TELEGRAPH TRANSMISSION

BIAS

A telegraph circuit has only two conditions; one, marking or closed, and the other, spacing or open.

The change itself, from one condition to the other, is called a TRANSITION.

The change from the spacing to the marking condition is more completely defined as a "space to mark transition", and the change from the marking to the spacing condition as a "mark to space transition". These are abbreviated "S-M transition" and "M-S transition".

At the sending end of a manual telegraph circuit, the closing of the key is a S-M transition and the opening of the key is a M-S transition. At the receiving end of the circuit the close of the sounder armature is a S-M transition and the release of the sounder armature is a M-S transition.

On every telegraph circuit there will be a delay between the closing of the key at the sending end and the closing of the sounder armature at the receiving end. There will be another delay between the opening of the key at the sending end and the release of the sounder armature at the receiving end. (The reasons for the delays will be discussed later). In other words, in considering transmission over a circuit, there will be a delay to the S-M transition and to the M-S transition. These two delays are called a "space to mark transition delay" and a "mark to space transition delay" and are abbreviated S-MTD and M-STD, respectively.

The magnitude of these delays on our present telegraph circuits ranges from a fraction of a millisecond to several milliseconds. Disregarding characteristic and fortuitous distortion effects for the present, the S-MTD and M-STD are determined entirely by the characteristics of the circuit, and, though the two delays may not be equal, each will always be a constant for any given circuit, under any given set of adjustments.

Transmission of intelligence over a telegraph circuit is accomplished by sending various combinations and various lengths of marks and spaces. The transmission is considered perfect if the received marks and spaces are exactly the same length as the sent marks and spaces.

Each mark, regardless of length, must start with a S-M transition and end with a M-S transition. The S-MTD cuts off the beginning of each mark and the M-STD adds to the end of each mark. If the two delays are equal the length of each mark will be unchanged by transmission over the circuit.

Each space, regardless of length, starts with a M-S transition and ends with a S-M transition. The M-STD cuts off the beginning of each space (it added to the end of each mark) and the S-MTD adds to the end of each space (it cut off the beginning of each mark). Each delay thus has the opposite effect on a space that it has on a mark. If the two delays are equal, the length of each space will be unchanged by transmission over the circuit.

The requirement for perfect transmission then is that S-MTD = M-STD. This is illustrated in Figure II.

If the two delays are not equal, if for instance, the M-STD is greater than the S-MTD, all marks will be lengthened, and all spaces will be shortened. This is a common condition on circuits and is called a "marking bias" since the circuit favors or lengthens the marks. If the S-MTD is greater than the M-STD, all spaces will be lengthened and all marks shortened. This is another common condition and is called a "spacing bias".

Since the lengths of the marks and spaces are indicated in milliseconds (MS), the amount that is added to or subtracted from each mark or space due to a bias condition is also indicated in milliseconds and is equal to the difference between the S-MTD and the M-STD. This amount is referred to as the "millisecond bias" of a circuit, and is a constant for any given circuit.

A marking bias is also called a positive bias, and a spacing bias a negative bias. If the difference between the S-MTD and the M-STD of a circuit is always taken as the M-STD minus the S-MTD, the sign of the result will automatically be the sign of the bias. Thus the formula for millisecond bias is: M-STD - S-MTD = MS bias. As an example; if the M-STD of a circuit is 6 MS, and the S-MTD is 3 MS, the millisecond bias is +3, indicating that every mark, regardless of length, will be increased 3 MS, and every space, regardless of length, will be decreased 3 MS. If the M-STD is 1 MS, and the S-MTD is 4 MS, the millisecond bias is -3, and the effect on marks and spaces would be opposite of that in the first example. MS Bias is illustrated in Figure I. It is desired to emphasize that a "millisecond" bias condition is determined entirely by the equipment, line facilities, overall length, etc. of a telegraph circuit and will be a constant for any given circuit, regardless of the speed or kind of signals that are transmitted over it.

The effect on transmission, however, of a given millisecond bias condition, does vary with the length of marks and spaces transmitted, though the millisecond bias condition itself is constant. As an example of this, let us consider a manual telegraph circuit where the dashes (long marks) are normally about three times the length of a dot (short mark). The lengths of the dots and dashes used in manual telegraph become less as the speed of transmission becomes greater. Assume first a slow speed of transmission where the dots are 30 MS long and the dashes are 90 MS long. A millisecond bias condition of +10 will make the dots 40 MS long and the dashes 100 MS long. The signals will still be quite readable since the three to one ratio has been changed very little. Next assume a much faster speed where the dots are 5 MS long and the dashes 15 MS long. The same +10 MS bias will make these dots 15 MS long and the dashes 25 MS long. Greater difficulty will be experienced in reading these signals since the dashes now are not even twice the length of the dots.

In manual telegraph transmission, while spaces are used to separate the dots and dashes, transmission is usually thought of in terms of the short and long marks. In discussing the transmission of teletypewriter signals, however, spaces are considered equally with marks.

Teletypewriter signals are made up of "unit" marks and spaces of always a definite length for a given speed of transmission. In addition there is one special mark, 1.4 times a unit mark in length, and various combinations of these such as a mark or space 2, 3, 4, 5, or 6 units long, or a mark 2.4, 3.4, 4.4, 5.4, or 6.4 units long.

One unit mark or space is considered as 100 per cent in length. The "margin" of a teletypewriter is expressed in per cent on this same basis. Any addition or subtraction to a unit mark or space will reduce the margin an amount that is measured in "per cent" by the teletypewriter. Since teletypewriters indicate bias on a percentage basis, it is desirable to convert millisecond bias to per cent bias in order that its effect on the transmission of teletype signals may be determined. If the speed of transmission is known, the length of the unit mark or space is known. "Per cent" bias is then calculated by expressing millisecond bias as a percentage of the unit mark or space. Thus, if the millisecond bias is +4, the per cent bias this would be to 60 speed teletypewriter signals (unit mark or space 22 MS long) is $\frac{+4}{22}$ or +18%.

The effect of a given millisecond bias depends on the length of the unit marks and spaces in teletypewriter transmission, as it did in manual telegraph. On forty speed signals (unit mark or space 33 MS long) the per cent bias caused by a +4 MS bias would be $\frac{+4}{33}$ or + 12%, as compared with the +18% it causes to 60 speed signals.

The per cent bias due to millisecond bias, is inversely proportional to the length of the unit mark or space.

The length of the unit mark or space is inversely proportional to the speed of transmission.

Per cent bias is, accordingly, directly proportional to the speed of transmission. In other words, the higher the speed of transmission the more a given millisecond bias on the circuit will affect the signals, and the lower the speed of transmission the less a given millisecond bias will affect the signals.

Thus in the two problems above, from the fact that a circuit caused +18% bias to 60 speed signals, the per cent bias the circuit will cause to 40 speed signals can be determined directly from the ratio of the speeds, i.e., $\frac{x}{18\%} = \frac{40}{60}$ or x = +12%.

Both millisecond and per cent bias add algebraically. That is, if the bias in each of several sections of a circuit is known, the overall bias can be determined simply by adding the section biases, considering the sign of each. When characteristic distortion is present in one or more sections this is not strictly true. This particular case will be considered later. On circuits where characteristic distortion is not present, this rule is as accurate as it is simple and transmission problems should not be complicated by a failure to use it.

An example is given below of a three section circuit on which the sum of the individual biases is zero, which indicates that transmission on the overall circuit is perfect.

Section	M-STD	S-MTD	MS Bias	% Bias (60 Speed)
1	6	2	+4	+18%
2	2	5	-3	-13%
3	3	4	-1	- 5%
Overall	11	11	0	0

A summary of this discussion is as follows:

1. Millisecond bias is the actual lengthening or shortening in milliseconds a circuit will cause to any mark or space transmitted over it. It is due entirely to a difference between the M-S transition delay and the S-M transition delay existing on the circuit. It is determined by the characteristics of the circuit alone and is independent of the code, or speed of signalling used. Its meaning is complete in itself. The formula is: MS Bias = M-STD - S-MTD.

2. Per cent bias is millisecond bias expressed as a percentage of the length of the unit mark or space of the code used.

   Per cent bias is inversely proportional to the length of the unit mark or space, and is, accordingly, directly proportional to the speed of signalling. Its meaning is not complete unless the speed of signalling to which it applies is included. In the Long Lines Plant, however, a teletype speed of 60 words a minute is assumed unless otherwise specified.

   The formula is: $\% \text{ Bias} = \frac{\text{MS Bias}}{\text{Unit Mark}} \times 100.$

3. Millisecond biases or per cent biases will add algebraically.

PROBLEMS ASSOCIATED WITH DISCUSSION OF BIAS

1. If the S-MTD of a circuit is 6 MS and the M-STD is 2 MS what is the MS bias?

2. In problem 1, what would be the per cent bias to 60 speed signals? To 40 speed?

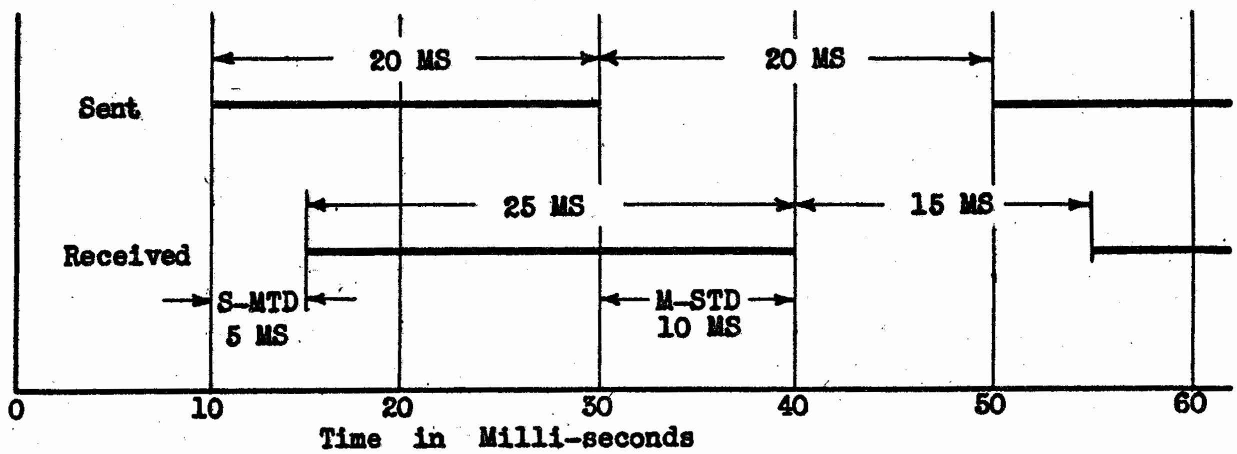
3. If the bias a circuit causes to 60 speed signals is +12%, what per cent bias will it cause to 40 speed signals? To 75 speed signals?

4. What is the millisecond bias of the circuit in problem 3?

JTN/LK
2-20-36

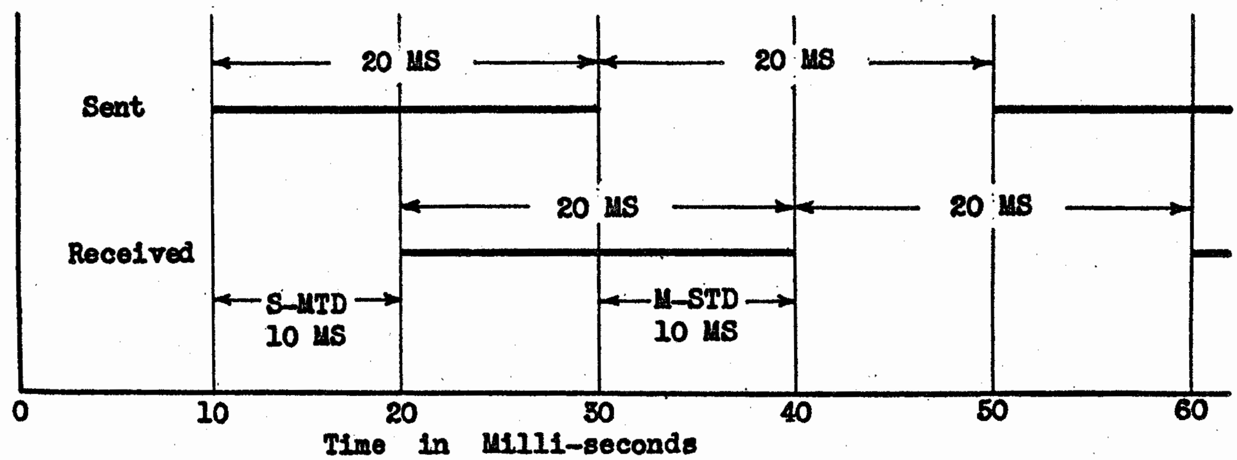
TELEGRAPH TRANSMISSION

Milli-second Bias



MS Bias = 10 MS – 5 MS = 5 MS Bias

FIGURE I



MS Bias = 10 MS – 10 MS = 0 MS Bias

FIGURE II

TELEGRAPH TRANSMISSION

NEUTRAL OPERATION

GENERAL

Neutral operation makes use of a flow of current on the line for the marking condition and zero current on the line for the spacing condition. The line current furnishes the power to operate the receiving relay to the marking position and a spring on the armature or a spacing "bias" current in another winding of the relay the power to operate the relay to the spacing position. The change from the condition of current to the condition of no current is obtained by opening and closing the circuit at the transmitting end.

The line current is normally about 60 mils "marking" and the current in the bias winding about 30 mils "spacing". From the standpoint of the amount of effective current in the relay under each condition this results in an effective current of 30 mils marking when the circuit is in the marking condition, and an effective current of 30 mils spacing when the circuit is in the spacing condition.

Drawing No. 3, Figure A, shows the change of current on the line of a neutral circuit containing no inductance or capacity. Since the receiving relay has a constant current in the bias winding of 30 mils, the value of line current at which the effective current in the relay is zero, or, in other words, the location of the zero effective current line on the wave shape, is at the plus 30 mil level, and the operating points of the relay are slightly above and below this line, as shown.

EFFECT OF ARMATURE TRAVEL TIME

The opening of a neutral circuit by the armature of the sending relay is almost instantaneous because the circuit is broken as soon as the armature has traveled only a very short distance from the marking contact. The closing of the circuit by the armature of the relay, however, involves the travel time of the armature from the spacing to the marking contact before the circuit is made. The M-STD of the circuit due to this cause is thus practically zero and the S-MTD is equal to the travel time of the armature, which is normally in the order of two or three miliseconds. The S-MTD exceeds the M-STD and the result is a spacing bias to telegraph signals.

Armature travel time in neutral operation thus normally causes a spacing bias. This effect is compensated for by proper adjustment of the spark killer as will be explained.

EFFECT OF SPARK KILLER

A spark killer is used across the contacts of a relay in neutral operation to reduce the sparking of the relay contacts and to introduce a M-STD to compensate for the S-MTD due to the travel time of the relay armature.

The action of the spark killer in reducing sparking is as follows: If any series inductance is present in the circuit being broken by the armature of the sending relay, the high voltage produced by the sudden change of current flowing through the inductance will cause a spark across the contacts of the relay as they are opened. The spark killer, which consists of a resistance and capacity in series connected across the relay contacts, as shown in Drawing No.3, Figure C, provides a temporary path around the contacts through which the current of the circuit can continue to flow. The opposition offered by the spark killer is equal at first only to the value of the resistance, since the uncharged condenser is a "short", and the current of the circuit drops immediately to the value determined by the voltage and total resistance of the circuit, which now includes the resistance of the spark killer. The condenser charges from this current and the voltage across its terminals increases until the flow of current in the circuit is stopped. The "stopping" is now gradual, however, in the normal manner of a condenser charge current, and the voltage induced across the inductance of the circuit is reduced to a point where the sparking effect is eliminated. The wave shape of the signals now include this condenser charge effect on the mark to space part of the curve, and, as is illustrated on the drawing (Figure C)the M-S operating point is delayed and a M-STD results. The amount of the delay is dependent upon the resistance and capacity of the spark killer, a large capacity allowing the current to flow for a considerable time after the relay contacts are opened, and a large resistance also delaying the opening of the circuit, but having the more important effect, as far as the M-STD is concerned, of lowering the value of the current that will flow in the circuit at the instant the relay is opened. Thus if the resistance of the spark killer were equal to or greater than the resistance of the circuit, the initial current would be half or less of the normal line current. Then if the operating point of the relay were at the normal value of half the line current, the operation of the relay from mark to space would occur as soon as the relay contacts opened and there would be no compensating M-STD for the S-MTD due to the travel time of the armature.

The purpose of the resistance in the spark killer circuit is to limit the flow of current across the relay contacts when the contacts are closed after an open and the spark killer condenser discharges across them. The value of both the resistance and the capacity are adjusted to give the proper wave shape on the M-S part of the signal that will result in the desired M-STD.

To summarize, a spark killer is used around the contacts of a relay in neutral operation to eliminate the sparking of the relay contacts when the circuit is opened, and to provide a M-STD equal to the S-MTD due to the travel time of the armature.

EFFECT OF LINE CAPACITY

CIRCUIT OPERATED WITH VOLTAGE AT ONE END AND GROUND AT THE OTHER

Drawing No. 4, Figure A shows a neutral circuit using battery at one end and a ground at the other. In the marking condition the voltage across the condenser simulating the line capacity is some positive value less than 130 volts.

When the key at the sending end of the circuit is opened the entire part of the circuit to the left of the condenser can be disregarded since no current can flow in it. The remaining part of the circuit then consists simply of a condenser in series with a resistance, the receiving relay of the circuit and ground. The natural action of this circuit is for the condenser to discharge through the windings of the receiving relay in the normal manner of a condenser discharge. The initial current of this discharge will be equal to the voltage of the condenser divided by the resistance of the receiving end of the circuit. The voltage of the condenser was determined, however, by the IR drop of the line current across the receiving end resistance of the circuit. The result of this condition is that the initial current through the receiving relay from the condenser will always be equal to the former line current and in the same direction, and will decrease to zero from this value in the normal manner of a condenser discharge current. This effect is illustrated on Figure B of Drawing No. 4. As can be seen, the M-S operating point of the relay is delayed under this condition. The amount of the delay will be proportional to the amount of line capacity.

After the condenser is discharged it becomes nothing more than a short across the line of the circuit and ground. When the key at the transmitting end is then closed, all the line current will flow across this "short" and none through the receiving relay. The flow of current begins to charge the condenser immediately, however, removing its "shorting" effect, and permitting the line current to build up in the receiving relay. The build up of the current in the receiving relay is gradual as the line capacity charges, and is illustrated on the space to mark curve of the wave shape in Figure C of the drawing. By Pollard's Theorem the charge of the line capacity can be shown to take place through a resistance, the value of which is equivalent to the two halves of the line resistance (on each side of the condenser) in parallel. This "resistance" is less, and will always be less, than the resistance the condenser discharges through on the M-S transition, which is the resistance of the receiving end of the circuit alone. This is the fundamental difficulty of neutral operation from a transmission standpoint, mentioned before, that the condenser action on the M-S transition takes place through a greater value of resistance than the condenser action on the S-M transition, with the result that the M-S curve of the wave shape is greater than the S-M curve and the resultant excess of the M-STD over the S-MTD causes a marking bias.

CIRCUIT OPERATED WITH BATTERY AT EACH END

Where the circuit is operated with battery at each end as shown in Figure C of Drawing No. 4, the condenser is at some low voltage value during the marking condition and charges up to the voltage of the receiving end battery during the spacing condition. The "charge" current acts the same as the "discharge" current of the previous case, flowing only through the receiving end resistance of the line, being equal in its initial value to the former line current, and decreasing in the normal condenser charge current manner as shown on the M-S curve of the wave shape of Figure B.

When the key is closed at the transmitting end the condenser discharges down to the voltage determined by the arrangement of the resistance of the line. The discharge currents flow in both directions from the condenser, since in the marking condition both ends of the circuit are closed. In this case the current from the condenser flowing through the receiving relay is now in the opposite direction of the line current, as can be seen upon examination of the voltages involved, and being in the opposite direction will reduce the line current in the receiving relay in proportion to its value. This value is of course, steadily decreasing as the condenser discharges until finally it becomes zero and the line current in the receiving relay reaches its full value. The effect is to delay the build up of the line current in a manner similar to the "shorting" effect of the uncharged condenser of the previous case. The resultant wave shape due to this effect is given on Figure B, being the same as for the S-M transition of the circuit of Figure A.

The action of the condenser on the S-M transition, takes place through both ends of the circuit in parallel, as is more apparent in this case, and will be quicker than the charge action on the M-S transition which takes place only through the resistance of the receiving end of the circuit.

The effect of capacity to ground on the line of a neutral circuit, then, is to cause both the S-M and M-S transitions of the wave shape to be curved, the M-S transition always more than the S-M transition, with the resultant marking bias due to the associated transition delays being unequal. Since this effect is in proportion to the amount of capacity, the quality of transmission of a neutral circuit, other things being equal, will be inversely proportional to the amount of line capacity. Thus better transmission will be obtained on a simplex pair or single wire than on a simplex phantom, and on a short circuit than on a longer one.

EFFECT OF AMOUNT AND LOCATION OF INSERTED LINE RESISTANCE

With the usual arrangement of a total of 260 volts line voltage on neutral operation, a total resistance in the circuit of approximately 4300 ohms is necessary to limit the current to the standard value of 60 mils. Since the resistance of the average line is only about 1000 or 1500 ohms, a considerable amount of resistance must be inserted in the circuit at the central office terminals of the circuit. The effect of this resistance on transmission will be discussed.

On the M-S transition of a neutral circuit, the line capacity either charges or discharges through the receiving end of the circuit alone. On the S-M transition the action of the condenser takes place through the resistance of the two halves of the line in parallel. Both actions produce a curved wave shape and transition delays, but the action on the M-S transition, taking place through the receiving end of the circuit alone, results in a greater transition delay than the action on the S-M transition and marking bias accordingly results.

Resistance in the sending end of the circuit will not affect the M-S transition at all since the sending end of the circuit is open when this takes place. On the S-M transition the effect of resistance in the sending end will be to delay the action of the condenser a small amount, since the resistance of the two halves of the line in parallel is now increased. This will increase the S-MTD, but since the M-STD was previously larger than the S-MTD, the increase will actually reduce the bias of the circuit. Thus a resistance inserted at the sending end of a neutral circuit will improve transmission a small amount by making the two transition delays more equal.

Resistance at the receiving end of a neutral circuit will delay the action of the line capacity on the S-M transition for the reason that, as in the case of resistance at the sending, the resistance of the two halves of the line in parallel is increased. The amount of the increase is not in direct proportion to the increase of the resistance of the receiving end of the circuit, however, since the sending end of the circuit is in parallel. The effect then is to increase the S-MTD of the circuit a small amount.

On the M-S transition, however, the delay to the action of the line capacity caused by resistance at the receiving end of the circuit is in direct proportion to the amount of the resistance, since all the capacity charge or discharge current must flow through the added resistance. The M-STD of the circuit is thus increased by this effect and by an amount considerably greater than the increase to the S-MTD of the circuit. The marking bias caused by the previous excess of the M-STD over the S-MTD is thus further increased.

From this, it is seen that resistance at the sending end of a neutral circuit reduces the marking bias caused by the line capacity, and that resistance at the receiving end increases the marking bias caused by the line capacity. <u>Transmission on a neutral circuit is thus best towards the end that has the least resistance.</u>

On a circuit on which transmission in both directions is neutral, an application of this rule is impractical since to make the resistance at one end of the circuit a minimum to favor transmission in that direction, requires increasing the resistance at the other end of the circuit to keep the line current the same value, and transmission to the other end of the circuit is thus degraded. The normal practice in such cases is to make the resistance at each end of the circuit of the same value, and transmission is thus the <u>same</u> in each direction, even if not as good as could be obtained in one direction or the other by a rearrangement of the inserted resistance.

If the voltage used on the circuit is reduced, however, the amount of inserted resistance required to limit the current is thus reduced and transmission in both directions will be improved. The reduction of the voltage is accomplished in two ways, one, to use potentiometers on the 130 volt battery taps at each end of the circuit, and the other to use 130 volts at one end of the circuit and a ground at the other, thus cutting the voltage of the circuit in half.

In the case of differential loop and upset duplex circuits, , where transmission is polar in one direction and neutral in the other, the rule of making the resistance of the receiving end of the circuit as low as possible to favor the neutral transmission can be applied, since placing all the resistance at one end of the circuit will not affect polar transmission in that direction.

The summary of this discussion is as follows: transmission on a neutral circuit is best toward the end of least resistance, and; the less the inserted resistance on a neutral circuit the better transmission will be. (The inserted resistance required may be reduced by reducing the applied voltage.)

EFFECT OF SERIES INDUCTANCE

Series inductance at the sending end of a neutral circuit limits the build up of the current on a S-M transition and, accordingly, causes a S-M transition delay. On the M-S transition, the opening of the key at the sending ends opens the circuit to the inductance immediately and the inductance has little effect on the M-S transition and, accordingly, the M-S transition delay. The wave shape of a neutral circuit with inductance at the sending end of the circuit is shown on Drawing No. 3, Figure B. As is evident from the wave shape, the effect of the inductance in causing a S-MTD but not a M-STD results in a spacing bias on the circuit.

Series inductance at the receiving end of a neutral circuit is in the circuit on both the S-M and the M-S transitions. In this location it is now separated from the sending end of the circuit, where the opens and closes take place, by the capacity of the line facilities. If this capacity is zero there will be no difference between the effect of inductance at the sending end or at the receiving end, since the circuit will be a simple series circuit containing only inductance and resistance, and the location of the inductance with relation to the resistance will make no difference in its effect on current changes. On a circuit with very little line capacity, then, an inductance will cause approximately as much spacing bias if inserted at the receiving end of the circuit as it will cause if inserted at the sending end.

In the case of a circuit with a considerable amount of line capacity, the current at the receiving end of the circuit builds up slowly on a S-M transition as compared with the current at the sending end which builds up instantaneously. The effect of inductance on a change of current is proportional to the rate of change of the current, and the effect of inductance at the receiving end of a circuit, on which the current change is slow, will therefore be less than the effect of the same inductance at the sending end of the circuit, where the current change, due to the surge of current into the line capacity when the circuit is first closed, is very rapid. The increase in the S-MTD of the circuit due to inductance at the receiving end of the circuit will therefore be less than the increase in the S-MTD due to inductance at the sending end of the circuit.

On the M-S transition the inductance is no longer eliminated from the circuit by the opening of the key at the sending end, but remains in the circuit to have an effect on the line capacity charge or discharge currents that flow out the receiving end of the circuit. This effect is somewhat difficult to predict, since it is dependent upon the relation between the value of the inductance and the value of the line capacity, which may have a resonant effect for certain combinations that will produce varied effects on the M-S transition curve of the circuit. In general, however, since the effect of receiving end inductance is less on the <u>S-M</u> transition than that of sending end inductance, and since the receiving end inductance probably delays, except for an occasional resonant condition, the <u>M-S</u> transition, where <u>sending</u> end inductance had no effect on the M-S transition, it can be said that the effect of inductance at the receiving end of a circuit in causing spacing bias is less than the effect of the same inductance when placed at the sending end of the circuit, and that the difference in the effect for the two locations is proportional to the amount of capacity on the line circuit between the receiving and sending end of the circuit.

LOOP LOADING

Use is made of inductance on long subscriber's loops where the capacity of the loop has increased the M-STD of the circuit to an amount considerably greater than the S-MTD and a marking bias is caused. On loops on which this effect is large enough to be objectionable, inductance is added in the circuit at the subscriber's office until the S-MTD of the loop is increased to equal the M-STD and the bias to signals from the subscriber's teletypewriter is thus eliminated. Where a differential loop type repeater is used to transmit into the loop from the central office the transmission in this direction is "effective polar" and the signals received by the subscriber from the repeater will be unbiased, both before and after the inductance is added. This action is called "loading" the loop, a term obtained from telephone terminology where the use of inductance to overcome the capacity effect of the line facilities on telephone circuits is called that, or "wave shaping" which comes from the fact that the inductance is used to "shape" the S-M part of the wave shape curve to make the S-MTD equal to the M-STD.

USE OF INDUCTANCE FOR NOISE KILLERS

At outlying points, inductance, in conjunction with a spark killer, is used in series with the contacts of the subscriber's teletypewriter or telegraph key to limit the sudden changes in current that cause interference to nearby telephone circuits. This causes a spacing bias effect in the telegraph circuit which must be considered in the line up of the circuit. On upset duplex operation, which employs neutral transmission from the outlying point to the central office, marking bias is usually present due to the capacity of the line facilities and the inductance serves to reduce this bias. If the spacing bias of the inductance more than compensates for the marking bias of the line facilities, the resistance in the duplex repeater at the central office can be increased which will increase the marking bias on the circuit, as explained in the discussion on the effect of receiving end resistance, until the two bias effects cancel each other. In the case of polarential operation, where the bias of the signals from the outlying point is adjusted by the bias current of the polarential repeater, the addition of inductance at the outlying point simply requires a readjustment of the bias current to compensate for the added spacing bias.

NEUTRAL TELEGRAPH APPARATUS CONTAINING INDUCTANCE

Series inductance on neutral circuits is present in telegraph relays and sounders, polar relays, composite sets and noise killers.

In the case of telegraph relays and sounders on manual telegraph circuits, and of polar relays on teletypewriter circuits, the effect of the inductance of this equipment is large enough to be objectionable only when several of either type of apparatus is in series on a circuit. In the case of composite sets, the inductive effect is partially offset by the capacity to ground in the composite set. The assignment of neutral circuits to composited facilities is limited to very short circuits, however, for the reason that the combined effect of the series inductance and capacity to ground is a poor signal wave shape that results in unstable transmission.

SUMMARY OF EFFECT OF INDUCTANCE ON NEUTRAL TRANSMISSION

The summary of the effect of inductance on neutral transmission is as follows:

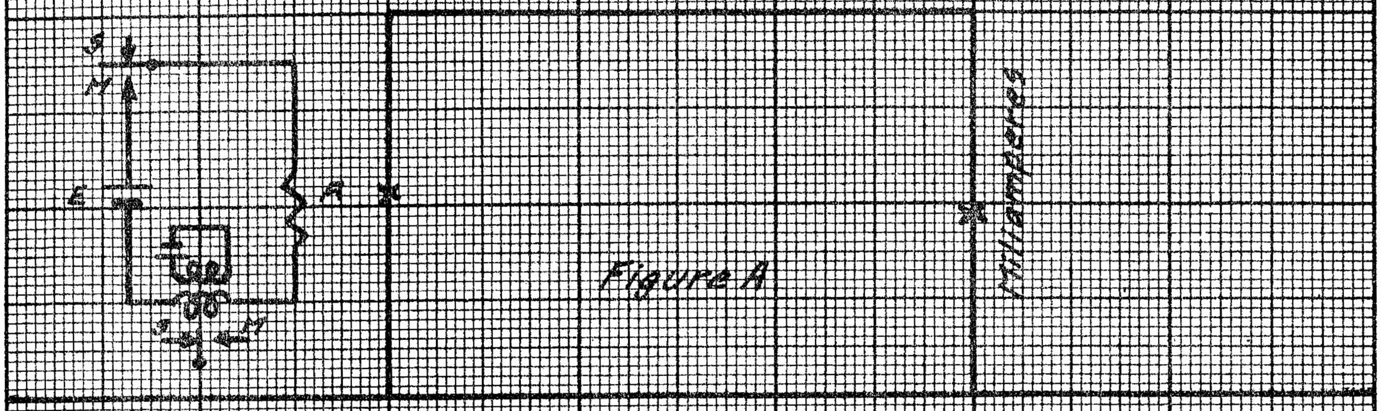
1. Inductance at the sending end of a neutral circuit delays the S-M transition, and has little effect on the M-S transition. The result is a spacing bias proportional to the value of inductance.

2. Inductance at the receiving end of a neutral circuit delays the S-M transition less than in the case of inductance at the sending end, and also has the effect of delaying somewhat (except possibly in some resonant conditions), the M-S transition of the circuit. The effect of inductance at the receiving end of a circuit in causing spacing bias is thus less than the effect of inductance at the sending end, and by an amount that is proportional to the capacity of the line between the sending and receiving end of the circuit. This statement is subject to modification for occasional combinations of line capacity and inductance that may produce an effect other than the one described.

JTN:HW

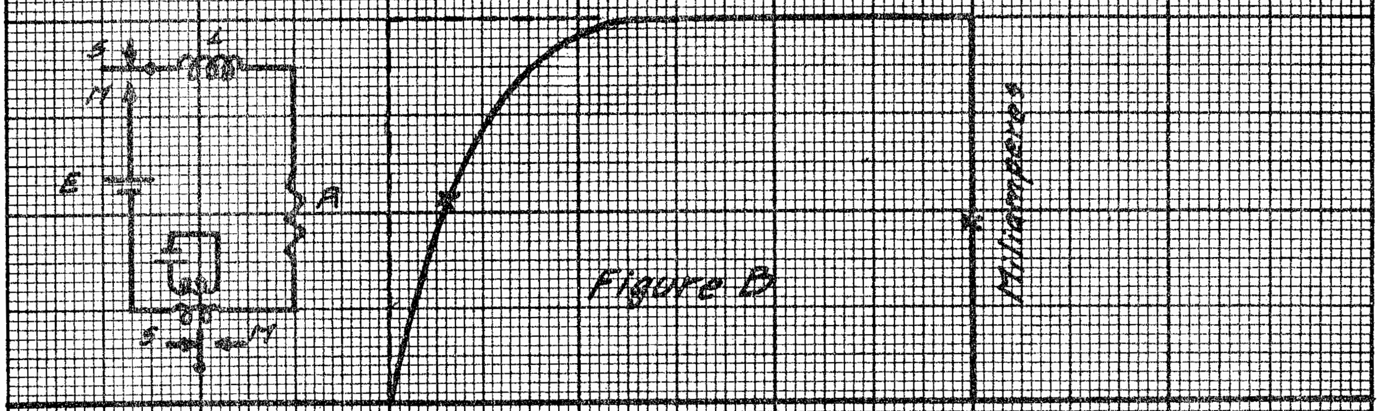
Drawing No. 3

Telegraph Line Current Plotted Against Time



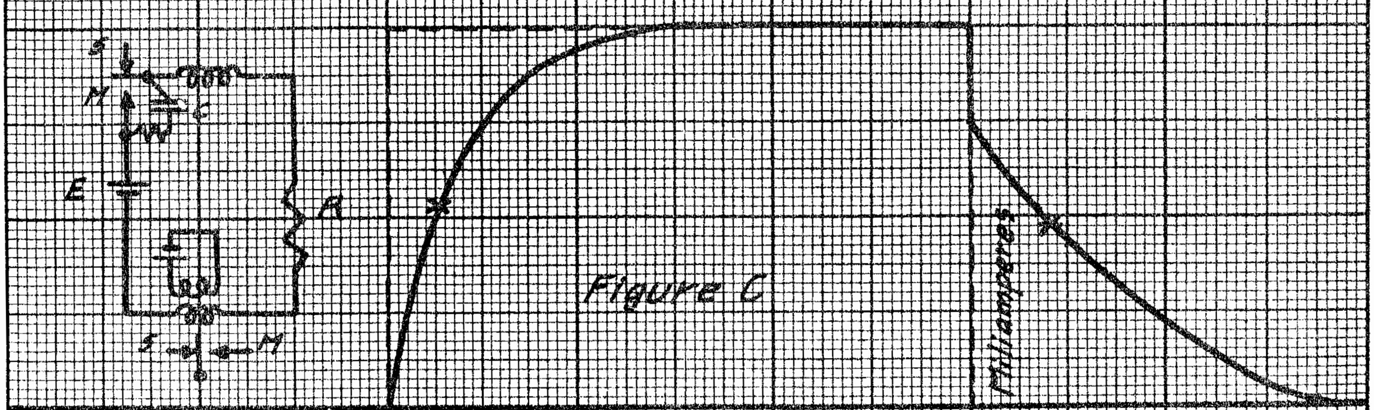
No Inductance or Capacity

Miliseconds



Series Inductance

Miliseconds



Series Inductance and Spark Killer.

Miliseconds

Drawing No. 4

Effect of Line Capacity on Neutral Telegraph Operation

Figure A

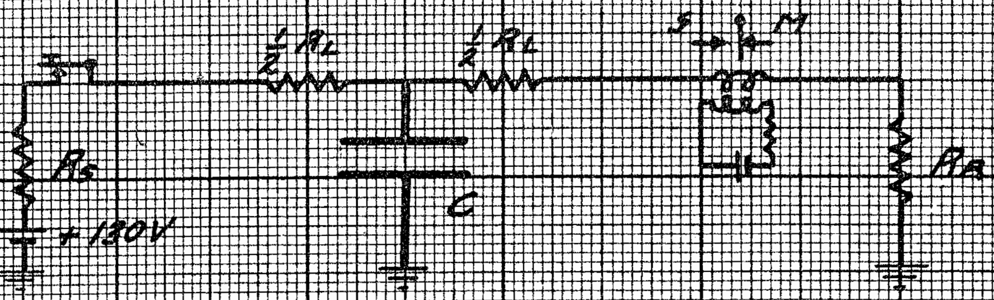


Figure B

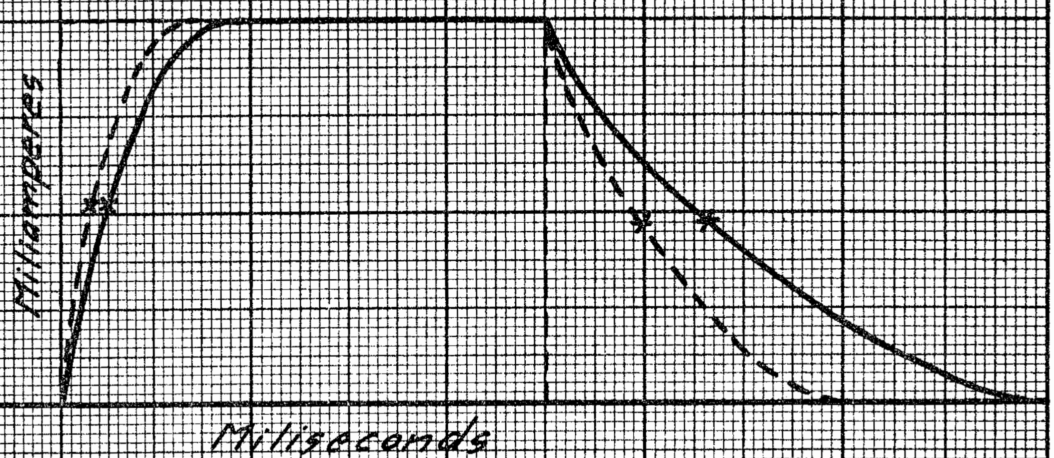
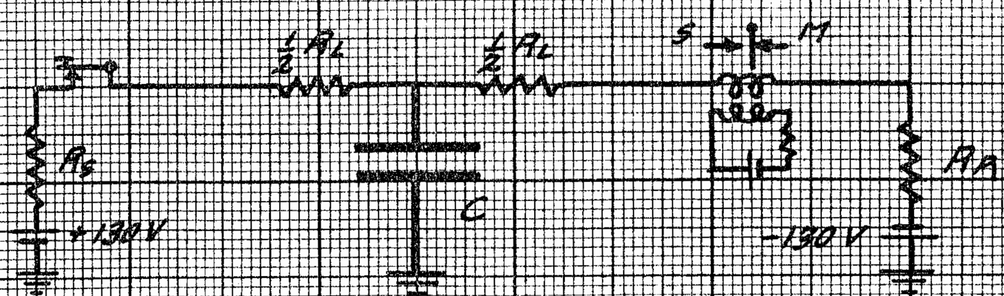


Figure C



POLAR TRANSMISSION AND CHARACTERISTIC DISTORTION

CIRCUIT DESCRIPTION

A one way polar circuit using a ground return is shown on Figure XII. The sending relay connects negative 130 volts to the line for the marking condition and positive 130 volts for the spacing condition. The resistance at the sending and is adjusted so that the line current is normally about plus 35 mils for the marking condition and negative 35 mils for the spacing condition. On a two way polar circuit an identical circuit arrangement is used for transmitting in the opposite direction.

On four wire metallic circuits, which also are polar in operation, the circuit arrangement is different only in the fact that a metallic instead of a ground return is used, which, of course, requires an extra wire in each direction. The metallic return, because it balances out outside interference, and because it is not affected by ground potential differences between the sending and receiving end of the circuit, permits the use of line currents in the order of only 3 or 4 mils. This makes it possible to use a low voltage on the contacts of the sending relay and this voltage has, accordingly, been reduced to plus and minus 34 volts. Double commutation, an arrangement using two sending relays instead of one, to permit using only one 34 volt battery, is used on most of the terminal metallic repeaters. Double commutation is used only for battery supply reasons, however, and has no effect on transmission.

EFFECT OF LINE CAPACITY AND RESISTANCE

On the polar circuit shown in Figure XII, the change of the line current from the marking to the spacing condition and from the spacing to the marking condition will be delayed for the following reason:

When the line current is in the steady state <u>marking</u> condition the voltage on the condenser representing the capacity to ground of the line facilities is -65 volts. (This assumes locating the condenser at the mid-point of the line resistance). When the line current is in the steady state <u>spacing</u> condition the voltage on the condenser is +65 volts. The change of the line current from the steady state marking to the steady state spacing condition then involves a change of the voltage on the line capacity from -65 to +65 volts, which means that the line capacity must discharge from -65 volts to zero, and charge from 0 to +65 volts. The part of the discharge current from the condenser that flows through the receiving relay of the circuit (the other part flows through the armature of the sending relay to ground), being in the same direction as the steady state marking line current, tends to sustain the line current formerly produced by the -130 volts on the marking contact of the sending relay. The charging current flowing into the condenser from the +130 volts on the spacing contact of the sending relay is current that is shunted away from the receiving relay, and the build up of the current to the steady state spacing value is thus delayed. The two actions combine to make the change of the line current from the marking to the spacing condition a gradual change which is represented by the curved wave shape shown on Figure XIII. The amount of time required for the change (which is indicated by the amount of curvature of the wave shape)is dependent upon the amount of line capacity that must be discharged and then recharged in the opposite direction on each transition, and upon the amount of resistance the charge and discharge currents must flow through.

PATHS OF CHARGE AND DISCHARGE CURRENTS

The discharge of the line capacity takes place through both halves of the circuit in parallel, as can be seen from inspection, since both halves of the circuit are available for the discharge currents to flow through to ground and back to the grounded side of the capacity. The charge of the capacity also takes place through what is effectively the two halves of the circuit in parallel. This condition is not as evident from inspection but can be shown by Pollard's Theorum to be true. The time required for the discharge and charge of the line capacity to take place, then, is dependent upon the resistance of the two halves of the line in parallel.

The combined resistance of two resistances in parallel is always less than the resistance of the lowest value. The combined resistance of the two halves of a polar circuit will always be less, then, than the resistance of the half of the lowest resistance. As far as the resistance of the line itself is concerned, of course, this resistance will usually be evenly distributed and equally divided between the two ends of the line. The resistance which is inserted to regulate the line current, however, can be inserted all at one end of the circuit or the other, or may be divided in a number of different ways. From the above discussion, however, it is apparent that the resistance of the two halves of the line in parallel will be the lowest, and, accordingly, the action of the line capacity will be the fastest, if the inserted resistance at one end of the circuit is made zero, which means that the inserted resistance at the other end of the circuit will be a maximum.

One of the rules of polar operation, then, is that the best wave shape, or in other words, the best transmission, is obtained when the inserted resistance at one end of the circuit is zero. As far as transmission is concerned, the effect will be the same whether this is the sending or the receiving end.

DIFFERENCE BETWEEN NEUTRAL AND POLAR TRANSMISSION

In both polar and neutral transmission the resistance of the circuit from the armature of the sending relay to the ground or battery at the receiving end of the circuit remains constant while the sending relay operates. From the armature of the sending relay back to the ground or battery at the sending end of the circuit, however, the resistance of the neutral circuit changes from a low value to an infinite value as the relay armature opens the circuit, and the resistance of the polar circuit remains constant if the resistances in the marking and spacing battery taps are equal. This constitutes the fundamental difference between neutral and polar transmission. The effect on the wave shape of the signals is as follows: In neutral transmission, as discussed previously, the change in resistance of the circuit between the marking and the spacing conditions made the resistance of the charge circuit of the line capacity different from that of the discharge circuit, and dissimilar M-S and S-M wave shape curves resulted. In polar transmission, if the resistance of the circuit is kept the same by making the resistance of the marking and spacing battery taps on the sending relay the same, the charge and discharge actions of the line capacity must always take place through the same value of resistance, and the M-S and S-M wave shape curves will be identical. Any circuit which maintains a constant resistance while the sending relay operates, and thus has identical S-M and M-S wave shapes, is considered as having "polar" transmission.

LOCATION OF RELAY OPERATING POINTS TO OBTAIN UNBIASED POLAR TRANSMISSION

The fact that in polar operation the S-M and M-S wave shapes are identical is a valuable feature of this type of operation. To get the full advantage of it, however, which is unbiased transmission regardless of the curvature of the wave shapes, the operating points of the relay must be located properly on the wave shape. The reason for this is as follows:

At the beginning of any curved wave shape, the transition delay that would be associated with the operating point of a relay located there is small. As the operating point is shifted farther along the wave from the starting point the transition delay increases. In the case of two similar waves, the locating of the relay operating point the same distance from the starting point on each, will result in equal transition delays for each operating point.

In polar operation the wave shape of the M-S and S-M transitions are alike. The only requirement for unbiased transmission in polar operation, then, is that the S-M operating point of the relay be located the same distance from the start of the S-M wave shape, as the M-S operating point is located from the start of the M-S wave shape.

In polar operation, as indicated in the wave shape on Figures XIII and XIV, the M-S transition curve starts at the top of the wave shape, and the S-M transition curve starts at the bottom of the wave shape. For unbiased transmission, the M-S operating point should be the same distance from the top as the S-M operating point is from the bottom. If these two points are the same distance from the top and bottom of the wave respectively, they will also be equal distances on each side of the middle of the wave. An application of this last statement will be made shortly.

LOCATION OF ZERO EFFECTIVE CURRENT LINE

Under "Relay Operating Points" it was stated that the operating points of an unbiased relay are located symetrically, or in other words, equal distances on each side of the zero effective current line of the wave shape of a circuit. In the previous paragraph it was stated that for unbiased transmission in polar operation, it is necessary that the operating points of the relay be located equal distances from the middle of the wave, or, in other words, equal distances on each side of a line drawn through the middle of the wave. The solution for obtaining unbiased transmission on polar operation, then, is to locate the zero effective current line of the wave shape at the mid point of the wave shape. With this arrangement, the requirement for an unbiased relay that the operating points be located equidistant on each side of the zero effective current line, and the requirement for unbiased polar transmission that the operating points of the relay be located equidistant about the mid point line of the wave will both be met.

EXAMPLES OF LOCATING ZERO EFFECTIVE CURRENT LINE AND RELAY OPERATING POINTS FOR ZERO BIAS

In the case of a polar circuit working to a ground at one end, the problem of locating the operating points of the relay is simple. The marking and spacing currents of the circuit are made equal (+35 and -35 mils for example) by applying the same positive voltage as negative voltage. The mid point of the wave shape on this type of circuit is thus at the zero current line which is also the zero effective current line, since there are no other currents in the relay, and the operating points automatically come in the proper places.

In the case of an upset duplex circuit (schematic in Figure XV) where the circuit works to a battery at the receiving end, and the line current, let us assume, is 60 mils in the marking condition and 0 mils in the spacing condition, the mid point of the wave is at the +30 mils level, and a bias current of -30 mils is used in the receiving relay to raise the zero effective current line of the wave shape to that value. If the line current were +70 mils and the spacing current were -10 mils, the middle of the wave would still be at the +30 mils level and the bias current of -30 mils would still be correct.

TRUE POLAR AND EFFECTIVE POLAR OPERATION

It should be noted at this point that circuits such as the upset duplex circuit referred to, though practically neutral in their operating characteristics, since there is approximately 60 mils current in the marking condition and 0 mils in the spacing condition, are still polar in their transmission characteristics since the impedance of the circuit remains constant regardless of whether the sending relay is in the spacing or marking position. The advantage of combining neutral operation with polar transmission in this manner is that it permits the use of neutral subscriber's equipment at the non repeatered end of the circuit. The disadvantage is, that to obtain unbiased polar transmission, the operating point of the relay at the non repeatered end of the circuit must be maintained at the mid point of the wave shape, and the location of the mid point of the wave shape varies with leakage on the line, which results in bias to transmission whenever leakage is present unless the resistances of the circuit are readjusted. Where the line facilities are entirely in cable, however, where little leakage is experienced, this type of circuit is more satisfactory.

This type of operation is sometimes referred to as "effective polar operation" as distinguished from the type of operation shown in Figure XII which is referred to as "true polar operation".

REQUIREMENTS FOR UNBIASED POLAR TRANSMISSION

Unbiased polar transmission thus depends on two conditions; one, that the resistance of the circuit remain constant while the sending relay operates, and the other that the operating points of the relay be located symetrically about the middle of the wave shape in order that equal transition delays will be obtained. A failure to meet either or both of these conditions will result in bias to transmission.

PART OF POLAR CIRCUIT NOT COMMON TO BOTH S-M AND M-S TRANSITIONS.

An examination of a polar circuit shows that the only parts of the circuit that are not common to both the S-M and M-S transitions are the battery taps connected to the contacts of the sending relay. Of these, one tap is connected to the circuit during the S-M transition and the other during the M-S transition. The resistance of these two taps is made the same which results in the entire resistance of the circuit being a constant during the operation of the sending relay.

Any inductance or capacity inserted in the marking battery tap of the circuit would, of course, change the shape of the S-M wave shape but would not affect the M-S wave shape, since the marking battery tap is not connected while the M-S change is taking place.. Likewise, any inductance or capacity in the spacing battery tap would affect the M-S wave shape but not the S-M. With the wave shapes no longer identical the transitions delays would no longer be equal and bias would result.

PART OF POLAR CIRCUIT COMMON TO BOTH TRANSITIONS

The part of the circuit from the armature of the sending relay to the receiving end of the circuit, however, is always in the circuit and thus will affect both the M-S and the S-M transitions alike. Any inductance or capacity in this part of the circuit, then, will cause the same change to the wave shape of the S-M transition as it will cause to the M-S transition, and regardless of what the change is the two wave shapes will remain identical and transmission will still be unbiased. This is another advantage of polar operation, then, that any changes in the circuit beyond the armature of the sending relay, such as patching line facilities, changing noise killers, adding additional repeaters or teletypewriters, etc., will not cause bias to transmission, and also that trouble in the line facilities, noise killers, composite sets, etc., will not cause bias unless a foreign voltage becomes connected to the line due to the trouble. This is an important point to remember in connection with maintenance work on polar circuits.

Conditions that do cause bias to polar transmission will be discussed in the following material.

TRANSITIONS AND TRANSITION DELAYS ON A POLAR CIRCUIT

DESCRIPTION OF CIRCUIT TO BE DISCUSSED

In the following discussion a circuit of the type shown in Figure XII will be considered. The line facilities of this circuit are assumed to have series resistance and capacity to ground, as shown, and the location and amount of any inductance in the noise killer or composite equipment of the circuit is assumed to be such that transient oscillations of noticeable magnitude are not produced at the time of a transition. The case where transient oscillations of appreciable magnitude are produced will be covered after the case just defined is completed.

M-S TRANSITION

In Figure XIII a M-S transition is shown. The transition starts from the +35 mil value of the marking line current, and ends when the current has crossed the zero current line of the wave shape and become large enough in the opposite direction to operate the receiving relay to spacing. This "operating point" of the relay is indicated by the cross on the wave shape. It is usually near the -3 mil value on the curve.

S-M TRANSITION

In figure XIV a S-M transition is shown. This transition starts from the -35 mil value of the spacing line current, and ends when the current has crossed the zero current line of the wave shape and has become large enough in the opposite direction to operate the relay to marking.

TRANSITION DELAY

The delay to each of the above transitions is the interval of time between the start and end of the transition, or, in other words, the time interval required for the line current to change from the 35 mil value to the 3 mil value of the opposite sign.

THREE CONSTANTS OF A POLAR CIRCUIT

For any given set of conditions on the circuit the following three statements apply:

1. The steady state line current is always the same.

   Thus, in the example, shown, the line current always goes to the -35 mil value after each M-S transition and to the +35 mil value after each S-M transision. (This statement assumes no characteristic distortion effect, a condition that will be covered later.)

2. The operating point of the relay on the wave shape is always the same.

   As long as the relay holds its adjustment the operating point of the relay will always be at the same current value. In the example being considered the value is 3 mils for each direction of operation of the relay.

3. The rate of change of the line current is always the same.

   As long as the resistance of the circuit remains the the same, the time required, at any time, for the current to change from +35 mils to -3 mils, will always be the same. The time required at any time, for the current to change from -35 mils to +3 mils will always be the same. The time required for the current to change between any other two values such as from +35 mils to -10 mils, -35 mils to +10 mils, or any other combination would also be constant, though these latter changes have no application in this discussion.

SUMMARY

The summary is that the starting point of all M-S transitions (35 mils), the finishing point (-3 mils) and the rate of change of the current in between the two points are all constant for any given set of conditions on the polar circuit.

CONCLUSION

The delay to each M-S transition sent over the circuit will then be the same.

In the example shown the M-S transition delay is 5 MS. Therefore every M-S transition sent over the circuit will have a delay of 5 MS.

Using the same reasoning the delay to every S-M transition sent over the circuit will always be the same, since the starting point (-35 mils) the finishing point (+3 mils) and the rate of change of the current in between again are all constants.

M-STD OF CIRCUIT IS THE SAME AS THE S-MTD

In the example used, the marking and spacing line currents are of the same magnitude (35 mils) the relay operating points are of the same magnitude (3 mils) the rate of change of the current in changing from +35 to -3 mils, or from -35 to +3 mils is the same (because the resistance of the marking and spacing battery taps of the sending relay is the same). The delay of the two transitions, M-S and S-M, is thus also the same.

With the M-STD of the circuit equal to the S-MTD, transmission over the circuit is then perfect, for the reason that marks or spaces transmitted over the circuit are unchanged in length.

CIRCUIT CONDITIONS FOR PERFECT TRANSMISSION

Perfect transmission was obtained on the polar circuit when the marking and spacing line currents were equal, the operating points of the relay were equal, (relay unbiased) and the rate of change of the current on the S-M and M-S transitions were the same. (Resistance of circuit same for spacing or marking condition).

CASE WHERE MARKING AND SPACING LINE CURRENTS ARE UNEQUAL

Figure XVI shows a case where the marking and spacing line current of a polar circuit are not equal, the marking current being +40 mils and the spacing current being -30 mils. This condition might be due to a difference in ground potential between the terminals that causes a ground potential current of +5 mils to flow on the line, adding to the normal +35 mils marking current and subtracting from the normal -35 mils spacing current, or to an unbalance between the voltages on the contacts of the sending relay. The operating points of the relay are still assumed as being at the +3 mils and -3 mils values, and the resistances of the sending relay battery taps are still assumed as being equal.

M-S TRANSITION INVOLVES CURRENT CHANGE OF 43 MILS

In this case, a M-S transition starts when the line current is at +40 mils and ends when the current is at -3 mils, a total current change of 43 mils. Each M-S transition will start from the +40 mils value, of course, and end at the -3 mil value, which means that the delay to each M-S transition will be the same.

S-M TRANSITION INVOLVES CURRENT CHANGE OF 33 MILS

A S-M transition will start when the line current is at -30 mils and end when the current is +3 mils, a total current change of 33 mils. Each S-M transition will start at the -30 mils current value and end when the current is +3 mils, so the delay to each S-M transition will be the same.

M-STD WILL THEREFORE BE GREATER THAN THE S-MTD

The total current change of the M-S transition is 43 mils, and of the S-M transition is 33 mils. Since the rate of change of the current in the two directions is still the same, the delay to the M-S transition will now be greater than the delay to the S-M transitions, since the current on the M-S transition has a 10 mils greater distance to change through. The M-STD of the circuit accordingly will be greater than the S-MTD.

EFFECT WILL BE TO LENGTHEN ALL MARKS AND SHORTEN ALL SPACES

The effect of this condition on transmission is that each mark, regardless of length (except for a characteristic distortion limitation, covered later) will be lengthened by an amount equal to the difference between the two delays, and each space, regardless of length, will be shortened by the same amount.

In the example used, the M-STD of the circuit is 5 MS, and the S-MTD is 3 MS. All marks transmitted over the circuit will thus be lengthened 2 MS, and all spaces will be shortened 2 MS.

OPPOSITE LINE CURRENT CONDITION WOULD CAUSE OPPOSITE EFFECT ON MARKS AND SPACES

If the bias condition on the circuit were reversed, which might be done by making the spacing line current greater than the marking line current, the delay to the S-M transitions would then be greater than the delay to the M-S transitions. Under this condition all marks would be shortened and all spaces would be lengthened and a spacing bias would exist.

CAUSE OF THE BIAS CONDITION

The cause of the bias in the example used above was a difference in the marking and spacing line currents of the circuit which resulted in a greater time being required for the larger current to change to the operating point of the relay than for the smaller current, and, accordingly, caused one group of transition delays to be greater than the other.

SHIFTED RELAY OPERATING POINTS WILL ALSO CAUSE BIAS

A situation similar to the one just described would have existed if the marking and spacing line current values had remained the same, or equal to each other, and the relay operating points themselves had been shifted one way or the other on the wave shape. This could be caused by a biased adjustment of the relay which, if it were a marking bias, would cause the relay to operate to marking more easily than usual, thus requiring less marking current to operate it, and shifting the S-M operating pointdown on the wave shape, and to operate to spacing less readily, thus requiring more spacing current to operate it, and shifting the M-S operating point also down on the wave shape. The shifting of the operating points would once again make the change of current from the marking condition to the M-S operating point on the wave shape different from the change of current from the spacing condition to the S-M operating point on the wave shape, and unequal transmission delays and bias to transmission would result, just as in the previous case where the unequal current changes were due to unequal values of marking and spacing line currents.

ALL M-STD ARE THE SAME, ALL S-MTD ARE THE SAME

In either case, the important thing, besides the fact that unequal transition delays result, is the fact that though the M-S transition delays are different than the S-M transition delays, both sets of delays are constant in themselves, and the difference between the two delays, which determines the amount of bias on the circuit, is also a constant. Thus if a circuit condition like the one described results in a M-STD of 5 MS and a S-MTD of 3 MS every M-S transition sent over the circuit will have a delay of 5 MS and every S-M transition a delay of 3 MS, regardless of the interval of time (determined by the length of the marks and space transmitted) that may exist between transitions. This condition is emphasized here to distinguish it clearly from characteristic distortion effects where the M-S and S-M transition delays of the circuit are not constant and independent of the length of the marks and spaces transmitted, as in the case of bias, but are closely related to the length of the mark or space immediately preceding the transition affected.

THE MAGNITUDE OF THE EFFECT OF UNBALANCING LINE CURRENTS OR OF SHIFTING RELAY OPERATING POINTS IS PROPORTIONAL TO THE CURVATURE OF THE WAVE SHAPE

The magnitude of the effect of unbalancing line currents or of shifting the operating points of the relay on the wave shape, as just described, depends entirely upon the degree of curvature of the wave shape, being considerable for wave shapes that are very much curved, and practically nothing for wave shapes that are nearly vertical. It is for this reason that a short circuit or a circuit on a simplexed pair, on which the wave shape is curved only to a small extent, will be less affected by unbalances in the marking and spacing line currents or by biased receiving relays, than a long circuit or circuit on a simplexed phantom (as compared to the simplexed pair circuit) where the wave shape of the signals is more curved.

CHARACTERISTIC DISTORTION

TRANSITIONS MAY START WHEN THE LINE CURRENT IS NOT IN STEADY STATE CONDITION

In the discussion so far, one reason for the constancy of a transition delay on a polar circuit has been that the transition has been always assumed to start when the line current was in the steady state marking or spacing condition, which, in itself, is a constant factor on a circuit. The start of every transition, however, will not always occur when the line current of the circuit is in the steady state condition for the following reason: A definite amount of time is required for the line current of a circuit to change from the steady state marking condition to the steady state spacing condition and vice versa. In figures XIII and XIV, used to illustrate the M-S and S-M transition on a polar circuit, the time required for the current to make the complete change from marking to spacing and from spacing to marking is indicated as being approximately 15 MS. In the discussion on bias it was assumed that more than 15 MS separated the transitions of the signals so that on each transition the line current would have time to reach the steady state value of the current it was approaching before the next transition occurred. Thus the following transition would start from the same current value as the preceding transitions and the transition delay would then be the same as the previous delays.

In actual practice, however, on some circuits the time required for the current to change from the one steady state condition to the other is greater than the minimum time interval between transitions in the signals, and some transitions then must occur while the line current is still in the process of changing from the previous transition. These transitions, as will be explained shortly, will therefore have a different delay time than the transitions starting when the line current is in the steady state condition. To study the effect of the different delay times of these transitions on the lengths of marks and spaces, these transitions and transition delays will be distinguished from the previous transitions discussed which always started when the line current was in the steady state condition.

STEADY STATE CURRENT AND CHANGING CURRENT TRANSITIONS

With reference to the condition of the line current at the time the transition starts, a transition starting when the line current is in the steady state condition will be called a STEADY STATE CURRENT TRANSITION, and the delay associated with it will be called a STEADY STATE CURRENT TRANSITION DELAY. A transition starting when the line current of the circuit is in a changing condition will be called a CHANGING CURRENT TRANSITION and the delay associated with it will be called a CHANGING CURRENT TRANSITION DELAY.

ILLUSTRATION OF A CHANGING CURRENT TRANSITION

In Figure XVII a case is shown where the line current requires 28 MS to change from the steady state marking condition to the steady state spacing condition. A spacing impulse 22 MS long is being transmitted, as indicated by the square wave shape in light lines.

The M-S transition at the start of the spacing impulse occurs when the line current of the circuit is in the steady state marking condition of +35 mils. This transition is thus a steady state current transition, and as such will have the normal M-S steady state current transition delay of the circuit, which is the same for all steady state current M-S transitions.

The M-S transition at the beginning of the spacing impulse starts the current changing towards the steady state spacing current value of the circuit, an action which, on this particular circuit, will require 28 MS to complete. 22 MS later, however, the S-M transition at the end of the spacing impulse occurs. At this time the line current of the circuit, in the process of changing from +35 mils to -35 mils, is only at the value of -30 mils. The operation of the sending relay at the end of the spacing impulse reverses the voltage applied to the line, and the line current accordingly ceases changing towards the spacing condition, and starts back towards the steady state marking condition of the circuit. Since this S-M transition occurred when the line current was in the process of changing, it is called a changing current transition.

When the line current reaches a value of +3 mils, the receiving relay operates to marking, completing the S-M transition on the circuit.

DISTINCTION BETWEEN STEADY STATE AND CHANGING CURRENT TRANSITIONS

The distinction between the steady state current M-S transition at the beginning of the spacing impulse, and the changing current S-M transition at the end of the impulse is as follows:

The delay to the steady state current M-S transition was the time required for the current to change from +35 to -3 mils, a total change of 38 mils. The delay to the changing current S-M transition was the time required for the current to change from -30 mils to +3 mils, a total change of 33 mils. The changing current S-M transition delay will thus be less than the steady state current M-S transition delay. The basic reason for the changing current transition delay being less than the steady state current transition delay is the fact that the line current at the start of the changing current transition was less than the value of the line current at the start of the steady state transition. In the example, the delay to the changing current transition is 3 MS as compared to the steady state current transition delay of the circuit of 8 MS.

We thus have a case of a transition delay on a circuit that is not due to a shifting of the operating points of the receiving relay, or to an unbalance between the marking and spacing currents of the circuit, but is due to a condition that is linked with the length of the impulse preceding the transition, since it is the length of the impulse transmitted that determines the interval of time between the transitions at the start and the end of the impulse.

EFFECT OF THIS TYPE OF CHANGING CURRENT TRANSITION ON LENGTH OF IMPULSES.

The effect on the spacing impulse being transmitted in Figure XVII will be to shorten it 5 MS, since the transition delay at the end of the impulse (3 MS), which adds to the impulse, is 5 MS less than the transition at the start of the impulse (8 MS), which subtracts from the beginning of the impulse.

On a polar circuit, the rate of change of the current in changing from marking to spacing is the same as the rate of change of the current in changing from spacing to marking. Accordingly, since on this particular circuit 26 MS were required for the current to change from +35 to -35 mils, 26 MS will also be required for the current to change from -35 mils to +35 mils. It also follows, then, that if a marking impulse only 22 MS long is transmitted, the M-S transition at the end of the impulse will occur when the current of the circuit is still in the changing condition and this transition will be a changing current transition.

Since, in the case of the current changing from marking to spacing, the value of the current at the end of 22 MS was -30 mils, it also follows that in the case of the current changing from spacing to marking the value of the current at the end of 22 MS will be +30 mils. This condition is illustrated in Figure XVIII. The total current change involved in the M-S transition at the end of the marking impulse will then be from +30 to -3 mils or 33 mils, the same as the total current change that took place at the end of the spacing impulse. The delay to this changing current transition will then be 3 MS, the same as the delay to the changing current transition of the first case. The marking impulse being transmitted will then be reduced 5 MS in length, the same as the spacing impulse of the first case.

RELATION OF CHANGING CURRENT TRANSITION DELAY TO LENGTH OF IMPULSE PRECEDING THE TRANSITION

The magnitude of the changing current transition delays just discussed is proportional to the time required for the current to change from the value it is at the start of the transition to the operating point of the receiving relay on the wave shape. In Figures XVII and XVIII the current change was from 30 mils to the value of 3 mils of the opposite sign or a total change of 33 mils. It is obvious, however, from an inspection of these figures, that if the impulse transmitted had been longer than 22 MS, the line current would have been at a higher value at the time of the transition at the end of the impulse, and the transition delay would have been greater. The limit to the increase in delay resulting from an increase in the length of the impulse will be the steady state transition delay of the circuit.

Also if the impulse transmitted had been less than 22 MS in length, the line current would have been at a lower value at the time of the transition at the end of the impulse, and the transition delay would accordingly have been less.

These conditions are illustrated in Figures XIX and XX. In these figures the perfect wave shapes of impulses 11 MS long(ABCD), 22 MS long (ABMN) and 36 MS long (ABXY) are shown in dotted lines, and the actual wave shapes on the circuit are shown in heavy lines. The delays to the steady state and changing current transitions are indicated as distance between the operating point of the relay on the square wave shape and on the actual wave shape.

In the case of the 36 MS impulse (ABXY) of Figure XIX, the impulse is longer than the time required for the current of the circuit to change from the one steady state condition to the other, and the transition at the end of the impulse is thus a steady state current transition the same as the transition at the start.

To simplify the discussion, a condition of no bias has been assumed for the circuit and under this condition the steady state current S-MTD of the circuit is equal to the steady state current M-STD and the transition delays at the start and end of the 36 MS impulse are thus the same. In the example they are indicated as being 9 MS each.

In the case of the 22 MS impulse (ABMN) the S-M transition at the end of it occurs when the line current is at the -30 mil value, instead of at the -35 mil value as for the 36 MS impulse, and this transition is thus a changing current transition starting at a current value less than the steady state current value. The delay to it is accordingly less than the delay to a steady state current transition. In the example this delay is shown as being 7 MS.

In the case of the 11 MS impulse (ABCD) the S-M transition at the end of it occurs when the line current is only at the -9 mil value. This transition is thus also a changing current transition, and due to the fact that the line current only changes 12 mils to reach the S-M operating point of the relay as compared to the change of 30 mils for the S-M transition of the 22 MS impulse, the delay to this transition is much less than to that of the 22 MS impulse. In the example this delay is indicated as being 3 MS.

AMOUNT OF CHANGING CURRENT TRANSITION DELAY DEPENDS ON VALUE OF LINE CURRENT AT START OF TRANSITION

The amount of a changing current transition delay is thus dependent upon the value of the line current at the start of the transition. The value of the line current is dependent upon the time interval between the changing current transition under discussion and the previous transition, which started the line current to changing.

The time interval between these two transitions is equal to the length of the impulse being transmitted. Thus the value of a changing current transition delay is dependent upon the length of the impulse it is associated with. In the example of Figure XIX, the 36 MS impulse has no changing current transition associated with it. The 22 MS impulse had a changing current transition delay of 7 MS as compared to the steady state delay of 9 MS, while the 11 MS impulse had a changing current transition delay of 3 MS as compared to the steady state transition delay of 9 MS.

Since, as stated before, the rate of change of the line current on a polar circuit is the same on S-M transitions as on M-S, the transmission of 11 MS, 22 MS and 36 MS marks instead of these lengths of spaces, should result in changing current M-S transition delays at the end of these marks that are the same as the corresponding S-M changing current transition delays at the ends of the 11 MS, 22 MS and 36 MS spaces just discussed. The case of the marks is illustrated in Figure XX.

EFFECT OF CHANGING CURRENT TRANSITION DELAYS ON LENGTH OF IMPULSES

The effect of the changing current transition delays on the lengths of the impulses transmitted is shown in the tables below the wave shapes in Figures XIX and XX. Here the sum of the original length of the impulse, minus the transition delay at the start of the impulse (which reduces the length) plus the transition delay at the end of the impulse (which adds to the length) is given. The 36 MS impulses, both spacing and marking, are unchanged in length since the delays at each end are both steady state current delays which, in the case of no bias assumed here, are equal. The 22 MS impulses were reduced to 20 MS in length, and the 11 MS impulses to 5 MS in length.

COMPARISON BETWEEN EFFECTS OF CHANGING CURRENTS AND STEADY STATE CURRENT TRANSITION DELAYS.

Figures XIX and XX illustrate the effect of changing current transition delays on transmission, which will now be compared with the effect of a constant difference between the steady state S-M and M-S transition delays of a circuit which is called bias.

In the case of bias, every impulse transmitted is affected, regardless of the length of the impulse.

In the case of changing current transitions, the effect of the condition depends directly on the length of the impulse, being large for very short impulses and decreasing to no effect at all on impulses the length of which is such that the line current of the circuit can reach the steady state condition before the transition at the end of the impulse occurs.

In the case of bias the effect on a space is always the opposite of the effect on a mark. That is, if it is marking bias, the marks will be lengthened and the spaces shortened. If it is spacing bias the spaces will be lengthened and the marks shortened.

In the case of changing current transitions as illustrated in the comparison between Figures XVII and XVIII and between Figures XIX and XX, the effect on marks and spaces of equal lengths is the same for each. Thus a 22 MS space will be shortened the same amount as 22 MS mark, a 11 MS space will be shortened the same amount as a 11 MS mark, etc.

EFFECT OF CHANGING CURRENT TRANSITION DELAYS ON IMPULSES STARTING AND ENDING WITH CHANGING CURRENT TRANSITIONS

An angle of this distortion effect not covered yet is as follows: In the examples used so far, the transition that started the line current of the circuit changing, or in other words the transition at the start of the short impulse under consideration has always been taken as a steady state current transition. This is not always the case in practice, since several transitions in a row may all have time intervals between them that are less than the time required for the current of the circuit to reach a steady state condition, and thus several of the transitions would be changing current transitions.

Considering Figure XVIII, a steady state M-S transition is shown at the start of the impulse. This transition started when the line current was +35 mils. The delay to the changing current transition at the end of the impulse was less than the delay to the steady state transition at the start of the impulse for the reason that the current at the start of the changing current transition was less than the current at the start of the steady state current transition. In the example, the delay of the changing current transition was 3 MS and to the steady state current transition 8 MS. Let us assume that the transition at the start of the impulse is now a changing current transition instead of the steady state transition shown. Under the circuit condition being discussed, the line current at the start of the transition will then be less than +35 mils.

If the value of the line current at the start of the transition is less than +35 mils at the time it starts changing towards the -35 mils condition, the value of the current after 22 MS will be greater than the -30 mils shown, or the current will be closer to the steady state value of -35 mils. Under this condition the delay to the changing current transition at the end of the impulse will be closer to the delay of a steady state transition than it was in the first place, since the current value at which it starts is now closer to the current value from which a steady state transition would start from.

Thus, in the example of Figure XVII, the changing current transition delay at the end of the impulse will now be something greater than the 3 MS shown. Let us assume that it is 5 MS. At the same time the transition delay at the start of the impulse, formerly a steady state current transition delay of 8 MS, is now a changing current transition delay, in accordance with our assumption that the impulse will start with a changing current transition, and as such has less delay than the normal 8 MS delay of a steady state current transition. Let us assume that it is 6 MS. The net change in the length of the short spacing impulse then is the difference between the two transition delays, which is now a shortening of 1 MS, as compared to the shortening of 5 MS that occurred when this impulse was assumed to start with a steady state transition.

MAXIMUM EFFECT OF CHANGING CURRENT TRANSITIONS IS ON SHORT IMPULSE STARTING WITH STEADY STATE CURRENT TRANSITION.

The conclusion from this is that the maximum effect of changing current transitions on a circuit having the characteristics assumed, is on a short impulse that begins with a steady state current transition, rather than on one which begins with a changing current transition. For this reason, in selecting signals to be transmitted over a circuit to determine the maximum amount of characteristic distortion present, the signals are chosen with a long mark or space preceding the short impulse to be tested, to permit the current of the circuit to reach a steady state condition before the start of the short impulse, and thus assure that the starting transition of the impulse will be a steady state current transitiion.

CHANGE OF IMPULSE LENGTHS DUE TO CHANGING CURRENT TRANSITIONS IS CALLED CHARACTERISTIC DISTORTION.

In the condition just described the lengths of impulses transmitted are affected by the presence of changing current transitions. This effect is called "characteristic distortion". The magnitude of the effect is inversely proportional to the length of the impulses transmitted, and the nature of the effect is to shorten both the spacing and marking short impulses. For this reason, since the impulses under consideration are shortened, the effect is called negative characteristic distortion. This effect is associated, it should be remembered, with polar circuits on line facilities on which resistance and capacity predominate, and on which the location and amount of the inductance of the noise killers and composite sets is such that oscillating transients are not produced on each transition. Most grounded polar circuits on non-composited line facilities are in this class.

The case where the amount and location of the inductance of the circuit is such that an oscillating transient is produced at each transition will now be considered.

CHANGING CURRENT TRANSITION ON WHICH LINE CURRENT EXCEEDS STEADY STATE VALUE MOMENTARILY.

In Figure XXI a circuit condition is shown in which the line current in changing from one steady state condition to the other, instead of slowly making the change, makes it with a surge that carries it momentarily beyond the steady state current value of the condition it is approaching, and then returns to less than the steady state value and oscillates above and below the steady state value as shown, until, when the oscillations have died out, it comes to rest at the steady state value. This condition exists when the inductances in the noise killers and composite sets of the repeater and line circuits are located with respect to the condensers of the noise killers and composite sets, and the capacity of the line facilities, so that the discharge current of the condensers is sustained by the inductances, and the condensers are caused to charge again in the opposite direction. The condensers then again discharge and once more are forced to recharge in the original direction by the inductances, though this time the amount of the charge is less than the original charge due to the power lost by the current flowing through the resistance of the circuit. This oscillation continues until the charge of the condensers becomes negligible. It has had its effect on the line current, however, in causing the oscillation of the line current above and below the steady state current value as described. These surges of the current are called transients.

If a transient lasts for more than 22 MS on a circuit, or for more than the length of the shortest impulse transmitted, changing current transitions will again be present. The important distinction between this condition and the previous condition is that in this condition the value of the current at the start of a changing current transition may be more or it may be less than the value of the steady state current, while in the previous case it could only be less.

CHANGING CURRENT TRANSITION DELAYS MAY BE GREATER THAN STEADY STATE CURRENT DELAYS.

For this reason the changing current transition delays may sometimes be greater than the steady state current delays, since if a changing current transition starts when the line current is at a value of +40 mils, it will require more time for the current to reach the relay operating point of -3 mils than it would require if the current started from the steady state value of +35 mils. Then if a short impulse starts with a steady state transition delay and ends with a changing current transition delay that is greater than the steady state delay, the impulse will have been lengthened by the characteristic distortion effect instead of being shortened, as was alwyas the case with the previous condition. This is illustrated in Figure XXII where the steady state delay is 5 MS, the changing current delay is 8 MS, and the impulse accordingly is lengthened 3 MS.

The result is the same for either S-M or M-S transitions since the inductances and condensers of the circuit will have the same effect on either direction of current. The effect on the short mark is shown in Figure XXIII where the lengthening effect on the mark is shown as 3MS, the same as for the short space of Figure XXII.

In the former case the effect of the changing current transitions was to shorten the impulses transmitted and it was therefore called negative characteristic distortion. In this case the effect illustrated is to lengthen the impulses transmitted and it is therefore called positive characteristic distortion.

A point to be noted in connection with the effect of "transients" is that, since the line current oscillates above and below the steady state current value before it comes to rest, a changing current transition starting at a time when the line current was less than the steady state current value would have a delay less than the steady state current delay and the effect would then be that of negative characteristic distortion. Thus transients may cause either positive or negative characteristic distortion, while the condition described previously, which is due only to a large amount of capacity and resistance on a circuit, and not enough inductance to cause transients, can only cause negative characteristic distortion.

TELETYPEWRITER CODE HAS TWELVE DIFFERENT LENGTHS OF IMPULSES

The fact that the value of a changing current transition delay as compared to the steady state current transition delay of a circuit depends upon the length of the impulse under consideration would make a consideration of the matter appear rather complicated because with a large number of different lengths of impulses to be transmitted, a large number of different changing current transition delays would have to be considered. In the teletypewriter code, there are, however, at a speed of 60 words a minute, only 12 different lengths of impulses produced by the sending distributor. These are: 22, 31, 44, 53, 66, 75, 88, 97, 110, 119, 132 and 141 MS. The 22 MS impulse is a single impulse. The 31 MS impulse is the "Stop" impulse. The multiples of 22 MS are combinations of two or more 22 MS impulses, and the remaining lengths are combinations of the "Stop" impulse and one or more of the 22 MS impulses.

The changing current transition delays we will be interested in then are those associated with values of the line current at 22, 31, 44, etc., MS after the current starts to change. The changing current transition at the end of each of these periods represents a distortion effect. To refer to these distortions in a simple manner, the distortions are named from the length of the impulse associated with them. Thus the distortion to a transition coming at the end of an impulse that is 22 MS long is called 22 Milisecond distortion, which is abbreviated 22 MSD. The distortion to the 31 MS impulse is called 31 MSD and the remaining distortions are 44 MSD, 53 MSD, etc.

PRESENCE OF VARIOUS DISTORTIONS (22 MSD, 31 MSD, etc.) ON CIRCUITS OF THE LONG LINES PLANT.

As stated previously, the study of the effect of characteristic distortion on transmission is somewhat simplified by the fact that there are only 12 different standard lengths of impulses in the sixty speed teletypewriter code. It is further simplified by the fact that on most circuits of the Long Lines Plant only the shorter lengths of impulses are affected, since on the longer impulses the current of the circuit has time to reach the steady state condition and no changing current transitions, and, accordingly, no characteristic distortion effects, are involved.

In the following table a summary is given of the general characteristic distortion conditions that exist on the various types of circuits in the Plant. The table assumes that the circuits have not been equalized.

Type of Circuit	Line Facilities	Length	Distortions Present
One and Two Way Polar	Cable	Under 125 Miles	-22 MSD on the longer circuits.*
"	Open Wire	Under 250 Miles	-22 MSD on the longer circuits.*
"	Cable	Over 125 miles	-22 MSD,-31 MSD, etc.in proportion to length.*
"	Open Wire	Over 250 Miles	-22 MSD,-31 MSD,etc. in proportion to length.*

* On one and two way polar circuits on composited line facilities it will usually be found that the amount of inserted line resistance(to adjust the line current)is rather critical,and, if the resistance is too large, that -22 MSD will be present, and if the resistance is too low, that +22 MSD will be present. The adjustment of this resistance to the value that results in zero 22 MSD may then result in the line current being considerably less or greater than the customary value of 30 to 40 mils. Where this occurs, equalization of the circuit, either by adding resistance at the receiving end to reduce +22 MSD, or by adding an inductive shunt at the receiving end to reduce -22 MSD, is recommended in order that normal line current values can be used.

Four Wire Metallic	MCX pairs or MX units.	Under 100 miles Over 100 miles	+22 MSD - 22 MSD
	MXX units	Any length	-22 MSD, -31 MSD, etc. in proportion to length.
V.F.Carrier	-	Any length	No characteristic distortion.
H.F. Carrier	-	Any length	+22 MSD, unless distortion correcting network is used.

From the above table it is evident that characteristic distortion problems on standard telegraph circuits are not as complicated as a general study of characteristic distortion would indicate, since on the shorter circuits (except metallic) no characteristic distortion is present, and on circuits of normal length usually only 22 MSD, with a smaller amount of 31 and 44 MSD at times, is present. It is only on the MXX metallic units that a large amount of characteristic distortion is present and on these units the problem of equalizing the circuits so that the characteristic distortion is reduced to 5 or 6% is not difficult for the reason that if the equalizer is adjusted so that the 22 MSD of the circuit, which is usually the largest of the distortions present, is removed, the other distortions will also be almost entirely removed.

EFFECT OF CHARACTERISTIC DISTORTION ON MARGIN

Each of the distortions (22 MSD, 31 MSD, etc.) considered in the case of changing current transitions, has an effect on a teletypewriter margin as shown in the following table:

REDUCES MARGIN ON LOW SIDE		REDUCES MARGIN ON HIGH SIDE	
+22 MSD		-22 MSD	
	-31 MSD		+31 MSD
+44 MSD		-44 MSD	
	-53 MSD		+53 MSD
+66 MSD		-66 MSD	

In the case of 22 MSD and any multiple of it (44 MSD., 66 MSD, etc.) being present on a circuit, the margin is reduced only by the amount of the largest distortion.

In the case of 22 MSD and 31 MSD being present on a circuit together, the effect of each on the margin is independent of the other. Thus on a circuit on which -15% 22 MSD and -9% 31 MSD are present, and the other distortions are of amounts less than -15% for the multiples of 22 MSD, and of less than -9% for the 53 MSD, 75 MSD, etc., which is nearly always the case, the teletype margin of the circuit would be -9 +15.

EQUALIZATION OF CIRCUITS TO REMOVE CHARACTERISTIC DISTORTION

The theory of circuit equalization will be covered in a separate memorandum. It will therefore simply be stated at this time that the addition of resistance in series with the windings of the receiving relay of a polar circuit, either grounded or metallic, will reduce +22 MSD, +31 MSD etc., and a high inductance (71-A coil, 25 Henries, suggested) in series with a variable resistance and connected in parallel with the windings of the receiving relay will reduce -22 MSD, -31 MSD, etc. In the case of a circuit having only +22 MSD and zero 31 MSD, it should be verified that the insertion of series resistance to reduce the +22 MSD does not produce -31 MSD. If it does, other methods of equalization must be used.

SUMMARY OF CHARACTERISTIC DISTORTION THEORY

The discussion of characteristic distortion effects on telegraph circuits has covered in considerable detail the effect of changing current transitions on the lengths of impulses transmitted over the circuits. A general understanding of characteristic distortion, however, involves only the following considerations:

The change of the line current from one condition to the other on a telegraph circuit requires a definite time to complete. If the time interval between the transitions of the signals at the sending end of the circuit is less than the time required for the line current to complete its change, changing current transitions will occur. These transitions will have delays either greater or less than the normal steady state transition delays of the circuit, and will lengthen or shorten the short impulses of the signals an amount depending upon the value of the changing current transition delay, which in turn, is dependent upon the length of the impulse that caused the changing current transition. If the effect is to shorten the short impulses it is called negative characteristic distortion. If the effect is to lengthen the short impulses it is called positive characteristic distortion.

There are twelve different lengths of impulses in the sixty speed teletypewriter code, and the effect of characteristic distortion is considered only for these twelve lengths. The consideration is further simplified by the fact that on the majority of circuits in the Plant only the shortest two or three lengths (22MS and occasionally 31MS and 44 MS) are affected, and by the fact that, in many cases, the removal of the effect on the shortest impulse (22 MS) automatically removes the effect on the longer impulses.

The contrasts between characteristic and bias are as follows:

1. The effect of characteristic distortion depends upon the length of the impulses transmitted. The effect of bias is independent of the length of the impulses.

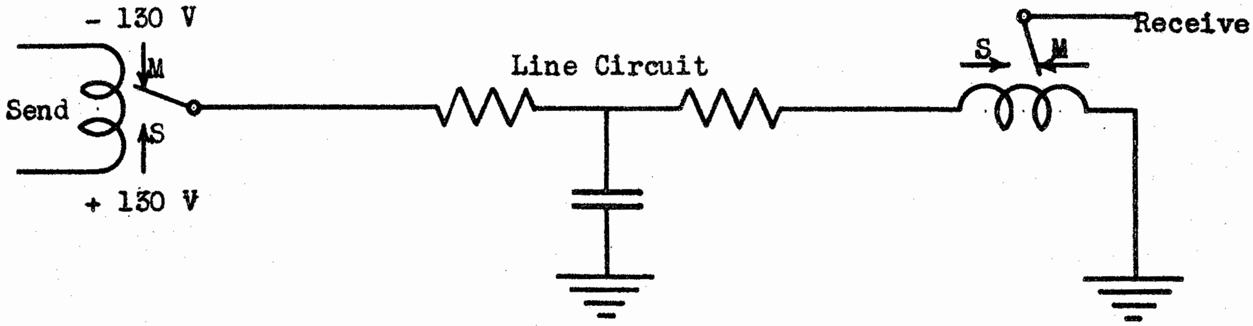
2. For a given length of impulse the effect of characteristic distortion is independent of whether it is a marking or spacing impulse. The effect of bias is always opposite on a mark to what it is on a space.

3. Characteristic distortion is related to the amount and arrangement of the capacity, inductance and resistance of a circuit. Except in neutral operation, these factors do not cause bias.

   Bias is caused by unequal marking and spacing line currents, biased relays, etc., conditions which do not cause characteristic distortion.

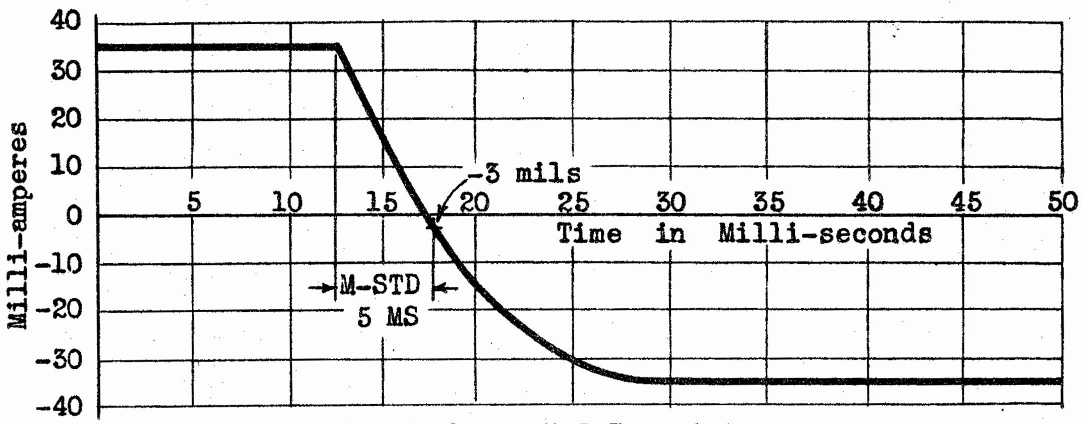
4. Characteristic distortion, because it is due to the capacity, inductance and resistance of a circuit, which, except for the resistance, are unchanging in value, varies only a small amount from day to day on a circuit. Bias, because it is caused by unbalanced voltages, ground potential, relays losing adjustment, etc., varies from hour to hour on a circuit.

JTN:HW



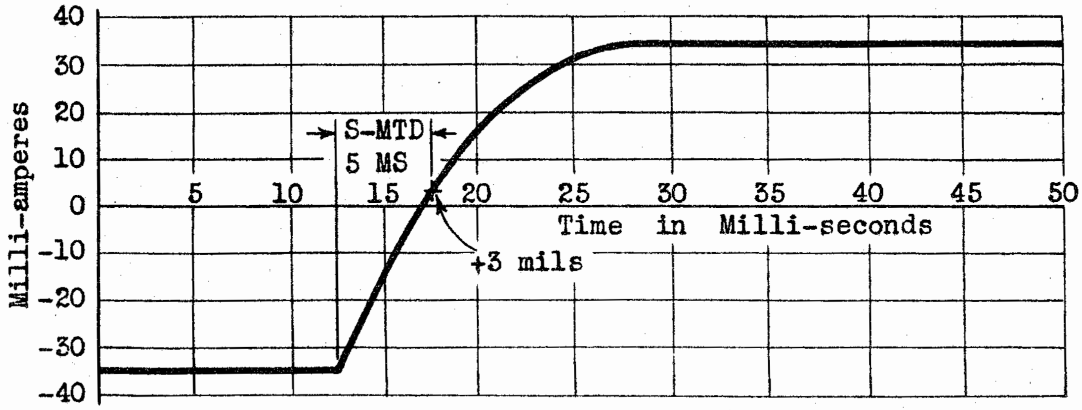
True Polar Operation

FIGURE XII



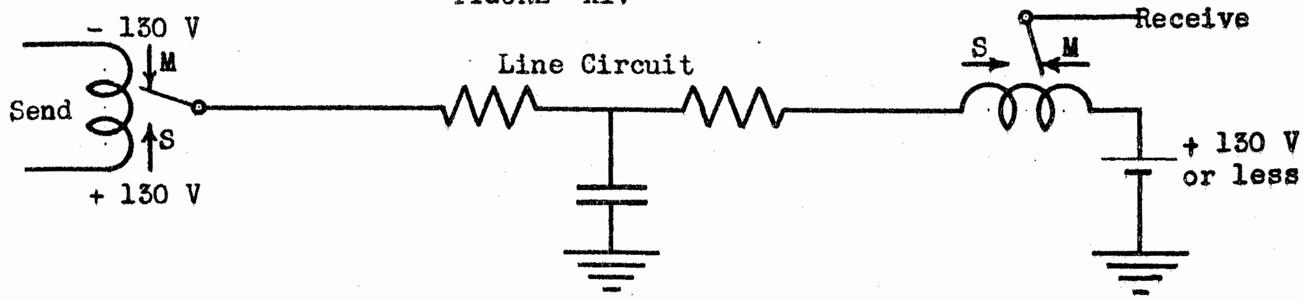
Steady State M-S Transition

FIGURE XIII



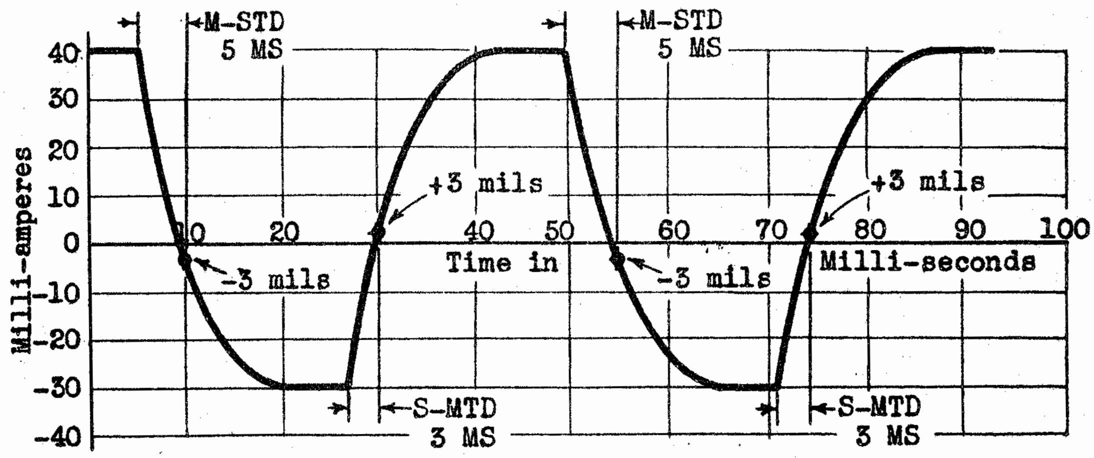
Steady State S-M Transition

FIGURE XIV



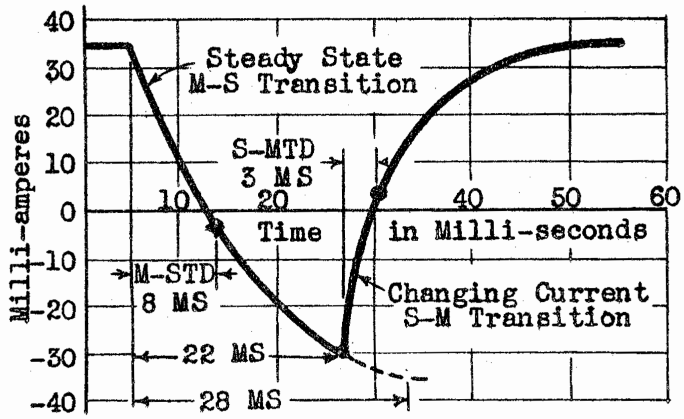
Effective Polar Operation

FIGURE XV



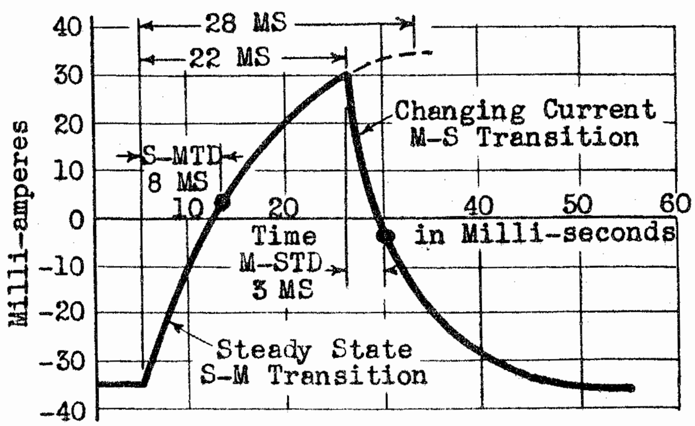
Bias on One Way Polar Circuit Due to Unequal Marking and Spacing Line Currents

FIGURE XVI



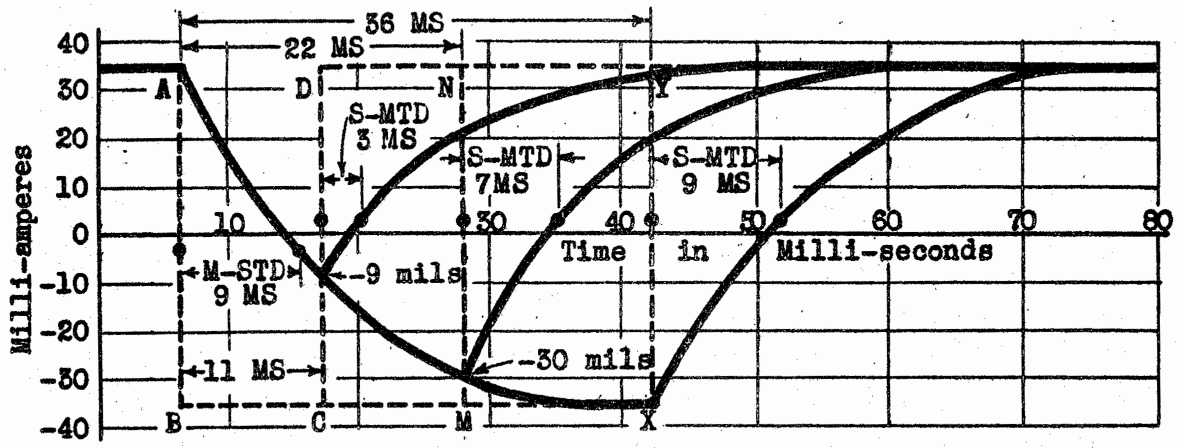
Negative Characteristic Distortion on Short Spacing Impulse

FIGURE XVII



Negative Characteristic Distortion on Short Marking Impulse

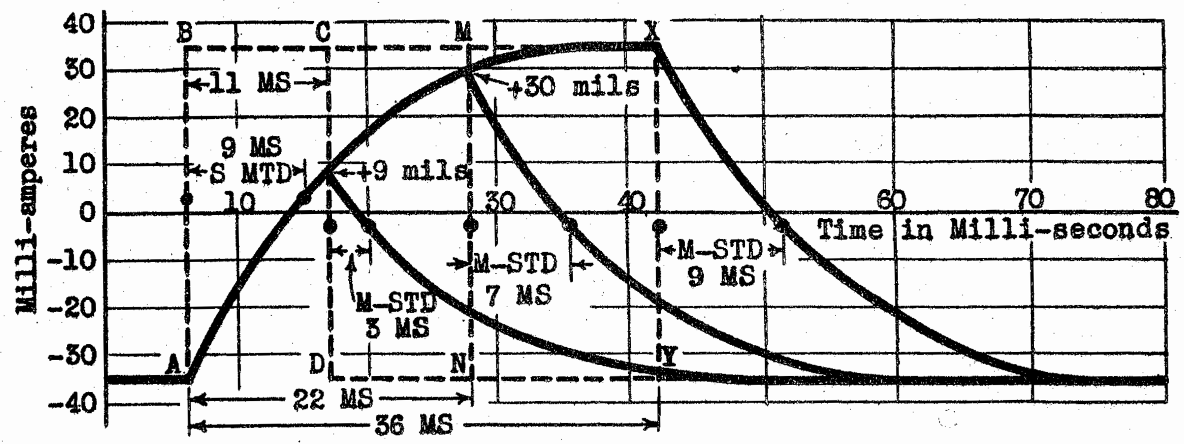
FIGURE XVIII



Received Length of 36 MS Space (ABXY): 36 - 9 + 9 = 36 MS
Received Length of 22 MS Space (ABMN): 22 - 9 + 7 = 20 MS
Received Length of 11 MS Space (ABCD): 11 - 9 + 3 = 5 MS

Effect of Negative Characteristic Distortion on Different Lengths Spacing Impulses

FIGURE XIX



Received Length of 36 MS Mark (ABXY): 36 - 9 + 9 = 36 MS
Received Length of 22 MS Mark (ABMN): 22 - 9 + 7 = 20 MS
Received Length of 11 MS Mark (ABCD): 11 - 9 + 3 = 5 MS

Effect of Negative Characteristic Distortion on Different Lengths Marking Impulses

FIGURE XX

Positive Characteristic Distortion on Polar Circuit Due to Transients

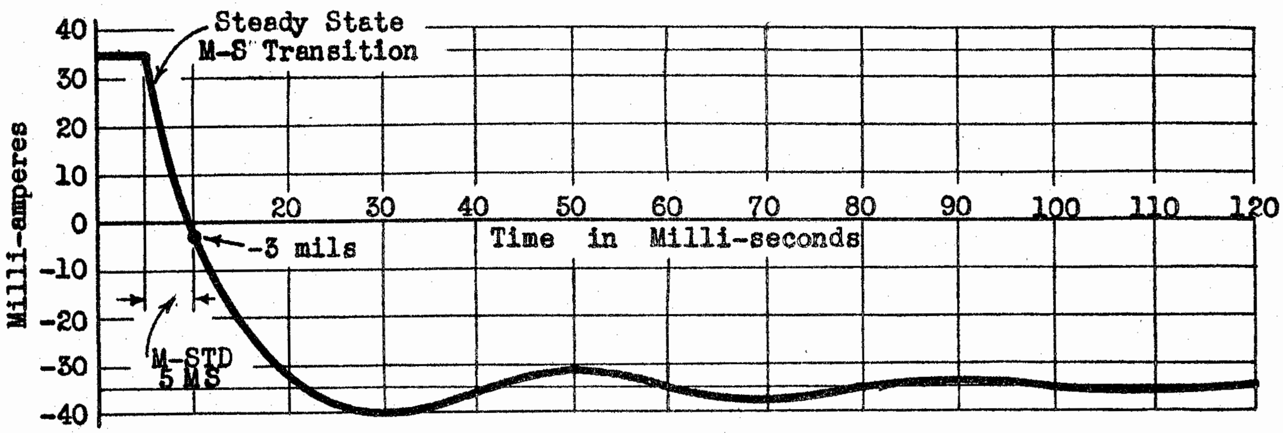
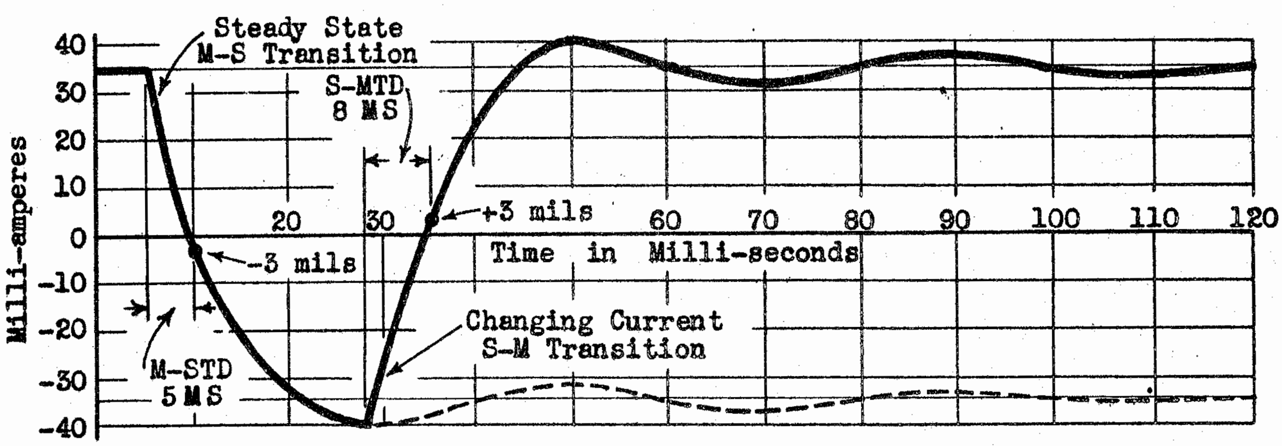
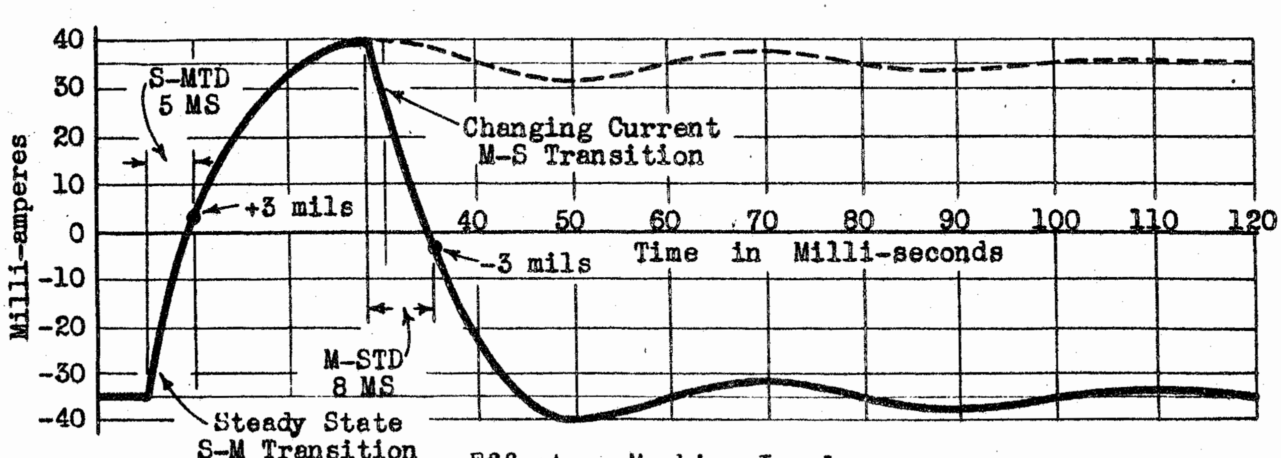


FIGURE XXI



Effect on Spacing Impulse

FIGURE XXII



Effect on Marking Impulse

FIGURE XXIII