is more like the type of curve actually obtained from life test data. It is seen that the rate of failure is usually greater during an initial period, after which the curve tends to follow the exponential pattern.

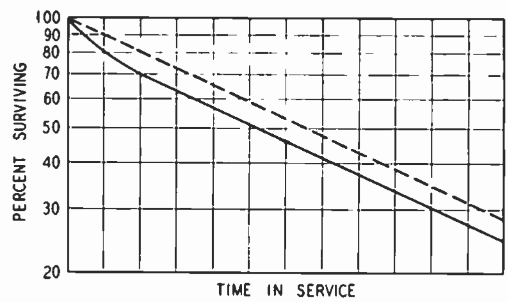


Figure 1. Vacuum tube survival curves

Service interruptions can often be forestalled by the periodic testing of vacuum tubes

There are a number of practical applications for information of this nature. The manufacturer engaged in the production of long-life tubes, can check on quality without needing excessively prolonged life tests. Life expectancy can be predicted from test data as soon as the prevailing failure rate is clearly indicated. A valuable conclusion about vacuum tube maintenance can be drawn from the properties of the exponential curves described above. Evidently it would be futile to attempt to insure continuity of operation by taking tubes out of service at the end of a specified period and substituting new ones. If the failure rate is independent of age, a tube removed while it is still good has the same probable future life as a renewal tube. In fact, the usual increased rate of early-life failure signifies that the new tube is more likely to fail than the old one! This prediction has been confirmed repeatedly by operating experience with large electronic devices, where a wholesale replacement of tubes has invariably been followed by a marked increase in the failure rate.

Because of the random nature of tube failures, it has been difficult to specify a satisfactory method of rating tube life. Of late there has been considerable demand for tubes with a rated life of at least 10,000 hours, but tube engineers have been reluctant to make such a commitment without knowing exactly how life expectancy is to be defined. Sometimes the average tube life is the figure quoted, but this is of limited practical value. On an exponential survival curve, the average life is the time when only 37 percent of the tubes are still in service. A somewhat better method of establishing a rating is indicated by the Joint Army-Navy Specifications. A life test is made on a group of tubes for the rated number of hours. Then the total tube-hours of service provided by the group must be at least 80 percent of the possible maximum. By this method a 10,000-hour rating would be considered justified if 20 percent of the tubes failed immediately and 80 percent served for the full 10,000 hours, or if all failed at the end of 8,000 hours, and so forth. This type of life evaluation is adequate for some uses, but still does not give the user sufficient information concerning reliability. Reliable life is thought of as meaning a small percentage of failures over a specified period of time, and hence is a different concept from long life. The point to remember is that a life rating of 10,000 hours cannot mean that every tube will certainly function for this length of time, any more than a year guarantee with a watch means that every watch will keep perfect time for 365 days.

Causes of Failure

All the different types of failures that terminate tube life may be classified in two general categories—failures due to mechanical defects and failures caused by deterioration of electrical characteristics. Mechanical faults cause the inoperable failures where tube life is ended suddenly by burnouts, glass faults, short circuits or open elements. Failure due to these types of defects definitely can be reduced by improved techniques and closer controls in manufacture. The aging of new tubes before accepting them for service is also helpful. From test data which have been taken by tube manufacturers and broken down to show the types of failures within specific portions of the life curve, it has been found that mechanical defects usually show up rather quickly. Rate-of-failure curves, similar to those given in Figure 2, show that early-life failures are due almost entirely to mechanical causes. Later in life when these inoperable failures have leveled off at a low rate, failures due to electrical deterioration begin to increase and soon become the majority. But mechanical faults are likely to cause premature failures, and for this reason aging tests make it possible to weed out many of the weaklings. A burning-in period ranging from 50 to 500 hours has been used for the purpose, with heater power connected to the tube and sometimes with normal electrical conditions applied to the other elements as well.

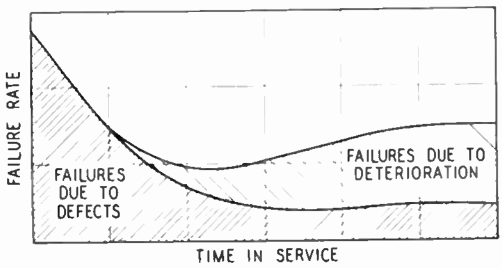


Figure 2. Causes of vacuum tube failures

Vacuum tube failures caused by inadequate electrical performance present a more elusive problem than the inoperable failures. Here the failure point is largely a matter of arbitrary definition. The life of a tube is commonly understood to mean the length of time that its characteristics remain within specific limits. A tube is considered to have reached the end of its life as soon as its characteristics fall outside the end-point limits specified for that particular type. The end-of-life requirements may be different for different applications. The aim of preventive maintenance is to forestall interruptions due to tube failures by replacing poor or marginal tubes before the deterioration is sufficient to cause operating difficulties.

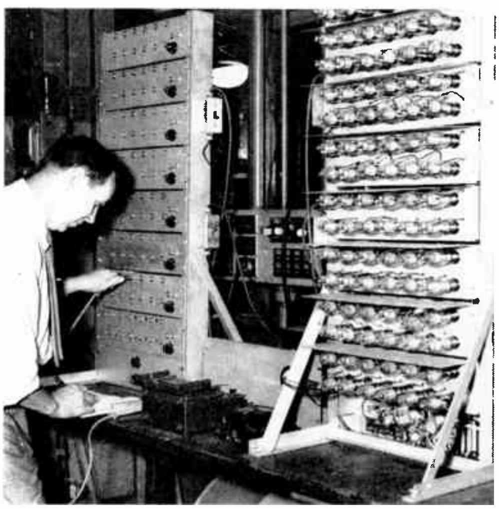
Preventive Maintenance

Tests can be made to determine the condition of vacuum tubes either by observing their performance in a working circuit or by measuring their characteristics in a separate tube checker. Transconductance has long been considered a good indication of tube condition, and tube testers which measure this quantity are in common use. A transconductance figure of about 65 to 75 percent of the design center rating of the tube is generally used as the replacement or end-of-life point. A somewhat better plan is to make the end-point limit for a tube a specified percentage of the initial transconductance as measured when that particular tube was new. Characteristics other than transconductance are sometimes used as a criterion, particularly for some of the more recent pulse applications where emission and cutoff conditions are more pertinent. In addition to those tube tests which are made under normal conditions, there are various methods of checking on operating margin by employing test conditions more exacting than normal. For example, a very sensitive marginal check on cathode emission is made by observing whether there is an excessive reduction in transconductance resulting from a small reduction in heater voltage.

A program of vacuum tube maintenance can be so planned and applied as to minimize the number of interruptions caused by tube trouble. The periodic testing of all tubes and the systematic replacement of those showing excessive deterioration will do much to forestall service failures. However, this practice does result in the rejection of many tubes before the end of their usefulness, and in some cases may require an intolerable amount of testing work. Hence it is not always warranted in situations where the consequences of a failure are not particularly serious or where other means can be employed to indicate impending failure. Many tubes are capable of giving satisfactory service for a prolonged useful life, even though they may not give optimum performance, provided the equipment in which they are used is designed with adequate margin for such a contingency.

Tube Maintenance Practices

A good example of vacuum tube maintenance can be illustrated by outlining the system followed with a large-scale computer containing about 18,000 tubes. All new tubes are given a preheat period of at least 50 hours and are then tested before being accepted for use. Routine tests are not made of the individual tubes in service. Operational tests to indicate the condition of the machine are made frequently, and marginal testing is achieved by solving a check problem with the machine operating at a considerably increased speed. Blanket changes in large numbers of tubes have been found impractical because of the increased incidence of early-life failures. On the other hand, replacing one tube at a time is undesirable because isolation of a single faulty tube requires time-consuming tests. As a compromise between those extremes, tubes are replaced in groups, the largest such group comprising eleven tubes. When a functional defect is discovered, the cause is traced to a particular circuit and then all the tubes in that circuit are replaced. The tubes removed are tested and those which still pass acceptance limits are returned to storage and eventually to service.



Aging tests are made on vacuum tubes before their acceptance for submerged repeaters

In the Western Union system there are close to 200,000 vacuum tubes in operation, mostly in carrier telegraph equipment. Tube maintenance methods have been evolved from years of experience with electronic apparatus of this type and have been designed to improve its dependability. All new tubes are tested before being placed in service, and for specialized applications they are sometimes aged as well. Tubes which fail to meet certain minimum requirements are rejected, including any exhibiting short circuits or excessive gas content. Transconductance is measured accurately in micromhos, rather than with the so-called English or "good-bad" type of meter scale. A special chart is provided for the tube tester showing the minimum acceptable value of transconductance for a new tube. To be acceptable for service, a new tube must give a micromho meter reading greater than the chart minimum. The measured value of transconductance is recorded for each new tube when it is first tested, and this record is consulted whenever that particular tube is checked again. If the transconductance of a tube at some later date has fallen below 80 percent of its recorded initial value, the tube is considered to have reached the end of its useful life and is discarded. As a marginal test of cathode emission, the heater voltage is dropped by 10 percent without changing other test voltages or conditions. If this causes the micromho meter reading to fall off by more than 10 percent, the tube is rejected.

The maintenance program currently specified for vacuum tubes acknowledges that the procedure to be followed is determined in part by the type of service involved. Routine tests are not made of any tube employed in a single telegraph channel. The advantages gained would be more than offset by the disadvantage of reduced life for an enormous number of tubes. These vacuum tubes are replaced whenever the advisability of doing so is indicated by normal circuit regulating practices. It is recommended that the six or seven tubes in a channel terminal be replaced by a complete new set whenever tube trouble is suspected, the tubes removed being tested at a more convenient time.

All vacuum tubes employed in equipment carrying a plurality of traffic circuits are tested periodically every three months. Inferior tubes are discarded even though there is no evidence of impaired circuit performance. Insofar as possible, tubes are prevented from failing in service in all situations where the consequences of a failure are serious. Successful vacuum tube maintenance has contributed much to the excellent continuity of service provided by the Western Union carrier network.

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F. H. Cusack joined the Research Division of Western Union on his graduation from Cornell University in 1929. His preparation for development work on carrier systems included a broad experience in d-c telegraph transmission, disturbance mitigation and carrier frequency transmission. Mr. Cusack's efforts have resulted in many advances in the carrier art, including basic improvements in the suppressed carrier modulator. Recently he has been concerned with problems in single-current telegraph transmission. Mr. Cusack is a Member of the AIEE.

Telecommunications Literature

PROPAGATION OF SHORT RADIO WAVES, Vol. 13—M. I. T. Radiation Laboratory Series—DONALD E. KERR, Editor—McGraw-Hill Book Co., Inc., N. Y., 1951. 728 pp., $10.00. This book is a joint effort of the Propagation Group to summarize the state of knowledge of microwave propagation at the close of the war. The authors cover the theory of propagation, meteorology of the refraction problem, reflections from the earth's surface, atmospheric attenuation, and some phases of radar performance. Also included are some experimental studies of refraction. The material covers primarily the work done at the Radiation Laboratory, although the authors have drawn on other sources for material that has not been available prior to this book except in reports, many of which were not accessible to the public. Though not a complete nor rigorous treatment of microwave propagation, the book is a well-organized summary of those phases of the subject that the authors chose to cover. It is recommended only for readers with more than a cursory interest in microwave propagation and with a good background in mathematics and physics.—R. E. GREENQUIST, Engineer, Radio Research Division.

WAVEGUIDE HANDBOOK- N. MARCUVITZ—M. I. T. Series Vol. 10—McGraw-Hill Book Co., Inc., N. Y., 1951. 428 pp., $7.50. This is the first handbook of its kind to be published and is the result of an intensive and systematic exploitation of both field and network analysis of microwave problems carried out at the Radiation Laboratory of M.I.T. from 1942 to 1946. Its primary aim is to present the equivalent circuit parameters for a large number of microwave structures. These parameters are presented usually both analytically and graphically in individual sections having a concise format to avoid repetition. The microwave structures include all types of waveguide: rectangular, circular, coaxial, elliptical, radial, and spherical, with apertures, slots, bends, junctions, and obstacles as circuit impedances within the waveguide. This handbook is very important in the design of microwave circuits and will aid engineers in designing microwave radio relay equipment—H. E. STINEHELFER, SR., Engineer, Radio Research Division.

COMPONENTS HANDBOOK, Vol. 17 — M.I.T. Radiation Laboratory Series — JOHN F. BLACKBURN, Editor—McGraw-Hill Co., Inc., N. Y., 1949. 626 pp., $8.00. A wealth of material on electrical and electronic components, heretofore available only in widely scattered sources, is here combined with information stemming from the wartime work of the Radiation Laboratory and many other laboratories in the electronic and high-frequency fields. A number of the important classes of components are covered, including wires and cables, resistors, potentiometers, iron-core inductors, rotary inductors, crystals, delay lines, relays, power supplies and receiving tubes. In addition to generalized surveys of the several classes, specific data on the commercially available types include electrical and physical properties, stability and methods of construction. It is to be regretted that the Office of Publication of the Radiation Laboratory was terminated before chapters on several classes of components were completed. The more serious omissions are fixed capacitors, air-core inductors and mechanical components. Nevertheless, this volume, with information as up-to-date as can be reasonably expected in a rapidly-changing field, should serve as a valuable reference work all those currently concerned with the development and design of communication equipments.—C. H. CRAMER, Ass't Transmission Research Engineer.

INDEX

JANUARY 1950 (Vol. 4, No. 1) — OCTOBER 1951 (Vol. 5, No. 4)

(For Index July 1947—October 1949 see Vol. 3, No. 4, October 1949)

SUBJECT

INDEX (Continued)

SUBJECT

AUTHORS

INDEX (Continued)

AUTHORS