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Effect of Telegraph Distortion on the Margins of Operation of Start-Stop Receivers

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Recent practical and theoretical investigations of the effect of signal distortion on the margins of operation of start-stop telegraph receivers have led to the development of improved methods of testing and adjusting receivers, have enabled criteria of distortion tolerance to be set up for subscribers' and monitoring receivers and regenerative repeaters, and have made possible the application of more convenient and accurate standards of telegraph transmission. This paper describes the causes of distortion occurring both externally and internally to the receiver and the effects of such distortion on the operating margins. Methods of determining the internal distortion of a receiver are described and some of the more important considerations involved in establishing distortion tolerance criteria are discussed.

DURING the past decade the proportion of Bell System telegraph service operated on a start-stop teletypewriter basis has shown a continuous increase. Whereas in 1930 about 65% of telegraph long-distance circuit mileage was manual Morse, the present proportion of teletypewriter and teletypesetter service stands at 92%. The rapid growth of teletypewriter switching facilities has been an important factor in this development.

Naturally, this situation has made increasingly important a thorough understanding of the factors which affect the performance of start-stop receivers. In the present paper, an effort will be made to show some relationships between signal distortion and the operating margins of start-stop receivers.

A properly designed start-stop telegraph receiver requires only a small portion of the time of each signal element to permit a selection to be made; i.e. to determine whether the signal element in question is marking or spacing. The remainder of the signal element gives an operating margin, and serves as a reserve to take care of imperfections in the receiver or distortions which the telegraph signals may suffer in their passage over lines and through repeaters. The greater the signal distortion is, the smaller will be the margin which remains in the receiver to overcome the effect of such factors as wear of parts, variation of adjustments, or differences in speed between transmitter and receiver.

A consideration of the effects of telegraph distortion on the margins of operation of start-stop receivers may well begin with a brief review of the nature and causes of the various types of distortion commonly experienced by telegraph signals. Telegraph distortion is generally considered to be divided into three types or components: bias, characteristic distortion, and fortuitous distortion.[1] The magnitude of the distortion is expressed in per cent of a unit pulse.

The Components of Telegraph Distortion

Bias, which is the simplest and most common component of distortion, may be positive (marking) or negative (spacing). Positive bias appears as a uniform lengthening of all marking pulses and an equal uniform shortening of all spacing pulses. Conversely, negative bias appears as a uniform lengthening of all spacing pulses and an equal uniform shortening of all marking pulses.

Bias is caused by an improper relation between the levels at which the relay or other receiving device responds and the steady-state marking and spacing levels of the signal. For example, Fig. 1(B) shows the signals of Fig. 1(A) as they might appear as a symmetrical wave on a line. With such a wave zero bias will be received when the currents at which the receiving relay operates from spacing to marking and from marking to spacing are symmetrically located with respect to the average of the steady-state marking and spacing currents. That is, zero bias will be received if the relay operates from spacing to marking and from marking to spacing at *B-B*, or if the relay operates from spacing to marking at *A-A* and from marking to spacing at *C-C*, or if the relay operates from spacing to marking at *C-C* and from marking to spacing at *A-A*. Negative bias will be received if the relay operates in both directions at *A-A*, and positive bias will be received if it operates in both directions at *C-C*.

In Fig. 1(C) is shown an unsymmetrical wave, in which the transient from space to mark is more rapid than that from mark to space. In this case, positive bias will result when the relay operates in both directions at *B-B* or at *C-C*, but no bias will result if the relay operates in both directions at *A-A*.

In the remaining diagrams of Fig. 1 it is assumed that the relay operates in both directions at a level midway between the steady marking and spacing levels. Fig. 1(D) shows a wave in which the transients are of such duration that the steady-state value is not attained in the shortest pulse length. It will be seen that the operation of the relay is delayed less after a short pulse than after a long one, and that this is true whether the pulse be marking or spacing. This effect is known as *negative characteristic distortion*, and it tends to shorten short pulses and lengthen long pulses. When a series of unbiased dots (called telegraph reversals) is transmitted, a steady-state condition is reached, in which the delays become equal on all transitions.

Hence, the signals are received as sent. When biased reversals are transmitted, the longer pulses are further lengthened and the shorter pulses are further shortened, causing the bias of the received signals to be of greater magnitude than that of the transmitted signals.

Fig. 1(E) shows a wave in which the current overswings the steady-state value, and fails to complete the return to steady state within the duration of the shortest pulse. It will be seen that the operation of a relay will be

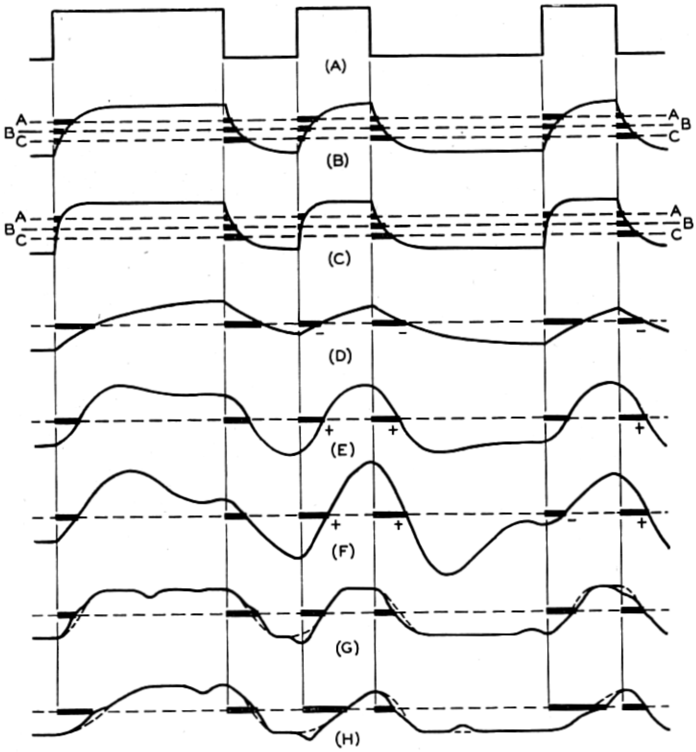

Fig. 1—Signal diagrams illustrating causes of distortion.

delayed more after a short pulse than after a long one, and that this is true whether the pulse in question be marking or spacing. This effect is known as *positive characteristic distortion*, and it tends to shorten long pulses and lengthen short ones. When unbiased reversals are transmitted, a steady-state condition is reached, in which the delays become equal on all transitions. Hence, the signals are received as sent. When biased reversals are transmitted, the shortening of the long pulses and lengthening of the short pulses causes the bias of the received signals to be less than that of the transmitted signals.

Fig. 1(F) shows a wave which performs a damped oscillation before settling to a steady state. This type of wave tends to produce a negative characteristic effect on certain transitions and a positive characteristic effect on others.

In general, if, on a given transition, the sum of all previous transients is such as to delay the operation of the receiving device, positive characteristic distortion is said to occur. If, on the other hand, the sum of all previous transients is such as to advance the operation of the receiving device, negative characteristic distortion is said to occur.

Bias and characteristic distortion, considered together, are called "systematic" distortion, because they occur with some regularity, and obey certain constant laws. There is another type of distortion that is not systematic. This is known as *fortuitous distortion.* It may be caused by the effect of various interfering currents on the receiving device. Fig. 1(G) shows a wave upon which interfering currents have been superposed. It will be noted that, for a given magnitude of interfering current, the more sloping the wave is in the region of the operating level of the receiving device, the greater will be the resulting fortuitous distortion.

Fortuitous distortion may also occur, in cases of extremely sloping wave-shape, due to the "indecision" of the receiving device, or, in other words, due to small variations of its effective operating level from signal to signal.

Fig. 1(H) shows a wave that is affected by interfering currents and in which the mark-to-space and space-to-mark transients have different slopes in the region of the operating level of the receiving device. The interfering current therefore causes fortuitous distortion of different magnitudes on mark-to-space and space-to-mark transitions. It will be shown later that distortion of this type affects a start-stop receiver in a particular manner which differs from the effect of distortion of the type illustrated in Fig. 1(G).

These, then are the generally-recognized components of telgraph distortion. More complicated effects ensue when characteristic distortion occurs on waves having dissimilar transients in the mark-to-space and space-to-mark directions, but a consideration of such phenomena is outside the scope of an elementary explanation of telegraph distortion, and is not necessary to an understanding of the effects of distortion on the margins of operation of start-stop receivers.

Start-Stop Displacements

The basic principles of operation of start-stop receivers have been described in previous articles[2,3]. A brief review of these principles will, therefore, suffice here.

The start-stop signal train consists of a start pulse, which is generally spacing, several selective pulses, each of which may be either marking or spacing, and a stop pulse which is generally marking. The receiving mechanism is started by the transition at the beginning of the start pulse, and its speed is such that it arrives at the stop position before the end of the stop pulse occurs, and remains stopped until the succeeding start transition takes place. Thus any speed difference between the transmitter and receiver is prevented from cumulating for more than the duration of one signal train.

Since the receiving device starts anew at each start transition, and the instants of selection of the selective pulses are spaced in time relative to the instant of starting, as shown in Fig. 2(A), the start transition acts as a basic reference point to which all other instants of time during the selective cycle may be referred.

The advances and delays of the transitions of the start-stop signal train from their normal times of occurrence, relative to the start transition, are known as "start-stop displacements." Fig. 2(B) shows the four types of displacement that may occur: *MB* or "marking beginning displacement," which is the advance of a space-to-mark transition (beginning of a marking pulse) relative to the start transition; *SB* or "spacing beginning displacement," which is the delay of a space-to-mark transition relative to the start transition; *SE* or "spacing end displacement," which is the advance of a mark-to-space transition (end of a marking pulse) relative to the start transition; and *ME* or "marking end displacement," which is the delay of a mark-to-space transition relative to the start transition.

Effect of Bias on Displacement

Since bias affects all pulses alike, and since in the usual start-stop receiver the start transition is mark-to-space, the succeeding mark-to-space transitions of the signal train are not shifted relative to the start transition. Hence the total effect of the bias appears on the space-to-mark transitions. Positive bias causes MB displacement alone, as shown in Fig. 2(C). Negative bias causes SB displacement alone, as illustrated in Fig. 2(D).

The total range through which the selective periods may be shifted, relative to the start transition, without producing an incorrect selection is known as the orientation range of the receiver. Its limits are read on a scale calibrated from 0 to 100 in per cent of a unit pulse-length. Figure 3 is a graph of teletypewriter orientation range versus input signal bias, for a receiver whose range is from 10 to 90 on unbiased signals. Diagrams of this type are called "bias parallelograms."

Effect of Characteristic Distortion on Displacement

Characteristic distortion does not affect all pulses of miscellaneous signals alike, because, as explained above, the effect on each transition depends upon the signal combinations that have previously been sent over the circuit. Hence the start transition and the transitions occurring between selective pulses are, in general, delayed by varying amounts. All four types of displacement shown in Fig. 2(B) occur, depending upon whether the transition in question is mark-to-space or space-to-mark and whether it has been

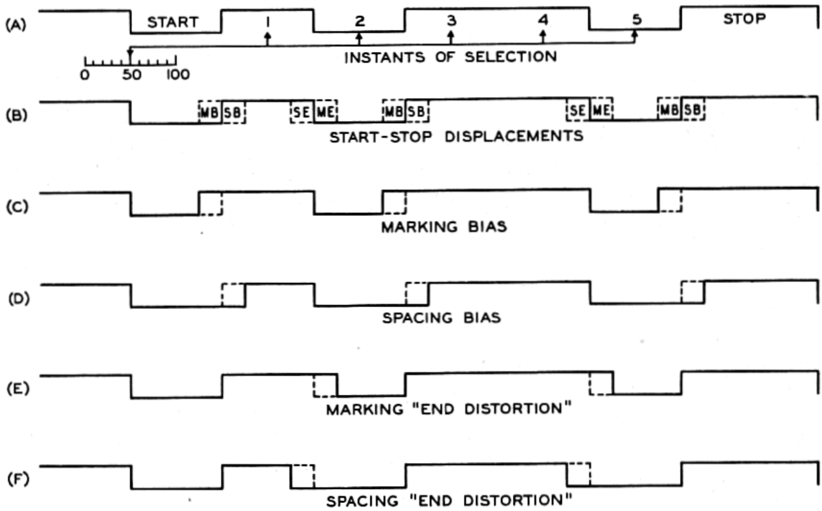

Fig. 2—Diagrams illustrating start-stop displacements.

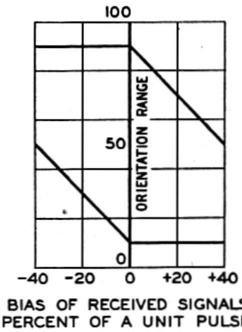

Fig. 3—The bias parallelogram.

delayed more or less than the start transition. For example, if a space-to-mark transition is delayed less (on an absolute time basis) than the start transition, *MB* displacement occurs; if more, *SB* displacement. If a mark-to-space transition is delayed less than the start transition, *SE* displacement occurs, if more, *ME* displacement.

Maximum Displacements Caused by Characteristic Distortion

The *maximum MB displacement* will occur when the start transition is delayed as much as possible and some space-to-mark selective transition is delayed as little as possible. This will take place, in the case of negative characteristic distortion, when as long a marking signal as is possible precedes the start transition and a combination of pulses as predominantly marking as possible precedes the space-to-mark transition in question. A marking signal sufficiently long to permit a steady state to be attained, followed by any signal train having the first selective pulse marking satisfies this condition, as shown at "*X*" in Fig. 4(B), but it will be noted that the *MB* displacement extends into the start pulse, where, in the case of a start-stop receiver, no selection is made. Hence it will not affect the margin of operation of the receiver, provided it is not so large as to prevent the receiver from starting. This particular distortion will, however, affect a start-stop distortion measuring set[4] or regenerative repeater which is so designed that measurements or selections are made during both the selective pulses and the start pulse. As far as a start-stop teletypewriter, in which no selection occurs during the start pulse, is concerned, the *maximum MB* displacement occurs on the fourth transition of the letter *K* following as long a marking signal as possible, as shown at "*Y*" in Fig. 4(B). This space-to-mark transition, being preceded by a spacing pulse of unit length which, in turn, was preceded by signals which are predominantly marking, is delayed for a short time, whereas the mark-to-space start transition, which was preceded by a long marking signal, is delayed for a longer time. Except in the case of unusual wave forms, there will be very little difference between the magnitudes of the displacements shown at "*X*" and "*Y*" unless they are both very large, since the wave will usually attain steady state during the steady marking interval constituted by the first, second, third and fourth selective signal intervals.

In the usual case of positive characteristic distortion, the maximum *MB* displacement will occur when the start transition is preceded by a combination of pulses as predominantly spacing as possible, and some space-to-mark transition is preceded by the longest spacing signal possible in the start-stop code. These conditions are met by repeated, "BLANK" signal trains, shown in Fig. 4(E).

The *maximum SB displacement* will occur when the start transition is delayed as little as possible, and some space-to-mark selective transition is delayed as long as possible. This takes place, in the case of negative characteristic distortion, when a combination of pulses as predominantly spacing as possible precedes the start transition and the longest possible spacing signal precedes the space-to-mark transition in question. As noted in the

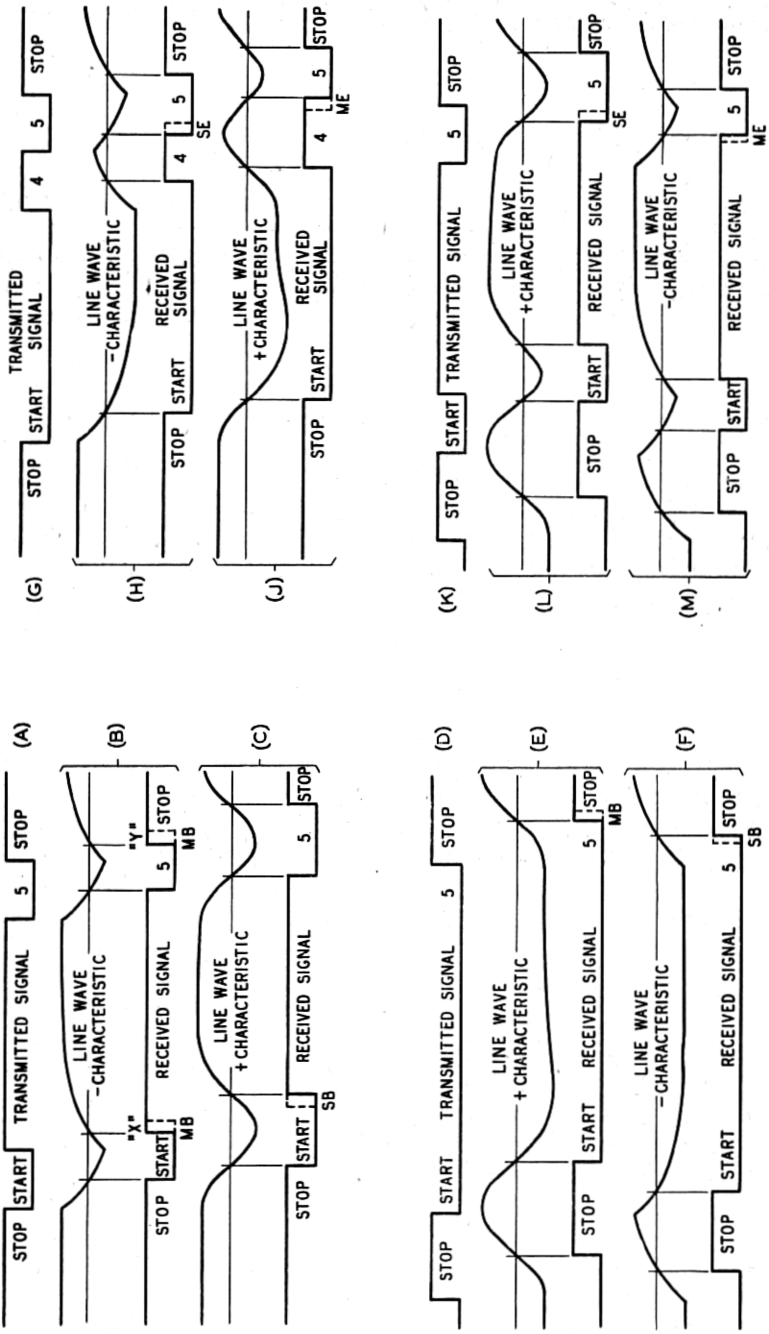

Fig. 4—Characteristic distortion.

preceding paragraph, repeated "BLANK" signals satisfy this description. Fig. 4(F) illustrates the effect of negative characteristic distortion on this signal combination. It will be noted that the resulting *SB* displacement extends into the stop pulse, where usually no selection takes place, and hence it would not affect the margin of operation of the start-stop receiver except, of course, in the case of a type of receiver, such as a regenerative repeater, in which selection of the stop pulse does occur. For the case of a receiver which does not select the stop pulse, the maximum *SB* displacement affecting the margin of operation occurs at the second transition of the letter "*T*" following repeated "BLANK" signals. Except in the case of very large distortions, this displacement will be of nearly the same magnitude as that illustrated in Fig. 4(F).

In the usual case of positive characteristic distortion, the maximum *SB* displacement will occur when the start transition is preceded by a long marking signal and some space-to-mark selective transition is preceded by a combination of pulses as predominantly marking as possible. As noted previously, this description is satisfied by a sufficiently long marking signal to permit the attainment of steady state, followed by any signal train having the first selective pulse marking. Figure 4(C) illustrates the effect of positive characteristic distortion on this type of signal.

The *maximum SE displacement* will occur when the start transition is delayed as much as possible and some mark-to-space selective transition is delayed as little as possible. This will take place, in the case of negative characteristic distortion, when a long marking signal precedes the start transition and a combination of pulses as predominantly spacing as possible precedes the mark-to-space transition in question. This description is answered by a long marking signal followed by a "CARRIAGE RETURN" signal train, as shown in Fig. 4(H). The *SE* displacement occurs at the end of the fourth selective pulse.

In the usual case of positive characteristic distortion, the maximum *SE* displacement will occur when the start transition is preceded by a combination of pulses which is as predominantly spacing as possible, and some mark-to-space selective transition is preceded by the longest possible marking signal. This description is satisfied by repeated "BLANK" signal trains followed by the letter "*K*," and, as shown in Fig. 4(L), the *SE* displacement occurs at the end of the fourth selective pulse.

The *maximum ME displacement* will occur when the start transition is delayed as little as possible and some mark-to-space selective transition is delayed as much as possible. This will take place, in the case of negative characteristic distortion, when the start transition is preceded by a combination of pulses which is as predominantly spacing as possible, and some mark-to-space selective transition is preceded by the longest possible marking signal. As noted in the previous paragraph, the letter "*K*" preceded by repeated "BLANK" signal trains satisfies this description, and the *ME* displacement is as illustrated in Fig. 4(M).

In the usual case of positive characteristic distortion, the maximum *ME* displacement will occur when the start transition is preceded by a long marking signal, and some mark-to-space selective transition is preceded by a combination of pulses as predominantly spacing as possible. As seen previously, this description is answered by a long marking signal followed by a "CARRIAGE RETURN" signal train. Fig. 4(J) illustrates the *ME* displacement.

Effect of Characteristic Distortion on Orientation Limits

In the usual start-stop system which employs a stop pulse longer than the unit selecting pulse, characteristic distortion affects the upper and lower limits of orientation differently. This effect is due mainly to the longer stop pulse, although the fact that the start transition is always mark-to-space contributes to the effect.

In the case of negative characteristic distortion, the displacements (*MB* and *SE*) which affect the upper end of the orientation range are those in which the start transition suffers a long delay and a selective transition suffers a short delay. The delay of the start transition can be quite large, since it may be preceded by a long marking pulse. Moreover, the delay of the selective transition may be very short, since the pulse which precedes the transition can be of unit length, and this, in turn, may be preceded by a signal of the opposite type which may be of as much as four units duration. Hence these displacements, being the difference between a large and a small delay, are large.

On the other hand, the displacements, *SB* and *ME*, which affect the lower end of the range are those in which the start transition suffers only a fairly short delay and a selective transition suffers a long delay. The delay of the start transition can not be very short for two reasons: first, the start pulse cannot be preceded by a steady spacing pulse; and second, what is of more importance, the stop pulse is of greater than unit length. The delay of a selective transition can be long, as when the transition is preceded by a pulse of four or five units in length. (This delay may not be so long as that suffered by a start transition which follows a steady-state marking condition, but it is not much shorter.) Hence the *SB* and *ME* displacements, being the difference between a long selective transition delay and only a fairly short start transition delay, are smaller than the *MB* and *SE* displacements.

For this reason negative characteristic distortion affects the upper end of the range more than it does the lower.

In the case of what we have termed "the usual type of positive characteristic distortion," the displacements (*SB* and *ME*) which affect the lower end of the orientation range are those in which the start transition suffers a short delay and a selective transition suffers a long delay. The delay of the start transition can be quite short, since it may be preceded by a long marking signal. Moreover, the delay of the selective transition may be very long, since the pulse which precedes the transition can be of unit length and this, in turn, may be preceded by a signal of the opposite type which may be four or more units in length. Hence these displacements, being the difference between a short and a long delay, are large.

On the other hand, the displacements (*MB* and *SE*) which affect the upper end of the range are, in this type of distortion, those in which the start transition suffers only a fairly long delay and a selective transition suffers a short delay. The delay of the start transition cannot be very short for the two reasons mentioned previously. The delay of the selective transition can be short, as when the transition is preceded by a pulse four to six units in length. Hence the *MB* and *SE* displacements, being the difference between a short selective transition delay and only a fairly long start transition delay, are smaller than the *SB* and *ME* displacements.

For this reason positive characteristic distortion of this type affects the lower end of the range more than it does the upper.

In the case of a wave which oscillates, causing positive characteristic distortion on some transitions and negative on others, no such general statements as are made above are applicable. In practice, cases have been observed in which one end of the orientation range was cut and the other was actually extended.

Due to the fact that characteristic distortion delays the start transition by different amounts from character to character, it causes the character length to vary during continuous automatic transmission. The maximum variation in character length is roughly of the same magnitude as the maximum displacement affecting the selective pulses.

Effect of Fortuitous Distortion on Displacement

Fortuitous distortion causes the start transition to be delayed more or less than normal, and has the same effect on the selective transitions. Since it is usually equally probable that the maximum fortuitous effects will occur on mark-to-space or space-to-mark transitions and will increase or decrease their delay, this type of distortion generally produces the four types of displacement in equal magnitude, and this magnitude is equal to the maximum increase or decrease in the length of pulse.

An exception to the above statement occurs when the mark-to-space and space-to-mark transients give the wave different slopes at the point where the receiving device operates. Then the magnitude of the fortuitous effect is different on mark-to-space and space-to-mark transitions. If the effect is greater on the space-to-mark transitions, *MB* and *SB* displacements are greater than *SE* and *ME*. If the opposite, *SE* and *ME* are greater than *MB* and *SB*. In all cases, however, the orientation range is reduced equally at both ends.

Fortuitous distortion also lengthens and shortens the character since it does not affect all transitions alike.

Internal Distortion

Telegraph signal distortion may occur within the start-stop receiver, and it should be expected that the components of distortion will have the same effect on the margins of operation as the same components external to the receiver. Consequently, it should be possible to determine the magnitudes of the various components of internal distortion by their effects on the margins of operation.

As mentioned previously, the upper end of the orientation range is determined by whichever of the displacements *MB* and *SE* is the greater; and the lower end by whichever of the disp'acements *SB* and *ME* is the greater. To discover the magnitude of the smaller type of displacement it is necessary to reduce the larger displacement by distorting the transmitted signals. For example, if a receiver has a large internal marking bias, the upper limit of orientation is determined by *MB* displacement, and hence the amount of *SE* displacement caused by internal distortion is concealed. However, by transmitting signals affected by *SB* displacement (in other words, signals biased to spacing), the total *MB* displacement is decreased until it is less than the internal *SE* displacement, whose effect on margin can then be found. Thus the internal distortion may be determined by observing the effect of external distortion on the margins of operation.

It is convenient to regard any start-stop receiver as a theoretically perfect receiver affected by certain types of internal distortion. The internal distortion is usually considered to be composed of bias, "skew" (defined later) and fortuitous distortion. (The internal characteristic distortion is generally included in "internal fortuitous distortion," since it is usually very small, and a fairly elaborate testing procedure is required to separate its effects from those of internal fortuitous distortion.) Internal bias and internal fortuitous distortion are of the same nature as the external effects previously described. Skew is said to occur when there exists the type of distortion, previously mentioned, in which the fortuitous effect on space-to-mark transitions differs in magnitude from that on mark-to-space transitions. When the former is greater the skew is said to be positive; when the latter, negative. Hence in positive skew, *MB* and *SB* displacements tend to be larger; in negative skew, *ME* and *SE* displacements tend to be larger. The magnitude of the skew is defined as the difference between the magnitudes of the fortuitous effects on space-to-mark and mark-to-space transitions.

Figure 3 showed the bias parallelogram of a receiver which had a local margin of 10 to 90. Figure 5 shows the bias parallelogram of a perfect

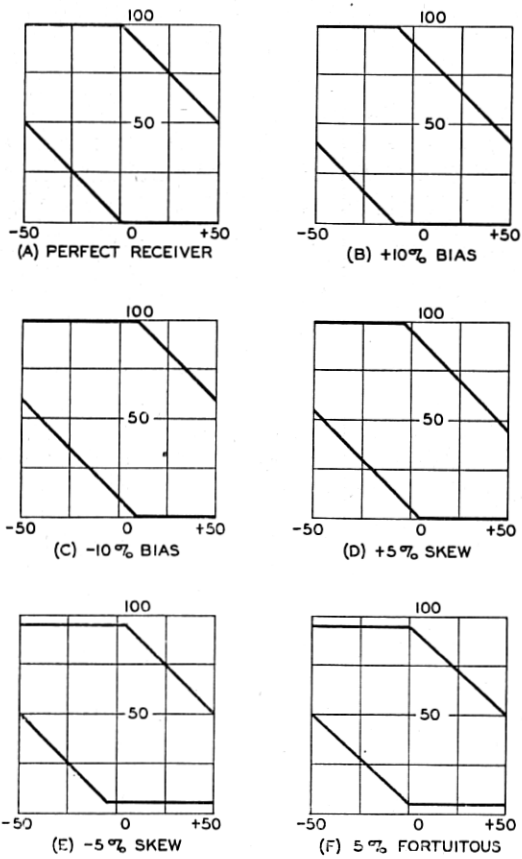

Fig. 5—Effect of internal distortion on bias parallelogram.

receiver and illustrates how the components of internal distortion affect the shape of the bias parallelogram. The skewing of the corners of the parallelograms shown in Fig 5(D) and (C) led to the use of the term "skew" for this effect.

In telegraph transmission systems skew may be caused by the effect of interference on a wave which has different slopes during mark-to-space and space-to-mark transitions. It may also result from an equivalent electromechanical effect in a start-stop receiver, as will be described later.

Measurements of Receiver Distortion Tolerance

In measurements of the distortion tolerance of start-stop receivers there is used a distributor which is arranged to transmit signals having any of the four types of displacement *MB*, *SB*, *SE* and *ME*. Positively biased signals are transmitted for *MB* displacement and negatively biased signals for *SB* displacement. The test signals having *SE* or *ME* displacement are said to be affected by "end distortion." These differ from any experienced on transmission circuits in that only the mark-to-space transitions of the selective pulses are shifted relative to the start transition, being delayed for *ME* displacement and advanced for *SE* displacement, as shown in Fig. 2(E) and (F). "End distortion" simulates the mark-to-space displacements produced by characteristic and fortuitous distortion, and it has been found in practice that it yields results which enable a receiver's tolerance to these components of distortion to be predicted with a high degree of accuracy.

When fixed values of displacement are transmitted, the limits of orientation are measured by means of the range scale of the receiver. Alternately, a distributor may be used in which the magnitude of displacement may be continuously varied, and this enables measurements of internal distortion to be conducted with the orientation fixed, or, indeed, on receivers having no means or a limited means of varying the orientation.

Orientation Settings for Best Tolerance to Test Distortions

Obviously, the best orientation setting is that which permits the receiver to tolerate the greatest amount of any distortion which is expected. If all four types of displacement are considered equally likely, the orientation should be set at that point at which the minimum tolerance to any type of displacement is as large as possible. For example, consider a receiver which, with an orientation setting of 49, has the following tolerances to test displacements:

MB	44
SB	38
SE	42
ME	44

Let the orientation setting be raised 2 per cent, to 51. Then the tolerances are as follows:

MB	42
SB	40
SE	40
ME	46

The shift of orientation has increased the minimum tolerance (spacing bias) from 38 to 40. Any further shift would make the tolerance to spacing "end distortion" less than the tolerance to spacing bias. This setting is called the "center of fortuitous distortion tolerance," since at this point the receiver will tolerate the maximum amount of fortuitous distortion.

If, on the other hand, bias is considered more probable than distortions which produce "end distortion" effects, the orientation might be adjusted to the point at which the tolerances to marking and spacing bias are equal. For example, suppose the orientation setting of the receiver under consideration were raised 1 per cent to 52. The tolerances would then be

MB	41
SB	41
SE	39
ME	47

This setting is called the "center of bias tolerance," since at this point the receiver will tolerate the maximum amount of bias regardless of the sign of the bias.

There is one more setting that is of interest. It is that at which the tolerances to marking and spacing "end distortion" are equal. Suppose the orientation of the receiver were lowered 4 per cent to 48. The tolerances would then be

MB	45
SB	37
SE	43
ME	43

This setting is called the "center of end distortion tolerance," since at this point the receiver will tolerate the maximum amount of "end distortion" regardless of its sign.

Calculation of Components of Internal Distortion

Figure 6 illustrates how the components of internal distortion are determined from measurements of distorted signals. Each diagram shows a portion of a teletypewriter character consisting of a start pulse, a marking selective pulse and a spacing selective pulse. The solid lines show an undistorted signal. The dashed lines show the displacement of a transition due to internal bias. The shaded area defines the fortuitous effect which is skew; that is, the transition in question may fall anywhere within the shaded area during repeated transmission of the signal. The arrows below the figure show the extent of the displacement occurring on each transition due to the presence of a given displacement of the transmitted signals. The four types of displacement are of equal magnitude D. The arrows above the diagram designated L_B and L_E show the lower limits of orientation with, respectively, spacing bias and marking "end distortion" (SB and ME displacements). The arrow U_B and U_E show the upper limits or orientation with, respectively, marking bias and spacing "end distortion" (MB and SE displacements).

Figure 6(A) shows the case of positive internal bias and positive skew; Fig. 6(B), positive bias and negative skew; Fig. 6(C), negative bias and positive skew; and Fig. 6(D), negative bias and negative skew. The following relationships hold, bearing in mind that $MB = SB = SE = ME = D$:

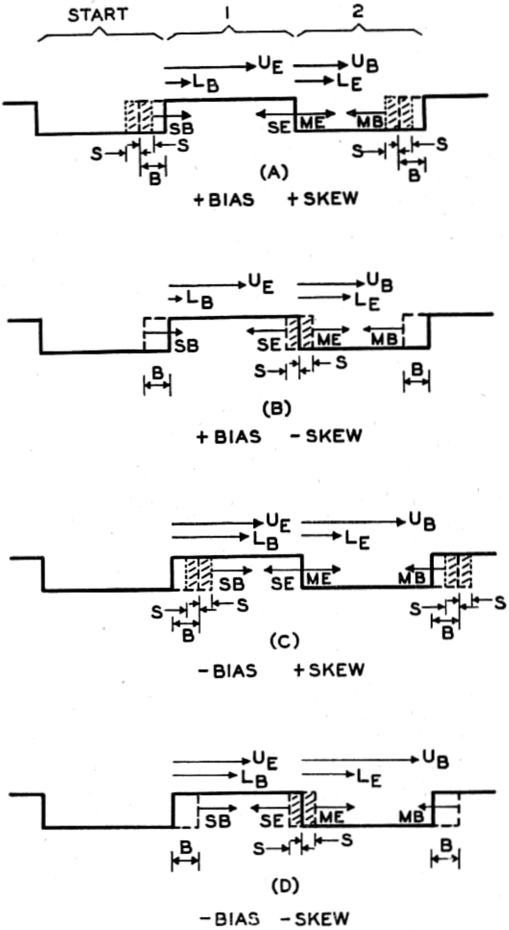

Fig. 6—Use of distorted test signals in measuring internal distortion.

Fig.	*Bias*	*Skew*	L_B	U_B	L_E	U_E
(A)	+	+	$D+s-b$	$1-b-s-D$	D	$1-D$
(B)	+	−	$D-b$	$1-b-D$	$D+(-s)$	$1-(-s)-D$
(C)	−	+	$D+s+(-b)$	$1+(-b)-s-D$	D	$1-D$
(D)	−	−	$D+(-b)$	$1+(-b)-D$	$D+(-s)$	$1-(-s)-D$

In any figure $L_B - L_E = s - b$
and $U_B - U_E = -s - b$
Adding and subtracting, we find that:

$$\text{Internal bias} = \frac{U_E + L_E}{2} - \frac{U_B + L_B}{2}$$

$$\text{Skew} = \frac{U_E - L_E}{2} - \frac{U_B - L_B}{2}$$

Any $\frac{U + L}{2}$ is the center of an orientation range. Hence it may be stated that the internal bias is equal to the difference between the *centers* of tolerance to "end distortion" and bias. It will also be noted that any $\frac{U - L}{2}$ is half of an orientation range. When the test signal displacements determining the range limits are equal, the amount of tolerance equals $\frac{U - L}{2} + D$ (assuming no curvature in the distortion parallelogram). Hence the skew is equal to the difference between the *amounts* of tolerance to "end distortion" and bias.

For example, the receiver cited previously has the following characteristics

$$\text{Internal bias} = 48 - 52 = -4\%$$
$$\text{Skew} = 43 - 41 = +2\%$$

Incidentally, this means that internal bias does not reduce the total bias tolerance of a receiver, but merely shifts the center of bias tolerance with relation to the center of "end distortion" tolerance. Hence the effects of internal bias may be compensated for, as far as the bias tolerance of the receiver is concerned, by setting the orientation at the center of bias tolerance. However, internal bias does reduce the minimum "end distortion" tolerance of a receiver whose orientation is adjusted to the center of bias tolerance.

"Switched" Bias

When biased signals are produced by the action of a biasing current on a relay driven by a symmetrical wave, and the sign of bias is suddenly reversed during the transmission of a teletypewriter character, all the succeeding transitions of that character are affected, not by bias, but by "end distortion." This is shown in Fig. 7, of which (A) shows the original unbiased signals, (B) shows the signals affected by bias which changes from positive to negative at time T, and (C) shows the effect on the same signals when the bias is changed from negative to positive.

Signals such as these, in which the sign of bias is changed at intervals, are said to be affected by "switched bias." Since all four types of displacement are present in equal magnitude in switched bias signals, the effect on a start-stop receiver resembles that of fortuitous distortion. Thus the center of switched bias tolerance is the center of fortuitous distortion tolerance and the amount of switched bias tolerance is the amount of fortuitous distortion tolerance. This center is also the center of orientation in a receiver having no curvature or symmetrical curvature of the displacement-vs.-orientation-limit characteristic. The switched bias tolerance is, of course, one-half the orientation range in a receiver having no curvature of the characteristic.

In actual field practice, switched bias signals, applied at a central office, are used as a test of tolerance of the teletypewriter at a subscriber station in combination with the subscriber loop. They provide a more accurate measure of transmission capabilities than an orientation range measurement with undistorted signals from the central office, since not only is the curvature of the distortion parallelogram taken into account, but the character

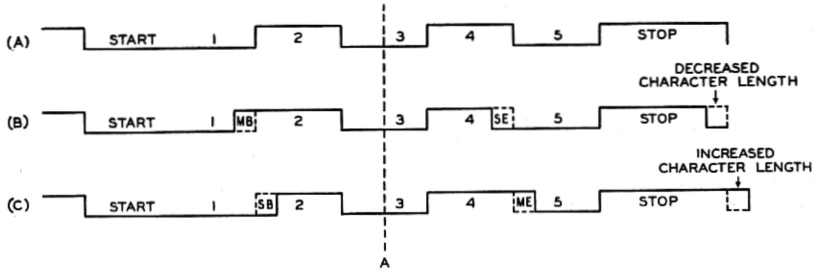

Fig. 7—Switched bias.

length changes in much the same manner as in signals affected with characteristic or fortuitous distortion.

The components of internal distortion of a receiver may be estimated from bias and switched bias measurements, but they cannot be accurately specified thereby. Figure 8 illustrates the difficulty in separating bias and skew by means of measurements of the difference between the amounts and centers of tolerance to steady bias and switched bias. Figure 8(A) shows the bias and end displacement parallelograms of a receiver having +24 per cent bias and +16 per cent skew. The center of tolerance to switched bias is 4 per cent above the center of steady bias tolerance and the steady bias tolerance is 4 per cent greater than the switched bias tolerance. Figure 8(B) shows the parallelograms of a receiver having +4 per cent bias and −4 per cent skew. Again, the center of tolerance to switched bias is 4 per cent above the center of steady bias tolerance and the steady bias tolerance is 4 per cent greater than the switched bias tolerance.

Of course, the components of internal distortion can be measured by observing both ends of the orientation range with positive and negative bias rather than observing the upper end with positive bias and the lower end with negative bias. This type of measurement is merely equivalent to using a fairly large percentage of bias and zero per cent of end distortion. The disadvantage of this measurement is that no account is taken of the curvature

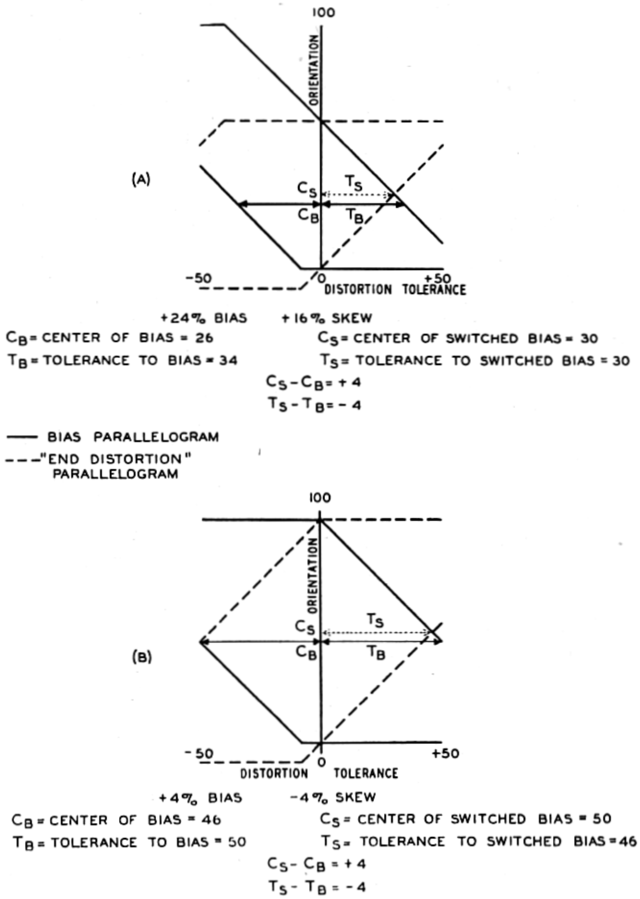

Fig. 8—Switched bias measurements

of the end displacement parallelogram, and hence the indicated values of tolerance may not be an accurate measure of the receiver's ability to receive distorted signals.

Internal Fortuitous Distortion

It is usually considered, in measurements of miscellaneous signals, that the difference between the maximum distortion tolerance and 50 per cent (the latter being the tolerance of a perfect receiver) is due to internal fortuitous effects, even though part of it may be due to the effects of internal characteristic distortion. Hence the internal fortuitous distortion is usually defined as the difference between 50 and the tolerance to bias or end distortion, whichever of the latter may be the larger.

For example, in the sample receiver considered on page 220, the internal fortuitous distortion is:

$$50 - 43 = 7 \text{ per cent}$$

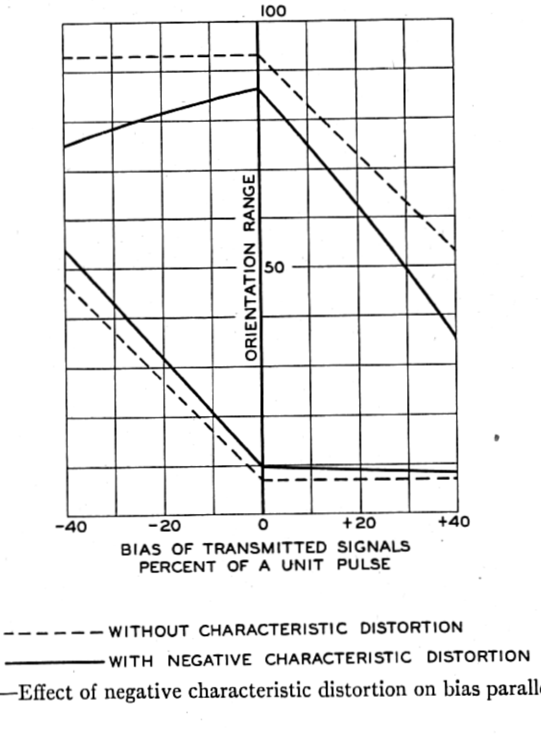

Fig. 9—Effect of negative characteristic distortion on bias parallelogram.

Internal Characteristic Distortion

In practice it is found that the relation between displacement and reduction of margin is sometimes not strictly linear. Especially at large values of displacement, the reduction in margin is often greater than the displacement causing it. This effect is due to internal characteristic distortion, which causes an increase in the distortion of shortened pulses. Internal characteristic distortion, like any other form of characteristic distortion, is caused by the failure of some circuit or mechanical element to attain steady state before the occurrence of a succeeding transition. Figure 9 shows an example of the bias parallelogram of a receiver suffering from internal negative characteristic distortion.

Some Considerations Involved in the Measurement and Adjustment of Start-Stop Receivers

Because of the effects of characteristic distortion, it cannot be assumed that the ultimate tolerance of a receiver is equal to the sum of the displacement of the received test signals and one-half the remaining orientation range, especially if the latter is large. To attain accurate results, the ultimate tolerance must be measured with the orientation adjusted to the center of tolerance.

For the same reason (the curvature of the "parallelogram" caused by internal characteristic distortion) measurements of internal distortion on a receiver which is, itself, to be used to measure distortion should be made with displacements of approximately the same magnitude as the distortions which the receiver is to measure. In a receiver which is to be used to measure small distortions, we are interested in the properties of the linear portion of the parallelograms. Hence we measure the receiver's internal bias and skew using small amounts of displacement in the measuring signals. The internal fortuitous distortion may generally be neglected, since it does not affect the shape, but only the size, of the distortion-vs-margin characteristic.

On the other hand, in a receiver which is to be used for receiving signals we are interested not so much in the shape of the characteristic as in the ultimate tolerance to telegraph distortion at an optimum setting of the orientation mechanism. For this reason, a receiver destined for service use is best tested with signals containing fairly large displacements. Internal fortuitous distortion is deleterious in such a receiver, since it decreases the tolerance to displacement of all kinds. Skew, depending upon its sign, affects the tolerance to either space-to-mark or mark-to-space displacements.

It should be realized that the removal of skew does not necessarily improve a service receiver. In the case of bias or characteristic distortion the introduction of distortion of a given sign will remove internal distortion of the opposite sign, and thus improve the performace of the receiver. But since skew is the difference between two fortuitous distortion effects, it may be removed either by reducing the larger or increasing the smaller effect. The former procedure will increase the receiver's total tolerance to distortion, whereas the latter will reduce it.

In practice bias tolerance is generally considered to be more desirable than "end distortion" tolerance. The reason for this is that most transmission circuits suffer from some bias (of unpredictable sign and amount) which uses up some of the receiver's bias tolerance but none of its "end distortion" tolerance. This is why the orientation of a service receiver is generally adjusted to the center of bias tolerance, and small amounts of internal bias or negative skew are not considered objectionable, since they do not affect the tolerance to bias at the center of bias tolerance. By the same token, the presence of positive skew, which indicates a lowered bias tolerance, usually calls for a readjustment of the receiver to reduce the fortuitous effect on the space-to-mark transitions. As explained above, removing the skew by introducing a fortuitous effect on the mark-to-space transitions will not, of course, improve the bias tolerance.

It is the present practice in the field to specify a minimum bias tolerance about 5 per cent greater than the minimum permissible "end distortion" tolerance, the orientation being adjusted to the center of bias tolerance for both measurements.

Some Causes of Internal Distortion

Up to this point internal distortion has been considered without regard to its probable causes. The more obvious causes will be found to be analogous to those which produce equivalent distortions in telegraph transmission circuits.

Bias will result when an element (whether electrical, mechanical, or electronic) of a receiver possesses dissymmetry toward marking or spacing. For example, a mechanical element may travel more slowly from spacing to marking than from marking to spacing and thus cause spacing bias, or its range of travel may be divided unequally into marking and spacing portions, thus producing an equivalent effect.

Characteristic distortion will result when an element (whether electrical or mechanical) of a receiver fails to attain a steady state before being acted upon by a succeeding transition, or otherwise depends, in its action, upon the previous history of the signal train. An example of characteristic distortion is found in the 20-milliampere holding magnet selector when it is equipped with a resistive shunt. In this type of selector the armature is actuated by a cam, which presents it to the pole-face at about the middle of each pulse, and then disengages it. The armature is then free to release or remain operated, according as the received pulse is spacing or marking. The shunt that is normally used presents so low an impedance to the magnet winding that the motional impedance effect which is produced by the sudden mechanical presentation of the armature to the pole-faces causes a sizeable reduction in the magnet current. In the case of a short marking pulse, the current fails to attain steady state before the next mark-to-space transition occurs. The magnet therefore releases sooner than it does at the end of a long marking pulse, during which the current has had time to attain steady state. It will be seen that this is really a characteristic distortion effect, since it is due to a failure to reach steady state and depends upon the previous history of the signal train. However, when miscellaneous signals are being received the effect appears similar to a fortuitous distortion occurring on mark-to-space selective transitions, and hence it is usually thought of as negative skew.

Fortuitous distortion will result when an element is irregular in its action, and if such action is more irregular on one type of transition than on the other, the result will appear as skew. For example, irregular action of the receiving clutch affects the selector alike in regard to all selective transitions, and appears as internal fortuitous distortion. Another source of internal fortuitous distortion is the period of indecision that occurs during the passage of a selective element past a locking member, at which time the choice between marking and spacing is largely fortuitous.

A common cause of skew in teletypewriters may occur in the following manner: If the armature stops are so adjusted that, for example, the armature travel is greater on the marking side than on the spacing side of the armature lock, positive internal bias results. If, now, this bias is compensated for by so adjusting the armature air-gap and retractive spring tension as to cause the receiving magnet to operate in a negatively biased manner (rather than by correcting the improper armature travel), the armature will be forced to operate in a region of the operating wave that is more sloping than the region in which it releases. Hence, it will operate more irregularly than it releases, and thus will be affected by positive skew.

Selector Action

Over and above the sources of internal distortion which are analogous in effect to sources of distortion encountered in telegraph transmission circuits, there is another whose action in causing internal distortion is not so obvious as those just described. This source of internal distortion may be termed "*selector action*," and it depends upon the relation between the operating time of a selector element and the period of time allowed for said element to act. For the purpose of explaining the effect of time relations within the selector on internal distortion, selector mechanisms may be classified as of three basic types: M, S, and P.

In a mechanism of type M each selector is initially in the spacing condition and either remains spacing or operates to marking when subjected to the action of the corresponding received signal element. When it attains the marking condition it becomes locked for the duration of the character. Early types of start-stop printers having an individual selector magnet for each pulse of the code and employing a separate receiving distributor,[2] are illustrative of type M.

In a device of type S each selector is initially in the marking condition and either remains marking or operates to spacing when subjected to the action of the corresponding received signal element. When it attains the spacing condition it becomes locked and cannot again operate to marking during that character. The Siemens-Halske five-selector teleprinter[5] is an example of this type.

In a mechanism of type *P*, the selector may be in either the marking or spacing condition initially, according to the type of the previous signal element to which it has responded. When subjected to the action of a received pulse the selector may go in either direction, and it remains responsive to the action of the signal during the entire selecting interval. The No. 14 and No. 15 teletypewriters[2] (not equipped with holding magnet selector) of the Teletype Corporation are examples of type *P*.

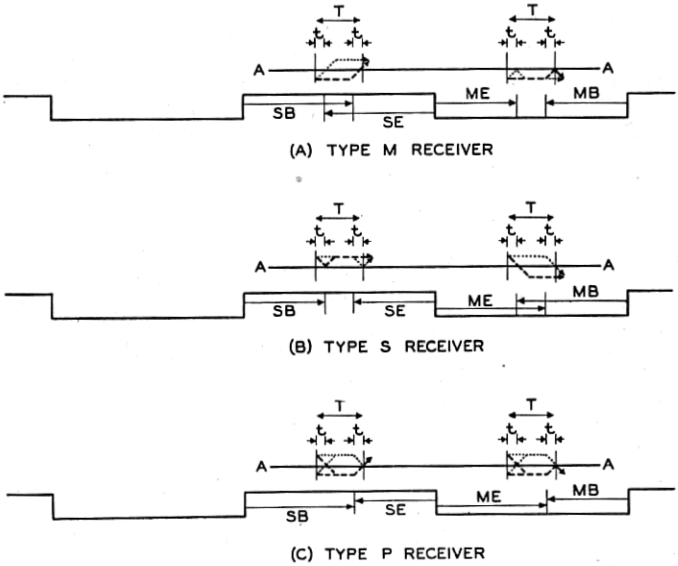

Fig. 10—Effect of selector action on internal distortion.

Figure 10 (A) illustrates the action of a type *M* selector. A portion of a teletypewriter character is shown, consisting of the spacing start pulse, a marking first selective pulse and a spacing second selective pulse. The undistorted signal is shown in solid lines. The maximum amounts of marking and spacing bias that the receiver will tolerate are shown by dashed lines and are designated *MB* and *SB*. The limiting amounts of marking and spacing end displacement are shown by dotted lines and are designated *ME* and *SE*. Above the signal train is shown a schematic representation of the action of the selective system. The periods of time *T* are those during which the selector is subject to the action of the received signal, and *t* is the time that the selector must be subjected to the operative force in order that it operate. The line A-A indicates the boundary between the marking and spacing positions of the selectors. In this type of receiver, as mentioned previously, when the selector crosses to the marking or upper side of line A-A it becomes locked and cannot again go to spacing even though the signal should subsequently become spacing during the selective period T.

It will be noted that the limits of end displacement tolerance occur at time t after the beginning of the selective period. This instant is sometimes called the "instant of decision for end displacement." On the other hand, the limiting tolerances to bias are determined at a time t before the end of the selective period, sometimes known as the "instant of decision for bias." If the selective periods were advanced relative to the start transition by lowering the orientation until the bias tolerances were equal, the instants of decision for bias would correspond with the center of bias tolerance. If, then, the selective periods were delayed, by raising the orientation, by an amount $T - 2t$, the instants of decision for end displacement would correspond with the center of end displacement tolerance. Since the difference between the center of end displacement tolerance and the center of bias tolerance is equal to the internal bias of the receiver, it will be obvious that the internal bias is also equal to the difference between the instant of decision for bias and the instant of decision for end displacement. In this type of receiver the internal bias is $T - 2t$, and will be positive, zero, or negative according as $2t$ is less than, equal to, or greater than T.

Figure 10 (B) shows the action of a type S selector. Here the instant of decision for bias occurs at time t before the end of the selective period and that for end displacement at time t after the beginning of the selective period. Hence, the internal bias is equal to $2t - T$.

The action of a type P receiver is illustrated in Fig. 10 (C). It is assumed in this figure that the selector operates toward marking at the same rate as toward spacing, since the effect of unequal rates of operation has been described previously. In a selector of this type, both instants of decision occur at time t before the end of the selective period and hence the internal bias is not dependent upon the relation between T and t. If, however, t is so long that the selector cannot pass from one extreme of travel to the other, attain a steady state, and return to the center position within time T, a sort of characteristic distortion occurs, in which the instant of decision depends upon whether the selector began the selective period in the same or the opposite condition from that finally selected. In measurements of miscellaneous signals this appears similar to a fortuitous effect, since it decreases all tolerances equally. Hence it is usually considered as internal fortuitous distortion.

Receivers equipped with holding magnet selectors are of Type S, since the armature may be released, but not operated, by the magnet. In this type of mechanism, the armature generally drives a subsidiary selective member, and the time T extends from the instant at which the armature is disengaged by its operating cam until the instant when the subsidiary selector becomes locked. As this period is often long in relation to the magnet releasing time t_1 and the subsidiary selector operating time t_2, holding magnet selectors are often subject to negative internal bias. In those mechanisms in which the subsidiary selector is flexibly coupled to the magnet armature, the former's operation is of type P. It, therefore, may be subject to the characteristic distortion effect noted in the description of type P operation, except that the effect, when it occurs in this type of mechanism, affects only the instant of decision for end displacement and hence resembles negative skew rather than internal fortuitous distortion.

An interesting, but somewhat unusual, effect occurs in any receiver, of whatever type, in which the lengths of selective period or selector operate time, or both, differ for the various selective pulses, or in which the spacing of the selective periods is improper. In a case of this sort, the receiver exhibits an internal bias equal to the difference between the average instant of decision for bias and the average instant of decision for end displacement, an internal fortuitous distortion equal to the variation of the instant of decision having the smaller variation, and a skew equal to the difference between the variations of the instant of decision for bias and the instant of decision for end displacement.

Conclusions

A working knowledge of the effect of telegraph distortion on the margins of operation of start-stop receivers is essential in dealing with a plant in which the use of teletypewriters, regenerative repeaters and start-stop distortion measuring sets is as widespread as it is in the Bell System. When a major portion of the communication system operates on a start-stop basis, it is desirable that transmission measurements be made on the same basis.

The knowledge of this subject that has been gained in recent years has made possible many improvements in technique both in the field and in the laboratory, and these have led to corresponding improvements in the mechanisms used in telegraph service. The analysis of new start-stop devices may now be carried out efficiently and accurately, and this often permits the formulation of suggestions leading to improved operation of the devices. The general level of service excellence has been raised by the setting up of criteria for the distortion tolerances of station teletypewriters, regenerative repeaters and other start-stop devices used in service, including those provided for switching. The sources of distorted test signals that are now available are useful not only in measuring the tolerances of service receivers, but also in determining the characteristics, and hence the accuracy, of start-stop distortion measuring sets and monitoring teletypewriters.

Finally, there has resulted an improved ability to analyze and predict the performance of transmission links from the results of distortion measurements made on a start-stop basis.

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