THEORY OF CHARACTERISTIC DISTORTION AND ITS REDUCTION BY EQUALIZATION

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1. General

1.01 This section discusses the nature and causes of characteristic distortion, with particular reference to the use of equalizers to reduce its effects in d-c telegraph circuits.

1.02 Adjustable circuit elements or equalizers whose values may be set for minimum characteristic distortion are available for connection to d-c telegraph line circuits, either metallic or grounded. The optimum values for the circuit elements are determined by field tests using the circuits with which they are normally associated. This adjustment procedure is termed equalization. It is an adjustment of the transmission frequency characteristic of a particular transmission path. Section 312-200-102 gives a detailed description of the standard equalizer arrangements available for use on metallic telegraph circuits and Section 312-200-500 describes methods for adjusting them. The equalization of grounded telegraph circuits is discussed in the Sections on the 16B1 and 16C1 repeaters, 312-303-500, 312-303-100, 312-304-500 and 312-304-100.

1.03 It is to be noted that v-f carrier telegraph circuits, which are now the backbone circuits in the telegraph plant, do not require equalizers even at the highest operating speed (100 speed). Loop wave shaping is not equalization, since it reduces bias, not characteristic distortion.

2. EXPLANATION OF TERMS

2.01 General

The explanation of terms given below is intended to supplement and bring up to date definitions taken from the latest preliminary draft of ASA 042 American Standard Definitions of Electrical Terms, Group 65, Communication.

2.02 Signal Transitions

(a) The change from a marking to a spacing condition is called an M-S (mark-to-space) transition.

(b) The change from a spacing to a marking condition is called an S-M (space-to-mark) transition.

2.03 Signal Element in telegraph communication is the shortest interval of a signaling code with undistorted signals. It is considered to be of unit duration in building up signal combinations.

In start-stop teletypewriter operation with 5-unit code the durations of undistorted signal elements are as follows:

Nominal Speed of Operation (words/minute)	Signal Element Duration (milliseconds)
40	33.8
60	22.0
75	17.6
100	13.5

2.04 Telegraph Signal Distortion is the time displacement of transitions between conditions, such as marking and spacing, with respect to their proper relative positions in perfectly timed signals. It is expressed in percentage of the undistorted signal element.

2.05 Bias in telegraph transmission is a uniform displacement of like signal transitions resulting in a uniform lengthening or shortening of all marking signals. Bias is expressed in percentage of a unit signal element.

$$\text{Bias} = 100\,\frac{(m - M)}{M}$$

where m = duration of the marking signal as received
M = duration of an unbiased marking element

Bias which lengthens the marking intervals is called marking or positive bias. Conversely, bias which shortens the marks is spacing or negative bias.

2.06 Mark-Space Time Difference in this section ("M-S Diff." on the Figs.) is the difference in duration between the sum of the marking elements of a single character and the sum of the spacing elements, expressed in per cent of the complete character length, including start and stop elements. This quantity was formerly called "Time Bias." However, in this section, the use of the term bias is restricted to the meaning given above.

2.07 Characteristic Distortion is a displacement of signal transitions resulting from the persistence of transients from preceding transitions. These transients may be electrical, where characteristic distortion arises in a transmission path, or mechanical, where the distortion arises in relays or other apparatus. With changing signal combinations, characteristic distortion varies from signal to signal.

Negative characteristic distortion shortens the short signal elements regardless of whether they are marks or spaces.

Positive characteristic distortion lengthens the short elements.

2.08 Systematic Distortion is the algebraic sum of the systematic components of distortion, i.e., bias and characteristic distortion.

2.09 Fortuitous Distortion is a random distortion of telegraph signals such as that commonly produced by interference. Common sources of fortuitous distortion are crossfire, power induction and lightning hits.

2.10 Total Distortion is the algebraic sum of the bias, characteristic and fortuitous distortions.

2.11 Lag, in a telegraph system, is the time elapsing between the operation of the transmitting device and the response of the receiving device.

2.12 Equalization, as applied to telegraph, refers to the process of adjusting the transmission characteristics of a telegraph circuit to reduce the characteristic distortion of telegraph signals transmitted over the circuit.

3. CAUSES OF CHARACTERISTIC DISTORTION

3.01 There are two important aspects of characteristic distortion, (1) its value is affected by the spacings between transitions in the signals and by the signaling speed; and (2) it results from the electrical and mechanical characteristics of the circuit. On a given circuit, characteristic distortion may be quite low at low operating speeds and increase rapidly as the operating speed is increased so that equalization may not be required excepting at the higher speeds. For instance, on 4-wire metallic telegraph circuits equalization is not as important at 60 speed as at 75 and 100 speeds. Also, since characteristic distortion is a function of the

signal combinations, if the combinations are altered by predistortion, as when a telegraph section is preceded by other telegraph sections, the magnitude of the characteristic distortion may increase sharply. The second aspect of characteristic distortion is important because it permits adjustment of equalizers which will not thereafter require adjustment excepting when the line facilities are changed.

3.02 In a line circuit containing capacitance or inductance a definite time is required for the current at the receiving end to change from its steady marking value to its steady spacing value and vice versa. This is due to the fact that the inductance and capacitance store energy and their demands must be met before the received line current can reach its steady value. If the characteristics of the circuit are such that it takes the received line current longer than the duration of a unit element to reach its steady value, a succeeding transition is affected by the remnant or tail of the previous transition. The result will be that the receiving relay will operate sooner or later than normal depending upon whether the remnant of the first transition is above or below the steady state value. This effect is an example of characteristic distortion. It is illustrated by Figs. 1, 2 and 3. Fig. 1 shows, at Curve B, a received current wave taking about 4 unit time intervals to build up from the steady state spacing value to the steady state marking value or vice versa. Starting from the steady state value a signal of 4 units duration (Curve A) is therefore undistorted (as indicated at B) while a shorter signal as in Curve C is shortened by about 20% as shown at D.

3.03 In Fig. 1 the received current builds up to its steady state slowly, producing negative characteristic distortion. However, two other conditions are possible; one is that after a transition the received current may build up to a value greater than the steady

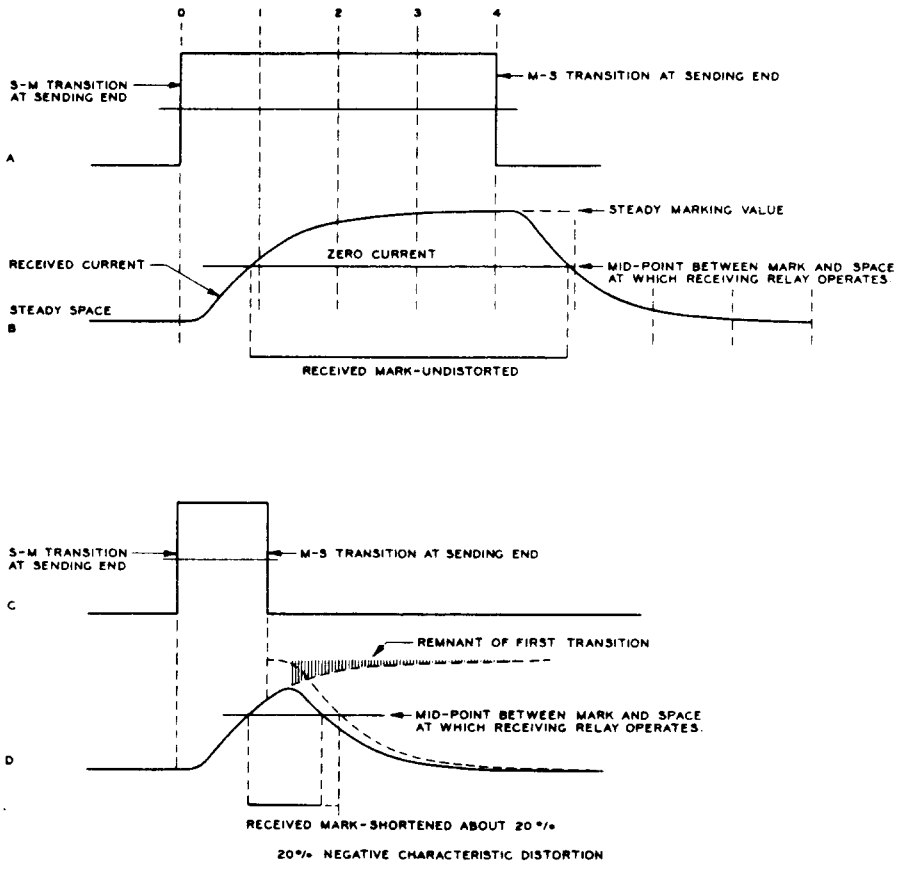

Fig. 1 - Illustration of How Slow Build-up of Received Line Current Can Cause Negative Characteristic Distortion

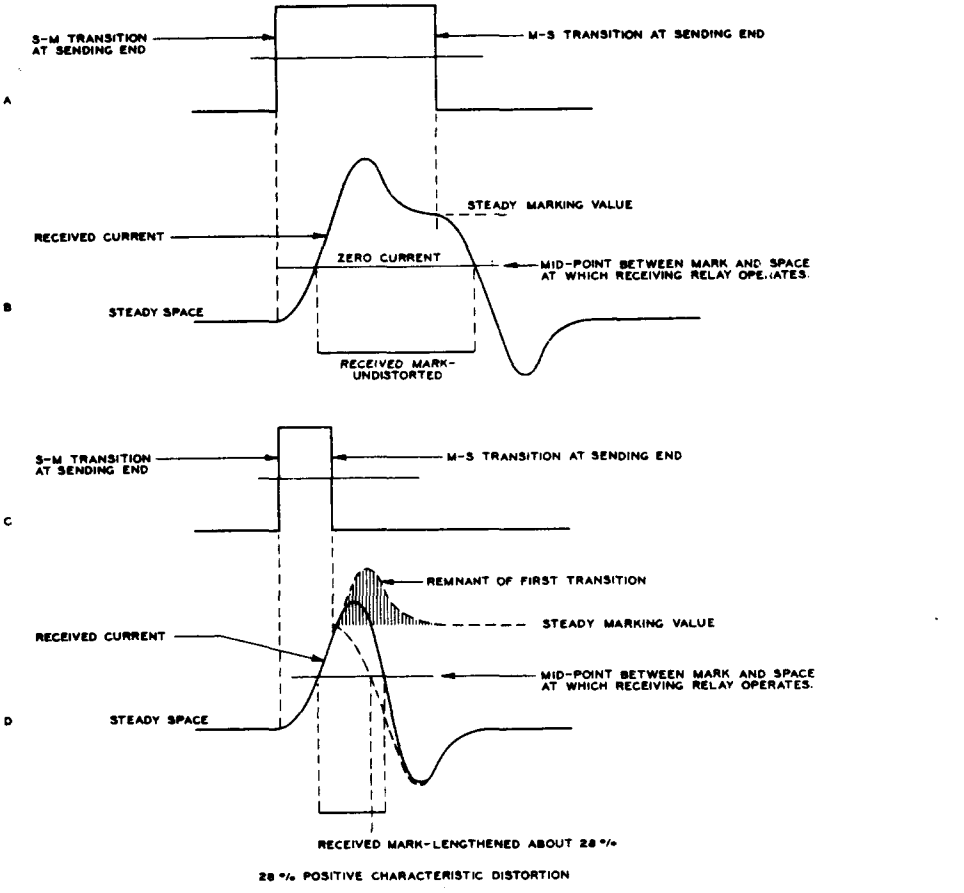

Fig. 2 - Illustration of How a Surge of Received Current above the Steady State Value Can Cause Positive Characteristic Distortion

state value and then gradually decrease to the steady state value. This condition may cause positive characteristic distortion and is illustrated in Fig. 2. A third possible condition is where the current builds up to a value above the steady state value and then falls below this value and subsequently varies back and forth in this manner until finally it comes to rest at its steady state value. In other words a damped oscillation takes place. This is illustrated in Fig. 3, Curve B. Either positive or negative characteristic distortion may result from this wave depending upon the duration of the signal element. Curve D shows negative characteristic distortion and Curve F positive characteristic distortion resulting from the damped oscillation.

4. DISTORTION MEASUREMENTS

(A) General

4.01 The systematic nature of characteristic distortion permits its measurement with relatively simple devices by means of which the average displacement of signal transitions in repeated signals is indicated on a meter. Also, as discussed further below, the use of certain selected teletypewriter characters as test signals facilitates the analysis of distortion measurements to separate the contributions of characteristic distortion from those of bias.

(B) Testing Apparatus

4.02 The following equipment, listed in the order of preference, is used to supply the test signals at the sending end:

(1) 100A Teletypewriter Test Distributor

(2) 1A Teletypewriter Test Set

(3) 14-type Transmitter-Distributor (Station type) with 119-type Telegraph Signal Biasing or Distorting Set.

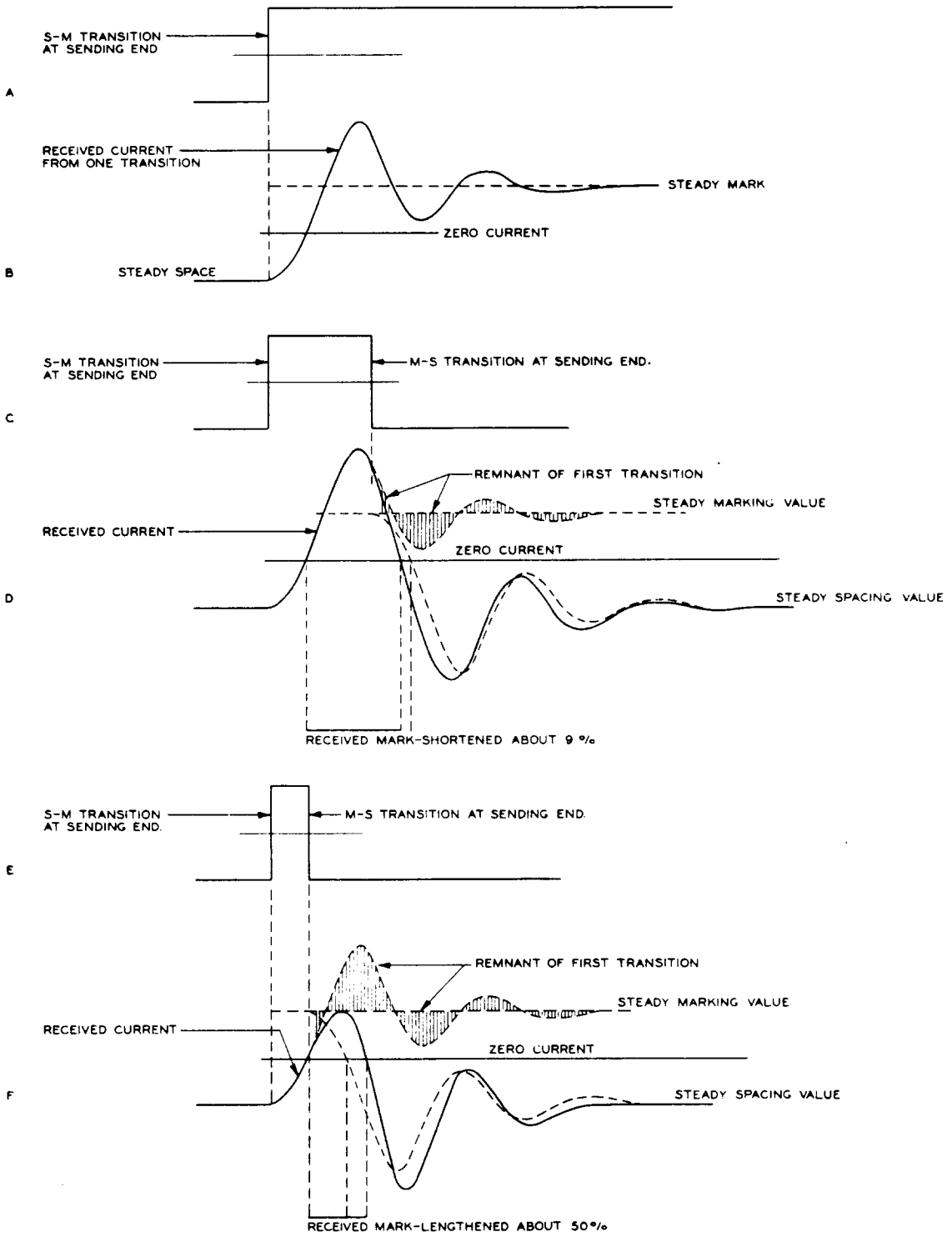

Fig. 3 - Illustration of How an Oscillatory Transient Can Cause Either Positive or Negative Characteristic Distortion Depending on Length of Pulse

4.03 Measurements of distortion at the receiving end are made with either a 161A Telegraph Station Test Set, a 118-type Transmission Measuring Set or an X-75041 Telegraph Transmission Measuring Set. The former is preferred for convenience and accuracy.

(C) Choice of Test Signals

4.04 Since, as discussed above, the effects of characteristic distortion depend on the spacings between transitions, the group of selected test characters covers a range of durations of time between the mark-to-space and the space-to-mark transitions, the greatest effects of characteristic distortion generally being obtained when the mark-space time difference in the entire character is largest. The test signals chosen for the determination of the characteristic distortion of a circuit are the simplest possible teletypewriter characters, i.e., having just two transitions in each character. As may be seen from Fig. 4, the characters Blank, T, O, M, V and LTRS have the desired features. Additional information may be obtained, if desired, by sending the Blank character with 20% spacing bias or the LTRS character with 20% marking bias, either of these being introduced by the sending device.

4.05 As Fig. 4 also indicates, the characters as a whole may be thought of as special cases of 6.1-cycle reversals (the speed of sending characters with 60-speed teletypewriter operation) with varying amounts of mark-space time difference. The mark-space time difference shown in the right-hand column of Fig. 4 is the difference between the marking and spacing portions of the entire character expressed in percentage of the duration of the character. This percentage difference is used for the scale of abscissae of Fig. 5 to provide a systematic base for the plotting of measured values of distortion.

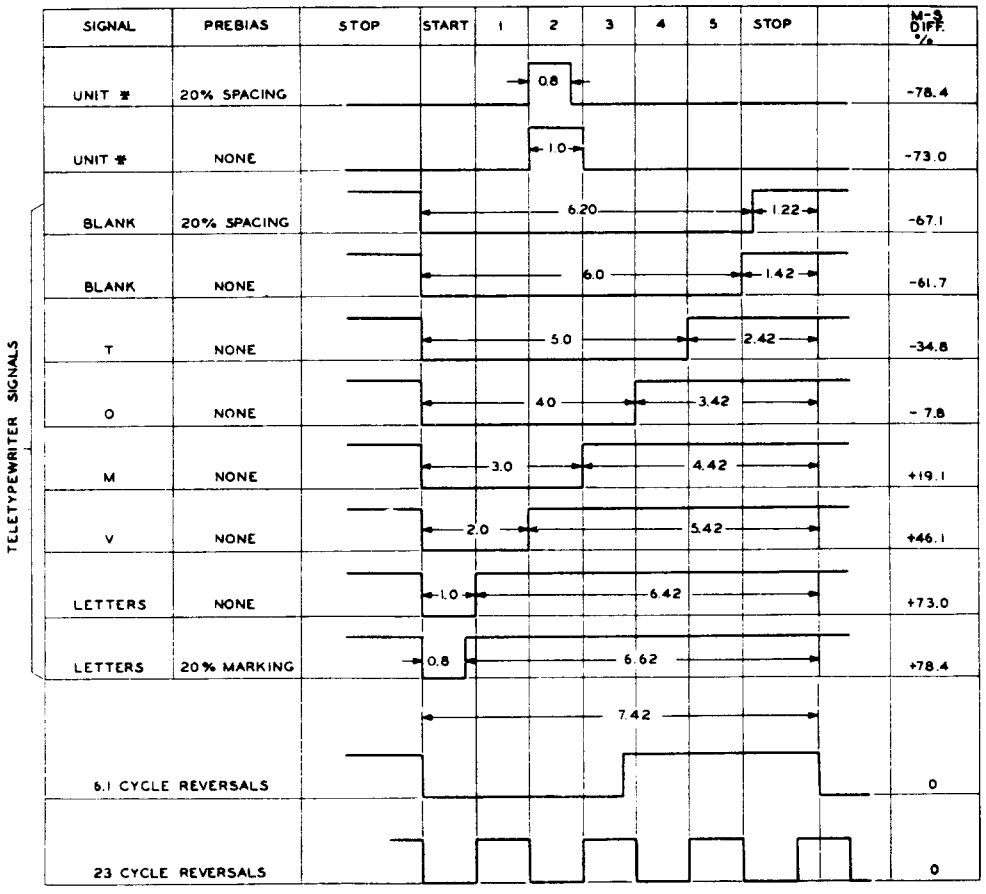

Fig. 4 - Signals Used in Measuring Systematic Distortion

*The unit signal is a special test signal, not a teletypewriter character. Its use is not called for herein.

(D) Measurement and Correction of Test Signals

4.06 Repetitions of each of the test characters in turn are sent over the line circuit and measurements of distortion made at the receiving end. Since the desired result is a measure of the characteristic distortion introduced by the circuit, corrections are made to remove the prebias, if any, introduced into the sent signal by the signal source, and the circuit bias caused in transmission. The prebias is known and therefore readily taken out. The circuit bias is given with sufficient accuracy by the distortion measured when the letter O is transmitted and can therefore also be taken out of the distortion readings on the other characters, as discussed below.

4.07 The distortion indication of 16lA1 sets needs no correction, except for errors in the sent signals. This is also true for the indication of X-75041 sets except that if noticeable fortuitous distortion is present, the recorded distortion should be the average obtained by observing the varying position of the spot on the face of the tube. The 118-type set is normally calibrated to measure the standard test sentence correctly. The average number of transitions in the characters of the test sentence is four. Consequently when the 118 set is used to measure the two-transition characters herein discussed, the BIAS meter readings need to be multiplied by two.

(E) Interpretation of Measured Distortion

4.08 A set of measurements on a circuit having negative characteristic distortion is shown plotted on Curve (b) of Fig. 5, against the mark-space time difference in the sent characters. The straight line of Curve (a) represents bias, which was either present in all of the transmitted signals at the sending end or was introduced by circuit bias. The value of the bias, in this case -4%, is given by the intercept on the vertical axis of the curve of measured distortion. (For practical purposes, as in the calculations below, the measured value of distortion for the letter O, here 5%, is taken as the bias.)

4.09 The departure of Curve (b) from Curve (a) is the contribution of characteristic distortion to the total measured distortion. It is this difference which it is the purpose of equalization to remove so far as possible. Successive sets of measurements, taken after successive adjustments of the equalizer should give curves with less and less slope, approaching

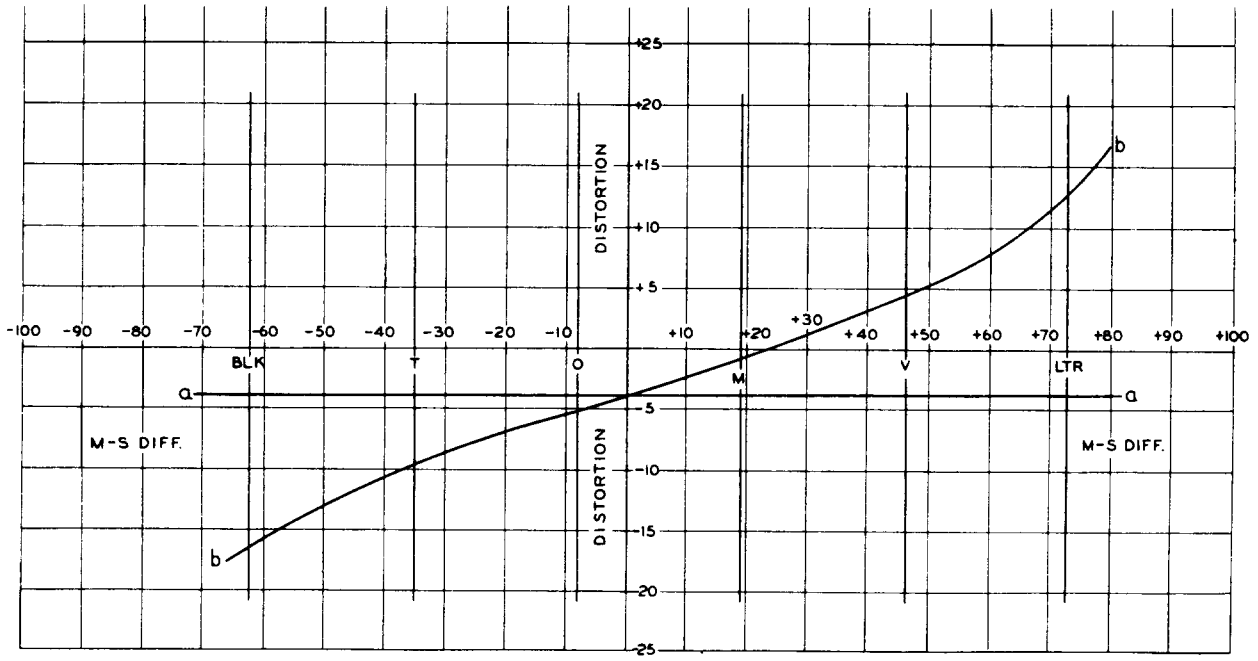

Fig. 5 - Measured Systematic Distortion vs. M-S Difference in Sent Characters

the horizontal line of bias. How closely this can be reached will depend on the circumstances in each individual case.

4.10 The algebraic signs of the measured values of distortion for the test characters M, V and LTRS (after correction for prebias, if any, and circuit bias) need to be changed to make their convention consistent with that of the rest of the characters. The reason for this is as follows: In the case herein discussed, the circuit is assumed to cause negative characteristic distortion, that is, the shorter elements are made still shorter. But, for the particular characters mentioned, the shorter element is a spacing element. Therefore, any further shortening produces marking bias, which is, by convention, read as positive by the measuring equipment used. The convention for the sign of the meter readings for M, V and LTRS characters is therefore opposite to that for the desired results. Changing the sign removes the inconsistency.

4.11 Illustration of Readings and Calculations for Determining Characteristic Distortion

(a) By correcting the measured values for the circuit bias and changing the algebraic sign of these results for the test characters LETTERS (20% prebiased) LETTERS, V and M the correct sign for the characteristic distortion measured on each character is determined.

(b) As an illustration assume that the measured values of distortion on the 16lA1 set are as follows:

O	M *	T	V *	BLANK No Prebias	BLANK 20% S	LETTERS No Prebias *	LETTERS 20% M *
At Sending End							
0	0	0	0	0	-19	0	+21
At Receiving End							
-5	-1	-10	+4.5	-16.5	-37.5	+13	+36.5
Reading Corrected for Sending End Bias (Curve (b) of Fig. 5)							
-5	-1	-10	+4.5	-16.5	-18.5	+13	+15.5

Using the -5.0% (spacing) bias obtained on the O character as the circuit bias, subtract this value algebraically from the other readings to correct for circuit bias.

Readings Corrected for Circuit Bias							
0	+4	-5	+9.5	-11.5	-13.5	+18.5	+20.5
***Reverse Signs for Starred Columns**							
0	-4	-5	-9.5	-11.5	-13.5	-18.5	-20.5

These last figures represent characteristic distortion.