Specifications
For
The Theory and Operation of
Single Morse Circuits

The Western Union Telegraph Company
Engineering Department

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Specifications
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See Appendix No.1.

SPECIFICATIONS

FOR

THE THEORY AND OPERATION OF

SINGLE MORSE CIRCUITS

SPECIFICATIONS AND DRAWINGS REFERRED TO:

Specifications:

Specifications for the Installation of Apparatus and Wiring in Telegraph Way Stations

Specifications for the Installation of Morse Operating Sets

Specifications for the Installation and Operation of Double Conductor Switchboard

Specifications for the Installation and Operation of Front Contact Shunt Locking Repeaters, and Half Repeaters

Drawings Included: None

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PREFACE

A Single Morse Circuit makes provision for the transmission and reception of telegraph signals by means of the Morse Code. There may be only one transmission at any one time but reception is simultaneously recorded on all receiving sets connected in the circuit.

These specifications are divided into two parts, the first of which is for the most part theoretical and the second of which applies the theory to practical operation.

In the first part, the elementary theory of electro-magnets is discussed and from this a simple Single Morse Circuit is developed. The causes of leakage, inductance and line capacity and their respective effects upon Single Morse Operation are also given brief consideration.

The second part gives a description of the instruments used on Single Morse Circuits and the adjustments necessary under varying conditions of operation. Consideration is given also to the layout of circuits, assignment of instruments and potentials and the determination of practical limits for satisfactory circuit operation.

The layout and installation of Single Morse Apparatus and its electrical relation to Switchboards and other apparatus are covered in detail by the following specifications and are not therefore discussed here:

Specifications for the Installation of Apparatus and Wiring in Telegraph Way Stations

Specifications for the Installation of Morse Operating Sets

Specifications for the Installation and Operation of Double Conductor Switchboard

The instruments which are described in these specifications have been designed to give adequate margins of operation under the imposed conditions at Morse operating speeds which are usually somewhat below 15 cycles per second. It should be understood, however, that the theory of operation of the Single Morse Circuit is applicable to any form of transmission using "open" and "closed" signalling; and that the limitations of margin and adjustment become more critical as the signalling speed is increased.

THEORY

SECTION A

Elementary Theory of Electromagnets

A-1 If an electric current of constant value is flowing through a straight conductor, this conductor is encircled at all points by stationary magnetic lines of force. The number of magnetic lines of force present depends upon the strength of the current flowing. When the flow of current in the conductor is interrupted or stopped, the magnetic lines of force, or, as it is called, the magnetic field collapses and disappears. Likewise, upon restoration of the current flow, the magnetic field reappears.

A-2 From the above, it follows that any change in strength of the current flowing will also change the number of magnetic lines or the strength of the magnetic field.

A-3 If the conductor is now wound spirally in the form of a coil spring, every point of the conductor will still be encircled by magnetic lines of force, but because the magnetic lines around adjacent turns of the conductor are in a direction to assist one another, some magnetic lines pass also axially within the coil and return in the opposite direction outside of the coil. If an iron core is inserted lengthwise within the coiled conductor the strength of the axial magnetic field will be greatly increased because iron offers much less resistance to the passage of magnetic lines of force than does air.

A-4 When magnetic lines of force are induced in an iron core by the flow of electric current through an encircling conductor, the core is said to be magnetized, and the combination of core and conductor is termed an "Electromagnet".

A-5 The iron core of an electromagnet is similar to a permanent magnet of the commonly known horseshoe type in that it will attract any other piece of iron which may be brought near to it. Unlike the permanent magnet, however, the magnetism in and consequently the tractive force exerted by the electromagnet may be readily controlled by regulation of the current flowing in the encircling conductor.

A-6 When the current in the encircling conductor is brought to zero by opening the electrical circuit, the magnetic field in the iron core also drops practically to zero* and the tractive force exerted by the iron core toward other iron objects becomes very small.

A-7 If, therefore, in the electrical circuit bringing current to the winding around the iron core, some device were included by which the electrical continuity could be broken and established at will, and a pivoted iron member were associated properly with the electromagnet, the resulting electromagnetic device would respond in a particular way, each time the electrical circuit was opened or closed.

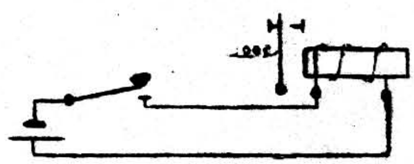

FIG.1.

A-8 Fig.1 shows such a device. A switch or key serves to open and close the electrical circuit through the encircling conductor or magnet winding. A piece of iron, which may be called an armature, is pivoted at one end and at the other is free to travel between two stops. A retracticle spring is attached to the armature in a way to oppose any tractive force exerted by the electromagnet.

A-9 When the key in the electrical circuit is open and no current is flowing through the winding of the electromagnet, the retractile spring holds the armature away from the electromagnet against its back-stop.

A-10 If the key is now depressed to close the electrical circuit and allow current to flow through the electromagnet winding, the electromagnet exerts its tractive force upon the

*Every piece of iron, once it has been magnetized, retains a small portion of that magnetism after the magnetizing force has been removed. This is called "Residual Magnetism" and may be disregarded in so far as it affects the purpose of these specifications.

armature and will pull the armature over to its front stop provided the tractive force is sufficient to overcome the tension exerted by the retractile spring.

A-11 By proportioning the relative forces exerted by the retractile spring and the electromagnet, therefore, the armature responds, each time the key opens or closes the electrical circuit.

SECTION B

The Electromagnet as the Basis of a Single Morse Circuit

B-1 The Electromagnet and its armature may be located at a station some distance from that at which the key is located, as shown in Fig. 2. The armature at Station B still responds to movements of the key at Station A, however, provided the electrical circuit remains unbroken at all other points.

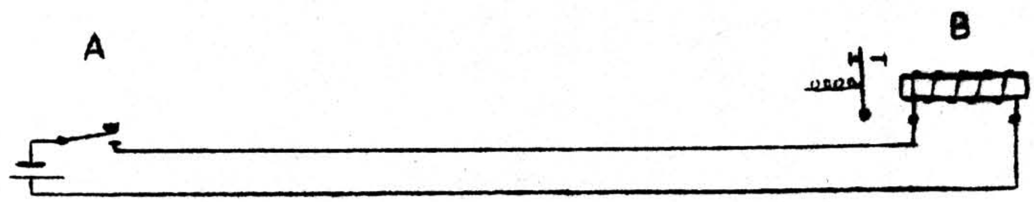

FIG.2.

B-2 By use of a letter code, therefore, in which each individual letter of the alphabet is represented by a particular combination of long and short pulses, the key in the above arrangement may be used for sending and the armature for receiving letters and words.

B-3 If the stops which limit the travel of the armature are so designed as to produce individual tones when struck by the armature, a listener is able to recognize the beginning of the periods during which the armature rests on its respective stops. With sufficient training, an operator is able to send the proper code combinations with considerable speed, and to recognize the various letters by the sequence of sounds emitted by the receiving instrument, or sounder as it is called.

B-4 In practice, it is found that the earth offers a very low resistance to the passage of current, and that it is unnecessary therefore to have two wires to join two remote stations.

B-5 If one of the wires joining stations A and B in Fig.2 is omitted and one side of the battery at A and one side of the magnet winding at B are connected to earth the resulting circuit will be as shown in Fig. 3.

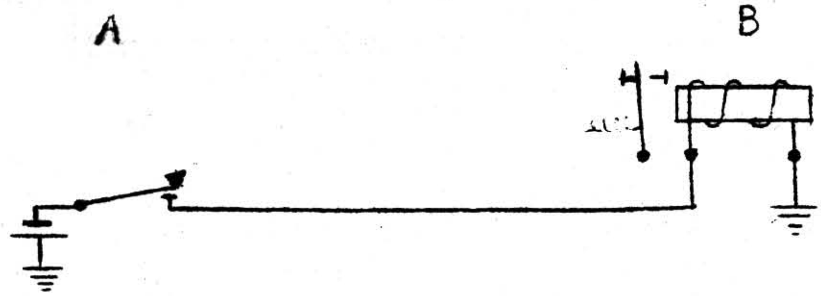

FIG.3.

The circuit shown in Fig. 3, operates exactly as before except that current sent from A to B returns through the earth instead of through a second wire.

B-6 With the arrangement shown in either Fig. 2 or Fig. 3, A may send signals to B and B may receive these signals but no provision is made allowing B to send and A to receive.

B-7 This may be accomplished by providing A with a sounder and B with a key connected as shown in Fig. 4.

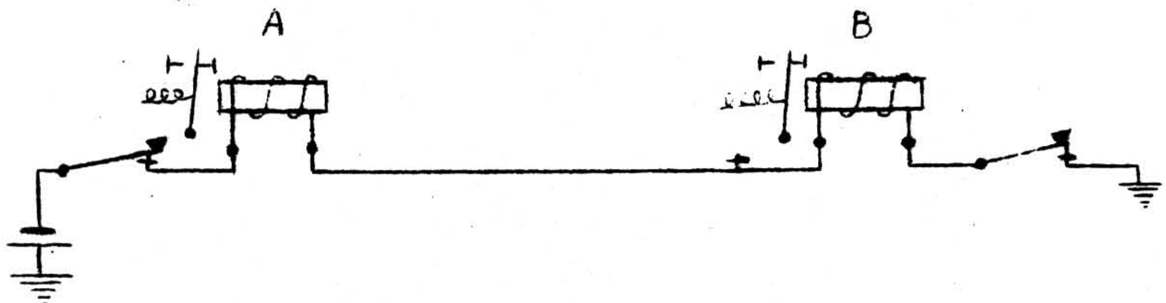

FIG.4.

With this arrangement, either A or B may send or receive.

B-8 Inasmuch as the two receiving sounders are in the same electrical circuit, they will both respond to signals from either station and a sending operator will hear his own signals.

B-9 In Fig. 4, both keys are shown in their closed position. When either A or B sends, the key at the opposite end must be kept closed to permit the flow of current to be completely controlled by the sending operator.

B-10 If it is desired to include a third station, intermediate to Stations A and B in the same circuit, it may be done as shown in Fig. 5.

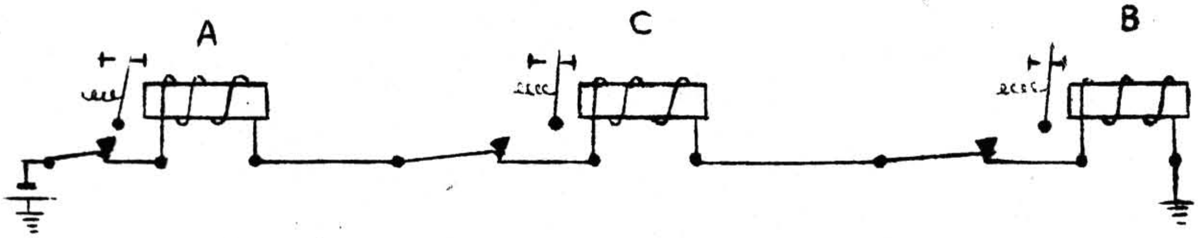

FIG. 5.

B-11 The same practice can be extended so that a single circuit may include a large number of stations.

B-12 The battery from which line current is drawn is shown in the above diagrams as being located at one end of the wire. The best results will be obtained if the operating battery is divided equally between all stations on the wire. This practice is seldom adopted however, because of the expense involved. Part of the advantage possible is gained by connecting grounded batteries so poled as to assist each other at each end of a circuit.

B-13 For this reason the longer and the more heavily loaded circuits are normally connected in this way. A single battery is used in the case of the shorter and less heavily loaded lines.

SECTION C

Ohm's Law Solution of the Single Morse Circuit

C-1 Fundamentally, the operation of a single Morse circuit depends upon Ohm's law which states that the current flowing in an electrical circuit is directly proportional to the voltage or potential applied, and inversely proportional to the ohmic resistance of the circuit.

C-2 The equation is:

$$I = \frac{E}{R}$$

in which,

I = Current expressed in amperes
E = Potential applied expressed in Volts
R = Ohmic resistance expressed in Ohms

C-3 The resistance of a Single Morse Circuit is equal to the resistance of the line wire between stations plus the sum of the resistances of the included receiving instruments. The resistance of the earth or ground return is so small that it may be neglected.

C-4 The resistances of the wires and cable conductors most commonly used in telegraph circuits are listed in the table below: See Appendix #1.

Kind and Size	Dia. in Mils	Ohms per Mile at 68° F.
Open Line Wires		
#8 A.W.G. Copper	128	3.48
9 " "	114	4.38
10 " "	102	5.49
9 " " Clad 30% Grade	114.4	14.39
9 A.W.G. Copper Clad 40% Grade	114.4	10.81
4 B.W.G. Iron	238	5.95
6 " "	203	8.19
8 " "	165	12.4
9 " "	148	15.4

Kind and Size	Dia. in Mils	Ohms per Mile at 68° F.
Cable Conductors		
#13 A.W.G. Copper	72	11.25
14 " "	64	14.51
16 " "	51	23
18 " "	40	36.4
19 " "	36	46
22 " "	25	92

C-5 The resistances of copper wires do not vary greatly with age from the above values. The resistances of iron wires, however, vary widely as corrosion reduces the effective cross section of the wire and may develop resistance in joints. A resistance of 20 ohms or more per mile for an 8 gauge iron wire which has been in service several years is not uncommon.

C-6 If the normal operating current required for the circuit is known, the correct potential to apply to the circuit may be calculated by use of the equation:

$$E = IR,$$

which is again Ohm's law expressed in a different form.

C-7 Unfortunately, however, the problem of Single Morse operation involves other factors than the obtaining of the correct amount of current through the windings of the receiving instruments under normal conditions.

C-8 The most important of these factors are leakage, inductance and capacity.

SECTION D

Line Insulation and Leakage Currents

D-1 The insulation resistance of an open line wire is the ohmic resistance between that line wire and the earth, which in the case of Single Morse Circuits, forms the return path for all current flowing through the line wire.

D-2 In the construction of open wire lines, care is taken to keep the insulation resistance of these wires high by fastening them to carefully designed glass "insulators" which are mounted high above the ground on suitable telegraph poles.

D-3 Little difficulty is experienced in maintaining high insulation resistance during clear dry weather. Insulation resistance should always be greater than 100 megohms per mile under such condition.

D-4 During rainy or foggy weather, however, the telegraph poles become wet and films of moisture are deposited on the glass insulators, forming high resistance paths for the flow of current between the line wire and ground. At such times the insulation falls far below normal, and insulation resistances of a fraction of a megohm are sometimes encountered.

D-5 Dust, soot and other impurities which continually lodge on the glass insulators and poles, aid the water in forming these leakage paths.

D-6 The cumulative effect of numerous leakage paths on a single Morse circuit causes changes of current flowing through the various receiving instruments. This change in current may be an increase or decrease depending upon the location of a particular instrument in the circuit.

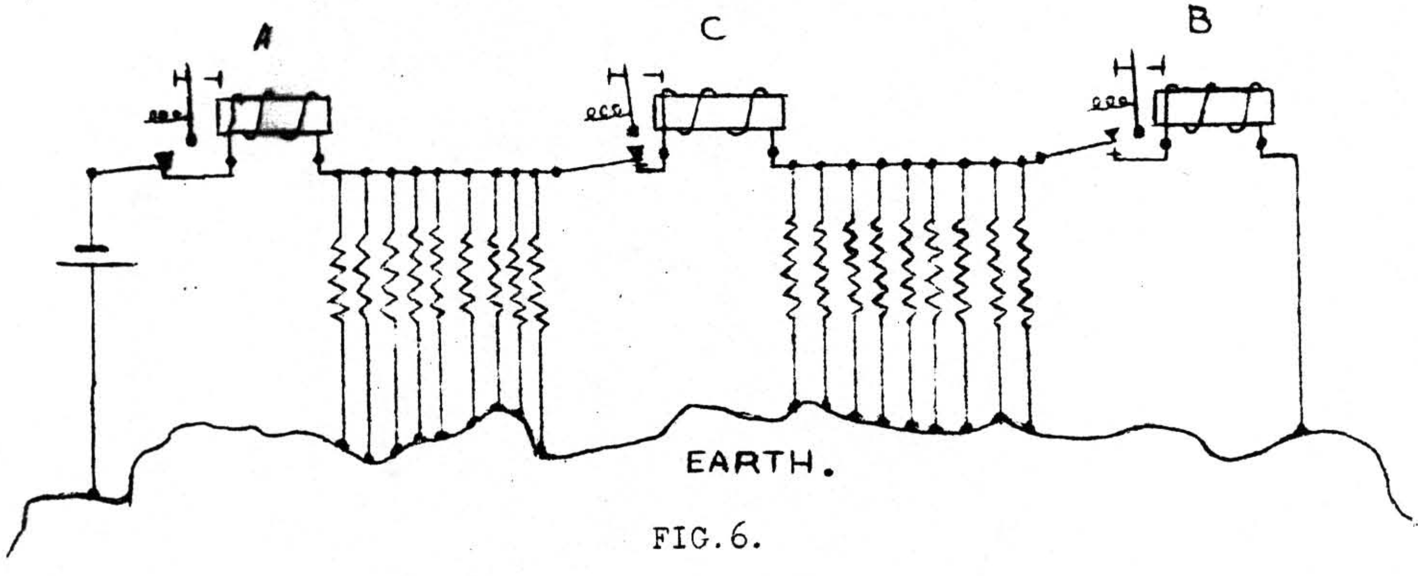

FIG. 6.

D-7 Fig. 6 shows a Single Morse Circuit with potential applied at only one end, Station A. Three stations are shown, one at each end and one in the center.

D-8 Numerous high resistance paths are shown connecting the line wire to earth. These represent leakage paths on an open wire which is exposed to rain or fog.

D-9 As the circuit is drawn, the sending key at Station B is open, and therefore no current is flowing to ground at B.

D-10 Current does flow through the numerous leakage paths, however, and all of this leakage current flows through the receiving instrument at A. A part of this current flows also through the receiving instrument at C.

D-11 When B closes his sending key, the current flowing through the receiving instrument at A is increased so as to include not only the leakage current but also that current which flows through the receiving instrument at B.

D-12 It follows, therefore, that when A is receiving from B under the above conditions, A must adjust his instrument so that the armature will not be pulled to the front stop by the leakage current which flows when the key at B is open but will be drawn over by the increase in current caused by the closing of the key at B.

D-13 Likewise when A receives from C, the same condition is true except that the leakage current flowing when the key at C is open will not be as great as it was in the above case.

D-14 When A receives from any other station on a leaky line such as is shown above, it is called marginal operation.

D-15 The operating margin at Station A is expressed in several different forms as follows:

Assume Station B is sending, then:

Current Margin at A equals the current at A when B's key is closed minus the current at A when B's key is open.

Margin ratio at A equals the current at A when B's key is closed divided by the current at A when B's key is open.

Percentage Margin at A equals the current margin at A expressed as a percentage of the current at A when B's key is closed.

D-16 In contrast to the marginal operation at A, reception at B is never of this character.

D-17 Current at B drops to zero when any key in the line is opened.

D-18 The closed circuit current at B, however, is less when leakage occurs than it is when there is no leakage.

D-19 This condition is caused by the leakage currents which cause an additional drop in potential in the line wire and intermediate receiving instruments, and leave a smaller effective voltage available for the operation of the receiving instrument at B.

D-20 Figures 7, 8, 9 and 10 represent graphically, current values at all points along a given Single Morse Circuit having potential or battery applied at only one end. In plotting these curves a line having a resistance of 9ω per mile conductor resistance, 0.4 megohms per mile insulation resistance, with 160 volts applied at A through a tap resistance of 300ω was assumed.

D-21 On each of these figures, the distance between "M" and "S" at each station represents the current margin under the given conditions, "M" being closed circuit current and "S" being open circuit current.

D-22 Fig. 7 represents a circuit with no leakage and the current margin is of the same value at all stations, regardless of which station is transmitting.

D-23 Fig. 8 represents the same circuit with leakage present and transmission is from Station B.

D-24 Fig. 9 represents the same circuit with leakage present and transmission is from Station A. The spacing current is zero at all points in the circuit.

D-25 Fig. 10 represents transmission from Station C on the same circuit with leakage present.

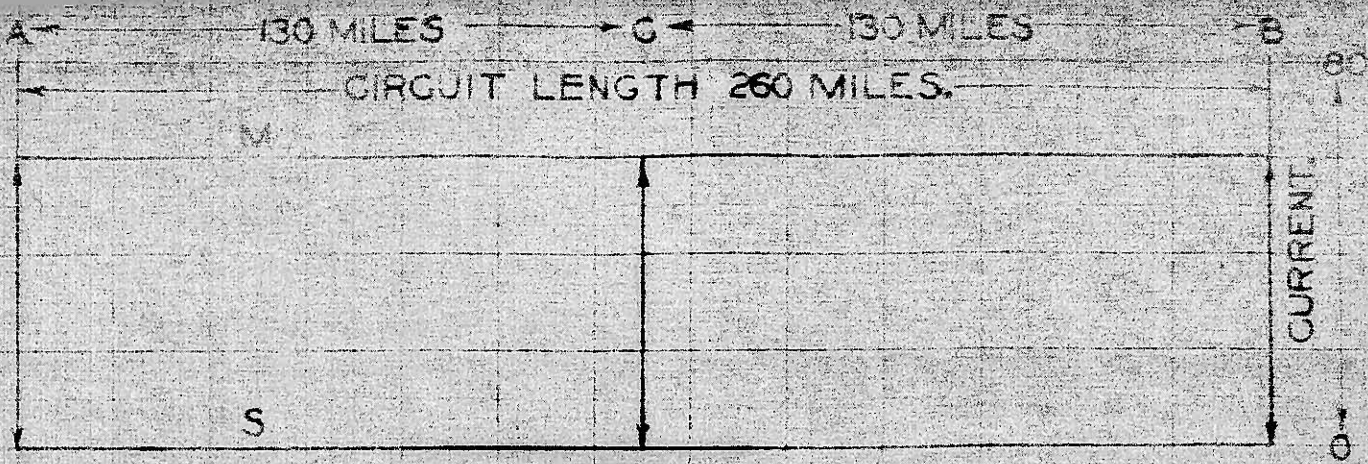

FIG. 7

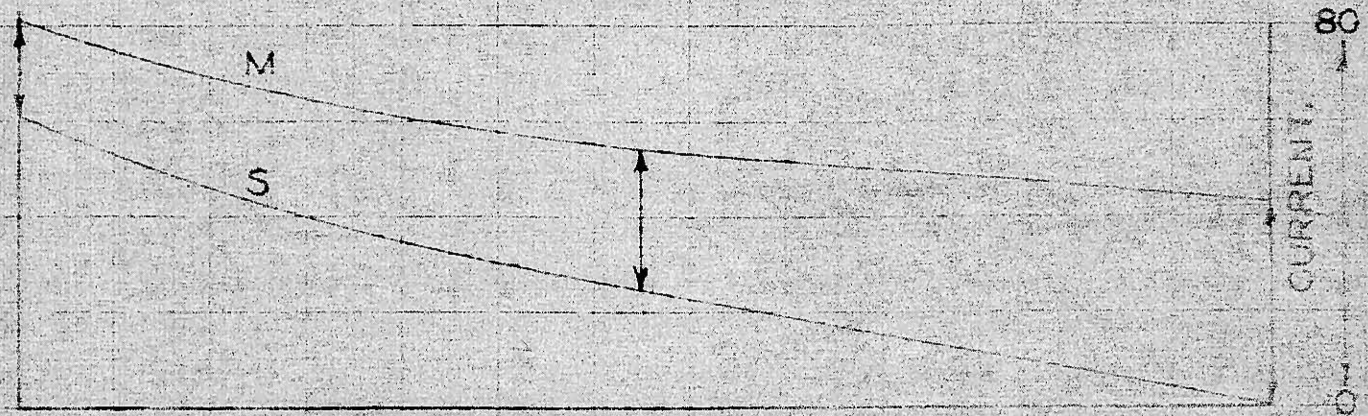

FIG. 8.

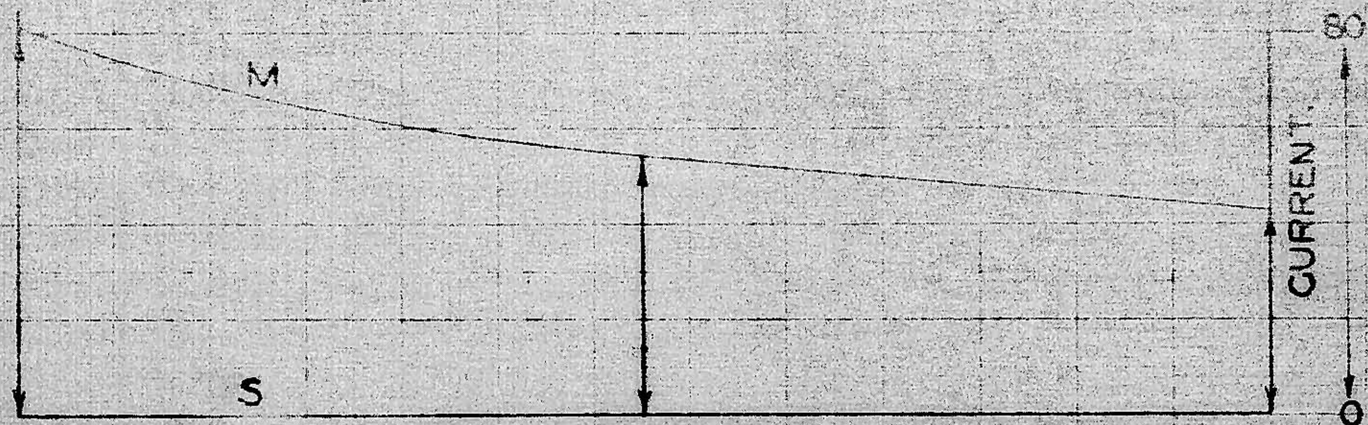

FIG. 9.

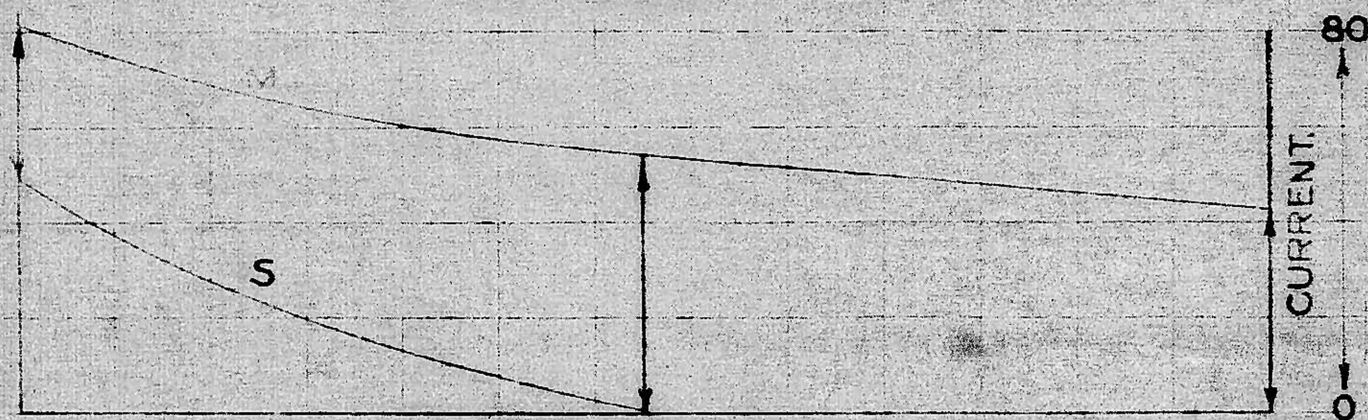

FIG. 10.

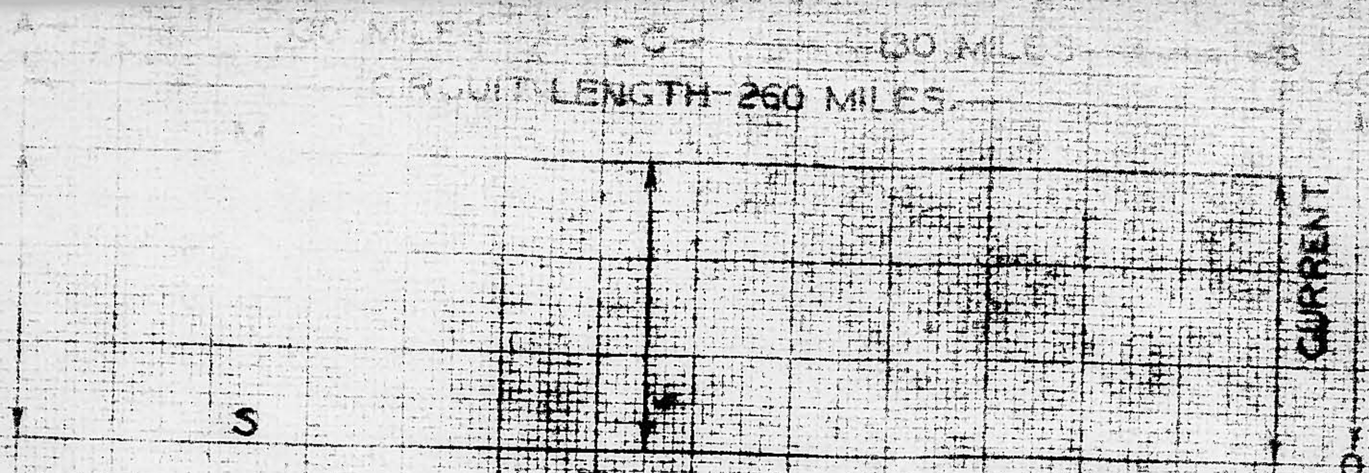

FIG. 11.

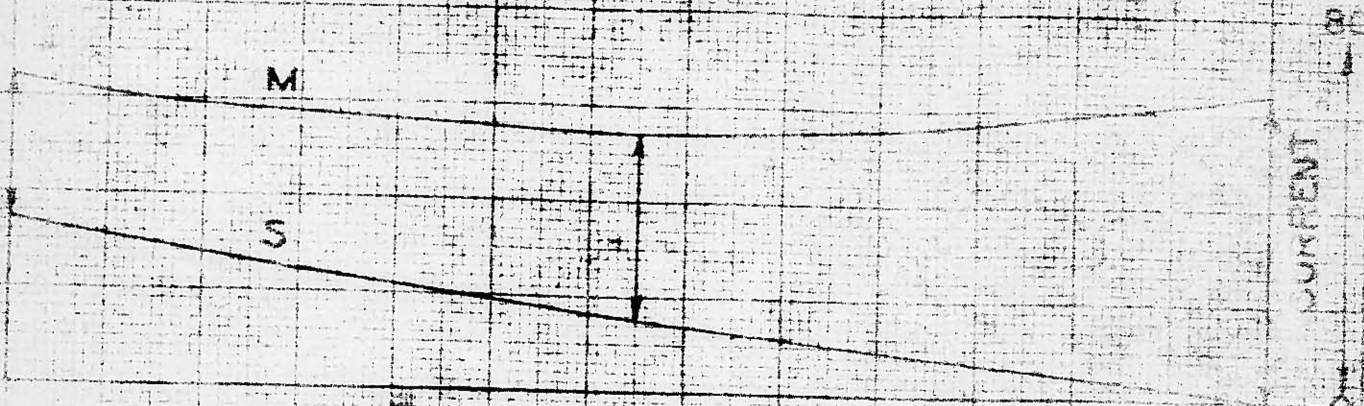

FIG. 12.

FIG. 13.

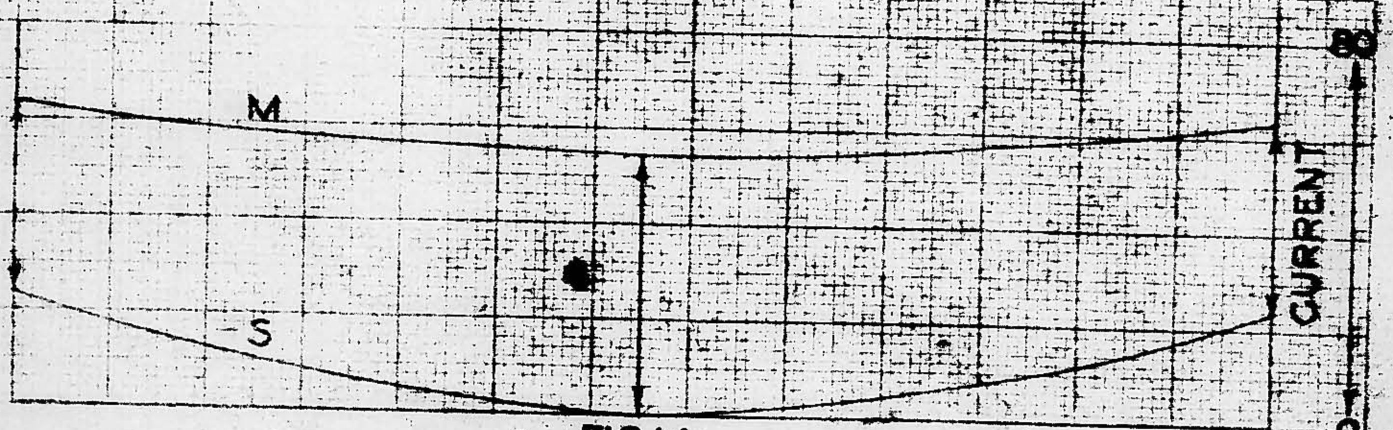

FIG. 14.

D-26 If the potential applied to this circuit at A were divided equally between A and B, the current curves would be as shown in Figures 11, 12, 13 and 14.

D-27 Fig. 11 shows the condition where no leakage exists and, as before, the current margin is of the same value at all stations regardless of which station is transmitting.

D-28 Fig. 12 shows current values for transmission from Station B. The current margin at A is larger here than that shown on Fig. 8. This is due to the reduced leakage current at A caused by the reduction in the applied potential.

D-29 Fig. 13 shows values of current for transmission from Station A and receiving currents at B are the same as those shown in Fig. 12 for reception at Station A.

D-30 Fig. 14 represents values for transmission from Station C. Receiving current margins are the same at A and B for this condition.

D-31 From the current graphs shown above, it follows that during wet weather, each station must adjust his receiving instrument to meet the current values existing in the circuit at that point.

D-32 When battery is applied at both terminals every station on the circuit receives marginal currents from transmission at any other station during wet weather.

D-33 The graphs show, however, that current margins and margin ratios on the circuit as a whole are much higher when battery is divided between the two terminals than when all of it is applied at one terminal.

D-34 Further improvement in current margin and margin ratio would be effected by introducing a single line repeater at Station C and connecting both sides of the repeater to ground instead of to battery.

D-35 With such an arrangement, the condition of no leakage would be represented by Fig. 11.

D-36 When leakage is present, the condition with all keys closed is the same as that shown by curve M on Figs. 12, 13 and 14.

D-37 When B opens his key, no current flows in the section from C to B and current in the section from A to C is the same as that shown in Fig. 14, Curve S from A to C.

D-38 When A opens his key, no current flows in the section from A to C and current in the section from C to B is the same as that shown in Fig. 14, curve S from C to B.

D-39 When C opens his key, the current in the circuit is the same as that represented by Curve S, Fig. 14.

D-40 Adjustment of instruments necessary to meet the various leakage conditions described above will be considered in later paragraphs.

SECTION E

Inductance in Single Morse Circuits

E-1 Inductance is that property of an electrical circuit which tends to resist any change in the value of current flowing. When inductance is present, therefore, currents rise and fall at comparatively slow rates when the circuit is closed and opened respectively.

E-2 Inductance in Single Morse Circuits is due almost entirely to the electromagnets of the receiving instruments, the line wire itself having an inductance of only about 0.003 henries per mile. The inductances of the various types of instruments used in single Morse circuits vary with the adjustment of the magnetic air-gap, increasing as the length of air-gap is reduced.

E-3 As current starts to flow through each turn of wire on an electromagnet, the magnetic flux surrounding the wire spreads outward and cuts across the adjacent turns setting up an induced potential which opposes the signalling potential applied to the circuit.

E-4 The result is that the rising current in the electromagnet windings is retarded in its tendency to attain immediately its full value as indicated by Ohm's law and, instead, it rises quite gradually.

E-5 After the current has attained its full or steady value, however, the inductance has no further effect until the current begins to decrease as it does when the circuit is opened at the end of a signal.

E-6 As this occurs, the magnetic flux around each turn of wire on the electromagnet falls back toward that wire and in so doing, cuts the adjacent turns in such a way as to develop an induced potential of the same direction or polarity as the applied operating potential.

E-7 The tendency of the induced potential is, therefore, to prolong the original current.

E-8 The retardation of the current rise is much more pronounced than the prolongation of current at the end of a signal.

E-9 The net result is a shortening of the received signal and this is one of the characteristics of all Single Morse Circuits.

E-10 The actual amount of the distorting effect is practically the same regardless of the length of signal transmitted.

E-11 For this reason and because of the fact that the Morse Code consists of both short and long pulses, it follows that the percentage distortion is much higher on short or dot pulses than it is on long or dash pulses.

SECTION F

Electrostatic Capacity of Line Wires

F-1 A condenser consists of two electrical conductors separated by an insulating medium or dielectric.

F-2 An open line wire separated by air from the earth and neighboring conductors is, in effect, therefore a condenser.

F-3 The electrostatic capacity of a condenser may be defined as the property it has of accumulating a charge of electricity on the surface of the two conductors or plates of which it is formed.

F-4 The unit of electrostatic capacity is the farad. This is very large, however, and capacity is usually expressed in microfarads. A microfarad is one millionth of a farad.

F-5 The electrostatic capacity existing between an open aerial wire and the earth is approximately 0.015 microfarad per mile of line.

F-6 The capacity between a cable conductor and the earth is ordinarily much higher than that above because of the proximity of the two and because of the nature of the dielectric.

F-7 This value varies approximately from 0.06 to 0.3 microfarad per mile, the lower value applying to paper cables and the higher value to rubber or gutta percha cables.

F-8 Cable conductors form only a small portion of the majority of Single Morse Circuits, however.

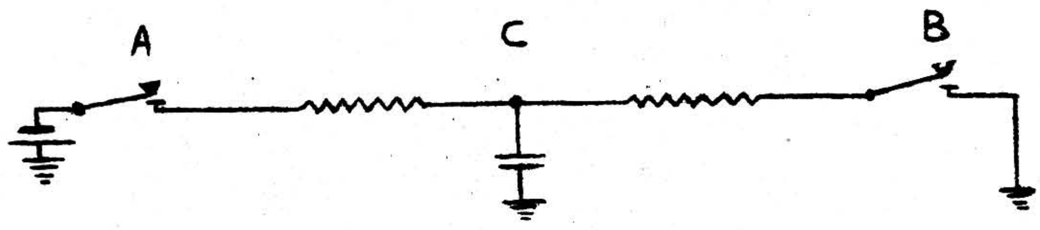

FIG.15.

F-9 Figure 15 shows a perfectly insulated circuit, with no instruments, in which the electrostatic capacity is concidered as concentrated at the center of the line.

F-10 Both keys are shown open.

F-11 If A closes his key while the circuit is open at B, a current will flow from A to C until the condenser is fully charged or in other words until the potential across its plates is equal to the applied potential at A.

F-12 The action of the condenser in this case is similar to a variable resistance which is at zero at the instant A's key is closed and which builds up to infinity as the flow of current continues.

F-13 This building up process is due to the fact that at the instant an electrostatic charge begins to accumulate across the condenser plates, a potential is created which opposes the applied potential at A.

F-14 As the charge increases the opposing potential also increases until the two potentials are equal and current ceases to flow.

F-15 Suppose, now that B's key is closed and A's key is again open.

F-16 When A closes his key, the same rush of current in the section A-C occurs but instead of dropping to zero, the current will drop only to the value which would be indicated by Ohm's law for the circuit A-B.

F-17 In the section of the line C-B beyond the condenser, however, there will be no initial rush of current because this section is shunted by the condenser, which, in the early stages of charging absorbs nearly all of the current drawn from the battery at A.

F-18 As the charge on the condenser gradually increases and the potential across its plates builds up, the current in the section C-B rises slowly until it reaches its steady or Ohm's law value.

F-19 If A's key is now opened, the potential existing across the plates of the condenser causes a current to flow through the only existing path, which is section C-B, thus prolonging the flow of current in this section after A's key has been opened.

F-20 It may be seen from the above that in so far as the reception of signals is concerned, the electrostatic capacity between a line wire and ground has the same kind of retarding and prolonging effect as inductance in the

F-21 It follows that since these two characteristic properties of every single Morse circuit act in the same direction on received signals, the resulting received signals are shorter in length than they would be under the influence of either inductance or electrostatic capacity alone.

F-22 The inductance in a Single Morse Circuit depends upon the number of offices and the type of receiving instruments used, and upon the adjustment of these instruments. It is therefore more or less under control and can be kept within reasonable limits.

F-23 The electrostatic capacity of a Single Morse Circuit, however, is almost completely fixed when the circuit is laid out and depends upon the length of open wire and cable. Because of the relatively high electrostatic capacity of cable, it introduces distortion much more rapidly than open line wire for a given increase in length.

SECTION G

Instrument Design

G-1 The transmitting instrument or key which is used for manually opening and closing a Single Morse Circuit, is not affected in any way by current conditions on the circuit and therefore requires no readjustments during changes in weather.

G-2 Because receiving instruments, however, depend directly upon the current flowing in their magnet windings, adjustments must be provided on these instruments when they are intended for operation under changing current conditions.

G-3 Receiving instruments connected in main line wires and consequently subjected to varying values of currents, therefore, have two adjustment features.

G-4 The magnetic air-gap between the magnet cores and the armature is made adjustable for the purpose of controlling the magnetic pull on the armature and the coil spring is adjustable for the purpose of controlling the pull exerted against the electromagnetic attraction.

OPERATION

SECTION H

Instruments Employed in Single Morse Operation

H-1 A single Morse set consists essentially of a Morse key and either a main line sounder or a Morse relay with a local sounder.

H-2 Legless Key 2-A. This key is used for manually opening and closing an electrical circuit for the purpose of transmitting Morse telegraph signals.

H-3 It is similar to Morse keys of older types in that it is a pivoted lever fitted with front and back stops and an insulated knob by means of which the lever is operated.

H-4 The lever, upon being manually depressed against the force of a compression spring closes the electrical circuit through two contacts which serve also as the front stop of the lever.

H-5 Because the key is normally in its upper or open position, it is equipped with an auxiliary switch which is used to close the circuit when the key is not in use.

H-6 When it is desired to use the key for sending, the auxiliary switch is moved to its open position to permit the manually operated lever to have control of the circuit.

H-7 The key is said to be in its marking or closed position when the lever is depressed closing the circuit and in its spacing or open position when it is held against the back stop by the force of the coiled spring.

H-8 Receiving Instruments. Each of the commonly used single Morse receiving instruments consists essentially of an electromagnet and a pivoted armature which a coiled spring tends to hold away from the electromagnet.

H-9 The electromagnet is in the form of a letter "U" with the magnet winding divided equally on the two parallel arms.

H-10 The armature is located across the open end of the "U" shaped electromagnet, forming a complete magnetic path of iron, with the exception of two small air-gaps between the armature and the two ends of the electromagnet.

H-11 The length of these two air-gaps controls to a certain extent the number of magnetic lines of force passing through the armature and consequently the tractive force exerted upon the armature by the electromagnet.

H-12 Every Single Morse receiving instrument is equipped also with front and back stops which limit the travel of the armature.

H-13 The instrument is said to be in a marking position when the armature is drawn to the front stop by the force of the electromagnet and in a spacing position when the armature is drawn to the back stop by the coiled spring.

H-14 <u>Main Line Sounder 15-B.</u> This instrument, as its name implies, is intended for use on main line wires and has been designed, therefore, to permit quick and easy adjustments of its magnetic air-gap and spacing spring.

H-15 A long brass or aluminum lever, fastened rigidly to the armature strikes the front and back stops and thus produces the sounds which determine the beginning of each marking and spacing interval.

H-16 The magnetic air-gap is adjusted by a Cam Arrangement which moves the electromagnet away from or toward the armature.

H-17 The coil spring is a compression spring and is adjustable by means of a thumb screw.

H-18 Main Line Sounders 15-AC and 15-C are intended for the same kind of service as Main Line Sounder 15-B and the three therefore are interchangeable.

H-19 Main Line Sounders 15-B, 15-AC and 15-C differ only in the method of adjusting the magnetic air gap and coiled spring.

H-20 In each of the latter two instruments the electromagnet is stationary and the magnetic air-gap is adjusted by changing the height of the arch which supports the armature trunnions and pivots.

H-21 The spacing spring of this instrument is a tensile spring and the force it exerts upon the armature is increased therefore by elongating the spring rather than by compressing it.

H-22 Morse Relay 4-D. This instrument, like the main line sounder is intended for main line operation and therefore it is equipped with the equivalent adjustments of spring and air-gap.

H-23 Each adjustment is obtained by means of a thumb screw the one elongating a tensile spring and the other moving the electromagnet toward or away from the armature.

H-24 Because the Morse relay is not intended to produce a large volume of sound, its armature is of light weight and has no attached lever. The armature moves in a horizontal direction and in so doing opens and closes a second electrical circuit through the magnet winding of a local sounder.

H-25 Because of the lighter armature of the Morse relay, this instrument is somewhat more sensitive to current changes in its magnet winding than is the main line sounder.

H-26 Morse Relay 4-C differs from Morse relay 4-D only in the mechanism used to move the electromagnet for variation of the magnetic air gap and the two types, therefore, are interchangeable.

H-27 The dimensions and magnet windings of the 4-B type Morse relay are somewhat different than those of the other two types. This difference is not great, however, and the 4-B type, therefore, should be considered interchangeable with the other two types.

H-28 Local Sounder 1-A and 1-B. In contrast to the purpose of the main line Sounder and Morse relay both of which are designed to operate on circuits connecting two or more remote points, the local sounder is intended to operate in a circuit which is entirely within a particular office.

H-29 A local sounder is somewhat smaller than a main line sounder and is of the same general construction except that the front and back stops must be moved to obtain adjustment of the magnetic air gap.

H-30 The magnet windings of the various single morse receiving instruments are wound to several values of ohmic resistance depending upon the type of circuit for which they are intended to operate.

H-31 **The** Ohmic resistances of the Single Morse receiving **instruments** and the current upon which they are normally intended to operate are as follows:

Instrument	Type	Resistance Ohms	Normal Operating Current Milliamperes
Morse Relay	4-B	35	60
" "	4-B	150	40
" "	4-C and 4-D	25	60
" "	" " "	100	40
Main Line Sounder	15-AC	35	70
" " "	15-AC	150	40
" " "	15-B	30	70
" " "	15-B	120	40
" " "	15-C	25	70
" " "	15-C	100	40
Local Sounder	1-A	4	*
" "	1-B (coils in series)	400	30
" "	1-B (coils in multiple)	100	60

*These sounders are used only in local circuits supplied by primary batteries, the current outputs of which vary with age and condition. Ordinarily, it will be found that one cell of gravity battery is sufficient for satisfactory operation. <u>In no case shall more than two cells be used.</u>

SECTION I

Adjustments of Instruments

I-1 The Morse key adjustments of lever travel and spring tension should be made ordinarily to meet the individual tastes of the operator.

I-2 To adjust the trunnions, however, the two lock nuts should be loosened and the trunnion screws turned simultaneously until the contacts under the key lever are in allignment. The trunnion screws should then be adjusted so that the lever operates freely but has no appreciable side play, and the lock nuts tightened.

I-3 On main line sounders and Morse relays the most satisfactory performance can generally be obtained by use of a weak spring adjustment.

I-4 The adjustment of the magnetic air-gap should always be used for compensation of current changes due to leakage.

I-5 To obtain this adjustment it is necessary to have some other station, preferably the most distant one, send on his key, during which the magnetic air-gap should be adjusted to the point where the incoming signals sound the clearest.

I-6 If leakage currents are high and this margin of adjustment is consequently small, the spacing spring may be used profitably for a refining adjustment only.

I-7 During wet weather, the greatest variation of leakage currents is at offices which supply the operating battery.

I-8 Such offices, as well as intermediate offices nearby, should, therefore, watch their adjustments carefully during weather changes.

I-9 Intermediate offices which are expected to work in both directions should make their adjustments by listening to alternate sendings from both terminals.

I-10 Armature travel measured at the contacts on a Morse relay should be approximately 0.005 inch, or twice the thickness of a telegraph blank.

I-11 Lever travel on a main line or local sounder should ordinarily be from 0.015 to 0.020 inch when measured between the lever and the back stop.

I-12 The magnetic air-gap on a local sounder should be adjusted to approximately 0.005 inch, which is the approximate thickness of two telegraph blanks, when the lever is in it's down or marking position and the spring should be adjusted to permit the most distinct repetition of signals.

SECTION J

Layout of Single Morse Circuits

J-1 When a receiving operator adjusts his main line receiving instrument for clearest reception, he automatically compensates for the shortening of received signals caused by the presence of inductance and electrostatic capacity.

J-2 The electrostatic capacity of a line wire never changes appreciably and it is not high enough usually to seriously shorten received signals.

J-3 The inductance in a Single Morse Circuit, however, depends upon the number and kind of receiving instruments included in the circuit.

J-4 When high resistance receiving instruments are used and the number of stations is large, the inductance in the circuit may be great enough to cause unsatisfactory operation of the circuit, especially in wet weather.

J-5 This condition may manifest itself in several ways, all of which are caused directly by the slow rise and fall of current in the circuit.

J-6 A general sluggishness occurs which is most apparent to an operator who is listening to his own sending. An appreciable space of time elapses between the time he closes his key and the time when his sounder operates.

J-7 Dot signals become short or light while dash signals become long or heavy. This is caused by the fact that the current rises so slowly, dot signals never reach a full current value. The magnetic gap of the receiving instrument when adjusted to compensate for these short dots, puts a marking bias on the dashes. If readjustment is made to remove the bias from the dashes, the dots appear light or drop out entirely.

J-8 The slow current rise is especially noticeable in the case of the main line sounder whose lever, under these conditions, is drawn toward the electromagnet so slowly that there is an apparent decrease in the volume of sound produced.

J-9 The introduction of non-inductive resistance and the increasing of voltages at terminals to improve operation on such circuits is not recommended for the majority of cases.

J-10 If the circuit is located in territory where rains and fogs are few and light, some improvement will undoubtedly be effected in the operation of such circuits by the insertion of non-inductive resistance.

J-11 In wet weather, however, such additional resistance at terminals cuts down the normal current margin on that circuit, and is liable therefore to make the circuit entirely unworkable.

J-12 A more satisfactory procedure on such circuits is the introduction of a single line repeater at some office near the middle of the circuit where testing and regulating attention is available.

J-13 If the circuit includes no office suitable for the location of a repeater, however, considerable gain may be expected by the substitution of low resistance for high resistance instruments over the entire circuit.

J-14 It must be remembered, of course, that such substitution can be made only if the resistance of the line wire plus that of the instruments to be used is low enough to permit obtaining with available potentials the higher current required for the low resistance instruments.

J-15 On some Single Morse Circuits, the intermediate offices are more or less bunched on a portion of that circuit and the remainder has no or only a few offices.

J-16 On such circuits, especially if there is some cable in the long stretch with no offices, the offices at the limits of the open stretch are very likely to get a scratchy effect on their receiving instruments.

J-17 This effect may occur when an operator at one of the ends of the clear line is listening to his own sending or when he is receiving from another station.

J-18 In either case the effect is due to a combination of inductance and electrostatic capacity existing in such relation to each other that one or more current oscillations are caused to flow over a section of the circuit.

J-19 This oscillation may occur at the beginning of either a marking or a spacing signal depending upon the conditions existing.

J-20 Such cases of current oscillation can ordinarily be eliminated by the insertion of non-inductive resistance at the office experiencing the trouble. (Usually a terminal).

J-21 The added resistance should be the lowest value which effectively eliminates the trouble.

J-22 If a circuit of this nature is encountered and the trouble cannot be eliminated by the above method, it should be referred through regular channels to the Vice President in Charge of Engineering.

SECTION K

Operating Limits for Single Morse Circuits

K-1 The following four tables of operating limits are included in these specifications as a guide in the laying out of new circuits and as a possible aid in the improvement of existing circuits which are not considered to be performing satisfactorily.

K-2 In determining the limiting values shown in these tables, consideration has been given to Operating Current, Margin Ratio, Inductance and Actual Performance.

K-3 Any circuit within the limits shown, therefore, should be expected to operate satisfactorily unless there are other limiting factors peculiar to the locality.

K-4 No recommendation is made in the tables for circuits which have terminal stations only. In general it may be assumed that operation even between terminals is not recommended for those cases where no intermediate stations are shown.

K-5 Because the limiting values shown in the tables were determined by the lowest value of insulation resistance which is generally found on open line wires and because there are sections of the country that seldom or never experience insulation resistances as low as this value, it is quite probable that there are some circuits now operating satisfactorily which the tables indicate as unsatisfactory.

K-6 The tables should not be taken as authority, therefore, for changing any existing circuits on which no operating difficulties are being experienced.

Maximum Number of Intermediate Offices Recommended for Single Morse Circuits

Length of Circuit Miles	Average Wire Resistance per Mile Ohms	120 Ohm Main Line Sounders* Voltage Available at Terminals					
		120 Ground	160 Ground	240 Ground	120 120	120 160	160 160
	4	12	12	12	20	20	20
	8	11	11	11	18	18	18
100	12	10	10	10	15	15	15
	16	7	9	9	13	13	13
	20	3	8	8	11	11	11
	4	10	10	10	17	17	17
	8	8	8	8	14	14	14
140	12	6	6	6	11	11	11
	16	-	4	4	8	8	8
	20	-	-	-	6	6	6
	4	-	-	-	13	13	13
	8	-	-	-	10	10	10
180	12	-	-	-	7	7	7
	16	-	-	-	5	5	5
	20	-	-	-	4	4	4

*The use of 120 ohm Main Line Sounders is not recommended for circuits over 200 miles in length. If battery is available at only one terminal, 150 miles should be the maximum length.

Maximum Number of Intermediate Offices
Recommended for Single Morse Circuits

Length of Circuit (Miles)	Average Wire Resistance per Mile (Ohms)	30 Ohm Main Line Sounders — Voltage Available at Terminals: 120 GND.	160 GND.	240 GND.	120 / 120	120 / 160	160 / 160
100	4	24	40	40	40	40	40
	8	11	30	40	40	40	40
	12	6	16	40	40	40	40
	16	-	3	40	40	40	40
	20	-	-	28	28	37	40
140	4	19	40	40	40	40	40
	8	-	19	40	40	40	40
	12	-	-	29	29	40	40
	16	-	-	10	10	29	40
	20	-	-	-	-	10	29
180	4	13	32	40	40	40	40
	8	-	8	18	37	40	40
	12	-	-	-	13	32	40
	16	-	-	-	-	8	26
	20	-	-	-	-	-	2
220	4	8	22	22	40	40	40
	8	-	-	-	26	40	40
	12	-	-	-	-	16	34
	16	-	-	-	-	-	5
	20	-	-	-	-	-	-
260	4	-	2	2	35	35	35
	8	-	-	-	15	26	26
	12	-	-	-	-	-	-
	16	-	-	-	-	-	-
	20	-	-	-	-	-	-
300	4	-	-	-	28	28	28
	8	-	-	-	-	-	-
	12	-	-	-	-	-	-
	16	-	-	-	-	-	-
	20	-	-	-	-	-	-

Maximum Number of Intermediate Offices Recommended for Single Morse Circuits

Length of Circuit Miles	Average Wire Resistance per Mile Ohms	100 Ohm Morse Relays — Voltage Available at Terminals: 120 / GND.	160 / GND.	240 / GND.	120 / 120	120 / 160	160 / 160
100	4	21	30	40	40	40	40
	8	17	26	40	40	40	40
	12	13	22	40	40	40	40
	16	9	18	38	38	40	40
	20	5	14	34	34	40	40
140	4	19	28	40	40	40	40
	8	13	23	35	40	40	40
	12	8	17	29	34	40	40
	16	3	12	24	29	39	40
	20	-	6	18	23	34	40
180	4	17	27	28	40	40	40
	8	10	20	21	37	40	40
	12	3	12	14	29	40	40
	16	-	5	7	22	33	40
	20	-	-	-	15	26	35
220	4	16	18	18	40	40	40
	8	7	9	9	33	40	40
	12	-	-	-	25	35	40
	16	-	-	-	16	26	36
	20	-	-	-	7	20	27
260	4	10	10	10	40	40	40
	8	-	-	-	30	40	40
	12	-	-	-	20	30	32
	16	-	-	-	9	21	22
	20	-	-	-	-	10	12
300	4	5	5	5	39	40	40
	8	-	-	-	27	28	28
	12	-	-	-	15	17	17
	16	-	-	-	-	4	4
	20	-	-	-	-	-	-

Maximum Number of Intermediate Offices Recommended for Single Morse Circuits

Length of Circuit	Average Wire Resistance per Mile	25 Ohm Morse Relays					
		Voltage Available at Terminals					
		120	160	240	120	120	160
Miles	Ohms	GND.	GND.	GND.	120	160	160
100	4	40	40	40	40	40	40
	8	24	40	40	40	40	40
	12	8	35	40	40	40	40
	16	-	19	40	40	40	40
	20	-	3	40	40	40	40
140	4	34	40	40	40	40	40
	8	12	38	40	40	40	40
	12	-	15	40	40	40	40
	16	-	-	40	40	40	40
	20	-	-	24	24	39	40
180	4	27	40	40	40	40	40
	8	-	25	40	40	40	40
	12	-	-	40	40	40	40
	16	-	-	21	21	36	40
	20	-	-	-	-	7	33
220	4	21	40	40	40	40	40
	8	-	12	36	40	40	40
	12	-	-	-	19	40	40
	16	-	-	-	-	10	36
	20	-	-	-	-	-	2
260	4	15	40	40	40	40	40
	8	-	-	-	40	40	40
	12	-	-	-	-	26	40
	16	-	-	-	-	-	11
	20	-	-	-	-	-	-
300	4	8	18	18	40		40
	8	-	-	-	28		40
	12	-	-	-	-		33
	16	-	-	-	-	-	-
	20	-	-	-	-	-	-

K-7 The values shown in the tables represent intermediate offices, exclusive of terminals.

K-8 Terminals are assumed to use a Morse Set on all circuits and terminals at which battery is applied are assumed to have battery tap resistances included in the circuit. The apparatus at the terminal stations is not included in the tables. Due allowance should be made if extra instruments connect to the circuit at terminal stations.

K-9 The maximum number of intermediate offices shown in the tables is 40.

K-10 In the majority of cases this should be interpreted as meaning "40 or more" and does not mean, therefore, that all circuits having more than 40 intermediate offices are unworkable.

K-11 All existing circuits having more than 40 intermediate offices should remain unchanged if operation is satisfactory.

K-12 When operation on circuits having more than 40 intermediate offices is not satisfactory, consideration should be given to the use of single line repeaters.

K-13 If this procedure is not considered practicable in the case of a particular circuit or if the repeater after installation does not affect an improvement in operation, the circuit should be referred through regular channels to the Vice President in Charge of Engineering.

K-14 Single line repeaters should be installed at offices where testing and regulating attention is available and according to Specifications for the installation and operation of Front Contact Shunt Locking Repeaters and Half Repeaters.

K-15 The potential to be applied to a Single Morse Circuit depends upon the ohmic resistance of the circuit and the voltage available at the terminals.

K-15 In general, this value should be the lowest potential that furnishes sufficient operating current for the type of receiving instrument used.

K-17 For the purpose of maintaining higher current margin and margin ratio, the battery supply should be divided between the two terminals where practicable. In the case of very short circuits, however, this consideration is not important.

K-18 The use of 240 volts is not recommended.

K-19 It is included in the tables of operating limits for emergency use only when the entire current supply must be furnished from one terminal and 160 volts is too low to furnish sufficient current.

K-20 Although the high resistance instruments are preferable to the low resistance instruments from a standpoint of current economy, the latter are more satisfactory from an operating standpoint, especially when a circuit includes any considerable number of offices.

K-21 In laying out new circuits, therefore, preference should be given to low resistance instruments for main line use.

K-22 On existing circuits, however, the change from high to low resistance instruments in the main line is not justified unless a circuit is considered unsatisfactory under present conditions.

K-23 Because main line sounders require no local battery, they should be used in preference to Morse relays and local sounders where practicable.

K-24 Where local sounders are required and a source of direct current supply is available, the 400 ohm local sounders 1-B should be used.

K-25 If no current supply is available, gravity battery should be installed to operate 4 ohm local sounders 1-A.

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Specifications
2298-A

Appendix No. 1.
October 10, 1928.

SPECIFICATIONS FOR

THE THEORY AND OPERATION OF

SINGLE MORSE CIRCUITS

OMIT: Paragraph C-4
ADD: Paragraph C-4 to read as follows:

The resistance of the wires and cable conductors most commonly used in telegraph circuits are listed in the table below.

Kind and Size	Dia. in Mils	*Normal Ohms per Mile at 68° F.
Open Line Wire		
Copper		
#8 B.W.G.	165	2.09
8 A.W.G.	128	3.47
9 A.W.G.	114	4.38
10 A.W.G.	102	5.48
Copper Covered Steel (40% Grade)		
8 A.W.G.	128	8.30
6 A.W.G.	162	5.21
Hard Drawn Bronze 80% Conductivity		
8 A.W.G.	128	4.15
Iron (5300 Mile-Ohm)		
#4 B.W.G.	238	6.73
6 B.W.G.	203	9.25
8 B.W.G.	165	14.00
9 B.W.G.	148	17.40

Kind and Size	Dia. in Mils	*Normal Ohms per Mile at 68° F.
Cable Conductors		
Copper		
#13 A.W.G.	72	11.25
14 "	64	14.51
16 "	51	23.00
18 "	40	36.40
19 "	36	46.00
22 "	25	92.00

*Based on the normal value of wire obtained under our wire specifications. Resistance values of the iron wire will probably differ at times from those given in the table due to the deterioration of the iron wire.

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It is suggested that the changed portions of these specifications be marked "See Appendix No.1".