WESTERN UNION
Technical Review

Facsimile Transmitter
With Involute Scanner

•

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With Automatic Loading

•

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of a Cam Contour

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Inventory Time

by G. STEWART PAUL
Vice President–Operation

AT the beginning of the year it is customary for businesses to take inventory. We check to see what we have, what we should discard, and what we need for the year ahead.

We have a company that is expanding with our country's expanding economy. We have new methods and new equipment to make our work more efficient. We have new and better services to offer. We have capable employees operating under a new and revitalized organizational structure. We have intelligent and aggressive leadership.

We should discard the old attitudes and methods that make our work less effective. We should discard petty grievances that make our work less pleasant. We should discard our doubts and have faith in the future.

We need a renewed enthusiasm for our performance of the tasks ahead. We need renewed faith in the future greatness of our company. We need renewed effort toward achievement of our progressive objectives. We need complete teamwork.

If our inventory taking is done effectively, we will enter the new year well equipped to continue our dynamic progress as a growth company. I join with the TECHNICAL REVIEW editorial staff in wishing all of you every personal success and satisfaction in your efforts toward making 1959 Western Union's greatest year.

G. Stewart Paul
Vice President—Operation

January 1, 1959

JOEL F. GROSS, Engineer, Telefax

ALVIN PORTNOY, Senior Project Engineer, Telefax

Telefax Transmitter with Involute Scanner

Elementary exploration of an optical image which is the basis of facsimile scanning may be done with a moving aperture or an equivalent arrangement to "pick up" light flux from which electrical signals may be generated. Size, shape and motion of an exploratory aperture influence the characteristics of such signals. Ingenious juxtaposition of a rotating spiral slit and a fixed slit can provide a suitable aperture.

DURING the course of the development of facsimile equipment, it was found that using a drum around which the subject copy was wrapped manually, as commonly had been done, put definite limitations upon attempts to design an automatic, unattended transmitter. Under the older system, time was lost between transmissions, time was consumed in wrapping a message on the drum, or the sizes of the subject copies that could be handled conveniently were limited. Attention was turned to employing new methods and types of transmission which would overcome these restrictions. This article describes a transmitter of the flat-bed type ("flat-bed" referring to the flat position assumed by the subject copy during scanning), one of two types developed by Western Union that will transmit sequentially and unattended a number of subject copies of different sizes and thicknesses. (See Figure 1.)

This transmitter, EM2196, is a self-contained, automatic unit for transmission of messages, designed to operate in conjunction with a 4-stylus page recorder with automatic cutoff, Western Union Number 7219. Operator functions have been kept at a minimum and, therefore, skilled labor is not required. Preloading of subject copies of various sizes provides continuous unattended transmission of one or two hours' duration. A rotating involute spiral produces edge-to-edge scanning of subject copy with no flyback time and no wear of scanning components. Illumination is provided by standard 18-inch fluorescent lamps, and an in-line (rather than folded) optical system simplifies construction and reduces maintenance problems. An electronic system maintains a constant level and contrast of copy.

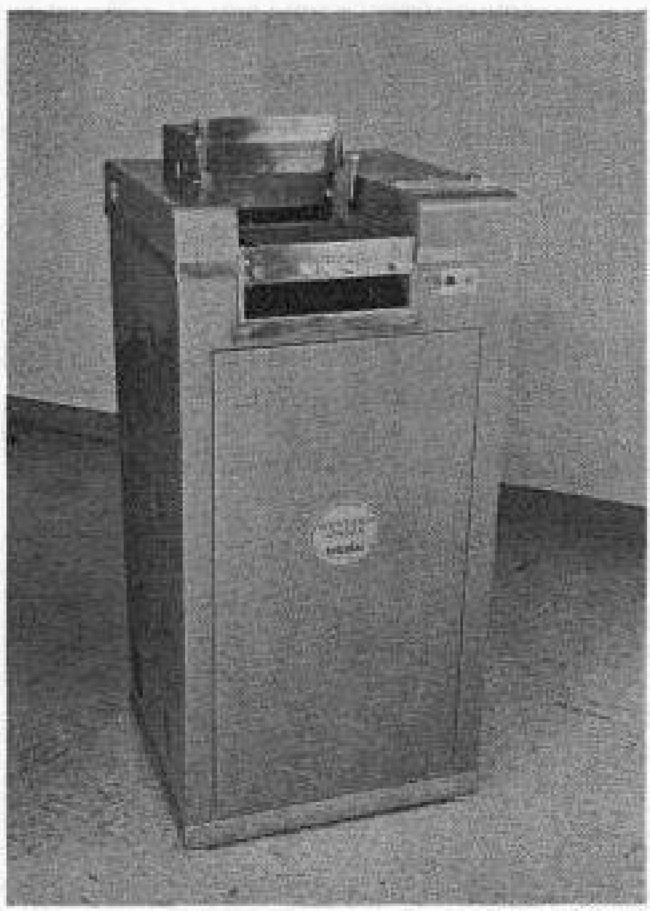

Photo R-11,388

Figure 1. Facsimile Transmitter EM2196 with involute spiral scanner

Transmitter EM2196 may be arranged to operate at a transmitting rate of 180 or 360 rpm at 100 lines per inch, with a carrier frequency of 2000 and 4000 cycles per second, respectively, depending upon circuit capabilities. Provisions are made for transmission to take place over either physical lines or carrier circuits. When operated over physical lines, d-c control signals are transmitted over the path provided by simplexing the line pair. For operations over a carrier, the d-c signals are converted to tone signals. Although designed to handle subject copy 8½ inches wide, the machine will accept subject copies 3½ inches to 8½ inches in width and of any length over 4½ inches. As many as 22 subject copies may be loaded at one time prior to transmission, thus it is possible to have one hour of continuous unattended transmission for sheets 8½ by 11 inches, at 360 rpm (or two hours of transmission at 180 rpm). Savings in transmission time are afforded by prepunching holes immediately below the message area of the subject copies to be sent, to initiate end-of-transmission, and by the uniform deletion of headings if desired. Provision is also made for the interruption of the transmission of the stack of subject copies and the insertion of a priority message.

In operation, the message loader at the top of the machine is stacked with as many as 22 subject copies, each placed face down in the message loader and separated from the succeeding message by a metal bar. (Note: A detailed description of the message loader is given in the article by Robert H. Snider, Flying Spot Flat-Bed Facsimile Transmitter with Automatic Message Loading, appearing in this issue of TECHNICAL REVIEW. The same loader, designed at the Telegraph Company's Water Mill Laboratories, is used in both transmitters.) The message loader then feeds the subject copy that is lowest in the stack into position over two fluorescent lamps where it is illuminated from below and is ready to be scanned.

The lighting is designed to produce uniform illumination of the scanned area, which is a narrow (0.010-inch) line extending the width of the subject copy (8.5 inches). A tubular fluorescent lamp is placed on either side of the scanning line

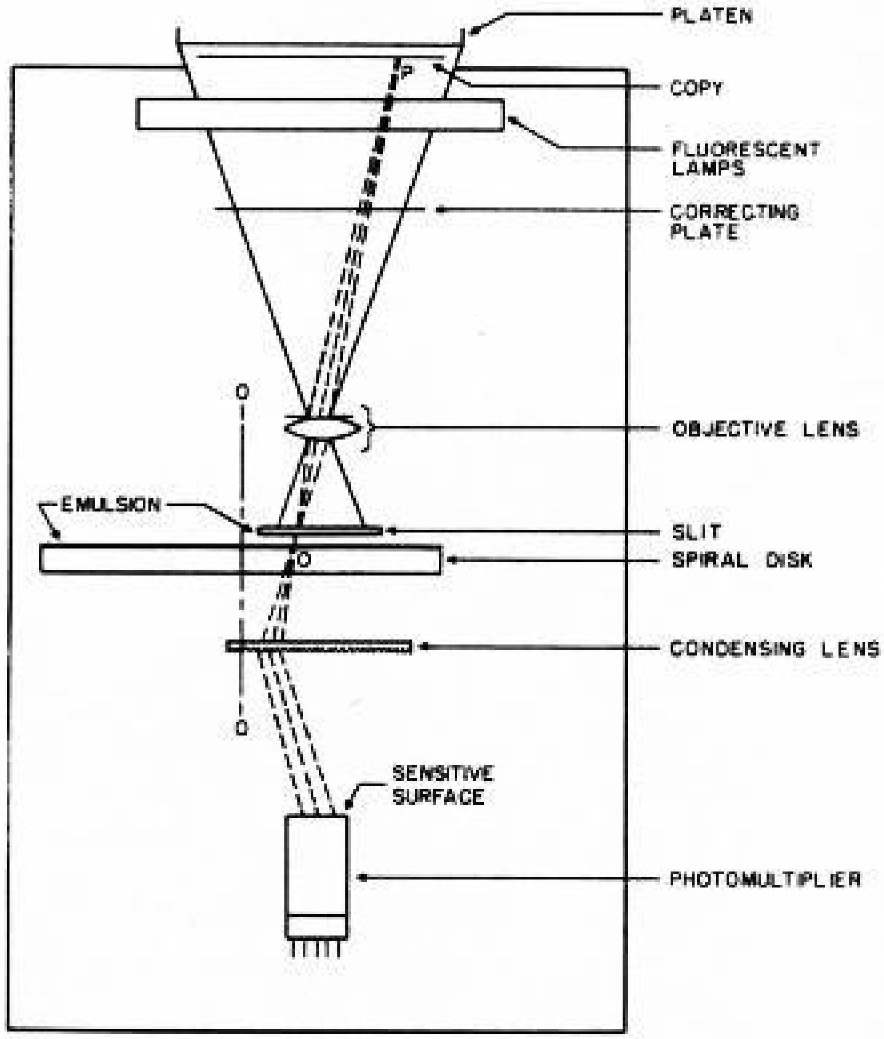

Figure 2. Basic components of the optical system

and parallel to it, and the lamps are spaced apart sufficiently to prevent glare from being picked up. The 18-inch length of lamp was chosen to be greater than the 8.5-inch subject copy width so that all points along the width of the copy are uniformly illuminated, even considering the normal darkening of the ends of the lamp that occurs with age.

It should be noted that the unique feature of Transmitter EM2196 is that it employs a rotating involute to produce scanning. A detailed description of this method of scanning is given in the paragraphs that follow.

Optical System

The scanning method used in Transmitter EM2196 is based on a mechanical system reminiscent of the Nipkow Disk used in early television. (See Figure 2.) The objective lens forms a reduced image of the copy, illuminated by the fluorescent lamps, on a plane between a "slit" and "spiral." The spiral is a circular glass disk that is opaque except for a thin one-turn spiral line and is rotated by a motor about its center. (See Figure 3.) The slit is a rectangular glass plate directly above the spiral disk with a straight transparent line on an opaque background. These slit and spiral lines are of equal width.

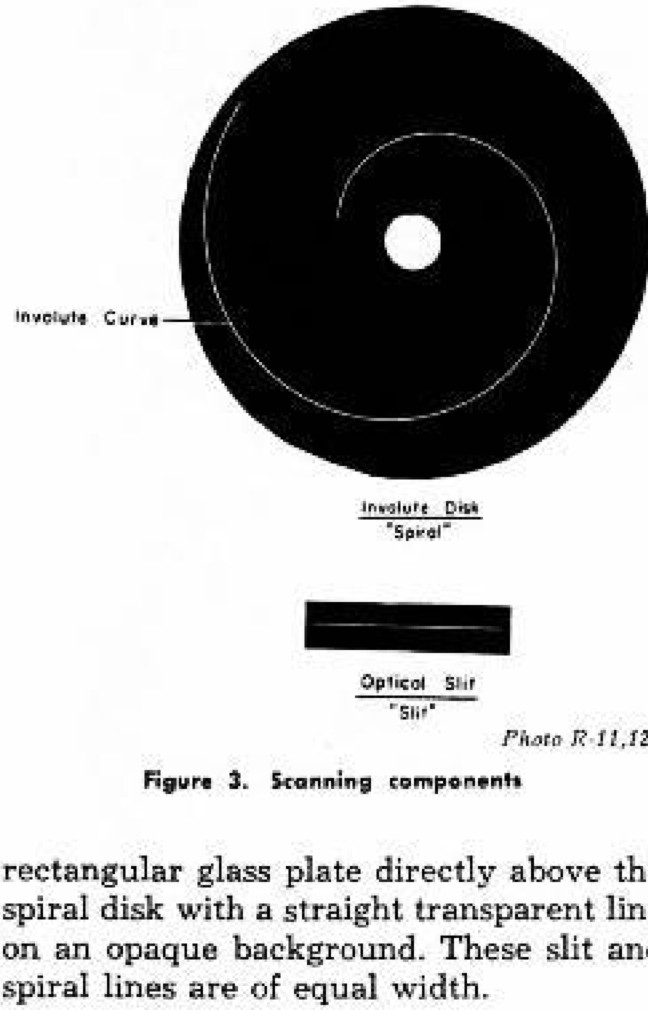

Photo R-11,123

Figure 3. Scanning components

Rotation of the spiral moves an instantaneous intersection "0" of the spiral and slit across the slit from left to right. (See Figure 4 A, B, C and D.) As the slit length is made equal to the distance between the innermost and outermost portions of the spiral, continuous rotation causes instantaneous switchover of the intersection from the right to the left edge of the slit, thereby producing uninterrupted scanning of a 0.010-inch line across the copy.

The shape of the spiral and the position of the slit determine the shape of the aperture produced by the intersection as well as the linearity of scanning. In general, the aperture formed using common spiral curves with a slit is a diamond shape whose acute angle changes during the rotation of the spiral disk. In addition, rotation of such spiral disks at uniform angular speed usually produces an intersection that moves across the slit with varying speeds. These two conditions are undesirable: the former produces varying resolution and signal amplitude, and the latter varies the scanning speed, thereby distorting the width of letters on the subject copy. A spiral curve was selected which overcomes both of these shortcomings. It is an involute of a circle, which is the curve produced by the end of a string which is kept taut while being unwound from the circumference of a circle. With the slit being positioned on a tangent to this generating circle of the involute, it can be shown that the intersection formed is a square aperture whose shape remains constant throughout the rotation of the involute disk. It is also true that uniform rotation of the involute produces linear motion of the intersection and corresponding scanning across the copy of an area 0.010 by 0.010 inch on the copy.

The production of slit plates and involute disks for this machine posed a problem because of the small aperture size involved. Both of these units are made on glass and require 0.0025-inch wide transparent lines on an opaque background. The lines need to be constant in width and transparency throughout their entire lengths in order to produce the uniform aperture required for scanning. The shape of the involute curve is likewise important for producing the required aperture shape and speed of scanning. A photomechanical method for producing these parts was attempted in the laboratory. It consisted of exposing a photographic plate to a moving spot of light, thus producing a negative print of a slit or involute line. From these slit and involute masters, photographic copies were made on glass for use in the machines. Making of masters by this method proved to be difficult, requiring mechanical precision and photographic finesse, and the resultant copies contained some imperfections. Later work with a competent supplier resulted in improvements in the quality of the master units, thereby enabling the production of slit plates and involute disks meeting the necessary requirements.

The transparent aperture produced by the slit and spiral moves across the reduced image of the message, thereby transmitting the variations in light intensity to a condensing lens. The condensing lens is positioned so as to image the circular diaphragm of the objective lens on the sensitive face of a head-on photomultiplier tube. It condenses the moving beam of light produced by the slit and spiral into a stationary circular spot on the photomultiplier, thereby nullifying the effect of varying sensitivities of different areas of the multiplier photocathode. An adjustable light baffle located in the path of the light primarily serves to counteract the effect of uneven light distribution produced by the two lenses in the system and, with proper adjustment, results in a background signal of less than 10-percent variation, as compared to the black signal.

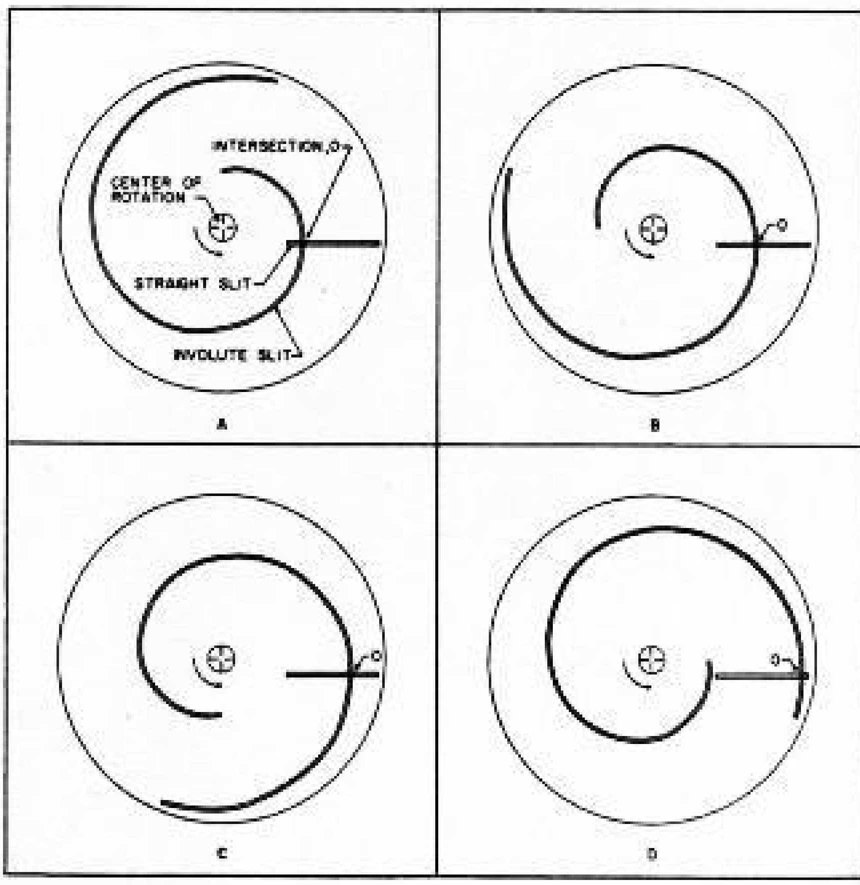

Figure 4. Theory of scanning

The light variations falling on the photosensitive cathode surface of the photomultiplier produce corresponding electrical signals in the cathode circuit. The signal produced is then amplified 50,000 times by the multiplying action of secondary emission in the photomultiplier tube. The signal is further amplified by a preamplifier stage, which is one of the electronic units in the machine discussed in the following section.

Electronics

The electrical portion of the transmitter may be considered to consist of four functional parts: (a) electronics associated with the facsimile signal; (b) power supplies for electronics; (c) control; and (d) auxiliary functions. These functions are performed by individual plug-in units. (See Figure 5.)

The preamplifier is a d-c amplifier designed for low drift that raises the level of the signal from the photomultiplier to the several volts required to operate the modulator section in the succeeding automatic contrast control unit.

Automatic contrast control is provided to produce a constant contrast between the signal level from the light background of the message and the dark typed, handwritten, or printed characters. This will vary with the background color of the original. Since the signal is clamped to the background, the greater the contrast, the greater will be the signal from the characters, and the darker the characters will appear on the facsimile copy. Clamping of background signals is needed to correct for the level shifts that are produced by drift in the d-c amplifier stages, as well as for the variations of background level with signal content produced by capacitor coupling circuits. Automatic contrast control ensures that the maximum black level and background level are each maintained constant, irrespective of the background of the copy or of any changes in signal level due to changes in illumination or sensitivity of the photomultiplier tube.

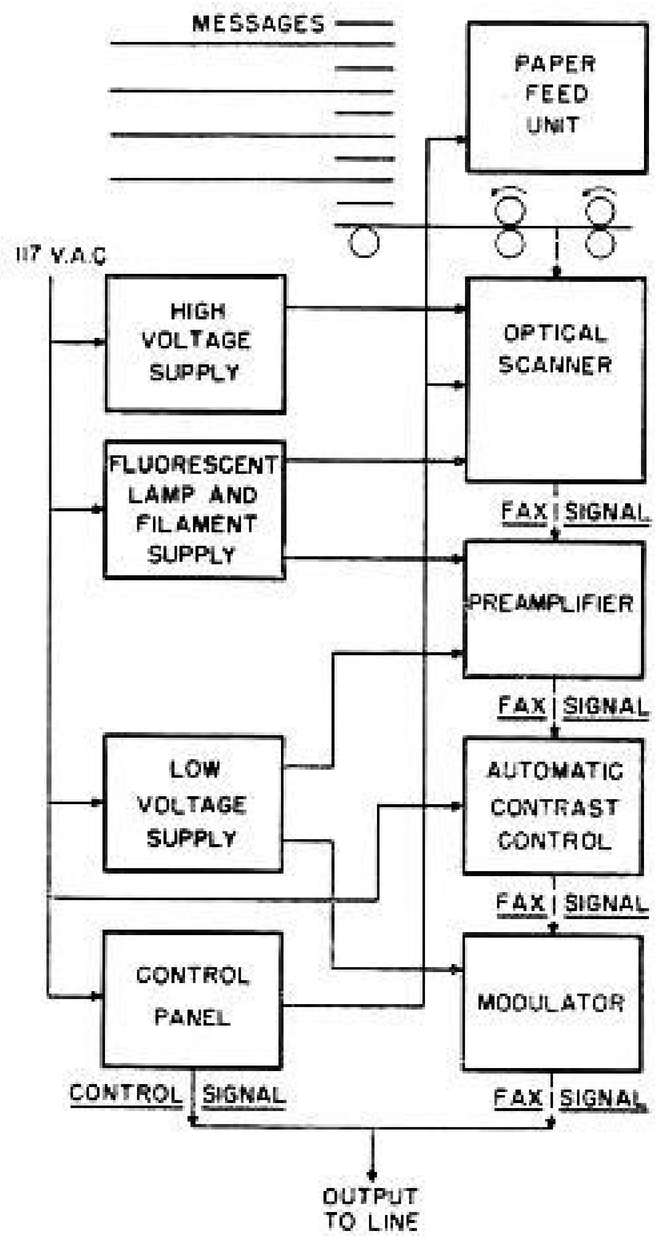

Figure 5. Block diagram of Facsimile Transmitter EM2196

The automatic contrast control unit operates as follows: the "video" signal from the preamplifier enters the automatic contrast control unit where it modulates a 10-kc carrier. This modulated signal is applied to a variable gain stage whose gain depends on the contrast between the copy background and intelligence marks. The modulated signal is then amplified, rectified, and filtered. The resulting unmodulated video signal of constant contrast and amplitude is ready to modulate the facsimile carrier in the next unit. The voltage proportional to contrast needed to control the variable gain stage is provided by a peak detector that senses the difference between the lightest or background level and an artificial black level. The artificial black level is produced by scanning two 3/32-inch strips of black painted on the paper guide pan on either side of the 8½-inch subject copy width. These black areas are scanned along with the message information once every revolution of the involute spiral but do not appear in the recorded copy because of the action of blanking contacts on the spiral shaft.

The facsimile modulator unit is a balanced diode modulator with plug-in oscillator that allows a carrier frequency change from 2 to 4 kc when converting from 180- to 360-rpm operation and vice versa.

The following units are provided to power the units which have just been described: lamp and filament supply, high-voltage supply, and low-voltage supply. The two 18-inch fluorescent lamps require operation on regulated direct current since the flicker associated with a-c operation would be objectionable. The lamp and filament power supply contains a voltage and current regulator and rectifier and filter to produce the direct current; associated ballasts and starters start and operate the lamps. A stepping relay in this unit reverses the d-c polarity across the lamps whenever the power switch is turned off. This occasional reversal is needed under d-c operating conditions to prevent one end of the lamp from becoming dim. An adjunct of this unit is a rectifier and filter to produce d-c filament voltage for the preamplifier unit. The photomultiplier requires a source of regulated high voltage and low current to supply dynode voltages. The high-voltage supply accomplishes this by means of an RF oscillator, rectifier and filter, and regulator tubes. Its output is a regulated d-c voltage, adjustable over a range sufficient to cover differences in sensitivities of various photomultiplier tubes. The low-voltage supply provides regulated and unregulated plate and filament voltages for the modulator and preamplifier units as well as collector dynode voltage for the photomultiplier.

Control functions that produce the automatic unattended operation of the transmitter are centered in the relay circuitry found in the control unit. Here phasing signals are produced (in conjunction with a phasing cam on the spiral shaft), automatic loading and feeding of subject copy is controlled, and line signals are produced to operate the recorder. Three auxiliary units (not shown in the block diagram) are sometimes used with this machine. For use of the equipment over carrier circuits, a carrier control unit converts the d-c control signals to tone signals. In those cases where the power sources at the transmitter and recorder are not synchronous, standard frequency generator and synchronous power amplifier units are required to operate the spiral motor.

Paper Feed

The paper-feed unit consists of a loader section and a rear feed section. (See Figure 6.) (The loader section is similar in operation with that described in Mr. Snider's article.) It is loaded manually with subject copies (face down) that are separated from each other by metal bars. When the loader is powered, the loader cam feeds a bar over the top of the lowest subject copy, thereby sandwiching it between the metal bar and the magnetic roller. Power is then applied to this roller, and the subject copy is fed out of the loader and into the rear feed section. Here it is guided and fed by rollers over a slot where it is illuminated from below by fluorescent lamps.

All rollers are driven through a system of gears and one-way clutches, by either one of two motors on the rear feed section. The normal feed motor operates to feed the subject copy during the transmission of the message, while the fast-feed motor produces high-speed entrance and exit of the subject copy. A paper-metering cam on the same gear train operates switches that control the sequence of operation of the two feed motors, thereby controlling the position on the message where transmission begins. The cam is made adjustable so that scanning can be begun at any position at or below the top of the message. However, once it is adjusted below the top of the message, it will delete headings from all messages. End-of-message transmission is controlled by a series of paper-detecting contacts located immediately beyond the scanning slot. Thus, the bottom edge of copy or a hole prepunched below the last line of text to be sent is detected by these contacts and end-of-transmission is produced. The message then fast-feeds out from under the rollers and drops into a hopper at the rear of the machine.

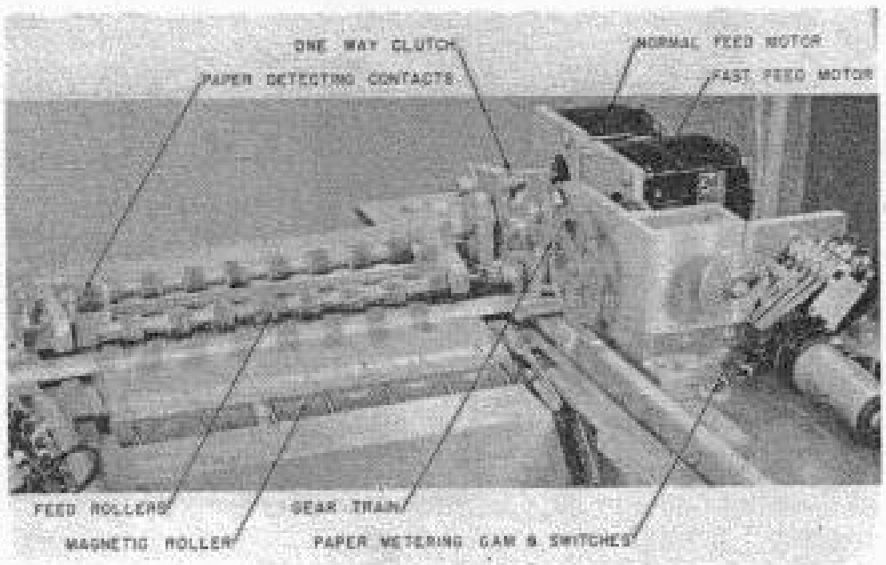

Photo R-11,357

Figure 6. Rear feed section

* * * * *

Several of these units have been placed in operation at two Strategic Air Command bases in the United States. Since they were installed only recently and have been in operation for a short time, it is too early at this time to determine what problems in maintenance, if any, may arise, or to make a proper evaluation of the over-all effectiveness of their operation.

The authors gratefully acknowledge the contributions of R. D. Parrott (mechanical design), G. B. Worthen (optical and electronic design), and innumerable contributions of other members of the Telefax Division. They would also like to thank the technical writing group of D&R for invaluable assistance in the preparation of this article.

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1. A Flat-Bed Facsimile Telegraph Transmitter, WILLIAM D. BUCKINGHAM, *Western Union Technical Review*, Vol. 10, No. 3, July 1956.
2. Flying Spot Flat-Bed Facsimile Transmitter with Automatic Loading, ROBERT H. SNIDER, *Western Union Technical Review*, Vol. 13, No. 1, Jan. 1959.

Joel F. Gross graduated from New York University in 1953 with a Bachelor of Mechanical Engineering degree. After being associated with Republic Aircraft Corporation for a short time he joined Western Union in 1954. As a member of the Telefax Division of D&R he has been engaged in the design, development and testing of facsimile equipment. Mr. Gross is an associate member of ASME.

Alvin Portnoy received a Bachelor of Electrical Engineering degree from the College of the City of New York in 1948, after interrupting his studies to serve as a radar technician in the United States Navy. Soon after, he joined Western Union in the Telefax Division and has since been engaged in the development of a number of facsimile systems. His work includes test installations of automatic type transmitters, design of facsimile terminal equipment for a ten-station Desk-Fax dial intercommunication system, and design of a two-way repeater for the Desk-Fax transceiver. Recently he has worked on the design of optical and electronic units of flat-bed transmitters as described in this paper. Mr. Portnoy is a member of the Inspections Trips Committee of AIEE, a member of IRE and Tau Beta Pi, and a licensed Professional Engineer in New York State.

ROBERT H. SNIDER, Project Engineer, Electronics

Flying Spot Flat-bed Facsimile Transmitter with Automatic Message Loading

A limited number of facsimile transmitters featuring flying spot scanning and automatic message loading are in service. Other Western Union facsimile machines have been equipped for automatic drum changing and for mechanical rather than manual message loading but now a new loading device readily accepts telegrams for priority transmission.

FACSIMILE TRANSMITTER WM207, a flat-bed scanner of the flying spot type, has been developed at the Water Mill Laboratory of The Western Union Telegraph Company using the basic concepts set forth in previous articles by W. D. Buckingham.[1, 2] (See Figure 1.) Several of these scanners are now in service at Strategic Air Command facilities.

Flat-bed scanners have these inherent advantages over the more common drum-type scanners: the copy is simply laid flat upon the bed of the machine; no manipulation of the message (rolling or wrapping) is necessary; no garters or other devices are needed to hold down the message, and no drums need be changed. A facsimile transmitter of this new type offers the important additional advantage of an automatic loading device which processes a number of pieces of copy sequentially and unattended after they have been properly placed in the machine. Rollers feed the copy straight through the machine, past the scanning device, and deposit it in a hopper at the rear. Because the subject copy is not curved around rolls or deflectors, or otherwise bent from its original plane, the handling of cards is facilitated. Fast paper feed is used to economize line time by quickly bringing the sheet to the scan line before scanning at the normal speed and by quickly removing it afterward. In addition, long rolls of page teleprinter copy can be continuously transmitted.

This machine is designed to operate at either 180 or 360 scans per minute. A significant advantage is realized in the ease of changing mechanical speeds simply by throwing switches. Output may be adjusted for either white or black maximum. The machine scans 100 lines per inch and operates with the Type 7219 letterfax recorder to produce 1 to 1 copy. The automatic loading system and new design features will be discussed.

Figure 1. Operating the flying spot scanner

AUTOMATIC LOADER

Any automatic loading device for use with the scanner must perform two functions: first, store messages awaiting transmission; second, cause the stored messages to be automatically transmitted, one by one. During the development of this loader several schemes were tried. First attempts were directed toward using the types of paper moving devices common to printing presses. Although these work well for any single grade or size of paper, they are not capable of satisfactorily loading the variety of types and sizes of messages which are commonly found in the telegraph business. There was also the possibility that two sheets might be fed through simultaneously with these systems; this potential loss of messages would be intolerable in any communication system.

Therefore, a loader was conceived which provided for physical separation of each message from the next by the use of a thin metal bar of dimensions 1 inch by 10 inches. Using these separator bars, an operator may load as many as 22 messages into the machine initially or at any time during the operation of the machine. The messages are transmitted one by one starting with the bottom sheet in the pile. A full load of letter size messages requires about one hour of unattended operation at 360 rpm or two hours at 180 rpm.

To load and start the machine the operator places a piece of copy to be transmitted face up on the felt-covered tray (Figure 1). The copy is indexed against the right side of the tray and against the felt curtain located under the bar magazine. Then the operator depresses the magazine lever which causes a bar to drop on top of the paper as shown in Figure 2. The weight of the bar operates a switch which starts the sequence of operations of the scanner.

When this bar switch closes, the loader motor is started and operates the bar actuator causing it to move the bar to its ultimate position over the top of a magnetic roller (the paper beneath does not move since its contact with the bar is loose). It is at this point that the paper detector circuit is energized to make certain that paper is under the bar before sending a start signal to the recorder. Then other switches are operated which stop the loader motor and start the paper feed and scanning sequence. After the message has been transmitted, the loader is again started and the bar actuator moves the bar off the magnetic roller and releases it into a storage bin.

Three lights, yellow, green and red, on the front panel indicate the condition of the scanner. A yellow light indicates that the automatic loader mechanism is moving a bar. A green light indicates that transmission is taking place. Should the operator wish to send a priority message ahead of several messages already stored and waiting, he pulls out the knob at the front of the loader. At the end of the current transmission, the loader will prepare itself to receive the priority message by locking up part way through its cycle and lighting the red indicator. The machine will remain waiting until an operator attends to it. To insert the priority message the operator raises the hinged tray containing the stored copy, slides the message in under the tray and under the lowest bar and then lowers the tray. (See Figure 3.) Then the operator pushes in the knob which extinguishes the red light and starts transmission of the priority message. The machine

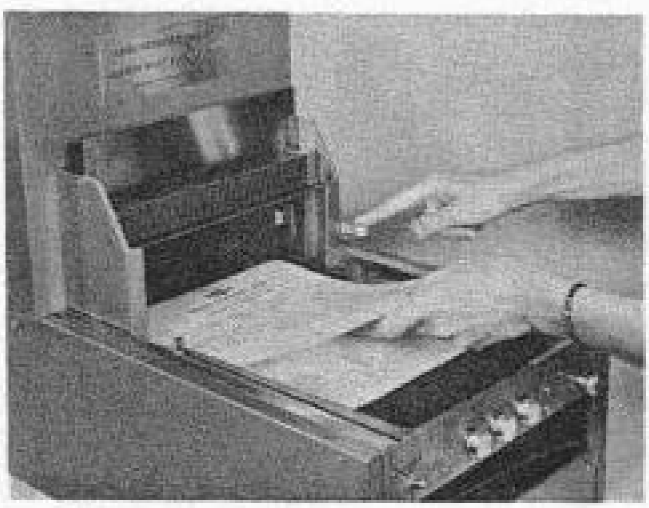

Figure 2. As many as 22 messages may be loaded at any time for future transmission in sequence

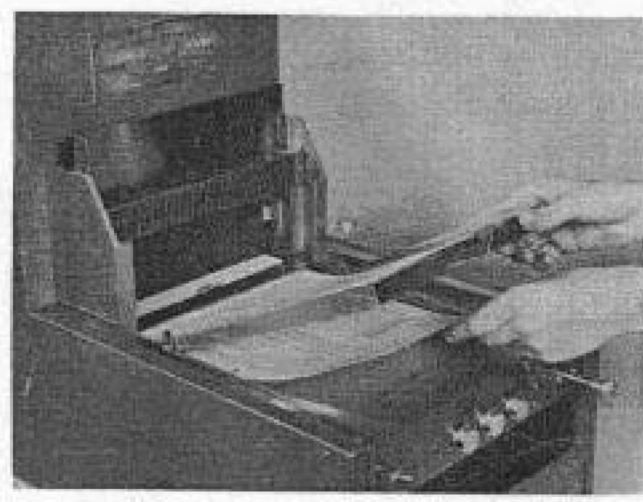

Figure 3. A priority message may be sent ahead of the stacked messages

then completes transmission of all remaining copy in normal fashion.

A front panel switch is provided to disable the loader if desired. Thus the messages may be loaded for future transmission without starting the machine.

A loading mechanism essentially identical to this model has been adapted for use in the EM2196 Rotating Involute Spiral Flat-Bed Scanner described elsewhere in this publication.[3]

NEW DESIGN FEATURES

Aside from the automatic loading device, this operational model has several design innovations which were not described in the original article.

Equalization of Light Intensity

Mr. Buckingham's article describes the long photocell and light pickup system used. Because the photocells may be non-

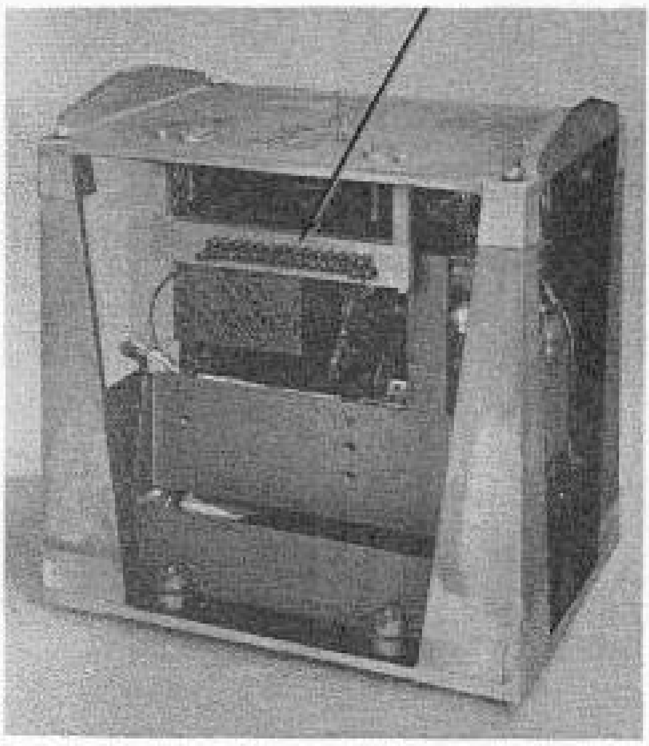

Figure 4. Set screws are used to equalize light intensity

uniform in sensitivity along their length, and pickup from the collecting mirrors is also not necessarily uniform for all points along the scan line, it becomes necessary to equalize for this condition. That is, the light intensity must be reduced at the regions of higher effective sensitivity to make the output of the photocell uniform over the length of the scan line.

To achieve equalization the ¼-inch diameter set screws shown in Figure 4 are adjusted as required; each one interferes with and partially blocks out a portion of the light beam before it gets to the scan line. (The beam is converging where it passes the set screws but still is about ½ inch in diameter, so that one screw will not completely mask the beam.) Since the set screws are located about midway between the spherical mirror and the scan line, the shadow of a single screw is spread over an appreciable length of scan line during the sweep. This effect when combined with similar characteristics of adjacent screws makes possible a smooth equalization.

Cam Unit

To generate the scan line, the concave spherical mirror, mounted in ball bearing

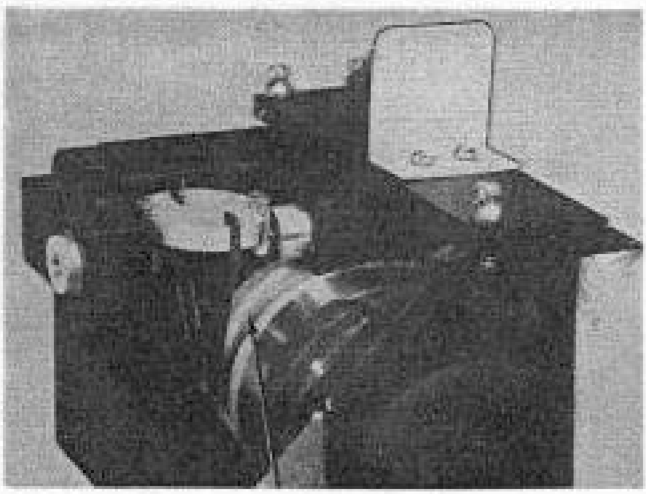

Figure 5. Nylon cam causes mirror to oscillate

supports, is caused to oscillate to and fro by action of a motor driven nylon cam. (See Figure 5.) This cam is the heart of the machine. While difficult to make, tests have indicated that the cam's life expectancy is very great. Cam motion causes the spot to sweep across the message during 95 percent of the time of one revolution leaving 5 percent for the retrace or flyback. An interesting problem which was encountered in the early stages of the development of this cam is discussed elsewhere in this publication.[4]

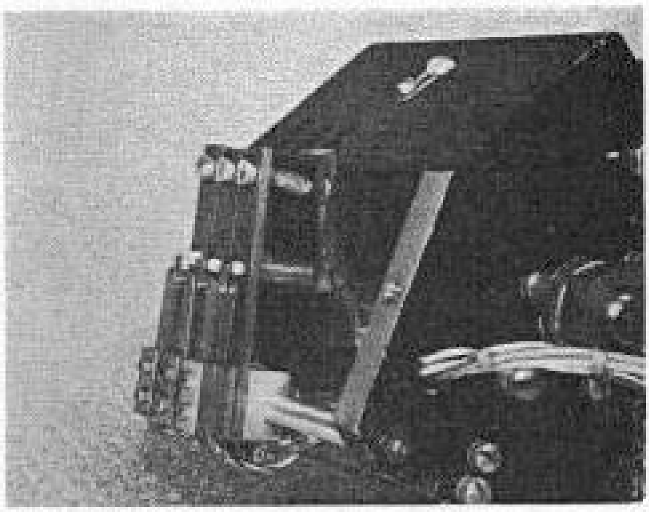

Figure 6. Nylon pushers operate control contacts for phasing, blanking and automatic gain control

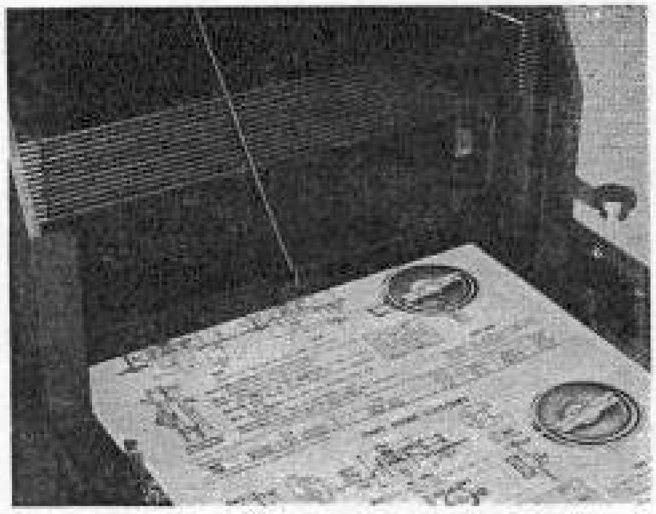

Figure 8. Copy being transmitted. Magnetic force presses paper between bar and roller

Figure 6 shows the three sets of cam driven contacts which are also located on this unit. One set is used for phasing, one for blanking the flyback, and the third is used for automatic gain control purposes.

Paper Feed

Paper feed is accomplished by two feed rollers, one forward of the scan line and one behind. The forward roller is composed of a steel cylinder core over which are placed cylindrical ceramic permanent magnets separated by rings of rubber slightly larger in diameter than the magnets. (See Figure 7.)

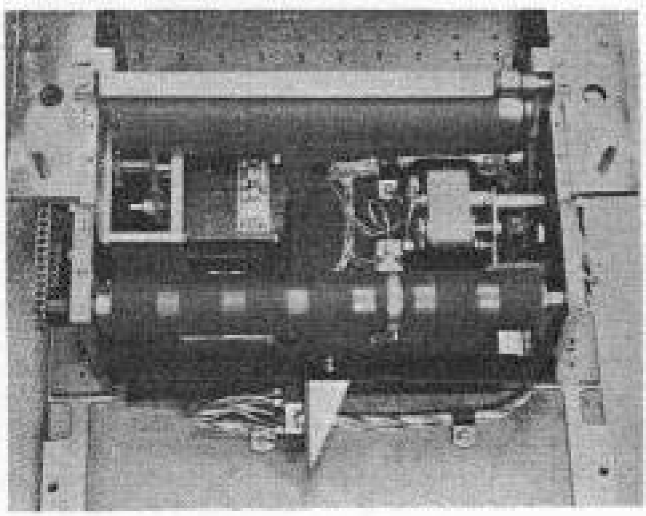

Figure 7. Paper feed rollers showing 2-speed normal feed drive at left and fast feed at right

A steel bar is placed over the magnetic roller and the paper is squeezed between it and the rubber rings. The bar is restrained and the paper slides under as it is forced forward by the rotation of the roller. (See Figure 8.)

After the paper progresses past the scan line it is gripped between the rear feed roller and a knurled idler roller. The rear feed roller is rubber covered and is similar in appearance to a typewriter roller.

The front feed roller is chain driven from the rear feed roller. Both normal feed and fast feed motors drive the rear roller. The fast feed motor operates through an overriding clutch arrangement.

The operator may let the full sheet of paper be transmitted or may elect to eliminate the last portion of the sheet (for instance, to save line time if that portion is blank). He does this before placing the sheet in the machine by punching a ¼-inch hole in the right margin of the copy following the last line to be transmitted. The punch is mounted on the console. When the hole reaches the rear feed roller during paper feed, three insulated floating contact rings mounted on the idler roller shaft detect the presence of the punched hole and thereby signal end-of-message. (See Figure 9.)

The magnetic feed roller also contains a similar contact ring which in conjunction with the bar detects presence or absence of paper and is used to prevent a false starting call from going to the recorder should the machine be operated without copy. (See again Figure 7.)

Ease of operation is the keynote of this WM207 scanner. Operator training is brief and simple. The operator is free after loading the machine. A switchboard operator, for instance, would probably have sufficient time to tend this machine in addition to other duties. Its ability to handle many types, sizes and background shades of copy paper is also of great value.

In compiling this article the author wishes to extend due credit to those responsible for the basic design: W. D. Buckingham, F. T. Turner, L. D. Root and G. H. Ridge. Assistance received in preparation of this article is also gratefully acknowledged.

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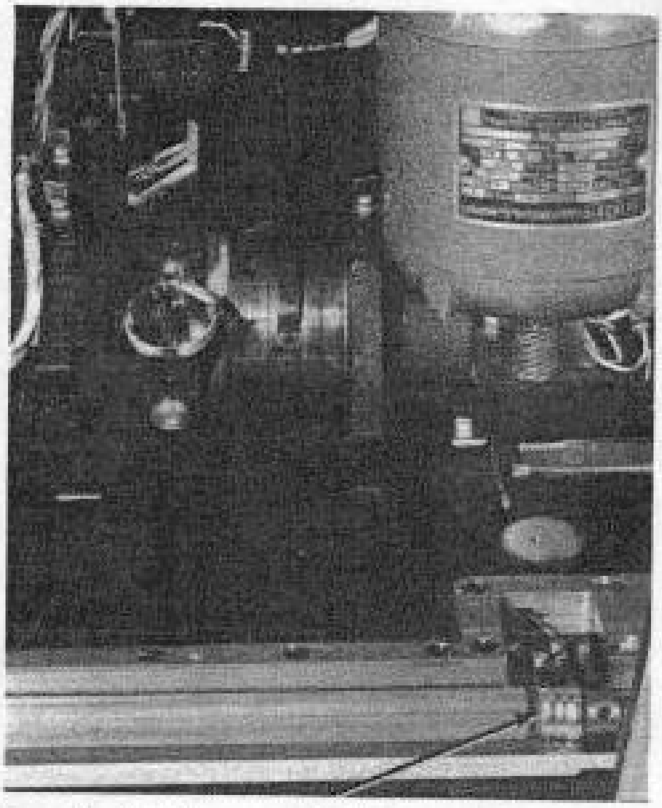


Figure 9. End-of-message hole detector at lower right

Robert H. Snider was graduated from Cornell University in 1948 with the degree of Bachelor of Electrical Engineering. Immediately after graduation he joined the Telegraph Company on the staff of the Electronics Research Engineer at the Water Mill Laboratory. There he contributed toward the design of the three-stylus hotel-type facsimile recorder and the high-speed facsimile program, and spent some time on design and initial production of Telegraph Terminal AN/FGC-29 for the Signal Corps. Since that time he has been concerned with extending the development of this flat-bed scanner from the prototype stage to its present form. Mr. Snider is a licensed professional engineer.

FRANK T. TURNER, Senior Project Engineer, Electronics

Derivation of a Cam Contour for Minimum Stress

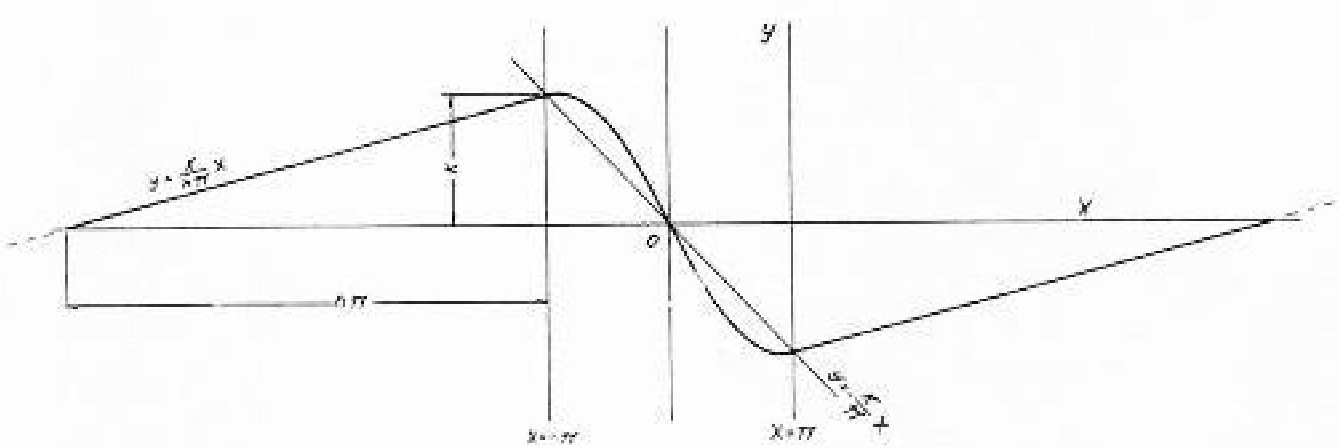
as Applied to Flying Spot Scanner

In any cam-operated mechanism operating at moderate to high speeds, noise and high stresses are frequently a problem. This paper discusses an approach to the design of cams which will yield a contour producing the minimum stress and noise, and gives in detail the development of a cam for a specific application.

Where the velocity of a cam follower must be rapidly changed in the course of movement of the cam, then high accelerations of the cam follower will be necessary. If, for example, the form of the cam is such that there is an abrupt change in velocity, the acceleration is applied over a short period of time and has a very high value. The resulting shock to the system produces a substantial amount of noise and high stresses which may result in early failure of moving parts.

A contour of this type would show an obvious discontinuity to the eye and would probably not be considered by an experienced designer. Another approach is that of a constant acceleration applied in such a manner as to achieve the desired velocity in the required length of time. This yields a smooth curve, but the sudden application of accelerating force can still produce transients which lead to noisy operation. A sine or cosine form for the transition portion of the curve may lead to a satisfactory solution, but a somewhat more fundamental approach is desirable.

If the cam follower and associated mechanism is considered as a dynamic system, it will be seen that a minimum of stress and noise will result if the motion of the system is free from any frequency components higher than the minimum required to accomplish the necessary travel in the desired time. This condition is satisfied if the acceleration itself is a sine curve. Application of this approach to a practical problem is given in the following example.



In the flying spot facsimile scanner[1,2] a small pivoted mirror causes the light spot to move across the copy at a uniform rate for scanning and to return rapidly to the starting point at the end of each scanning line. The mirror is caused to move by a cam follower riding in a groove on a cylindrical cam. Scanning must proceed at a uniform rate for 95 percent of the period of rotation of the cam, and only 5 percent is allowed for the return of the mirror to the starting point. When the scanner operates at 360 rpm, or 6 strokes per second, only about 8 milliseconds is allowed for the return stroke. Until a satisfactory form for the return portion of the cam was developed, considerable difficulty was experienced with mechanical failures of the cam follower and mirror assembly, and operation was noisy.

The accompanying illustration shows the cam in developed form. The period allowed for the return stroke is assigned the value of 2π, and the following conditions are stipulated:

The acceleration; i.e. the second derivative of cam-follower displacement, should be a sine function of cam rotation, and should be equal to zero at the point of entry into the return curve and at the center of the return curve, reversing in sign for the second half of the return curve, and again equal to zero at the end of the return curve upon entry into the straight portion of the cam. (1)

The velocity; i.e., the first derivative of cam-follower displacement, will be the integral of acceleration, and should be equal to the velocity of the cam follower in the straight portion of the cam at the points where the return curve meets the straight portion (2)

The displacement at the beginning of the return curve must obviously be the same as that at the end of the straight portion, and for convenience in the mathematical treatment is taken to be zero at the midpoint of the return curve. (3)

Then, according to (1) above,

$$A = p \sin x \tag{4}$$

where p is an undetermined coefficient, and A is acceleration and is equal to 0 when $x = 0$ and $x = \pm\pi$.

Then, according to (2),

$$\begin{aligned} V &= \int A\,dx = \int p \sin x\,dx \\ &= -p \cos x + C_1 \end{aligned} \tag{5}$$

where V is velocity and is equal to m when $x = \pm\pi$. Then

$$\begin{aligned} m &= -p \cos \pi + C_1 \\ &= -p(-1) + C_1 \\ &= p + C_1 \\ C_1 &= m - p \end{aligned} \tag{6}$$

According to (3),

$$\begin{aligned} D &= \int V dx \\ &= \int(-p \cos x + C_1)dx \\ &= -p \sin x + C_1 x + C_2 \end{aligned} \tag{7}$$

where D is displacement (y in the illustration). Since $D = 0$ when $x = 0$, $C_2 = 0$; and since $D = \kappa$ when $x = -\pi$,

$$\begin{aligned} \kappa &= -p \sin(-\pi) + C_1(-\pi) \\ &= -\pi C_1 \\ C_1 &= -\frac{\kappa}{\pi} \end{aligned} \tag{8}$$

Substituting (6) in (8),

$$\begin{aligned} m - p &= -\frac{\kappa}{\pi} \\ p - m &= \frac{\kappa}{\pi} \\ p &= \frac{\kappa}{\pi} + m \end{aligned} \tag{9}$$

Substituting (8) and (9) in (7),

$$D = -\left(\frac{\kappa}{\pi} + m\right) \sin x - \frac{\kappa}{\pi}x \tag{10}$$

As seen in the illustration, $m = \frac{\kappa}{n\pi}$, therefore from (10),

$$\begin{aligned} D &= -\left(\frac{\kappa}{\pi} + \frac{\kappa}{n\pi}\right) \sin x - \frac{\kappa}{\pi}x \\ &= -\frac{n\kappa + \kappa}{n\pi} \sin x - \frac{\kappa}{\pi}x \\ &= -\frac{\kappa}{\pi}\left(\frac{n+1}{n} \sin x + x\right) \end{aligned} \tag{11}$$

Equation (10) is the basic form, while (11) is rearranged to a more convenient form for numerical computation. Note that x is an angle expressed in radian measure.

In setting up a milling machine to cut this cam, the interval from $x = -\pi$ to $x = \pi$ is divided into a number of "stations", s, suitable for the milling machine used and the order of accuracy desired. Then at any station, r,

$$D = -\frac{\kappa}{\pi}\left(\frac{n+1}{n} \sin \frac{r\pi}{s} + \frac{r\pi}{s}\right) \tag{12}$$

For convenience in consulting an ordinary function table, (12) may be changed to read:

$$D = -\frac{\kappa}{\pi}\left[\frac{n+1}{n} \sin \left(\frac{180r}{s}\right)^{o} + \frac{r\pi}{s}\right] \tag{13}$$

In this practical case, the first 10 percent of the return trace was found to deviate so little from an extension from the straight line portion of the cam that the effect would be undetectable in the copy. The curve was, therefore, recalculated to allow the return portion to begin somewhat before the theoretical end of the straight line portion resulting in a somewhat lower maximum velocity for the cam follower.

*   *   *   *   *

Cams cut according to the above curve have been run for many thousands of hours without sign of deterioration of the cam or failure of the cam follower assembly.

Reference 3 discusses a similar problem, arriving at substantially the same solution but presenting different concepts in its development.

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A biographical sketch of the author appears in the October 1958 issue of TECHNICAL REVIEW.

D. A. PAWSON, Engineer, London

Pulse-Echo Tests on Multicore Submarine Telegraph Cables

Pulse-echo tests on multicore submarine telegraph cables of modern construction are complicated by the mutual coupling existing between cores which may produce as many as three echoes, received after different delay times, from a single discontinuity. Propagation of pulses in such cables has been examined and a method for an approximation to the echo amplitudes has been developed.

THE application of pulse-echo methods to submarine telegraph cable fault localisation, with particular reference to cable ship operations, has been described previously.[1] The present article concerns the interpretation of echo displays obtained from pulse tests on multicored shore-ends of submarine telegraph cables, which have more complex propagation and reflection characteristics than the single-cored sections forming the major part of such cables.

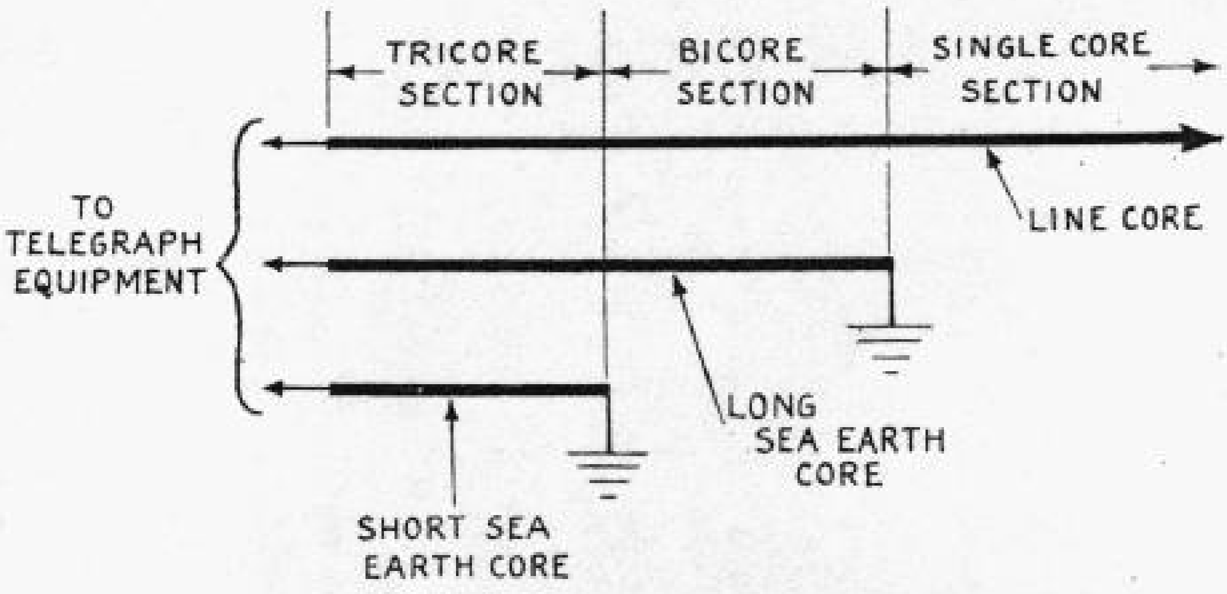

Figure 1. Submarine telegraph cable shore end—line diagram

The first few miles of submarine telegraph cable from the shore termination is usually multicored and is shown in line diagram form in Figure 1. The two sea earth connections are formed by joining the conductor of one core to the armouring wires at the seaward ends of the tricore and bicore sections. The short sea earth core is used to make a sound earth return for transmitted signals. The long sea earth core is used for receiving. The separate sending earth core provides for stability of duplex adjustments and reduction of crossfire between cables, while the receiving earth core causes the effects of natural electrical disturbances, which induce equal voltages in both cores of the bicore section, to cancel out at the receiving amplifier.

The length of the tricore section is usually quite short, about 0.5 nm; that of the bicore section is a compromise between capital cost, the electrical attenuation permissible, and the degree of freedom required from natural disturbances which latter decrease in magnitude with increasing depth of water. Most non-loaded cables have a long sea earth core of about five miles—well within pulse-echo fault localisation range.

Multicore submarine telegraph cables are manufactured by laying up two or three cores, each served with jute, around a jute heart and covering the whole with a further jute serving and the armouring wires. In older cables the core insulant is gutta-percha which is protected against marine biological attack by wrapping the cores with a continuous brass tape. Modern cables employ polyethylene as the core insulant; this is apparently not attacked by marine borers and the brass tape is omitted.

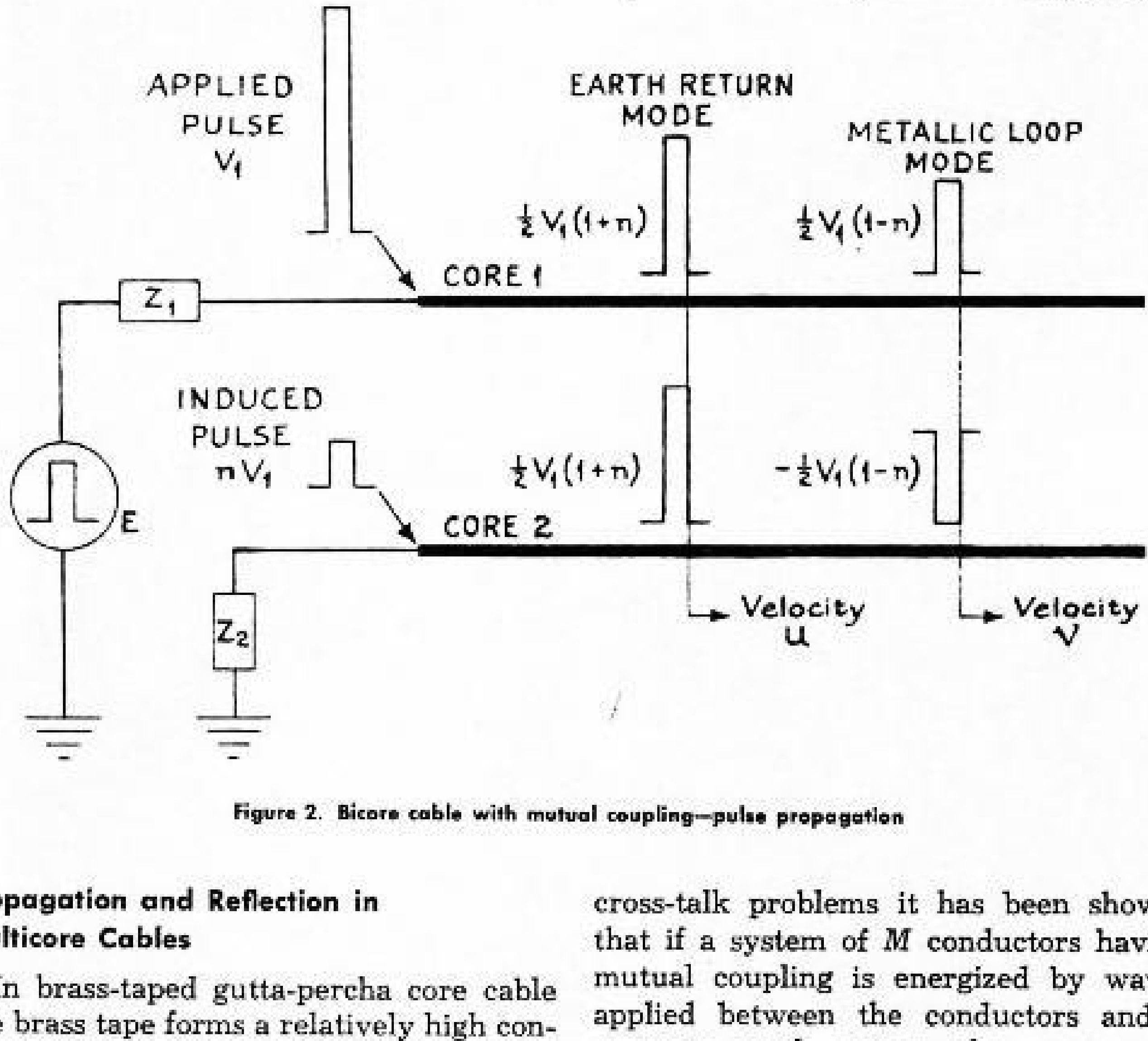

Figure 2. Bicore cable with mutual coupling—pulse propagation

Propagation and Reflection in Multicore Cables

In brass-taped gutta-percha core cable the brass tape forms a relatively high conductivity return path for pulses applied to the core conductor. The magnetic fields of the conductor and the return path virtually cancel each other outside the brass tape and therefore the external magnetic field is small. The brass tape also reduces the capacitative coupling between cores so that each core of a multicored brass-taped gutta-percha cable can be assumed to behave as a coaxial cable and can be pulse tested as if it were the only core in the cable, having one distinct velocity of propagation and obeying the normal reflection laws.

Propagation in multicored cable without brass tape around each core is more complicated as the return path for pulses applied to the conductors is the sea-water-saturated jute around the cores. Each core lies in the magnetic field of the other cores and there is thus mutual inductive coupling between them. The finite return path resistance of the cores gives a mutual capacitance. In a general investigation of cross-talk problems it has been shown[2] that if a system of M conductors having mutual coupling is energized by waves applied between the conductors and a common earth return the waves are propagated in a maximum of M modes. One or more modes may disappear, depending upon the terminating conditions of the cores. In the special case in which the couplings between all the conductors are equal, which may be assumed to correspond to multicore telegraph cables by virtue of their symmetrical construction, the waves are propagated in a maximum of two modes only—one around the metallic loop path formed by the conductors alone and the other around the path formed by the conductors and their common earth return. The waves are propagated at velocities and into impedances characteristic of each mode. Thus, a pulse applied to one core, travelling in two modes, arrives at a discontinuity after two different delay periods x/u and x/v. Each reflected pulse may return in two modes so that echoes from the single discontinuity can be received after delays of $(x/u+x/u)$, $(x/u+x/v)$, $(x/v+x/u)$ and $(x/v+x/v)$ giving, in effect, three successive echo pulses.

Propagation and Reflection in Bicore Cables

The propagation of a step wave along a resistanceless high-frequency bicore cable with mutual coupling between cores is analysed in Appendix I. The modes of propagation when a pulse V_1 is applied to one core only are shown in Figure 2.

The characteristics of the modes are:

Earth return mode:

Velocity of propagation

$$u = \frac{1}{\sqrt{C(L+M)}}$$

Characteristic impedance

$$Z_u = \sqrt{\frac{(L+M)}{C}}$$

Metallic loop mode:

Velocity of propagation

$$v = \frac{1}{\sqrt{(C+2C_1)(L-M)}}$$

Characteristic impedance

$$Z_v = \sqrt{\frac{(L-M)}{(C+2C_1)}}$$

where L, C, M and C_1 are the distributed inductance, capacitance, mutual inductance and mutual capacitance, respectively. When pulses balanced with respect to earth (i.e., of opposite polarity with $n = -1$) are applied to the respective cores they are propagated in the metallic loop mode only, but when equal pulses are applied to both cores ($n = +1$) they travel in the earth return mode only. If a pulse is applied to one core only and the second core is earthed at the near end the induced pulse nV_1 is zero and equal pulses are propagated in both modes.

The magnitude of the pulse induced in the second core and appearing at its near terminal is a discontinuous function of the characteristic impedances of the two modes and of the near-end impedance terminating the second core. In a resistanceless cable the latter can be chosen so that pulses are propagated in one mode only or so that the input impedance of core 1 is zero, but a finite pulse is induced in and appears at the terminal of core 2.

In practice a submarine telegraph cable has considerable resistance at high frequencies. Two possible modes of propagation still exist but the relative amplitudes of the pulses travelling in the two modes and of the induced pulse are much less dependent upon the core terminations than in the ideal high-frequency cable. It appears in practice that the ratio of the magnitudes of the applied pulse and induced pulse in the second core is always less than the limiting value of n when the near-end terminating impedance is infinite, being small and less than

$$\frac{Z_u - Z_v}{Z_u + Z_v}$$

The attenuation for each mode of propagation is different since the characteristic impedances and the path resistances are not the same.

The reflection coefficient of a discontinuity in a propagation path is a function of the path characteristic impedance. The reflection coefficient of a discontinuity in a bicore cable with mutual coupling between cores thus has two values according to the mode in which the incident pulse is propagated unless the discontinuity is an open or short circuit giving complete

TABLE I. BICORE CABLES – ECHO AMPLITUDES

DELAY TIME	$\frac{2x}{v}$	$\frac{x}{v}+\frac{x}{u}$	$\frac{2x}{u}$
CORE 1 (PULSE V_1 APPLIED)	$\frac{1}{4}V_1(1-n)(s_1+s_2)$	$\frac{1}{4}V_1\left\{(1-n)(s_1-s_2)+(1+n)(r_1-r_2)\right\}$	$\frac{1}{4}V_1(1+n)(r_1+r_2)$
CORE 2 (PULSE nV_1 INDUCED)	$-\frac{1}{4}V_1(1-n)(s_1+s_2)$	$\frac{1}{4}V_1\left\{(1-n)(s_1-s_2)-(1+n)(r_1-r_2)\right\}$	$\frac{1}{4}V_1(1+n)(r_1+r_2)$

Note: *r* and *s* are the reflection coefficients of discontinuities on cores 1 and 2, denoted by subscripts, for pulses incident at velocities *u* and *v* respectively.

reflection. The reflected pulse from a discontinuity in one core induces a pulse in the other whose magnitude depends upon the impedance at the second core.

Exact analysis of the relative amplitudes of the echo pulses received from discontinuities in a bicore cable gives unwieldy expressions of little practical value. An adequate approximation is made for submarine telegraph cables by neglecting the pulse induced by the reflected pulse, and determining the amplitudes of the pulses propagated in the two modes satisfying the boundary conditions set by the pulse

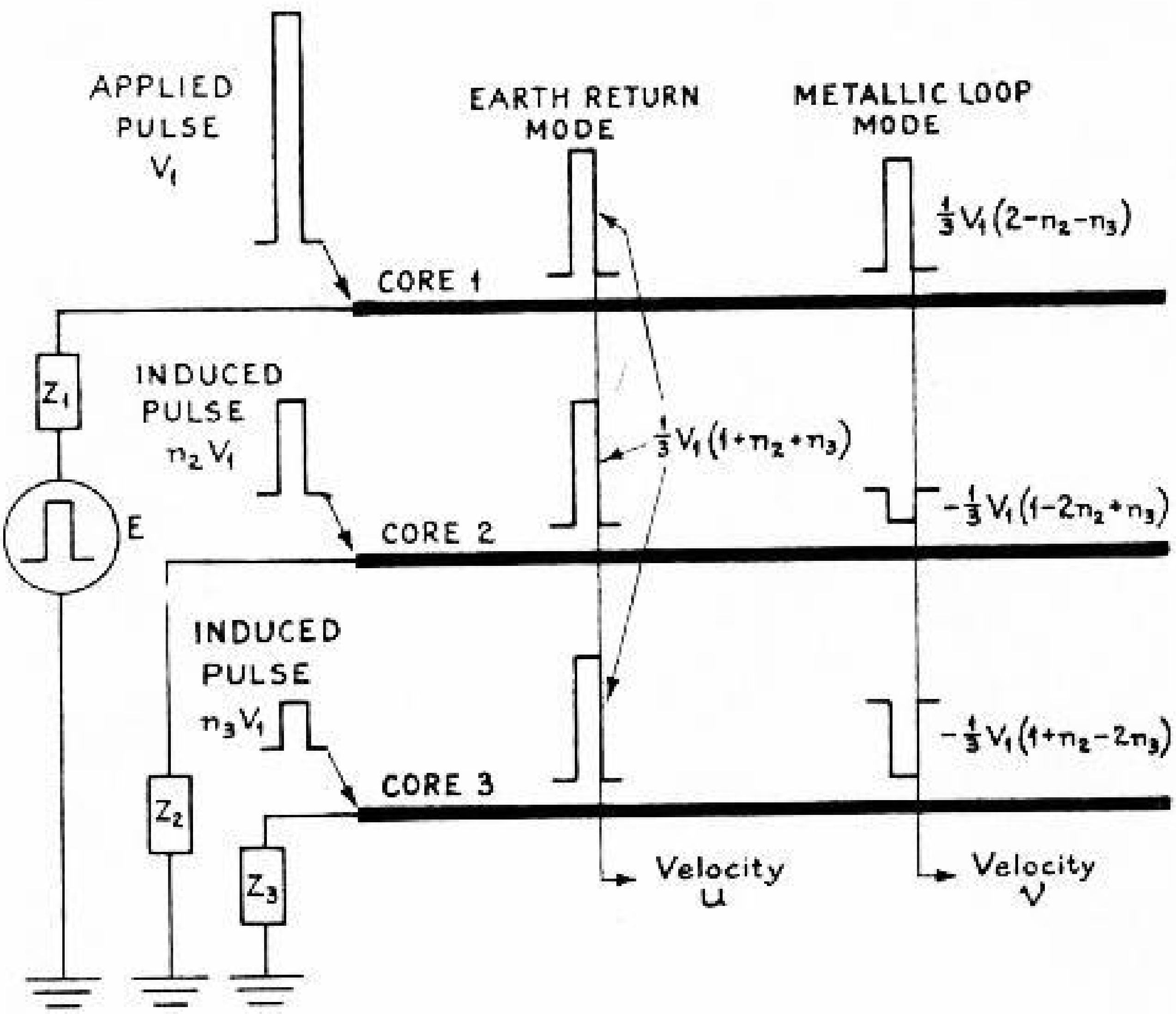

Figure 3. Tricore cable with mutual coupling—pulse propagation

amplitudes on both cores at the point of transmission and at the point of reflection. Approximate echo amplitudes from discontinuities on both cores distance x from the source, and with a pulse amplitude V_1 applied to core 1 and a resultant pulse of amplitude nV_1 induced on core 2, are shown in Table I.

Propagation and Reflection in Tricore Cables

The propagation of a step wave along a resistanceless high-frequency tricore cable with mutual coupling between cores is analysed in Appendix II. The modes of propagation when a pulse is applied to one core are shown in Figure 3.

The characteristics of the modes are:

Earth return mode:

Velocity of propagation

$$u = \frac{1}{\sqrt{C(L+2M)}}$$

Characteristic impedance

$$Z_u = \sqrt{\frac{(L+2M)}{C}}$$

Metallic loop mode:

Velocity of propagation

$$v = \frac{1}{\sqrt{(C+3C_1)(L-M)}}$$

Characteristic impedance

$$Z_v = \sqrt{\frac{(L-M)}{(C+3C_1)}}$$

The relative amplitudes of the pulses propagated in the two modes when they are applied to two or three cores are found by putting n_2 or n_2 and n_3 equal to unity. (Figure 3.)

More general analysis of a resistanceless tricore cable shows that the variation of the magnitude of the pulse induced in the second and third cores with their terminating impedances is similar to that of the resistanceless bicore cable; again the high-frequency resistance of a submarine telegraph cable is so large that the induced pulses for any impedance termination are reduced to relatively small magnitudes. Similarly, the attenuation and, in general, the reflection coefficients of discontinuities will be different in the two modes.

An exact analysis of the echo amplitudes received from discontinuities on one or more cores can be adequately approached, as in the case of the bicore cable, by neglecting the pulses induced in the adjacent cores at the position of the discontinuity from the reflected pulses. A further simplification in the expressions for the echo amplitudes is made by making the restriction that at least two of the cores are identically terminated at the sending end; that is, that $n_2 = n_3 = n$. The amplitudes of the echoes arriving at the source after the three possible delay times are shown in Table II.

Practical Application

Pulse-echo tests are conducted on non-faulty cables to determine the velocities of propagation of the various sections of which the shore-ends are composed and to provide reference echo displays. Subsequent changes in the displays facilitate the recognition of fault echoes, particularly if the fault is unresponsive to d-c polarising currents, and may possibly show potential faults—for example, extensive mechanical damage to a cable caused by fishing gear.

Echo displays obtained from both bicore and tricore polythene-insulated cables show that pulses are propagated in the earth return mode at a velocity of about 0.7×10^5 nm/sec and that the metallic loop mode velocity is about 25 percent higher. Detailed analysis has shown that the mutual capacitance between cores is negligibly small and that the mutual inductance is about 35 percent of the line inductance for bicore cables and about 15 percent for tricore cables. The line inductance is about 0.5 mh/nm for 650/325 TE cables or nearly double that calculated from the geometry of the individual cores on the assumption that they behave as ideal coaxial cables. The characteristic

TABLE II TRICORE CABLES – ECHO AMPLITUDES

DELAY TIME	$\frac{2x}{v}$	$\frac{x}{v}+\frac{x}{u}$	$\frac{2x}{u}$
CORE 1 (PULSE V_1 APPLIED)	$\frac{1}{9}V_1(1-n)(4s_1+s_2+s_3)$	$\frac{1}{9}V_1\left\{(1-n)(2s_1-s_2-s_3)+(1+2n)(2r_1-r_2-r_3)\right\}$	$\frac{1}{9}V_1(1+2n)(r_1+r_2+r_3)$
CORE 2 (PULSE nV_1 INDUCED)	$-\frac{1}{9}V_1(1-n)(2s_1+2s_2-s_3)$	$\frac{1}{9}V_1\left\{(1-n)(2s_1-s_2-s_3)+(1+2n)(2r_2-r_3-r_1)\right\}$	$\frac{1}{9}V_1(1+2n)(r_1+r_2+r_3)$
CORE 3 (PULSE nV_1 INDUCED)	$-\frac{1}{9}V_1(1-n)(2s_3+2s_1-s_2)$	$\frac{1}{9}V_1\left\{(1-n)(2s_1-s_2-s_3)+(1+2n)(2r_3-r_1-r_2)\right\}$	$\frac{1}{9}V_1(1+2n)(r_1+r_2+r_3)$

Note: r and s are the reflection coefficients of discontinuities on cores 1, 2 and 3, denoted by subscripts, for pulses incident at velocities u and v respectively.

impedances of 650/325 PE cables are about 47 ohms and 33 ohms in the earth return and metallic loop modes, respectively.

The interpretation of the echo displays obtained from multicore cables does not require precise measurement of individual echo amplitudes because the only reflection coefficients of practical interest are those of complete reflection (coefficient +1 or −1) from a fault or sea earth and relatively small reflection (coefficient approximately zero) from a change in cable type.

If a pulse is applied to a multicore cable containing a discontinuity, all the cores being joined together at the testing end, then a pulse travels along each core in the earth return mode. In the general case, at the discontinuity position the degree of reflection, and thus the magnitude of the reflected pulse, will be different on each core. Consequently the reflected pulses will return in both the metallic loop and earth return modes but, since the pulses received in the metallic loop mode sum to zero at the common connection between the cores at the testing end, only the echo pulses received in the earth return mode are observed. In the special case in which equal reflection occurs in each core (for example, a similar fault or change of cable type in each core) the reflected pulses travel back in the earth return mode only.

As a first step, then, this method of testing a cable is employed to produce the simplest possible display showing a single echo from each discontinuity. The distance to the discontinuity is calculated from the delay time for the reception of

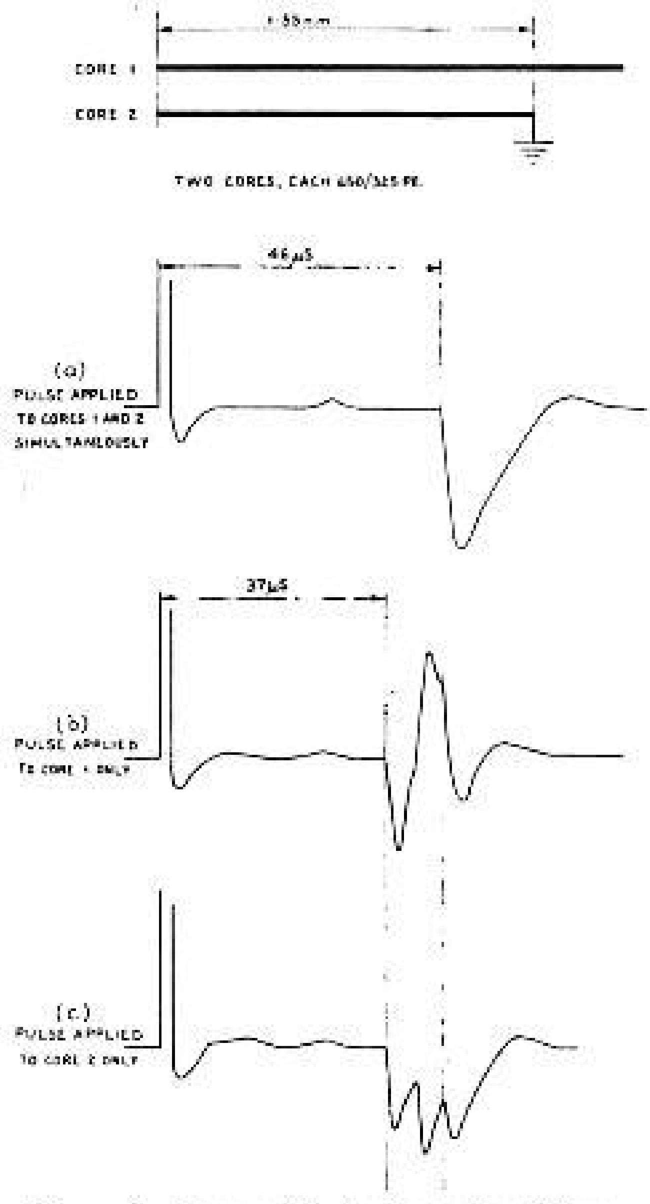

Figure 4. Bicore cable — typical echo displays

the echo and the velocity of propagation in the earth return mode. In practice, this test is sufficient to localise a discontinuity although the localisation may be confirmed by applying pulses to one core only and considering the metallic loop velocity and the time for the reception of the first of the three echoes received from the discontinuity.

An example of the echo display obtained when pulses are applied simultaneously to both cores of a bicore cable containing an earth in one core is shown in Figure 4 (a). From Table I the amplitude of the echo received is obtained by putting $n = 1$, and is proportional to $(r_1 + r_2)$ where r_1, r_2 are the reflection coefficients at the discontinuity position for each core. The polarity of the echo is thus that of the reflection coefficient having the greater magnitude. In this case the reflection coefficient from the earth on one core, -1, is much greater than that due to the slight reflection due to the change of cable type, so that the echo pulse is of the opposite polarity to the applied pulse.

Similarly the single echo obtained when pulses are applied to the three cores of a tricore cable has an amplitude proportional to the sum of the coefficients on the individual cores and, in the case illustrated in Figure 5 (a), takes the polarity of the predominant reflection.

The single echo obtained by the above method of testing can give no information as to the magnitude of the reflection on a particular core. This is obtained by applying the pulses to the individual cores in turn and comparing the echo displays, each of which can contain three echoes from each discontinuity position.

For a bicore cable, Table I shows that the amplitude of the first and last echoes is proportional to the sum of the reflection coefficients on each core in the particular modes in which the pulses travel. In the case illustrated in Figure 4, the reflection on one core caused by the change in cable type is small for either mode of propagation and the earth reflection predominates. Figures 4 (b) and 4 (c) show the first and last echoes of similar polarity due to the predominant earth reflection when pulses are applied to either core. The middle echo, however, is of amplitude proportional to the difference of the reflection coefficients in both modes of propagation and takes the polarity of the predominant reflection coefficient only when the pulses are applied to the core in which it occurs. The middle echo of Figures 4 (b) and 4 (c) illustrates this. (The middle echo disappears when the reflection coefficients in both modes on both cores are equal — for example, when the discontinuity is a change of type of bicore cable or the bicore has earth faults on both cores.)

The velocities of propagation for the cable illustrated in Figure 4 are 0.67×10^5 nm/sec and 0.84×10^5 nm/sec in the earth return and metallic loop modes, respectively.

The magnitudes of the discontinuities on the individual cores of a tricore cable can be more easily estimated. If pulses are applied to one core only of a tricore cable then the amplitude of the first echo received is, from Table II, proportional to $4s_1 + s_2 + s_3$ where s_1 is the reflection coefficient of the discontinuity on the core to which the pulses are applied and s_2, s_3 are the coefficients on the other two cores. The magnitude and polarity of this echo are thus predominantly proportional to the reflection coefficient of the discontinuity on the core under test. Figure 5 illustrates this—in (c) the first echo is large and of the opposite polarity to the applied pulse due to the earth on this core only, whereas in (b), although the echo is also of the opposite polarity to the applied pulse, its magnitude is very much smaller.

The velocities of propagation of the tricore cable illustrated in Figure 5 are 0.68×10^5 nm/sec and 0.88×10^5 nm/sec in the earth return and metallic loop modes, respectively.

The considerable amplitude and phase distortion suffered by rectangular pulses propagated along multicore submarine telegraph cables may be seen from the displays of Figures 4 and 5. This distortion leads to difficulty in identifying echoes when, for instance, groups of three echoes are received from two closely spaced dis-

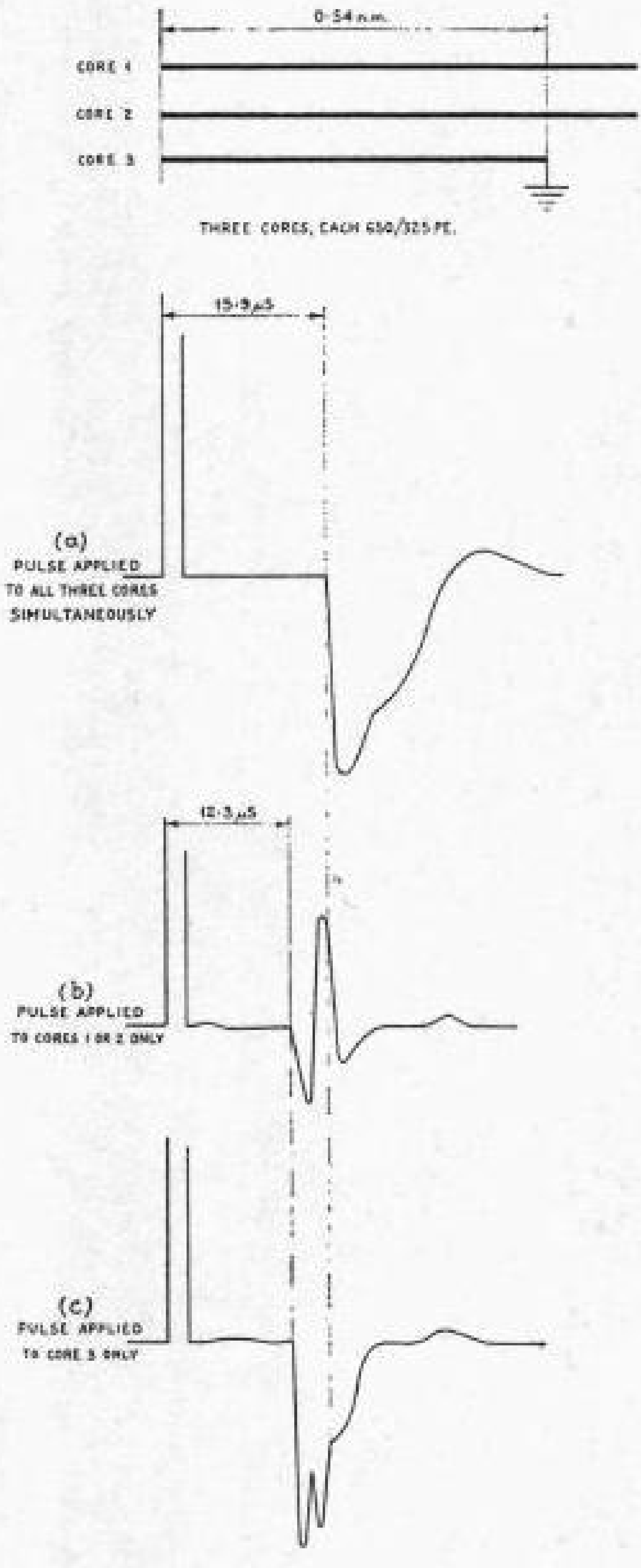

Figure 5. Tricore cable — typical echo displays

continuities. However, when pulses are applied to one core only of a multicore cable and the other cores are first left free and then earthed at the testing end, the first echo in each group will be seen to increase in amplitude. This is because the earthing of the cores reduces to zero the induced pulse appearing at the testing end, thus increasing the factor $(1 - n)$ appearing in the general expression for the amplitudes of the first echo in Tables I and II. The last echo in each group will similarly decrease in amplitude but can be otherwise identified by comparison with the display obtained with all the cores bunched.

In general, tests have to be made on the bicore and single core sections beyond the initial length of tricore cable. Pulses are always applied firstly to all the cores bunched to give the simplest possible echo display and thereafter the nature of individual discontinuities assessed by comparison of the displays obtained from individual cores.

Faults in shore-ends localised by pulse-echo methods to date have all been within a range of about one nm but tests on non-faulty cables show that a range of at least seven miles should be quite possible. (An exception is on loaded cables—the considerable attenuation caused by the high resistivity and permeability of the loading tape around the core conductor makes it impossible to receive echoes from discontinuities more than about half a mile away.)

* * * * *

The author would like to record his appreciation of the encouragement given during this work by Mr. R. A. Goodman, European Plant Engineer, London.

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APPENDIX I

Propagation of a Step Wave Along a H.F. Bicore Cable with Mutual Coupling Between Cores

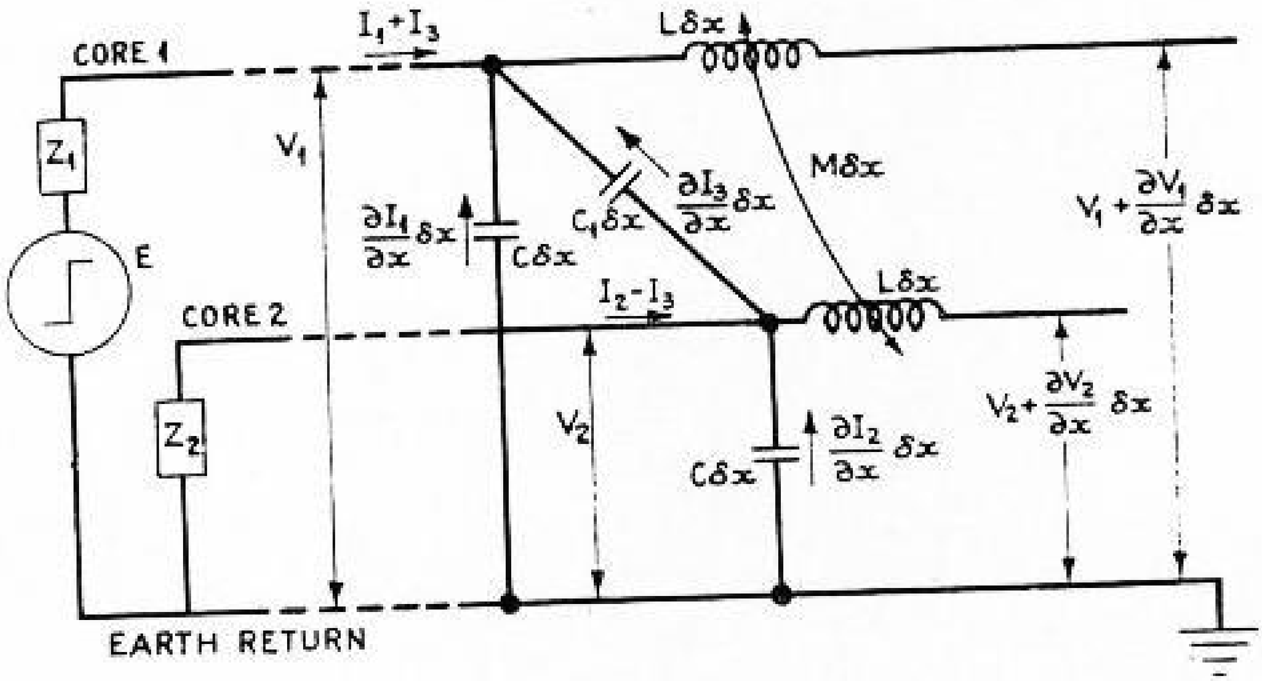

Figure 6

An infinitesimal portion of a semi-infinite uniform bicore cable with coupling between cores is represented in Figure 6.

The basic partial differential equations are

$$-\frac{\partial V_1}{\partial x} = L\left(\frac{\partial I_1}{\partial t}+\frac{\partial I_3}{\partial t}\right) + M\left(\frac{\partial I_2}{\partial t}-\frac{\partial I_3}{\partial t}\right)$$

$$-\frac{\partial V_2}{\partial x} = L\left(\frac{\partial I_2}{\partial t}-\frac{\partial I_3}{\partial t}\right) + M\left(\frac{\partial I_1}{\partial t}+\frac{\partial I_3}{\partial t}\right)$$

$$-\frac{\partial I_1}{\partial x} = C\frac{\partial V_1}{\partial t}\ ;\quad -\frac{\partial I_2}{\partial x} = C\frac{\partial V_2}{\partial t}\ ;$$

$$-\frac{\partial I_3}{\partial x} = C_1\left(\frac{\partial V_1}{\partial t}-\frac{\partial V_2}{\partial t}\right)$$

Taking Laplace transforms, putting zero initial conditions and rearranging yields

$$(D^2-a)\bar V_1 + b\bar V_2 = 0$$

$$b\bar V_1 + (D^2-a)\bar V_2 = 0$$

where $\bar V_1$, $\bar V_2$ are the Laplace transforms of V_1 and V_2 and

$$a = p^2[LC + C_1(L-M)]$$
$$b = p^2[LC_1 - M(C+C_1)]$$

These equations can be solved to give

$$\bar V_1 = A_1\epsilon^{-px/u} + A_2\epsilon^{px/u} + A_3\epsilon^{-px/v} + A_4\epsilon^{px/v}$$

$$\bar V_2 = A_1\epsilon^{-px/u} + A_2\epsilon^{px/u} - A_3\epsilon^{-px/v} - A_4\epsilon^{px/v}$$

where A_1, A_2, A_3, A_4 are constants.

Since $\bar V_1$ and $\bar V_2$ must be finite as x increases

$$A_2 = A_4 = 0$$

and the subsidiary equations become

$$\bar V_1 = A_1\epsilon^{-px/u} + A_3\epsilon^{-px/v}$$

$$\bar I_1 = \frac{A_1}{Z_u}\epsilon^{-px/u} + \frac{A_3}{Z_v}\epsilon^{-px/v}$$

$$\bar V_2 = A_1\epsilon^{-px/u} - A_3\epsilon^{-px/v}$$

$$\bar I_2 = \frac{A_1}{Z_u}\epsilon^{-px/u} - \frac{A_3}{Z_v}\epsilon^{-px/v}$$

where

$$u = \frac{1}{\sqrt{C(L+M)}} \qquad Z_u = \sqrt{\frac{(L+M)}{C}}$$

$$v = \frac{1}{\sqrt{(C+2C_1)(L-M)}} \qquad Z_v = \sqrt{\frac{(L-M)}{(C+2C_1)}}$$

Inverting gives

$$V_1 = A_1 \cdot 1\left[t - \frac{x}{u}\right] + A_3 \cdot 1\left[t - \frac{x}{v}\right]$$

$$I_1 = \frac{A_1}{Z_u} \cdot 1\left[t - \frac{x}{u}\right] + \frac{A_3}{Z_v} \cdot 1\left[t - \frac{x}{v}\right]$$

$$V_2 = A_1 \cdot 1\left[t - \frac{x}{u}\right] - A_3 \cdot 1\left[t - \frac{x}{v}\right]$$

$$I_2 = \frac{A_1}{Z_u} \cdot 1\left[t - \frac{x}{u}\right] - \frac{A_3}{Z_v} \cdot 1\left[t - \frac{x}{v}\right]$$

where $1[t]$ is Heaviside's Unit Function.

These solutions show that equal step waves are propagated along both conductors with an earth return path at a velocity u and equal but opposite step waves are propagated along both conductors, giving an effective metallic loop path, at velocity v.

The constants A_1 and A_3, the amplitudes of the two pairs of step waves, can be evaluated from considerations of the boundary conditions. In the simplest form, if a step wave of amplitude V_1 is applied to core 1 and an induced step wave of amplitude nV_1 appears at the terminal of core 2 then, when $x = 0$ and $t = 0$,

$$V_1 = A_1 + A_3$$

$$nV_1 = A_1 - A_3$$

from which

$$A_1 = \frac{1}{2} V_1 (1 + n)$$

$$A_3 = \frac{1}{2} V_1 (1 - n)$$

In the more detailed case a step wave of amplitude E is applied to core 1 from a source of impedance Z_1 and core 2 is terminated in an impedance Z_2 at the sending end. Thus, when $x = 0$ and $t = 0$

$$V_1 = E - I_1 Z_1$$

and

$$V_2 = I_2 Z_2$$

from which

$$A_1 = \frac{E\ Z_u(Z_v - Z_2)}{(Z_u + Z_1)(Z_v - Z_2) + (Z_v + Z_1)(Z_u - Z_2)}$$

$$A_3 = \frac{E\ Z_v(Z_u - Z_2)}{(Z_u + Z_1)(Z_v - Z_2) + (Z_v + Z_1)(Z_u - Z_2)}$$

and the step wave applied to core 1 is

$$V_1 = E\left\{\frac{Z_u(Z_v - Z_2) + Z_v(Z_u - Z_2)}{(Z_u + Z_1)(Z_v - Z_2) + (Z_v + Z_1)(Z_u - Z_2)}\right\}$$

The induced step wave is V_2 and

$$V_2 = nV_1$$

where

$$n = \frac{Z_u(Z_v - Z_2) - Z_v(Z_u - Z_2)}{Z_u(Z_v - Z_2) + Z_v(Z_u - Z_2)}$$

The expression for n is discontinuous at

$$Z_2 = \frac{2\ Z_u Z_v}{Z_u + Z_v}$$

At this value the input impedance of the cable, Z_i, given by the equation

$$Z_i = \frac{V_1}{I_1} = \frac{Z_u(Z_v - Z_2) + Z_v(Z_u - Z_2)}{(Z_v - Z_2) + (Z_u - Z_2)}$$

is zero.

APPENDIX II

Propagation of a Step Wave Along a H.F. Bicore Cable with Mutual Coupling Between Cores

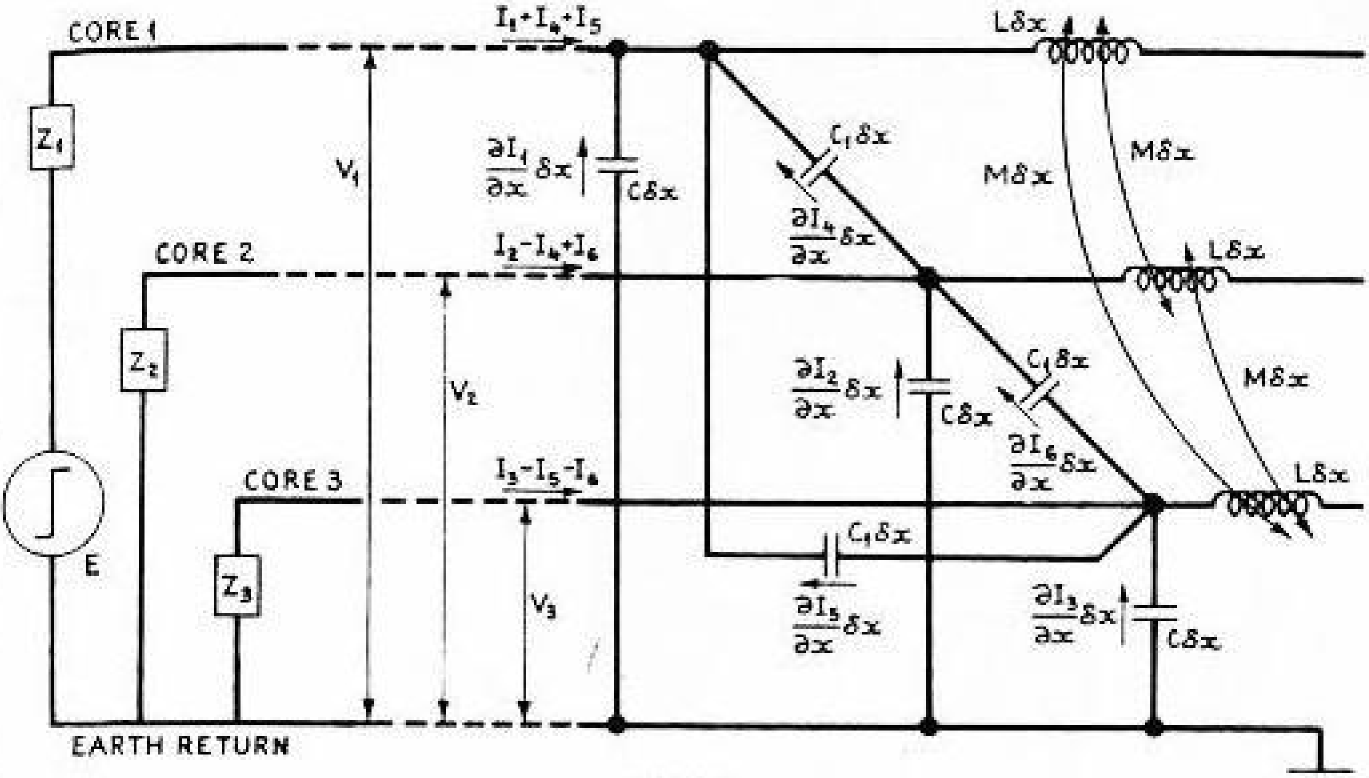

Figure 7

An infinitesimal portion of a semi-infinite uniform tricore cable with coupling between cores is represented in Figure 7.

Typical basic partial differential equations are

$$-\frac{\partial V_1}{\partial x} = L\left(\frac{\partial I_1}{\partial t}+\frac{\partial I_4}{\partial t}+\frac{\partial I_5}{\partial t}\right) + M\left(\frac{\partial I_2}{\partial t}+\frac{\partial I_3}{\partial t}-\frac{\partial I_4}{\partial t}-\frac{\partial I_5}{\partial t}\right)$$

$$-\frac{\partial I_1}{\partial x} = C\frac{\partial V_1}{\partial t}\ ; \quad -\frac{\partial I_4}{\partial x} = C_1\left(\frac{\partial V_1}{\partial t}-\frac{\partial V_2}{\partial t}\right)$$

Taking Laplace transforms, putting zero initial conditions and rearranging the nine differential equations yields

$$(D^2-a)\overline{V}_1 + b\overline{V}_2 + b\overline{V}_3 = 0$$

$$b\overline{V}_1 + (D^2-a)\overline{V}_2 + b\overline{V}_3 = 0$$

$$b\overline{V}_1 + b\overline{V}_2 + (D^2-a)\overline{V}_3 = 0$$

where

$$a = p^2[LC + 2C_1(L-M)]$$

$$b = p^2[LC_1 - M(C+C_1)]$$

These equations can be solved to give

$$\overline{V}_1 = A_1\epsilon^{-px/u} + A_2\epsilon^{px/u} + A_3\epsilon^{-px/v} + A_4\epsilon^{px/v}$$

$$\overline{V}_2 = \overline{V}_3 = A_1\epsilon^{-px/u} + A_2\epsilon^{px/u} - \frac{1}{2}A_3\epsilon^{-px/v} - \frac{1}{2}A_4\epsilon^{px/v}$$

where A_1, A_2, A_3, A_4 are constants.

Since $\overline{V}_1$, $\overline{V}_2$ and $\overline{V}_3$ must be finite as x increases

$$A_2 = A_4 = 0$$

and the subsidiary equations become

$$\overline{V}_1 = A_1\epsilon^{-px/u} + A_3\epsilon^{-px/v}$$

$$\overline{I}_1 = \frac{A_1}{Z_u}\epsilon^{-px/u} + \frac{A_3}{Z_v}\epsilon^{-px/v}$$

$$\overline{V}_2 = \overline{V}_3 = A_1\epsilon^{-px/u} - \frac{1}{2}A_3\epsilon^{-px/v}$$

$$\overline{I}_2 = \overline{I}_3 = \frac{A_1}{Z_u}\epsilon^{-px/u} - \frac{1}{2}\frac{A_3}{Z_v}\epsilon^{-px/v}$$

where

$$u = \frac{1}{\sqrt{C(L + 2M)}} \qquad Z_u = \sqrt{\frac{(L + 2M)}{C}}$$

$$v = \frac{1}{\sqrt{(C + 3C_1)(L - M)}} \qquad Z_v = \sqrt{\frac{(L - M)}{(C + 3C_1)}}$$

The subsidiary equations are of the same form as those for the bicore cable in Appendix I, showing that equal step waves are propagated along the conductors with an earth return path at velocity u and step waves are propagated along the metallic loop path at velocity v.

The constants A_1 and A_3 can be evaluated from considerations of the boundary conditions. In the general case the voltages and terminating impedances on all three cores will be dissimilar although the solution obtained above gives equal voltages on two cores. This restriction is overcome by applying unequal but coincident step waves on two cores each inducing step waves on the other two cores so that the total of the waves on every core satisfies the terminating conditions.

If a step wave of amplitude e_1 *is applied to core 1 then, at* $x = 0$, $t = 0$

$$e_1 = g_1 + g_3$$

$$e_2 = e_3 = g_1 - \frac{1}{2}g_3$$

where g_1 *and* g_3 *are the constants of integration.*

Similarly, if a coincident step wave of amplitude f_2 *is applied to core 2*

$$f_2 = h_1 + h_3$$

$$f_1 = f_3 = h_1 - \frac{1}{2}h_3$$

If the total step wave at core 1 is V_1 *and step waves of amplitudes* n_2V_1 *and* n_3V_1 *appear at cores 2 and 3 respectively, then*

$$e_1 + f_1 = V_1 = g_1 + h_1 + g_3 - \frac{1}{2}h_3$$

$$e_2 + f_2 = n_2V_1 = g_1 + h_1 - \frac{1}{2}g_3 + h_3$$

$$e_3 + f_3 = n_3V_1 = g_1 + h_1 - \frac{1}{2}g_3 - \frac{1}{2}g_3$$

from which

$$g_1 + h_1 = \frac{1}{3}V_1(1 + n_2 + n_3)$$

$$g_3 = -\frac{1}{3}V_1(1 - n_3)$$

$$h_3 = -\frac{1}{3}V_1(n_2 - n_3)$$

and thus a step wave of amplitude $\frac{1}{3}V_1(1+n_2+n_3)$ *is propagated along all three cores in the earth return mode at velocity* u *and step waves of amplitude*

$$\frac{1}{3}V_1(2 - n_2 - n_3) \qquad \text{on core 1}$$

$$-\frac{1}{3}V_1(1 - 2n_2 + n_3) \qquad \text{on core 2}$$

$$-\frac{1}{3}V_1(1 + n_2 - 2n_3) \qquad \text{on core 3}$$

are propagated in the metallic loop mode at velocity v.

In a more detailed analysis it can be shown that the magnitudes of the step waves induced in the cores and the corresponding input impedance of the cable are functions of the impedances terminating the cores, as they are for the bicore cable.

A biographical sketch of the author appeared in the July 1957 issue of TECHNICAL REVIEW.

Telegraph History

MORSE METHOD GIVES WAY TO MULTIPLEX

Adoption by Western Union of the Murray multiplex followed a study of existing telegraph systems which culminated in a recommendation dated January 16, 1912 favoring Murray's method. Excerpts from that recommendation follow.

"We are of the opinion that where the amount of telegraph traffic between two cities situated over 400 or 500 miles apart, is sufficient to fill two or more hand worked circuits, it would be economical to install some form of automatic printing system, and throw one or more wires spare and available for leasing or other purpose.

"Such a system should possess the following features:

(1) Use a 5 unit alphabet with "Shift".

(2) Use keyboard perforators in the preparation of slips at the transmitting end.

(3) Receive the signals on a perforated tape at the distant end.

(4) Print up from the perforated slip, on a page or slip form as may be found most suitable.

(Above) Multiplex Printer 1-A developed about 50 years ago to meet Western Union requirements. (Below) Synchronous rotating distributors and other multiplex apparatus outmoded by FM carrier systems

"On circuits between large towns where the distance is not greater than 500 miles, the systems which might be considered are as follows:

Baudot Multiplex	Creed
Murray Multiplex	Wheatstone.
Murray Automatic	

"If, however, the Western Union Telegraph Company does not contemplate adopting the Continental Morse alphabet, the Wheatstone and Creed systems need not be further considered.

"In the handling of traffic, the Murray multiplex and Baudot differ only insofar as the former is a page printer whilst the Baudot prints on tape. In both systems the preparation of the messages may be done by keyboard perforators. The Murray keyboard, however, perforates the slip lengthways so that it can be used for an Automatic High Speed System using the same alphabet. The Baudot keyboard perforates each letter signal across the tape and this limits its use to a system where a rotating distributor is employed.

"As both systems use a 5 unit alphabet they are equal so far as line transmission efficiency is concerned. In view of the fact that such a multiplex system would be confined to shorter lines than the high speed (Murray) Automatic system, and would therefore be less subject to line interruptions, we are of the opinion that page printing should be used, and recommend the adoption of a system on the line of the Murray multiplex."

In the 25 years after 1915, Western Union developed and operated a vast network of multichannel time division "multiplex" telegraph circuits based upon the patents of Donald Murray. Today, with carrier facilities readily available almost everywhere to provide ample circuit capacity without employing "mux" euipment, there are comparatively few multiplex circuits left in landline service in the U. S. A.

ALDER F. CONNERY, General Supervisor—Applied Engineering

Modernized Quarters for a Comprehensive Branch Office

NEWLY located in modernized quarters overlooking historic Bowling Green and Battery Park, Western Union's financial district branch office and international telegraph cable center in New York City now occupies the entire third floor of a 32-story office building in downtown Manhattan. From the operating room there is a commanding view of New York Harbor and the majestic Statue of Liberty.

Formerly on Broad Street

For the past 37 years, Western Union's New York "cable office" had been located at 40 Broad Street in the heart of the city's financial district where business was conducted in a six-story building specially equipped in part for the company's international operations. Through the years there had been many additions, changes and improvements in types of equipment and methods of operation, but multifloor operation had become a serious handicap in efforts to provide the best possible service.

During May and June of 1958 operations were transferred to a new and modern plant in a building formerly occupied by Standard Oil companies at 26 Broadway, which also is in the financial district about one short block from the old 40 Broad Street location. To meet commitments with Dow Jones & Company, who had contracted to acquire the Broad Street building, it was necessary to plan, arrange and move into the new quarters in a period of 20 months. The layout of the operating equipment was the joint effort of the several interested Western Union departments. The detailed specifications for all of the work were prepared by the Plant and Engineering Department. The actual building work and heavy power construction were performed by contractors. All of the telegraph installation was done by the installation forces of the company.

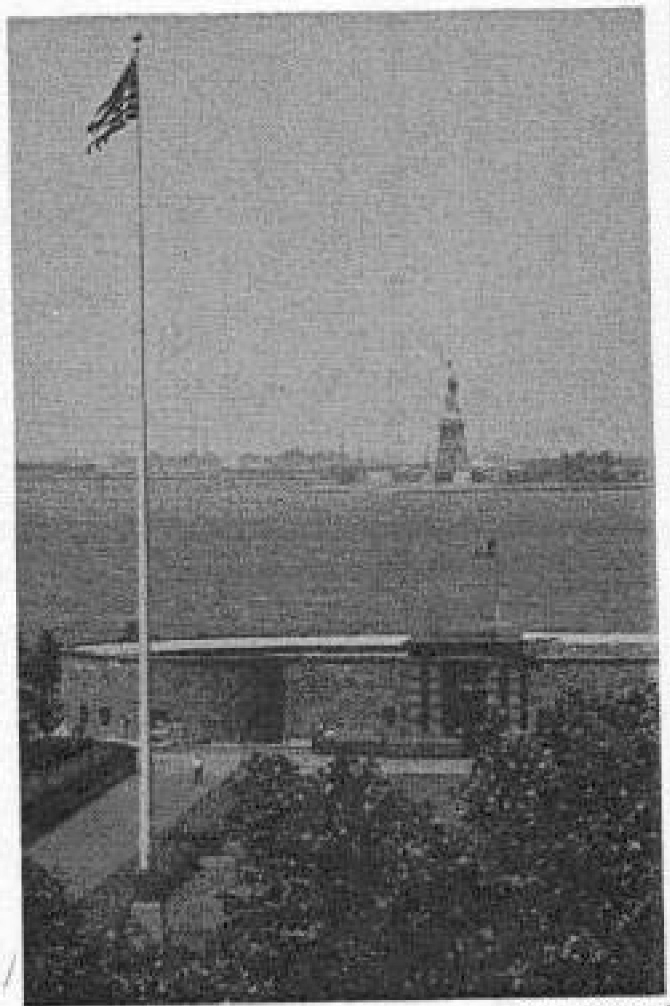

Photo H-2320-C

Western Union's New York financial district and cable office now overlooks Battery Park and the harbor

Operations were shifted to the new location without halting service or delaying telegraph traffic, in one of the most difficult moving jobs ever undertaken by Western Union. The transfer involved the removal and reinstallation of a vast and complicated network of cable, wires, teleprinter and facsimile equipment, while maintaining continuous round-the-clock service. This was accomplished by setting up duplicate cable and telegraph circuits in the new location, and cutting over service during off-peak, week-end periods. The complete move was made over a span of several weeks.

Extensive Alterations Made

It was necessary, of course, to do considerable building work to change the character of the newly acquired area from miscellaneous business offices to meet requirements of a telegraph cable operating room. Included in the building work was the provision of modern lighting, new flooring and air-conditioning equipment. Fluorescent lighting with intensities corresponding to current high standards was specified. The flooring material is asphalt tile using a mixed pattern of travertine and Genoa green. The operating room walls are finished in a "suntone" yellow with a green dado, and the ceilings are white. The ceilings are all acoustically treated using Acousti-Celotex perforated mineral fiber tile one inch thick.

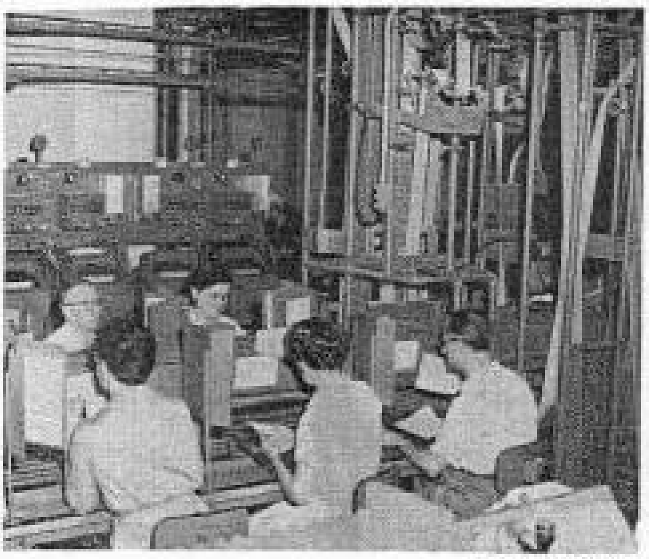

Photo H-2322-B

Figure 1. Regular incoming telegraph and cable traffic is sorted onto fast-moving belts

In the new location, Western Union now has approximately 33,000 square feet of floor space above street level, and some 3000 square feet of pneumatic tube system compressor room area and storage space in the basement. The total area is approximately the same as in the old location but more efficient utilization is possible by having all operations on a single level.

In addition to the work in the 26 Broadway building, there was much to be done in rearranging underground pneumatic tube and cable plant. This in itself was a very formidable task which had to be performed in an area which is extremely congested, both above and under ground. Much of the street work had to be done after normal business hours. An additional complication in connection with that was caused by work on the 30-story Produce Exchange Building, which was being erected directly across the street from the new Western Union location.

"CO" office, as the cable section is known, is Western Union's New York gateway center for transmission of the nation's cablegrams to and from worldwide points. It is the terminal point for 80 overseas cable channels, of which 51 are transatlantic channels with a capacity of more than 3,500,000 words daily. The telegraph center, known as "CD" office, serves all telegraph offices in Manhattan's financial district. It is connected by direct wires with more than 1,200 telegraph and cable using firms in the city.

Photo H-2322-C

Figure 2. Intricate belt conveyors at route desk whisk messages away in all directions

Power and Pneumatic Tubes

The planning provided distinct physical separation of the "CO" and "CD" activities, including separate power feeders and metering arrangements. A 4-wire 120-208-volt a-c service, with a capacity of 800 amperes per phase wire, has been provided for "CO" and the same for "CD." Separate 600-ampere feeders have been provided for the compressor room in the basement.

Groups of mercury vapor type rectifier units, each of 60-ampere d-c capacity, supply the d-c requirements. A total of five, which includes one spare, were installed for each of the two operating rooms. Both "CO" and "CD," therefore, currently have available capacity of 120 amperes direct current for each polarity. The power provisions are considerably in excess of present demands.

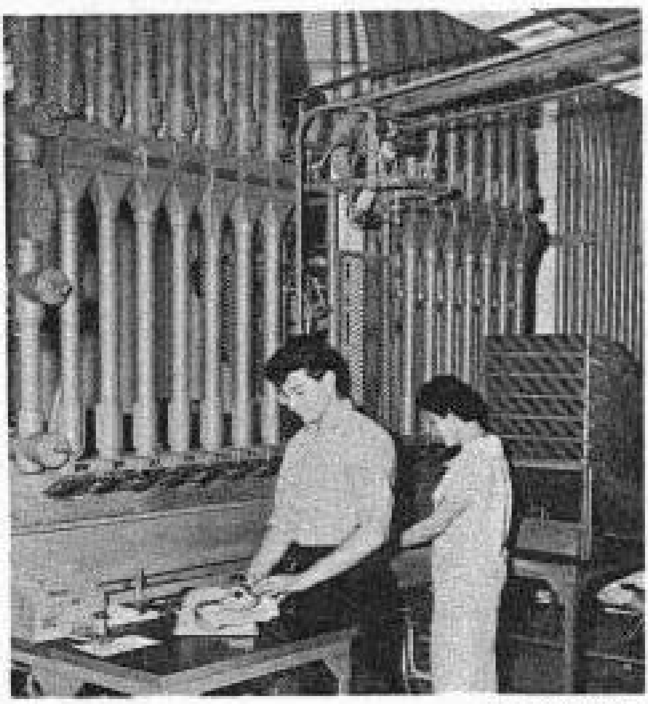

Photo H-2322-A

Figure 3. Pneumatic tube conveyor system gives fast service to main office and nearby branch offices

In order to meet the peculiar requirements of international operations, it was necessary to provide an extensive specially designed pneumatic tube and belt conveyor system. In fact, the magnitude of the tube and belt system, as indicated by Figures 1, 2 and 3, was greater than had been encountered since the New York main office installation of 1930. A total of 50 "V" belts and 50 track belts were installed. The longest run is 300 feet with two intermediate automatic transfer points.

It was necessary to provide for the termination of 13 pairs of underground tubes. The tubes are connected to the old location at 40 Broad Street, where a commercial office has been retained, and to the main ("N") office, various branch offices, some patrons, and other international carriers.

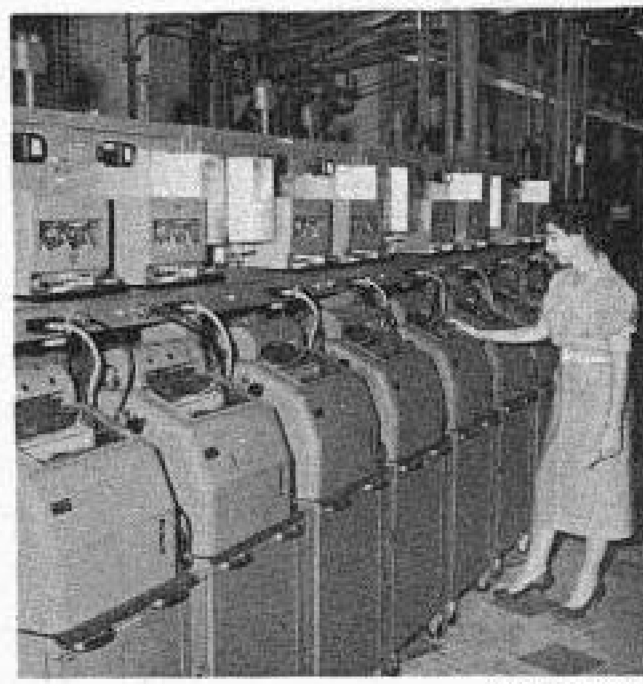

Photo H-2320-A

Figure 4. Unattended page teleprinters check numbers of all incoming messages, drop them on belts

The tube terminal in the operating room is shown in Figure 3. The main compressor room is located in the basement. One new compressor was acquired. The others were moved from the old location but all were completely overhauled before being placed into regular service.

The compressor installation consists of one 15 in. by 9 in. Worthington (new), two 22 in. by 14 in. Worthingtons (relocated), and one 14 in. by 8 in. Ingersoll-Rand (relocated). In addition, air for the house tubes is provided by two new 10-hp centrifugal compressors located on the operating room floor near the automatic tube sending equipment. The street tubes normally operate under a pressure of three pounds per square inch and the vacuum on the return tube is equal to six inches of mercury.

Traffic Handling Facilities

It was necessary to provide several traffic routing centers. In Figure 1 is shown one of the regular routing centers, and a special routing center is shown in Figure 2. There are 34 direct channels from "CD" to 20 American cities, including Mexico City, Montreal, and St. John's, Newfoundland.

The bulk of the receiving in the "CD" office is done automatically with message-separator or "burster" type teleprinters as shown in Figure 4. These teleprinters permit unattended reception of messages on page teleprinters with roll paper and provide automatic separation or cut-off of each telegram. Incoming messages are

Photo H-2320-D

Figure 5. Desk-Fax section has facsimile equipment and circuits to serve 800 customers

Photo H-2320-B

Figure 6. Some of the 24 message recording position terminations for over 200 voice tie lines

ejected from the teleprinter onto a conveyor belt so that messages from all the "burster" type printers are automatically directed to central editing and sorting positions. A description of the message-separator teleprinter is contained in an article by Fred W. Smith in the July 1958 TECHNICAL REVIEW.

Figure 5 shows the Desk-Fax section of "CD" office, where a total of eight 100-line concentrators were installed.

In Figure 6 is shown a view of the telephone room where the PBX board has a capacity of 160 extensions and 40 trunk wires. There are 24 message recording positions. There is also a customers' phone board with a capacity of 400 lines, of which 219 are in use for customer voice tie lines.

* * * * *

With the new and modern equipment that has been provided, and with all operations confined to a single level, it is possible now to provide the highest grade of service to patrons with maximum efficiency in operations and supervision.

Alder F. Connery received his first telegraph experience with the Great Northwestern Telegraph Company of Canada at Winnipeg, Saskatoon and Montreal. He worked for Western Union from 1920 to 1922, then was with Postal from 1923 to 1928; International Communications Labs from 1929 to 1932, and All America and Commercial Cables from 1933 to 1938, during which time he was engaged in telegraph development engineering. He became Chief Engineer of Postal in 1939 and under his direction the Postal semiautomatic tape relay system was developed and installed. At merger in 1943 he became Central Office Engineer for Western Union and was appointed Director of Installation in 1950. He was appointed General Supervisor — Applied Engineering in 1958. A number of U.S. Patents have been issued in his name on regenerative and drop channel repeaters, switching systems, cable bias control equipment, cable code printers and cable translators. Mr. Connery received his technical education at Pratt Institute and Brooklyn Polytechnic Institute. He is a licensed professional engineer for the State of New York and a member of AIEE.

MATTHEW E. A. HERMANS, Engineer, Telefax

Semiconductor Current Regulation

Although disarmingly small, transistor or semiconductor components have proved eminently satisfactory for certain power supply units and their current regulators. Having no need for filament transformers, the regulators may be compact, light and rugged. A feedback network eliminates cascading transistors.

THE best way to determine cause and effect in an experiment is to vary one and only one variable at a time, and measure all the effects due to it. In electronics, examples of variables that one may wish to keep constant are supply voltages or supply currents. This is one reason why voltage or current regulation is used.

The problem of maintaining supply voltages constant in vacuum tube circuitry is not new,[1] and considerable literature exists on the subject of voltage regulation. In some applications, current rather than voltage is the desired variable to keep constant; for example, in electron microscopes a constant current through coils keeps the magnetic field constant,[2] minimizing image aberration; repeaters require constant current to obtain faithful operation.[3] Another important application is in the design of circuits which are the dual of circuits requiring constant voltage supplies.

Literature reveals that low output resistance from semiconductor voltage regulators has been obtained by cascading a number of transistors.[5-12] This article presents a method whereby very high or even negative output resistance may be obtained from a current regulator by the use of an active feed-back network, thus eliminating the cascading of transistors.

COMPONENTS

Transistors

Characteristic curves of a typical germanium power transistor are shown in Figure 1(a). It will be assumed that the static characteristics are all parallel straight lines; i.e., the slopes of the curves, $\frac{1}{r_d}$, are constant where r_d is the dynamic output resistance.

The choice of an operating point is limited by two factors: one, the maximum collector voltage; and two, the maximum allowable temperature of the collector junction. The maximum collector voltage is a constant depending on the particular transistor chosen, and it is usually higher for silicon transistors than for germanium transistors. The collector junction temperature is a function of the power dissipated, the ambient temperature, and the total thermal resistance. Manufacturers usually specify the thermal resistance between the junction and the case of a transistor as well as that of washers used to insulate the transistor from the heat sink electrically. Curves may also be supplied to find the thermal resistance of heat sinks in still air with square areas as a function of size, thickness, material and physical orientation. The units of thermal resistance are normally given in centigrade degrees per watt. The junction temperature may be found by adding the product of the total thermal resistance and the power dissipation to the ambient temperature. For most germanium transistors the conservative rating of junction temperatures varies between 65 and 100 degrees C and for silicon it varies between 150 and 200 degrees C. These ratings differ between manufacturers, and values exceeding the above given ranges may be encountered.

If the supply voltage is within the maximum voltage rating, then a purely resistive load may go to zero provided the bias is such as to limit the power dissipated to the maximum allowable junction temperature. The largest value of load resistance which will keep the operating point on the linear portion of the characteristics is slightly less than the supply voltage divided by short circuit collector current. Between these two extremes of load variations, the collector current, see Figure 1(b), is given by:[13]

$$I_c = BI_b + \frac{V_{ce}}{r_d} + I_o' \qquad (1)$$

where B is the large signal, short circuit, current amplification factor, I_b the base current, V_{ce} the collector-to-emitter voltage, and I_o' is that portion of I_c where the $I_b = 0$ line, extended, intersects the $V_c = 0$ axis. It can be seen from the spacing in the static characteristics, Figure 1(a), that B is in turn a function of the current, Figure 1(c); I_o' is an exponential function of temperature, doubling its value for approximately every 10 C degrees, Figure 1(d). At room temperature, I_o' is about an order of magnitude smaller for silicon transistors than for germanium transistors.

Some second order effects are that both B and r_d are functions of temperature and collector voltage, but these changes are very small compared to the changes discussed above, and hence will be neglected.

The Zener Diode

The function of the Zener diode[14-17] is to provide a constant voltage independent of current through it. The complete current-voltage characteristics of a diode are shown in Figure 2(a). If the reverse voltage on a diode is increased, a nondestructive breakdown region will be reached, called the Zener region. A Zener diode is a diode especially manufactured to have low dynamic resistance over a wide current range in this region.

After passing the knee of the curve, the noise region, the dynamic resistance decreases with increasing current. To find the best operating point, a regulation factor has been defined which is the ratio of dynamic to d-c resistance. The regulation factor reaches a maximum shortly after passing the knee of the curve.

Zener diodes come in a large range of breakdown voltages. The temperature coefficient and the dynamic resistance of a Zener diode are functions of the breakdown voltage, see Figure 2(b).[15] Most Zener diodes have a minimum dynamic resistance between 5 and 6 volts, and the temperature coefficient goes through zero

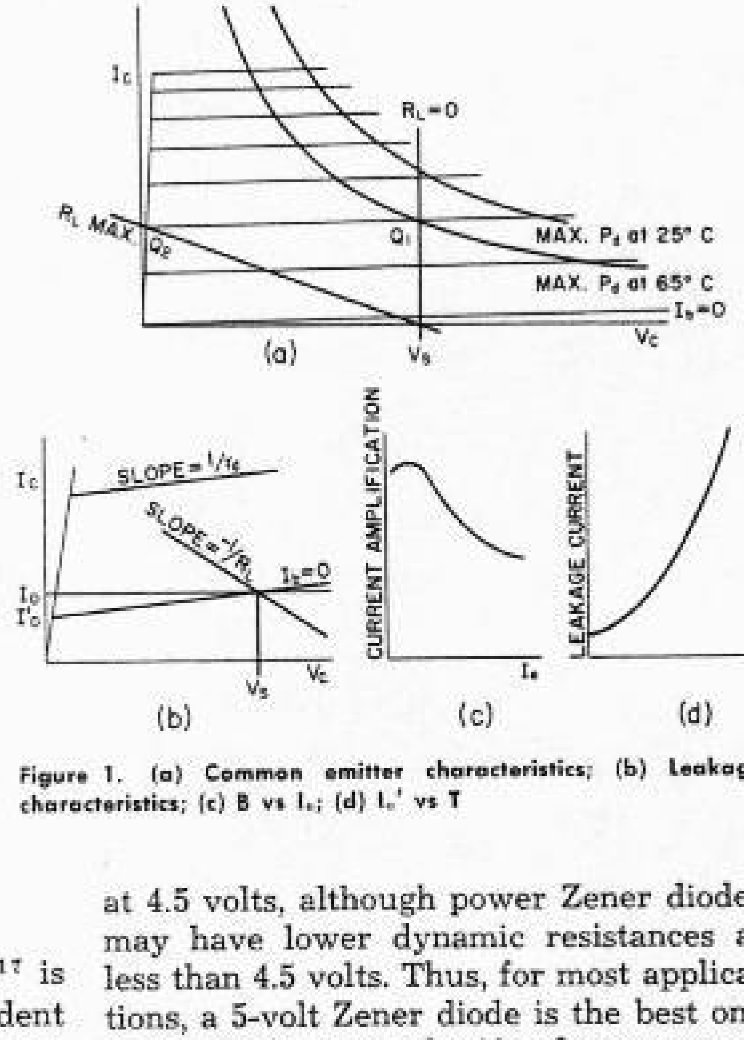

Figure 1. (a) Common emitter characteristics; (b) Leakage characteristics; (c) B vs I_e; (d) I_o' vs T

at 4.5 volts, although power Zener diodes may have lower dynamic resistances at less than 4.5 volts. Thus, for most applications, a 5-volt Zener diode is the best one to use. If, for example, 10 volts are necessary, two 5-volt diodes should be connected in series to keep the temperature coefficient down to zero. This may also yield a dynamic resistance of an order of magnitude less than that of a single 10-volt Zener diode.

The Thermistor

A thermistor is a resistor having a high temperature coefficient. Commercial thermistors made of semiconductor material usually exhibit a high negative temperature coefficient; i.e., the resistance decreases as the temperature increases. The actual temperature coefficient of most thermistors is between −3.4 percent/C degree and −5.8 percent/C degree at room temperature depending on the grade of the material. For given grades the temperature coefficient will vary with temperature, generally increasing as the temperature decreases and vice versa. A

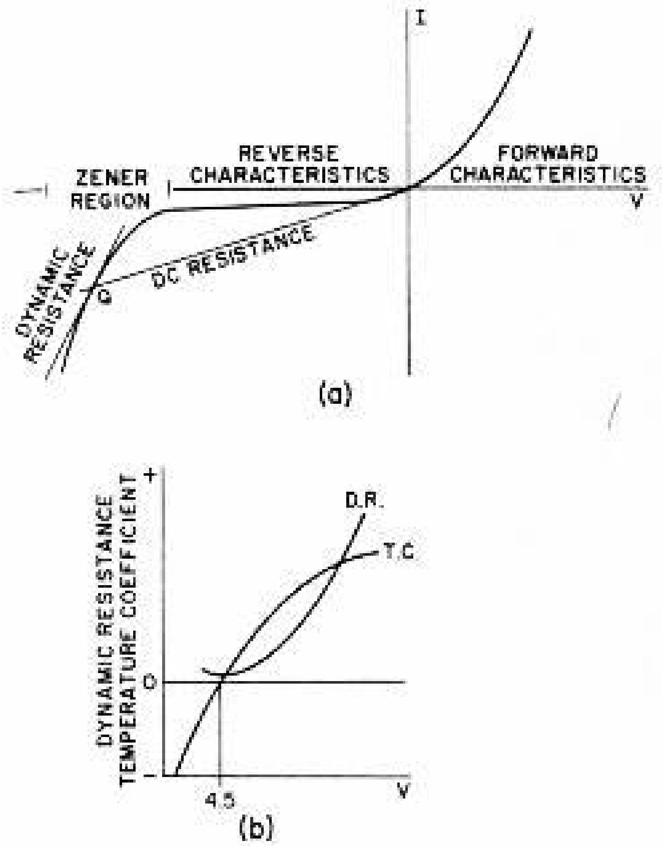

Figure 2. (a) Complete diode characteristics; (b) A-c resistance and temperature coefficient vs breakdown voltage

typical resistance vs. temperature curve of a thermistor is shown in Figure 3; note copper having a small positive coefficient for comparison.

A thermistor may be used thermally, the internal power dissipated being insufficient to heat the unit above ambient temperature. Thermistors so used are controlled by the ambient temperature, and find application in temperature control, temperature measurement, and temperature compensation. Thermistors used electrically are controlled by the power dissipated in the unit rather than by the ambient temperature. The heating may be done directly or indirectly by means of a heater coil. The thermal lag of these units is short for small bead type thermistors and long for large massive types. Furthermore, the temperature differential between the unit and the ambient surroundings depends on those surroundings themselves. It will reach a higher differential in still air than in moving air.

Bead and rod type thermistors are used suspended by their leads, while disc and washer types are mounted to heat sinks.

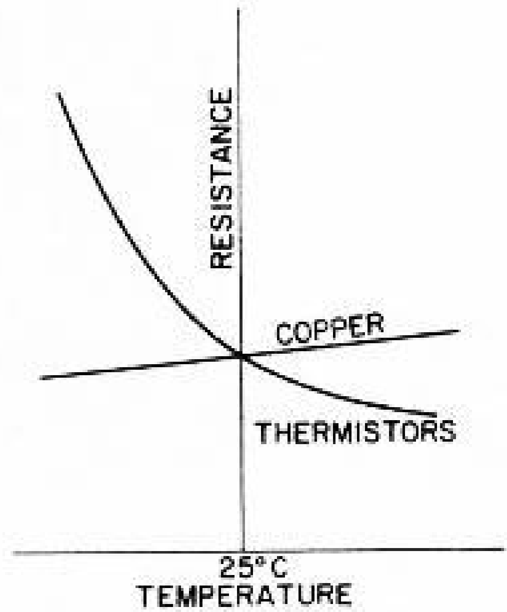

Figure 3. Temperature characteristics of copper and thermistors

REGULATION FACTORS

In order to compare different regulators, it is convenient to define certain regulation factors. For comparison of constant current regulators—all operating at the *same* nominal output current—it will suffice to find factors relating the *changes* in output current to *changes* in input voltage and to *changes* in output voltage. These factors are: $g_x = \frac{\triangle I_o}{\triangle E_i}$ called the transconductance, and $g_o = \frac{\triangle I_o}{\triangle E_o}$ called the output conductance. For a good current regulator, these factors should be as small as possible.

To compare regulators having *different* output currents, it is more useful to compare *percentage changes* in output current to *percentage changes* in the independent variables. Input voltage, load resistance, and ambient temperature are the three principal independent variables.

Relating percentage changes of output current to percentage changes in input voltage by the regulation factor F, one may write:

$$\frac{\triangle I_o}{I_o} = F \frac{\triangle E_i}{E_i} \qquad (2)$$

and solving this for the regulation factor F, one obtains:

$$F = \frac{\dfrac{\triangle I_o}{\triangle E_i}}{\dfrac{I_o}{E_i}} \qquad (3)$$

F is thus the ratio of dynamic to static transconductance. Similarly G and H are defined as the fractional output current changes to the fractional load resistance and temperature changes, respectively:

$$G = \frac{\dfrac{\triangle I_o}{I_o}}{\dfrac{\triangle R_L}{R_L}} \qquad (4)$$

$$H = \frac{\dfrac{\triangle I_o}{I_o}}{\dfrac{\triangle T}{T}} \qquad (5)$$

Factors F and G are of primary importance as the need to regulate with respect to input voltage and load resistance is usually present. The factor H is not important if the regulator is used at room temperature such as in the laboratory, but becomes very important when the regulator is used at elevated temperatures. It can be seen from the regulation expressions that the factors F, G, and H must be as small as possible, for good regulation.

Later on in this paper, regulation factors will be given as one part in 100, for example. To get a feeling of what this means, assume that the input voltage varies by 10 percent, then if F is one part in 100, the output current varies by 0.1 percent due to these input voltage variations.

BASIC CURRENT REGULATOR

Principle of Operation

Figure 4 (a) shows the basic principle of degenerative current regulation, using a Zener diode and a transistor. The resistor R_B provides current to the Zener diode. As a first approximation, assume the dynamic resistance of the Zener diode to be zero, making the Zener voltage independent of the input voltage. The emitter current is essentially determined by the Zener voltage and the emitter resistor R_E, neglecting the small base-to-emitter voltage. In turn, the emitter current determines the collector current, neglecting collector voltage and leakage current for the moment. Assume an increase in collector current. This increases the emitter current, decreasing the base voltage (referred to the emitter). This in turn tends to cancel the original assumed increase in collector current and, therefore, the collector current is stabilized.

The regulation of this basic circuit with respect to the three external variables quoted before is extremely poor. The reasons are that the resistance of the Zener diode is not zero (its variations in voltage being amplified by the transistor), the collector resistance of the transistor is not infinite, nor is the leakage current zero. These last two terms contribute to the collector current as shown by the second and third terms of equation (1). The above three sources of error must be corrected in order to make factors F, G, and H as low as possible.

Collector-to-Emitter Voltage Compensation

When the input voltage is increased or the load resistance decreased, the collector-to-emitter voltage increases, which in turn increases the collector current. Figure 4 (b) shows a method which will compensate for changes in the collector-to-emitter voltage of the regulating transistor. This method employs a second transistor which contributes to the current through R_{E1}. When the collector-to-emitter voltage of the regulating transistor increases, the current through R_{E2} increases proportionally, and consequently the current through R_{E1} increases. This in turn decreases the base-to-emitter voltage, tending to cancel the original increase in collector current. Making the value of R_{E2} approximately equal to r_{d1} renders the collector current independent of V_{ce}.

This compensation does not load down the regulating transistor as the input resistance of the compensating transistor is approximately B_2R_{E2}. The advantage of this compensating stage over simple cascading of two transistors is that the effective output resistance has been made infinite, and can be made negative by increasing the feedback (decreasing R_{E2} below r_{d1}). Negative output resistance merely means that the collector current can be made to decrease with increasing collector-to-emitter voltage. The power handling capabilities of the compensating transistor may be much lower than that of the regulating transistor, although it must be rated for the same collector voltage.

Zener Dynamic Resistance Compensation

As explained in the section on components, the dynamic resistance of Zener diodes is not zero. The operating point of these diodes is chosen such that the regulation factor of the diodes alone is a maximum. When the input voltage increases, so does the Zener voltage, causing the base voltage (referred to the emitter) of the control transistor to increase, hence increasing the collector current. The resistor R_{E2}, which compensated for the collector-to-emitter voltage, also partially compensates for the Zener dynamic resistance. A second resistor, R_C, connected as shown in Figure 4(c), makes the compensation complete. Letting R_{AC} be the dynamic resistance of the Zener diode, the following ratio may be set up to give the approximate value of R_C.

$$\frac{R_B}{R_{AC}} = \frac{\dfrac{R_{E2}R_C}{R_{E2}+R_C}}{R_{E1}} \tag{6}$$

Solving for R_C results in:

$$R_C = \frac{R_BR_{E1}R_{E2}}{R_{AC}R_{E2} - R_BR_{E1}} \tag{7}$$

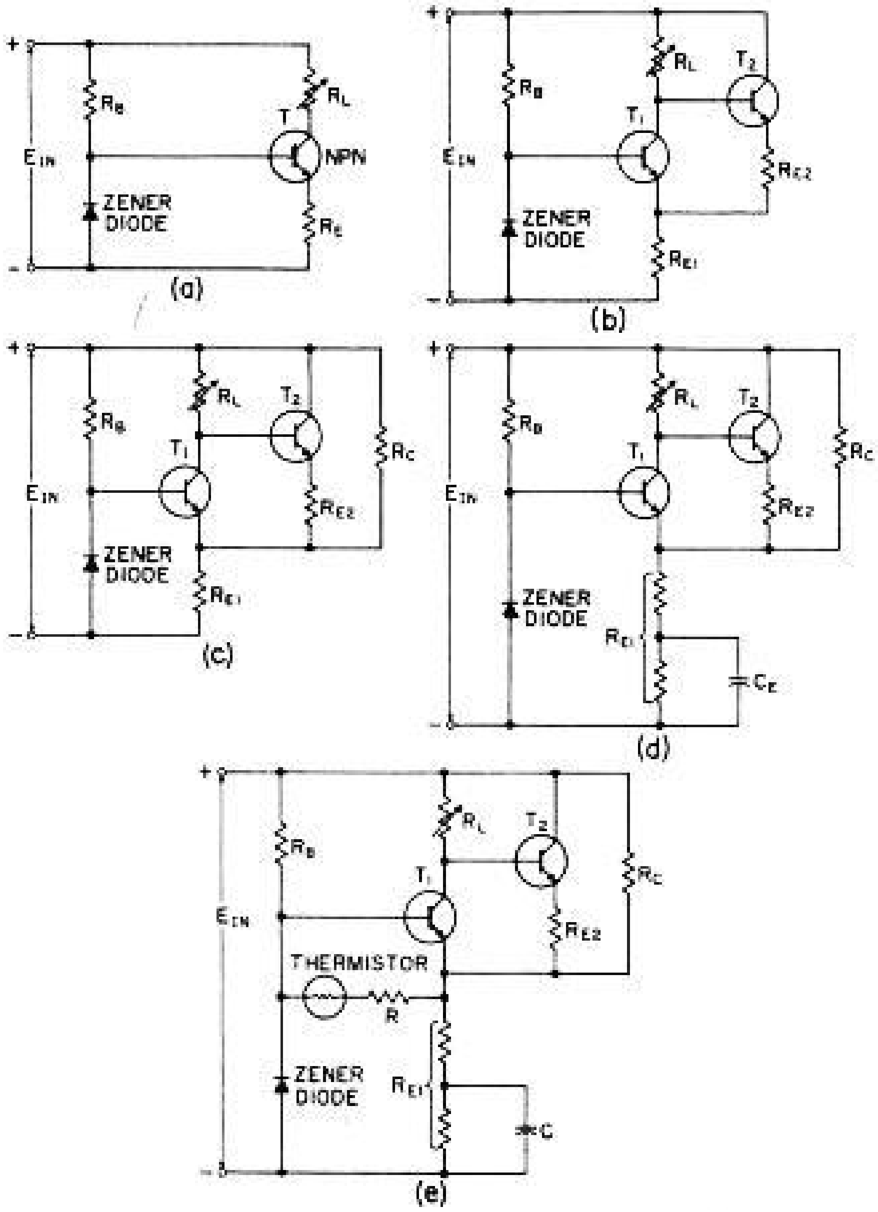

Figure 4. (a) Basic regulator; (b) V_{ce} compensation; (c) Zener diode compensation; (d) Ripple compensation; (e) Completely compensated circuit

Ripple Compensation

The experimental value of R_C agrees with the theoretical value for fast changes in input voltage (such as ripple voltage). For slow changes it is found that a smaller value of compensating resistance is necessary, and hence equation (7) derived above is good for fast changes only. The reason for this discrepancy is the increase in collector dissipation. An increase in the collector dissipation of the control transistor increases the junction temperature, which increases the leakage current of the transistor.

The actual compensating resistance used is that one which compensates for slow changes, and its value is experimentally determined. This value, however, now overcompensates for ripple voltages. In order to compensate for slow changes in input voltage and for ripple simultaneously, part of the emitter resistance, R_{E1}, is bypassed, Figure 4(d). Having determined the value of R_C experimentally, one may now use the same ratio, equation (6), as before, to determine the unbypassed portion of R_{E1}. The capacitor setting on R_{E1} has been experimentally verified by observing 60-cycle ripple across the load resistance on an oscilloscope.

Temperature Compensation

As the temperature increases, the leakage current I_o' of the regulating transistor increases, and consequently its collector current increases. To compensate for this effect, one must decrease the base-to-emitter voltage when the temperature increases.[20] There are various ways to accomplish this. One way is to select a material of positive temperature coefficient for R_{E1}. This resistance then increases with temperature, which increases the voltage across R_{E1}. This in turn decreases the base-to-emitter voltage, and decreases the collector current, thus achieving compensation. Another method is to insert a thermistor in place of R_C. When the temperature increases, the resistance of the thermistor decreases, increasing the current through it and also the current through R_{E1}. This decreases the base-to-emitter voltage again with the same consequences as before. A parallel or series resistor may have to be used with the thermistor in order to obtain the correct over-all temperature coefficient. Still a third method is to insert a thermistor from base to emitter directly, as shown in Figure 4(e). This thermistor is connected to a heat sink, and its resistance is controlled by the ambient temperature. A series resistor with the thermistor produces the correct over-all temperature coefficient.

PRACTICAL CURRENT REGULATOR

A practical 100-ma current regulator, having an output from 0 to 40 volts, is shown in Figure 5. The first stage of this current regulator is in itself a voltage regulator. The first stage is similar to the current regulator described before, except that its load resistance is nearly constant. This means that the voltage across the load is also nearly constant, and it may then be used to provide a constant voltage to the second stage. Actually the load resistance is made up of a resistor, R_{L1}, in series with a second Zener diode, Z_2, and the input resistance to the next stage. This means that the second order effects, neglected before, but which may change the collector current by a very small amount, do not appear in the reference voltage to the second stage. The series resistor, R_{L1}, is used to limit the dissipation of the collector junction, thus prolonging transistor life. Since the load resistance is essentially constant, no load compensation is incorporated. The resistor, R_C, which compensates for the dynamic resistance of the first Zener diode is still used. With this well-stabilized output voltage, it was found that temperature compensation was unnecessary for a silicon transistor, if the temperature is limited to a maximum of 65 degrees C. Ripple compensation was found to be unnecessary, as the ripple across the second Zener diode, Z_2, was already well below the noise level without this compensation.

A voltage has now been obtained which is independent of input voltage. Since this voltage is used as the reference voltage to the second stage, this stage needs no input voltage compensation. The second stage employs a Minneapolis-Honeywell H2 power transistor. To compensate this transistor for load variations, a less expensive Transitron 2N85 medium power transistor is used. Both transistors are bolted to the same heat sink, the H2 transistor being electrically insulated from it. One might now consider using another H2 power transistor simultaneously to compensate for temperature, since the thermal time constant would be the same. This is not feasible, however, because when the control transistor's collector voltage is high, that of the compensating transistor is low, and vice versa. Also, since the compensating transistor dissipates less power, the junctions will never be at the same temperature, even though the cases are forced to be. The best value of resistance R_{E3} to compensate for load variations has been found to be 10,000 ohms.

In this particular circuit, it was found easier to compensate for temperature using a material of positive temperature coefficient in the emitter, rather than the thermistor method shown before. Actually an RF choke, made of copper wire, has been used. Since the resistance of copper varies linearly with temperature, and the leakage current, I_o', is exponential, a dip in output current is observed at a temperature between 25 and 65 degrees C, the extremes over which the circuit is compensated. The maximum variation in collector current due to temperature changes is thus the difference between the initial or final value and the value at which the dip occurs. Obviously the regulation factor with respect to temperature cannot be zero for linear compensation over a finite temperature interval taking into account the dip at the intermediate point.

The experimentally determined value of F is minus one part in 335 for an input voltage varying from 42 to 54 volts; the value of G is minus one part in 2230 for load variation from short circuit to 400 ohms; the value of H is one part in 10.4 for temperature variations from 302 to 342 degrees K. The minuses indicate overcompensation.

The efficiency of this circuit has been determined at 67 percent by measuring input voltage and current, also output voltage and current, at the maximum load resistance of 400 ohms.

This circuit was designed so that, at short circuit output conditions and maximum input voltage, the junction temperature is within its rating even when the ambient temperature reaches 65 degrees C, provided an adequate heat sink is used.

Vastly improved compensation can be achieved over the above figures F and G, if the components R_{E2} and R_C are chosen more carefully. The above-mentioned regulation factors were obtained with 10 percent randomly selected resistors.

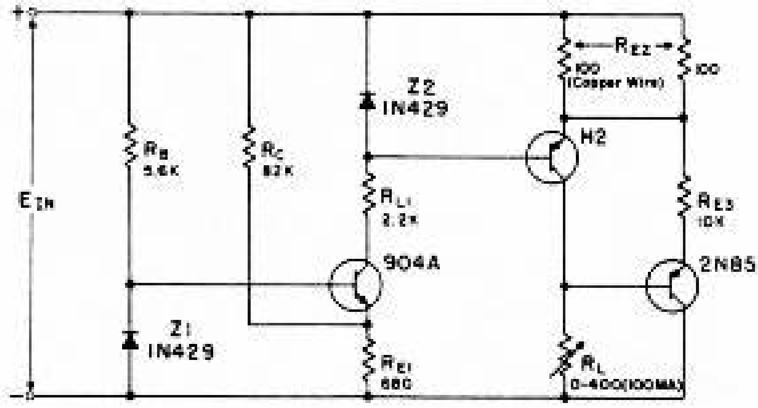

Figure 5. Practical current regulator

Two stages were used to eliminate interaction which would otherwise arise between V_{cc} and Zener diode compensation. No gain is derived from the additional stage, nor is it used to increase the input or output resistance of the control transistor. It must not be confused with cascading two transistors as is conventional to obtain increased output resistance and gain.

VARIABLE CURRENT REGULATOR

It is often convenient to have a variable current regulator for laboratory purposes. Such a regulator has been constructed. The output is regulated for input voltage variations and load resistance variations, but not for temperature variations. The output current was varied by varying the emitter resistor of the control transistor, see Figure 6. The first stage is the same as before, and hence the input voltage variations are stabilized by the same amount. To compensate for load variations over the entire current range from 12½ to 100 ma, a variable R_{E3} must be used. The resistance value of R_{E3} was found experimentally at both ends of the range, and a suitable potentiometer was ganged to the emitter potentiometer, so that when R_{E2} is increased, R_{E3} increases also. Good regulation has been obtained with respect to variations in input voltage and load resistance over the entire current range. The maximum load resistance at 100 ma is 400 ohms and at 12½ ma it is 3200 ohms.

★ ★ ★ ★

The current regulator described can be used with a compact semiconductor power supply. The advantages over vacuum tube supplies and regulators are no need for filament transformers, smaller size and weight, more rugged and longer life. Little maintenance should be required.

The advantages of the particular circuitry of the series current regulator herein described are its few active elements, no need for large filters as ripple may be eliminated by negative feedback, and no worry about overload.[21] The circuit is designed to operate at short circuit, and if the load resistance becomes too large, no voltage will exist between the collector and emitter of the series control element, hence rendering the circuit inoperative.

Regulators may be built to control several amperes of current by means of the above circuitry. Transistors will handle up to 13 amperes and dissipate up to 70 watts at room temperature, with an infinite heat sink, and no washer. Zener diodes, the reference elements, are now made to handle up to 50 watts.

Additional circuit flexibility may be obtained by the use of sensistors. A sensistor is a resistor similar to the thermistor except that its temperature coefficient is positive. The use of a sensistor in series with the emitter lead (in place of the copper wire discussed earlier) should bring much improved regulation with respect to temperature.

A 4-ampere regulator based on the principles described has been built in the Telegraph Company's facsimile laboratory to regulate the filament current in exciter lamps. The supply is regulated with respect to input voltage and filament resistance variations.

It seems probable that transistor voltage regulators can be built upon similar principles as described in this paper. They can be used for regulating the filament supply voltage to exciter lamps, or as a power supply for a 10-watt 20-volt transistorized recording amplifier already built.

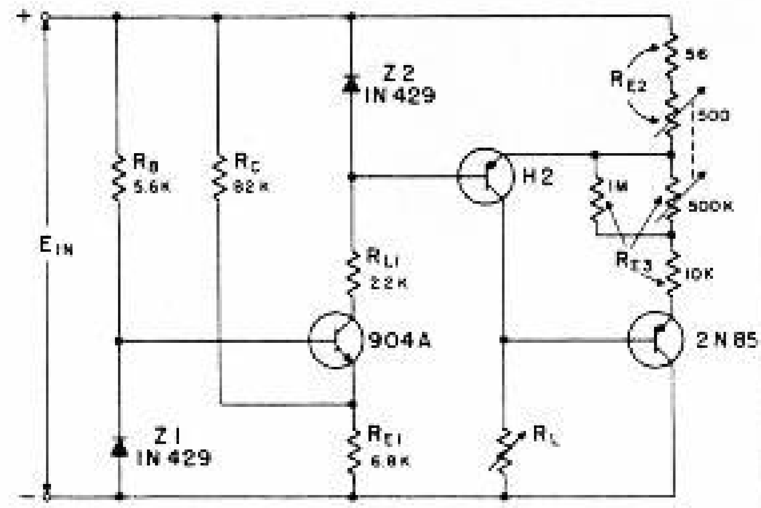

Figure 6. Variable current regulator

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Matthew E. A. Hermans graduated from Northeastern University in 1955 with the degree of Bachelor of Science in Electrical Engineering and in 1958 with the degree of Master of Science in Electrical Engineering. In 1955 he joined Western Union's Telefax Division of the D. & R. Department where he worked on transistorizing existing telefax equipments. He was on leave of absence when he returned to school. His thesis entitled "Current Regulation by Semiconductors" formed the basis for this article. Upon his return to Western Union he again turned to the design and development of semiconductor circuitry in the fax division. Mr. Hermans is an associate member of AIEE and a member of IRE.

Patents Recently Issued to Western Union

Optical Scanning Apparatus for Facsimile Transmitters

R. J. Wise, G. H. Ridings
2,843,756—July 15, 1958

A facsimile scanner and inverter in which a single carrier-modulated light source illuminates two photocells via separate paths, the one including the scanned copy and the other a light-regulating wedge. The photocells are embodied into a balanced bridge and amplifier circuit so adjusted by means of the wedge and other controls that the photocell outputs cancel when scanning white and are unbalanced to produce full output on black. Light source intensity variations are compensated by a gain controlling third photocell. A concentrated-arc lamp is illustrated as the light source.

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Self-Adjusting Stylus

R. J. Wise, D. M. Zabriskie
2,850,350—Sept. 2, 1958.

Mechanism for automatically compensating stylus wear in a moving stylus type of recorder in which chucks holding the styli are frictionally mounted in guideways attached to the belt, disc or other stylus carriage and the chucks are tapped at the rear periodically to advance the styli against a gauging stop. The stylus hammer is energized by local cam-generated pulses or by incoming phasing pulses. Once during each revolution of the belt, each stylus engages a stationary brush to remove debris therefrom. In another version, each stylus is urged forward by an individual spring under restraint, and periodically the restraint is removed so that the stylus can move forward against the gauge.

•

Spindleless Paper Roll Holder

D. M. Zabriskie, William F. Moore
2,853,251—Sept. 23, 1958

Mechanism for loading into the paper magazine of a facsimile machine a paper roll wound on a large cardboard tube. Vertical brackets at each end of the paper magazine each mount a pair of horizontally spaced short supporting rollers at the top and a pair of spaced loading seats for the roll at the bottom. When the brackets are swung outward, the rollers move aside and the seats are slightly uplifted so that a new paper roll can be lowered thereon into the magazine. As the brackets are restored to vertical position, the rollers enter the ends of the paper tube to support the weight of the paper roll as the seats subside from contact therewith. By axially displacing the alignment of the roller shafts slightly from the roll axis, the roll tends to creep to one side and against a braking member so as to align the paper and facilitate braking.

•

Facsimile Stylus Belt and Stylus Holder

E. E. Bedell
2,853,358—Sept. 23, 1958

To prevent generation of displacement disturbances in a stylus belt as the stylus holders and the belt splice pass over the end pulleys, the holders are attached to elongated sections punched from the belt but remaining attached at one end, the line of attachment serving as a transverse hinge line about which the holder may flex to avoid contact with the pulleys. Where the belt ends abut at the splice a large perforation symmetrical to both ends is entered, a transverse strip is welded to one belt end but overlaps the other and the two ends are held together by two narrow straps riveted thereto and crossing the overlapping strip over the perforated area.

•

Molded Modular Terminal Block

W. F. Markley, M. Haifter
2,857,583—Oct. 21, 1958

A terminal block in which all wiring terminals are accessible on one face, comprising a stack of assemblies of nested U-shaped lengths of square or other polygonal cross-section wire either molded into or lying in surface grooves between slabs of insulating material. The single face feature adapts the block for mounting in restricted enclosures and the square cross-section terminals are suitable for use with wrapping tools.