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INTERCONTINENT TELEGRAPHY VIA LONG OCEAN CABLES

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The fundamental problems associated with submarine cable signalling are the same today as they were 80 odd years ago, although the relative importance of some of the problems has changed somewhat. Occasional reference will be made to earlier work and thought in this discussion. After dwelling upon certain limiting factors, the story will develop more or less chronologically. There is a practical limit to the speed of operation of any ocean cable because, for a given sending voltage, the amplitude of the received signals diminishes rapidly as the speed of signalling is increased. This limit depends upon the electrical characteristics of the cable and the magnitude of the extraneous interference at the receiving terminal. In practice there are several problems to be met to obtain the maximum signalling speed. The following factors in varying manner and degree place rather definite limitations upon the ultimate speed of a cable:

1 *The Cable Itself:* The electrical parameters of the cable attenuate and shift the phase of the signals. A non-loaded cable has conductor resistance, dielectric capacity between the conductor and the sea water and insulation resistance—or its reciprocal—leakage. Non-loaded cables possess very little inductance. Inductance is introduced in loaded cables in the form of wire or thin, narrow tape of high magnetic permeability wound spirally around the conductor. This, of course, decreases the attenuation but increases the propagation time and considerably complicates the problem of duplex balance. The operating speed of a cable is limited, because of ever-present interference, by its attenuation. The attenuation can be reduced, to a certain extent, by designing the cable to lower the product of the resistance and capacity. This can be done only by increasing its size which proportionally increases its cost. An economically justifiable design must obviously be decided upon.

The attenuation of a cable is an exponential function of its length. Therefore, it is important to make the length of the longest section as short as possible by judiciously spacing repeater points within the geographical limits encountered on a logical route. The layout of the Western Union North Atlantic cable system is shown in Fig. 1.

2 *Duplex Balance:* The duplex balance is frequently the most important limiting factor upon which the speed of signalling is dependent because, after obtaining a satisfactory balance, it is subject to change due to variations in the temperature of the ocean.

Duplex operation requires that the characteristic impedance of the cable, throughout the signalling frequency band, be simulated within very close limits by an artificial line. For non-loaded cables the main considerations are conductor resistance and distributed capacity. Also leakage and inductance are important in balance.

Artificial lines are usually designed and built to suit the particular cables with which they are to be used. They must be capable of adjustment, however, especially near the terminal end, where the simulation must be most exact. They are

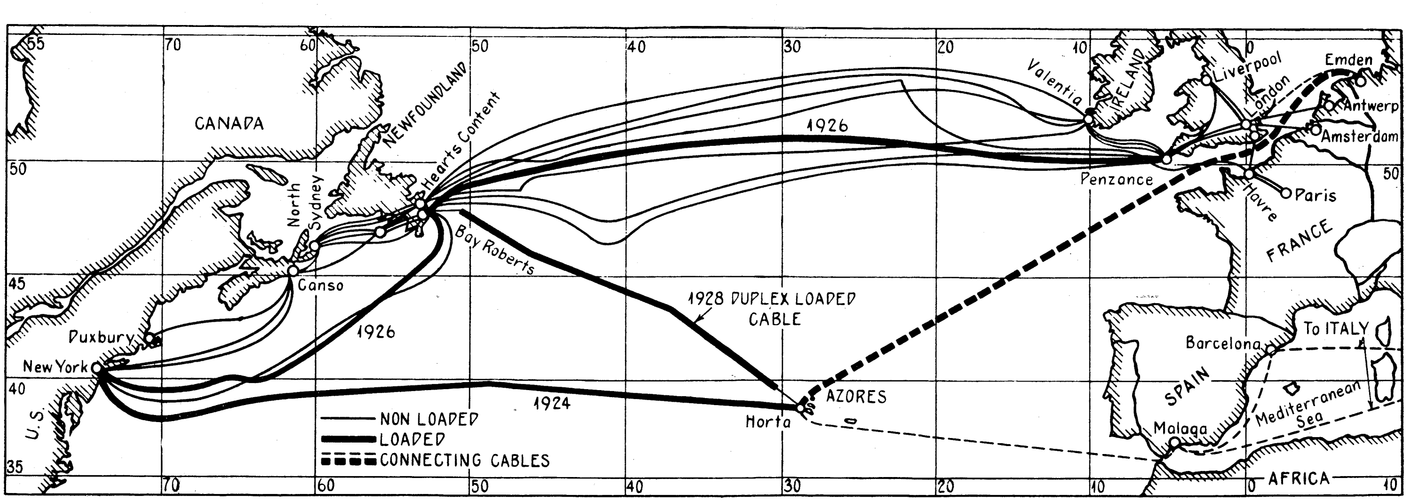


Fig. 1—Western Union Cable System in North Atlantic.

placed in heat-insulated cabinets located in temperature-controlled rooms where the humidity is maintained at a low value.

Considerable time and patience are required to obtain the original balance because the effective values of the cable parameters vary with frequency and it is necessary to balance throughout a comparatively wide frequency range. For many years this was a long and tedious process and the results obtained were subject to the skill of the station electrician. Today the cable characteristics are better understood and the time required to balance a cable has been considerably reduced.

A duplex balance theory and a new type of artificial line was announced by Mr. Milnor in 1922 (1). Prior to 1922 a balance accurate to 1 part in 7,000 was considered to be good. Considerable progress has since been made and duplex balances accurate to better than 1 part in 30,000 are now common.

Continuously loaded cables are still operated simplex due to the difficulties in simulating the non-linear characteristic of the loading but it would be unwise to prophesy that this problem will never be solved. The 1928 duplex loaded cable indicated in Fig. 1 is a taper loaded cable which has been balanced for high-speed duplex operation. The shore ends of this cable are not loaded and the loading in following sections is increased in steps to the middle section where the loading is greatest (2).

3 *Extraneous Interference* (3) (4): Submarine cables are continuously subject to interference due mainly to induction from extraneous magnetic fields in the sea water produced from artificial and natural sources. Electric power and railway systems near the cable terminals, due to currents flowing between their various earth connections, produce magnetic fields in the earth and sea water. Natural sources of interference include electric storms which produce the well known static in radio communication. It is presumed that these disturbances produce a difference of potential at the surface of the ocean which gives rise to electro-magnetic waves which are propagated in all directions. The magnitude of the interference produced from natural sources depends upon geographical location, season of the year, and various other factors. Severe magnetic storms, accompanied by unusual sunspot activity and display of aurora, may induce up to several hundred volts in cables. The occasions are fortunately rare and usually of short duration when such manifestations prohibit the operation of a cable.

These electrical disturbances are attenuated as they penetrate the sea water. The high frequency components suffer greater attenuation than the lower ones. The greater part of the cable is under such a depth of water that it is affected by only the extremely low frequency components of the surface disturbance. This low frequency interference is discriminated against by the low frequency cut-off of the receiving networks.

The shore ends of the cable, where the water is comparatively shallow, pick up higher frequency components of the disturbance which are usually most troublesome. It is customary to extend the receiving earth connection several miles from shore to deep water to neutralize this interference. To obtain equivalent reactions at the receiving terminal, the cable and the receiving earth connection should have equal impedances in both directions from the point where the disturbance is picked up. The impedance of the loaded cable can be approximated sufficiently closely by a resistance for frequencies above 15 to 20 cycles per second. Resistance termination is practical and loaded cable receiving earths are so terminated. The characteristic impedance of the non-loaded cable is comparable to the characteristic of the loaded cable below about 15 cycles. At higher important frequencies the reactive component of the characteristic impedance is still large compared with the resistance component. Therefore, simple resistance termination of the receiving earths for non-loaded cables is only partially effective; and the problem of interference neutralization of the higher frequencies is more difficult for non-loaded cables than for loaded cables.

In the final analysis it is the extraneous interference which places an ultimate limit upon the speed of a cable. It is common practice to limit the speed to a point where the interference from all sources is no higher than 20 per cent of the received signal.

4 *Limited Transmitting Voltage:* The amplitude of the received signal is dependent upon the value of the transmitting voltage. The higher the voltage the greater the discrimination against interference, but the voltage is necessarily limited to a value where there is no danger of injuring the insulation. While during manufacture the cable is tested with several thousand volts, when laid it may have certain weak spots which might be broken down at a much lower voltage. Also, cables laid in fishing areas are subject to injury from trawler gear. Cable repairs are expensive and for this reason voltages have been kept down to a very conservative value. For many years the customary operating potential for long cables was 50 volts and it is still held under 100 volts. The voltage used on loaded cables may be limited to a value considerably under 50 volts because of distortion introduced by the loading material.

5 *Receiving Equipment:* A highly sensitive receiving device is essential to record the rather feeble received signal at reasonable speeds. Sensitive moving coil instruments patterned after the d'Arsonval galvanometer were developed for cable service. While vacuum tube amplifiers are gradually replacing them, there are many moving coil instruments still in use. Their development over a long period of years, from the mirror galvanometer to the siphon recorder and to the delicate Huertley magnifier and the drum relay, makes interesting history.

The application of vacuum tube amplifiers to ocean cables has seemed rather slow. In addition to the problems associated with the development of an amplifier sufficiently stable for cable operation, the delay has been due to a large extent to the difficulty in obtaining the discrimination against duplex unbalance and certain types of interference which is inherent in the mechanically moving coil system. Also the moving coil instrument has certain beneficial signal shaping characteristics which must be duplicated electrically by correction networks for vacuum tube operation. The speed of sensitive moving coil instruments is definitely limited. The advent of loaded cables created a demand for a much faster receiving device and it was to loaded cables that amplifiers were first successfully applied. Our first two loaded cables were, and still are, operated simplex due to the difficulties in obtaining a duplex balance. The problem was, therefore, somewhat less difficult without duplex unbalance to contend with. Similar amplifiers were later used for duplex operation on a cable having non-uniform or tapered loading, but considerable care was exercised in the design and shielding of the input and pre-amplifier shaping networks to exclude interference.

6 *Signal Shaping or Equalizing Networks:* If a direct-current voltage is suddenly impressed upon a cable grounded at the far end, the current at the far end increases slowly. The rate of increase of the received current is so slow—it may extend over several seconds—that rapid signalling over a simple cable circuit is impossible. At practical signalling speeds the received current for the highest frequency is a very small fraction of the maximum. To equalize the amplitude of the received signal for the various signalling frequencies and to correct for delay distortion, condensers and coils are introduced in the cable circuit. They act to remove the greater part of the received current while retaining the sharp initial rise of current or in

common cable parlance "shape" the signals. Condensers of about one-tenth of the total capacity of the cable placed in series with the cable at both the sending and receiving ends and an inductive shunt across the coil of the receiving instrument are very effective when used with moving coil instruments. Vacuum tube amplifiers require something more than these simple shaping elements to include the frequency response characteristics inherent in the moving coil system.

7 *Method of Operation* (5): The most popular code for recorder operation of cables is the modified continental code. It is a 3-element code requiring distinction between positive, zero and negative impulses. Some administrations also use the 3-element code for printer operation (6). Means for automatically translating 3-element signals into 2-element signals of higher frequency have been developed for the purpose of transmitting recorder signals over land line systems equipped to repeat only 2-element signals (7).

Western Union has favored the use of the 5-unit, 2-element Baudot code for printer operation due in part to the facility with which channel extensions can be made over standard land line systems.

The 3-element code is of non-uniform length and requires an average of 3.71 impulses or 1.86 cycles per character. The Baudot code is longer and requires 5 impulses or 2.5 cycles per character. The Baudot code is handicapped with a higher line frequency greater than the ratio of 2.5 to 1.86 due to abbreviations and short figures commonly used with the recorder code and because of type shifts required for printer operation. This handicap is overcome somewhat by the fact that nearly twice as much power is transmitted with 2-element signals as with 3-element signals for a given voltage to ground permitting a 10 to 15 per cent increase in frequency. The greatest gain is realized by increasing the speed until the single unit impulses are greatly decreased in amplitude and interpolating these attenuated impulses by means of a suitable regenerative repeater. At first glance it might seem possible to double the speed by filling in the attenuated single impulses. Practically the speed may be raised about 65 per cent by this means.

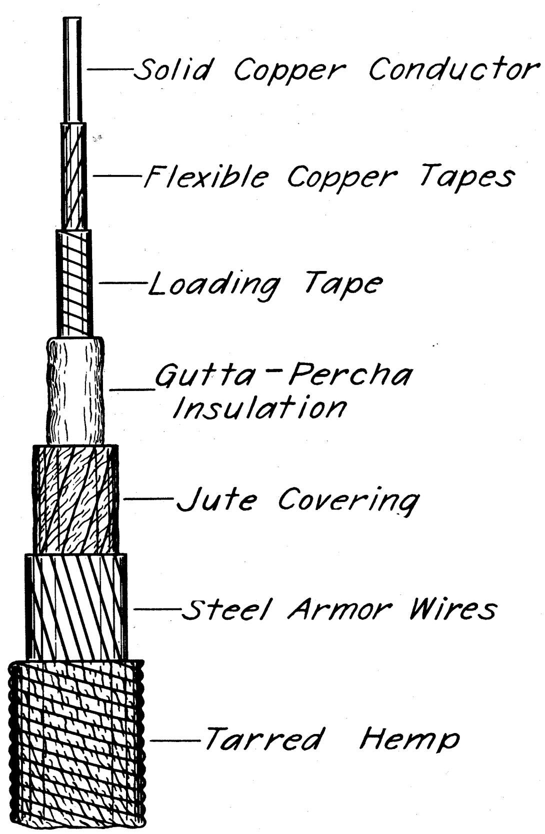


Fig. 2—Loaded Cable Construction.

Physical Characteristics

One type of construction of submarine cables is shown in Fig. 2. Several copper tapes are wound spirally around the solid central conductor to preserve continuity should the solid conductor become broken. The loaded cable has a layer of magnetic material wound around the conductor. The principles of loading to improve the transmission characteristics had been known for many years prior to the laying of the first long loaded cable in 1924. The continuously loaded cable was made practical by the discovery of an alloy having high permeability in weak magnetic fields. Until recently gutta-percha insulation has been used exclusively because both its physical and electrical properties were preferable to any other known material. The insulation is protected by a layer of jute over which the steel armor wires are placed.

Arrival Curve

If a voltage is suddenly impressed on a cable grounded at the far end, the sending current has a characteristic as illustrated by curve 1, Fig. 3. Curve 2 shows the rise in current at the

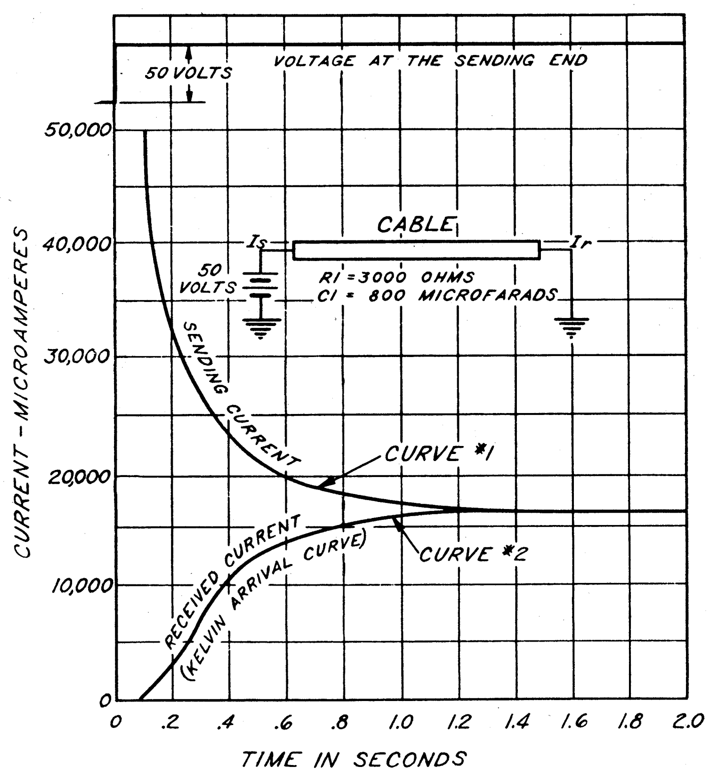


Fig. 3—Sending and Received Current.

distant end of the cable. This is known as the Kelvin Arrival curve in honor of Lord Kelvin who first calculated it in 1855. It will be seen that for this particular cable the current does not rise to a steady value until about 1.2 seconds after the voltage is applied at the sending end. If the received current were allowed to reach the steady state value for each signal impulse the speed of signalling would be about 2 words per minute. In practice the speed is increased to the point where the received signal amplitude is about 5 times the size of the interference. At this point the amplitude of a signal of unit length is a rather small percentage of the maximum.

Signalling with Moving Coil Instruments

If a signal is formed by the combination 3 dots-dash-dot where the duration of a unit pulse is 0.1 second the received current will be as illustrated in Fig. 4. This curve is built up by adding

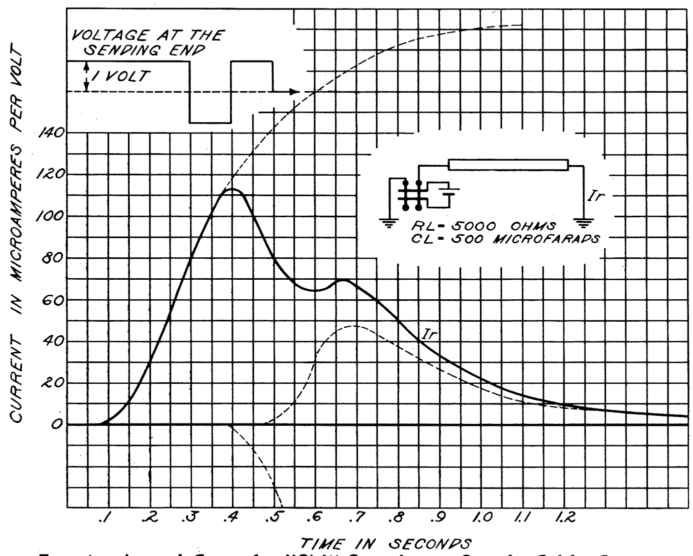


Fig. 4—Arrival Curve for "SN" Signal over Simple Cable Circuit.

arrival curves. Severe distortion is quite evident and without correction signalling at this speed is impractical.

Earthing the cable during a part of each pulse while reducing the amplitude greatly improves the shape of the received signal. It is common practice to use in the neighborhood of 70 per cent marking, the cable being grounded at the sending end for about 30 per cent of each pulse. This type of transmitted signal is shown in Fig. 5. Condensers placed in series with the cable

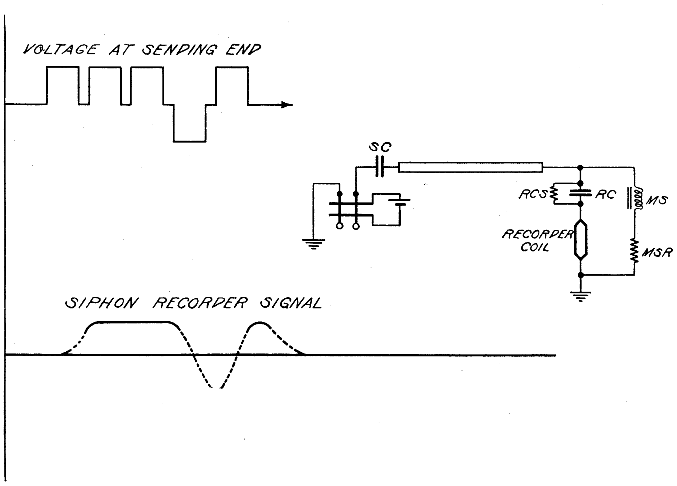


Fig. 5—Siphon Recorder Signal for "SN."

at both the sending and receiving ends will improve the signal definition and produce a steeper front to the arrival curve. The large low-frequency component still present can be diverted from the receiving instrument by shunting the instrument with a coil known as a magnetic shunt. The trace produced by the siphon recorder as shown in Fig. 5 has the benefit of these shaping aids. The desirable qualities of the recorder signal are due to a certain extent to the motional impedance of the recorder coil.

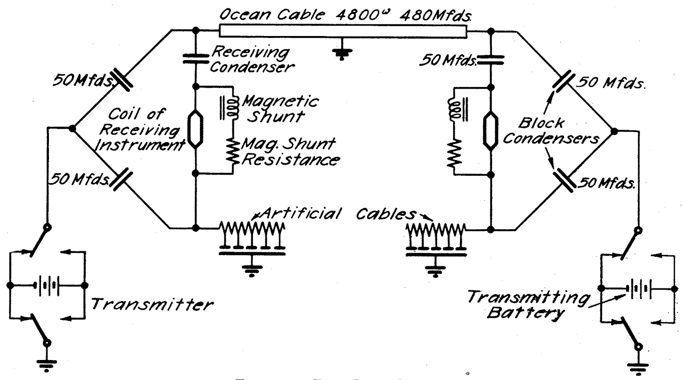


Fig. 6—Duplex Circuit.

Figure 6 shows a fairly complete duplex circuit for siphon recorder operation. The bridge circuit, with condenser bridge arms, is universal for long cable operation. Here the magnetic shunt is shown across the recorder coil only. Whether connected in this manner or across the receiving condenser and coil makes little practical difference. The bridge arm or block condensers are also the sending condensers. With the condensers unshunted as shown, the recorder current will fall off on very long signals of one polarity. This is not serious on the usual traffic signals as considerable signal zero wander can be tolerated with siphon recorder reception. The condensers may be shunted by resistances to admit sufficient low frequency component to hold up the signal indefinitely. This would greatly reduce the discrimination against earth currents. Earth currents are frequently of such magnitude as to seriously interfere with signalling, but they generally vary at a very low frequency and unshunted condensers are very effective in reducing them to a negligible size. Thus, low-frequency cut-off is obtained to discriminate against low-frequency interference. The high-frequency cut-off is obtained by virtue of the inertia of the moving coil. Excellent discrimination against high-frequency duplex unbalance is obtained, as was pointedly demonstrated when vacuum tube amplifiers were first substituted for moving coil receivers.

The maximum current through the coil of the recorder may be about 2 micro-amperes per volt, or for a 50-volt sending battery the maximum current may be about 100 micro-amperes. The current at the dot frequency may be a small fraction of this value. The tension of the coil suspension is adjusted to give it a free period corresponding to 1.2 to 1.5 times the dot frequency. The response is such that a coil current of from 20 to 30 micro-amperes at the critical frequency rising to 100 micro-amperes at some lower frequency will move the coil to produce the well defined signal shown in Fig. 5.

The current values mentioned are about the minimum allowable for satisfactory siphon recorder operation and the speed cannot be increased much beyond the point where these values are obtained. If the speed is not limited by interference, then the sensitivity of the receiving instrument is the limiting factor.

Several different types of mechanical amplifiers or magnifiers, much more sensitive than the siphon recorder, have been developed for cable service. A common type is the Huertley hot wire magnifier. Its current output may be from 10 to 15 times the current output which permits a considerable increase in speed.

The Huertley magnifier has 2 pairs of wires, heated by an electric current, which form 2 arms of a Wheatstone bridge circuit. One wire of each pair may be caused to move a few thousandths of an inch closer to or farther from its mate by the magnifier coil. A movement in one direction increases the temperature of one pair of wires and decreases the temperature of the other pair, which changes their resistance accordingly. The bridge circuit becomes unbalanced as the resistance of the wires is changed due to their change in proximity. The maximum output of the magnifier is about 200 micro-amperes, which is quite sufficient to operate a cable relay, permitting cable signals to be repeated.

Relay operation requires a better defined signal and one which holds a closer zero than the signal which can be tolerated for the siphon recorder. The condensers permit a long series of signals of the same polarity to fall towards zero. This tendency is neutralized by a correction circuit which builds up a current in the relay correction coil proportional to the decrease in current in the main coil.

The safe output of a cable relay is about 5 milliamperes—sufficient to operate more rugged relays to repeat either cable code or printer signals. Signals from long cables are usually repeated through synchronous regenerators.

There have been many interesting developments with moving coil instruments but the inertia of the moving coil and the controlled devices sets a rather definite limit to the speed at which they may be used, since the sensitivity decreases roughly as the square of the natural frequency to which they are adjusted.

The laying of the first long loaded cable in 1924 marked a most radical change in ocean cable operation. The loaded cable (8) is capable of a signal capacity several times that of an equivalent non-loaded cable.

Where the level of interference is low, the operating speed may be such that the maximum received voltage is from 2 to 5 millivolts at the fundamental frequency. On an average long cable the power available at this voltage is too low to operate a moving coil instrument except at very low speeds. The loaded cable demanded an amplifier, no more sensitive, but capable of much higher speed than the moving coil magnifiers, and the vacuum tube amplifier was successfully applied.

Signal Shaping Vacuum Tube Amplifiers

When speaking of an amplifier as applied to cables, the word is generally used to include the signal shaping networks associated with it. The requirements that a cable signal-shaping amplifier must fulfill are many and 15 years ago they were justifiably considered severe (9). It must be capable of handling a wide band of frequencies from a small fraction of a cycle up to 1.6 or 1.7 times the maximum signalling frequency. The high frequencies must be amplified much more than the low frequency components. Perhaps the most important function, especially for loaded cable operation, is to advance the phase of the low frequencies to correct for the delay distortion of the cable. The amplifier must be sufficiently sensitive to amplify weak signal components of the order of one-half millivolt and signal amplitudes possibly 20,000 times as great must not saturate the magnetic circuits or cause overloading of the amplifier. The output must be capable of operating suitable relays. Also the amplifier must be as insensitive as possible to interference outside the frequency band necessary to the signal. It should be mechanically rugged and protected against local electrical fields and mechanical vibration and its operation should not be affected by conditions of high humidity.

An amplifier may be used for shaping either 2- or 3-element signals. The signals shown in Fig. 7 are 2-element. The maximum frequency is 100 cycles per second which corresponds to 2400 letters per minute. The attenuation of the 100-cycle or unit pulses is such that it is impractical to equalize their amplitude with respect to the longer signal combinations.

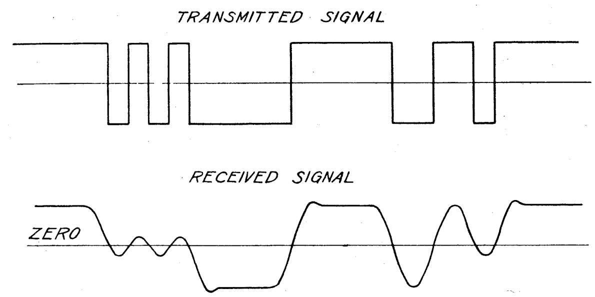


Fig. 7—Two-Element Cable Signals with Received Single Impulses Greatly Attenuated.

The receiving equipment is made insensitive to the weak unit pulses which are interpolated or filled in by a synchronous vibrating circuit. The vibrating circuit, while under the control of the full amplitude signals, anticipates a signal reversal. When the signal falls to within a certain range of zero, the vibrating circuit automatically reverses the polarity of the receiving elements, and continues to reverse the polarity of each baud until the signal again approaches full amplitude.

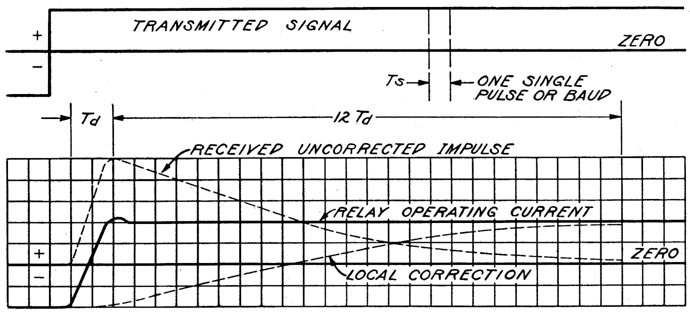
The signal amplitude is practically uniform for frequencies from 50 cycles down to about ½ cycle per second. On this particular cable circuit traffic signals seldom have combinations exceeding 12 to 15 units of one polarity. It is necessary to shape the signal to hold up much longer combinations to decrease the tendency of the signal to fall and change its zero due to a preponderance of combinations of one polarity. The tendency still persists, however, and produces a changing zero which reduces the operating margin and decreases the circuit stability.

Zero wander can be reduced to a certain extent by applying correction to the amplifier. A 3-element high-speed relay, capable of discriminating accurately between currents of slightly different values, may be used to apply correction. This relay is made insensitive to signals of normal amplitude and may be adjusted to operate when the normal amplitude is exceeded by 3 or 4 per cent. Correction is applied to the grid circuit of the last stage tube of the amplifier through a resistance-capacity network. This zero correcting network is adjusted to shape the correction pulse to conform as closely as possible to the natural tendency of the signal to fall after the final shaping adjustments have been made.

This corrector also offers a limited facility for the suppression of earth currents. The frequency of the earth currents is subject to considerable variation and to be very effective the correction must follow the same frequency.

A system employing local correction almost entirely eliminates the tendency towards zero wander due to a preponderance of one polarity and improves the discrimination against earth currents. The received signal is shaped to permit it to fall to zero soon after it has attained full amplitude. Local correction is then applied in such a manner that the resulting signal maintains uniform amplitude regardless of its length.

Figure 8 illustrates a signal reversal to positive after a long negative impulse. It is necessary to observe only the signal cross-over after a comparatively long impulse to obtain a satisfactory shape. The time of cross-over is especially important. It should be $1/2f$ seconds where f is the maximum signalling



FOR CABLE CODE
$T_d = T_s = \frac{16.25}{L.P.M.} = \frac{1}{2f}$ SECS.
f = CYCLES PER SEC. TRANSMITTED = .0308 X L.P.M.

FOR PRINTER CODE DEVELOPED SIGNALS
$T_d = T_s = \frac{1}{2f}$ SECS.

FOR PRINTER CODE INTERPOLATED
$T_s = \frac{12}{L.P.M.} = \frac{1}{2f}$ SECS.
$T_d = 2\,T_s = \frac{24}{L.P.M.} = \frac{1}{f}$ SECS.
f = CYCLES PER SEC. TRANSMITTED = .0416 X L.P.M.

Fig. 8—Received Signal with Local Correction.

frequency in cycles per second. Mr. Milnor (1) has pointed out that to obtain signal definition suitable for relay reception, it is necessary to transmit frequencies up to 1.65 times the dot frequency. For printer signals where the attenuated single impulses are received considerably under full amplitude, the critical frequency is $2f/3$. Applying the factor 1.65 indicates that frequencies up to $1.1f$ are required for printer operation although the receiving equipment responds only to pulses corresponding to frequencies of one-half f or lower.

The time allowed for the signal to decay to zero may be made relatively short when dealing with 2-element developed signals. For 3-element signals or for interpolated 2-element signals, which require distinction of zero, the fall to zero must take place over an appreciable time so that the correction will have little influence on the slope of the signal cross-over. A theoretical diagram of a signal shaping amplifier is shown in Fig. 9.

The signal-shaping elements are between the cable bridge and the amplifier input. In practice the shaping elements are made symmetrical about the center of the bridge. This is essential if shaping adjustments are to be made without disturbing the duplex balance. The circuits shown are their electrical equivalents insofar as their signal shaping functions are concerned.

The shaping elements across the bridge together with the capacity of the cable, artificial line and the bridge condensers form a parallel resonant or anti-resonant network. The network between the isolating transformer and the input transformer is a series resonant network. The transfer admittance of these networks is maximum at the resonant frequency and decreases at frequencies above and below resonance. The shape of the admittance curve below resonance determines the effectiveness with which the frequency distortion of the cable is equalized within the signalling range. The shape of the curve above resonance determines the discrimination against high frequency interference.

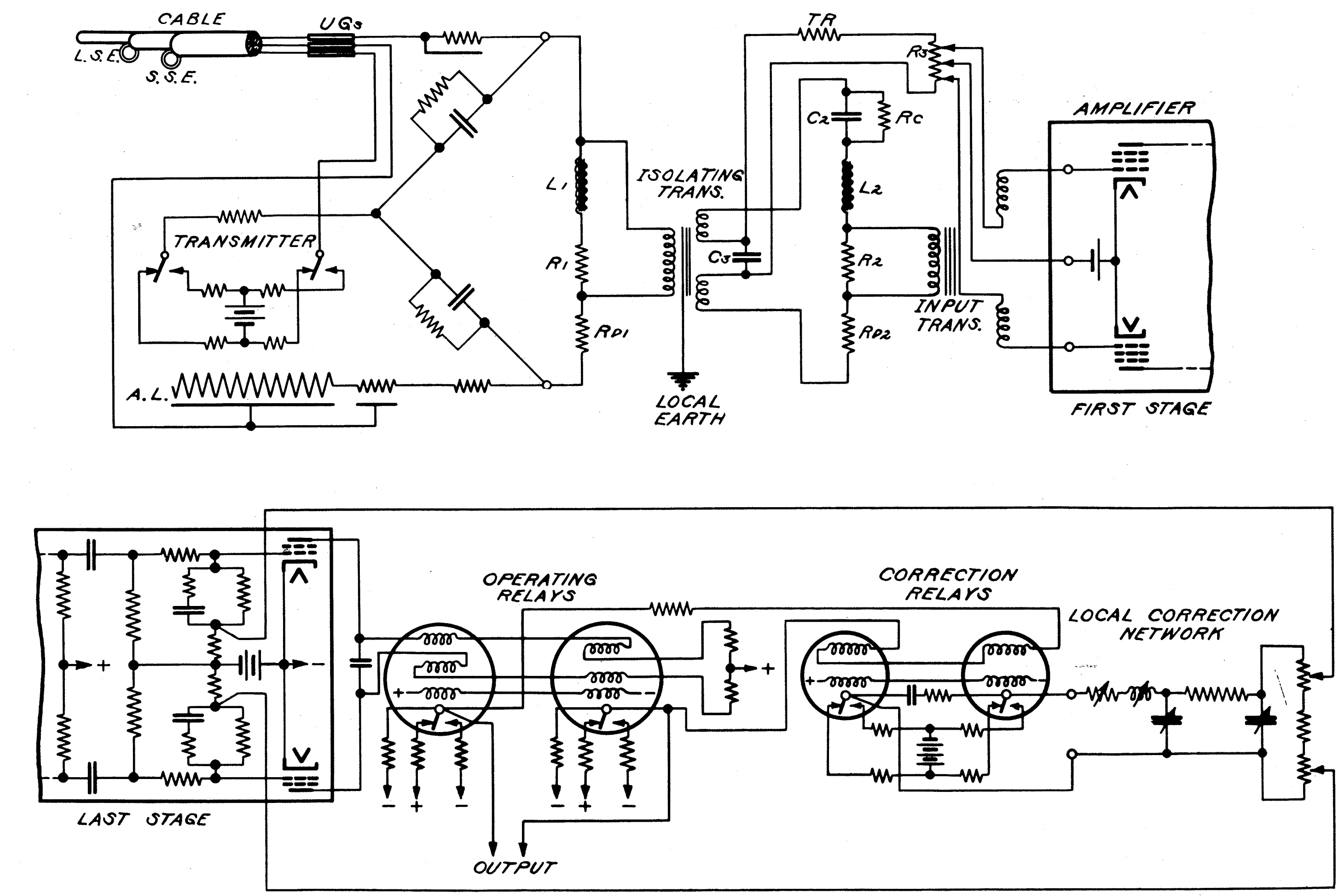


Fig. 9—Signal Shaping Amplifier.

At resonance the reactance of the network is zero. Below resonance the reactance is such that the lower frequencies are advanced in phase to correct the delay distortion of the cable.

Undershoot correction is obtained by means of condenser C_3 and its associated resistances. Local correction is applied as shown in the lower diagram.

Several variations of the shaping networks shown are practical. Loaded cable shaping networks must be arranged to effect comparatively stronger correction over the low frequency portion of the signal spectrum.

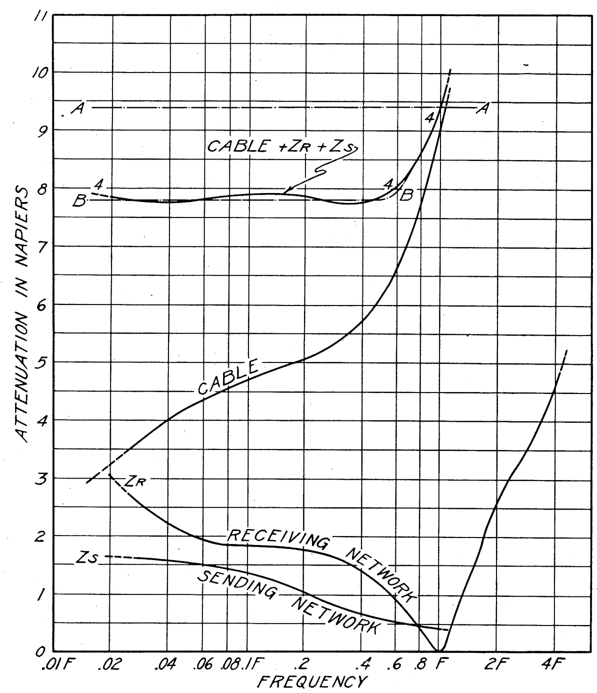


Fig. 10—Attenuation Curves for Cable and Shaping Networks.

Figure 10 shows attenuation curves for a cable and shaping networks adjusted to produce a satisfactory signal shape. Curve B is the theoretical attenuation of the complete facility under ideal conditions where the amplitude at the maximum signalling frequency F is 25 per cent of the amplitude at $1/2F$. For perfect equalization of frequency distortion, the combined attenuation of the cable and the shaping networks would lie on this curve. Curve 4 shows that the actual results come very close to the ideal.

Present solutions of the problems presented by one of the oldest of the electrical arts are considered far from final. Efforts are being directed towards improvements in duplex balance and interference elimination, also the development of more effective receiving equipment to produce signals, suitable for the operation of translating devices, which require a minimum frequency band.

Cable operation was once somewhat veiled in mystery. Today a cable is considered as little more than another transmission line and many problems once considered peculiar to cables are losing that distinction.

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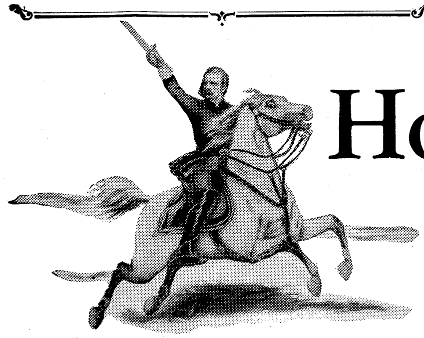
"Rain-In-The-Face" might have been Liquidated *by Radio*

Misled by faulty information from his scouts, General Custer was trapped in ambush at the junction of the Big Horn and Little Big Horn rivers on June 25, 1876. Modern communications might have prevented this tragedy. Scouts could have reported the vast number of Indians present under the command of the Chief, Rain-In-The-Face, and stayed Custer's attack. Custer could have sent word back to the main army of which he was the advance guard.



How the Family of RCA would save Custer

WHEN General Custer arrived at the junction of the Big Horn and Little Big Horn rivers, he'd send up scouting planes immediately. Pilots noting the vast numbers of the enemy, would report back to Custer by means of a light efficient airplane radio transmitter designed in RCA Laboratories built by the RCA Manufacturing Company, one of the members of the family of the Radio Corporation of America. General Custer would, of course, abandon his intention to attack. Using portable RCA broadcasting equipment he'd radio back to the main army for help, and dig in to await rescue.

Word of his plight would be broadcast to the whole nation by the two great NBC networks which provide the broadcasting service of the Radio Corporation of America. Forty-three foreign nations would listen via RCA Communications, the world-wide radio message service of RCA.

Tens of thousands of listeners would sit glued by their RCA Victor Radios. And shortly motion picture audiences throughout the world would see and hear talking pictures describing the rescue of General Custer . . . the scenes voiced by the RCA Photophone Magic Voice of the Screen.

Naturally there would be a great rush on Victor Record Dealers for Victor and Bluebird Records of patriotic character. And Americans everywhere would play these records on RCA Victrolas.

. . . Since, fortunately, no American General is now in need of rescue . . . RCA stands ready to serve the American people in every other respect in every field of radio.

Radio Corporation of America

RADIO CITY, NEW YORK

RCA Manufacturing Co., Inc. · National Broadcasting Company · RCA Laboratories

Radiomarine Corp. of America · R.C.A. Communications, Inc. · RCA Institutes, Inc.