THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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TELEGRAPH DISTORTION

PREVIOUSLY CP 407

		Page.
1.	INTRODUCTION	1
2.	DEFINITIONS	2
3.	MACHINE MARGIN	6
4.	TYPES OF DISTORTION	12
5.	BIAS DISTORTION	12
6.	CHARACTERISTIC DISTORTION	19
7.	FORTUITOUS DISTORTION	23
8.	DISTORTION IN A.C. TELEGRAPHY	23
9.	DISTORTION AND ORIENTATION LIMITS	27
10.	TESTING SIGNALS	33
11.	TEST QUESTIONS	34

1. INTRODUCTION.

1.1 In machine telegraphy the information is transmitted in the form of a pre-determined code, produced by sudden changes in voltage during the process known as telegraph modulation.

The modulation elements are in one of two significant conditions (Mark or Space) for specific intervals of time; the conditions and their time duration vary with the combinations being transmitted.

1.2 In other fields of telecommunication, "distortion" is said to exist when the wave shape of the received signal differs from the wave shape of the original signal.

However in telegraphy, although there may be considerable change in the wave shape of an element, the term "distortion" is applied to those changes in the characteristics of the signal elements which, when excessive, result in incorrect translation of the received signals.

1.3 This paper deals with the type, sources, and effects of distortion as applied to machine Telegraphy.

2. DEFINITIONS.

2.1 The significance of the elements in a telegraph signal is fixed by the time intervals between changes of condition. The receive device should reproduce these time intervals when assuming a series of conditions during the process known as telegraph restitution.

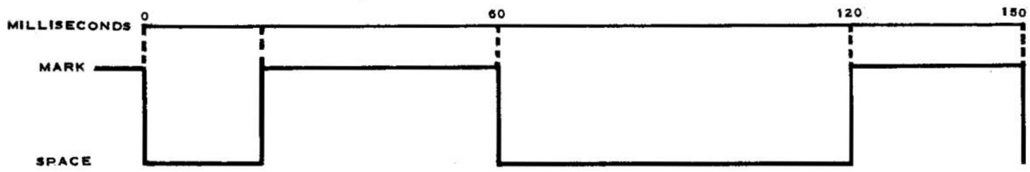
Restitution is generally achieved by the response of some form of relay to the incoming element currents. The relay produces electrical or mechanical changes at instants corresponding to a pre-determined value of current.

When the intervals between these instants differ substantially from the theoretical time intervals, the receive device obtains the wrong information, and this, without error correction, results in mutilation of the printed intelligence. Para. 2.2 shows that telegraph distortion, therefore, is defined in relation to the departure of element time intervals from their prescribed durations.

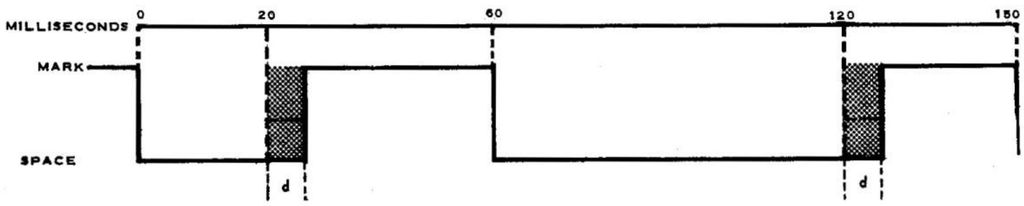
2.2 Telegraph Distortion exists when the significant intervals of a modulation or restitution differ from their theoretical durations.

Fig. 1a shows the theoretical time intervals in the start-stop 5 unit code combination which represents the letter "A".

Fig. 1b shows the actual time intervals of a modulation or restitution differing from the ideal signal in Fig. 1a.



(a). Theoretical time intervals.



(b). Actual time intervals when distortion is present.

FIG. 1. TELEGRAPH DISTORTION.

In Fig. 1 the times "d" indicate the distortion which when excessive, results in incorrect translation. The amount of time difference regarded as excessive is dependent upon the ability of the telegraph machines to tolerate degrees of distortion without mistranslation.

2.3 Start-Stop Distortion. In start-stop system all timing starts at the commencement of the start signal.

The start signal therefore, is used as a reference point from which the succeeding transitions should occur at unit intervals, or multiples of unit intervals.

Fig. 2 shows the letter "Y" with theoretically correct time intervals (dotted line), and the same signal with time intervals differing from the correct signal (full line).

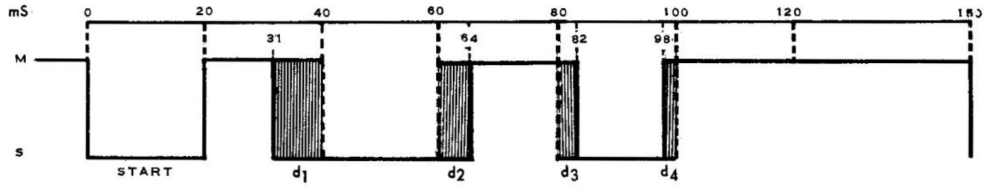


FIG. 2. START-STOP DISTORTION.

The transitions are shown occurring 9mS early (d1), 4mS late (d2), 2mS late (d3), and 2mS early (d4).

2.4 Distortion and Instants of Selections. The time differences given in milliseconds (Fig. 2) are usually expressed as a percentage of the unit interval.

When the unit interval is 20mS, d1 in Fig. 2 is 45% early, d2 is 20% late, d3 is 10% late, and d4 is 10% early. The various time deviations within a telegraph signal are expressed individually because of their relationship to the instants of selection of the receive machine.

We saw in the paper 'Telegraph Machine Principles" that the instants of selection are the actual instants when the code combination is selected and mechanically stored. In the ideal case the first selection is made 1½ units after the commencement of the start element, and the 2nd, 3rd, 4th and 5th selections are made at unit intervals from the 1st selection. (Fig. 3).

The selecting process is generally considered to last for about 4mS, and this is 20% of a unit interval when the signalling speed is 50 bauds.

Fig. 3 shows the instants of selection in relation to the early and late transitions of the signal considered in Fig. 2.

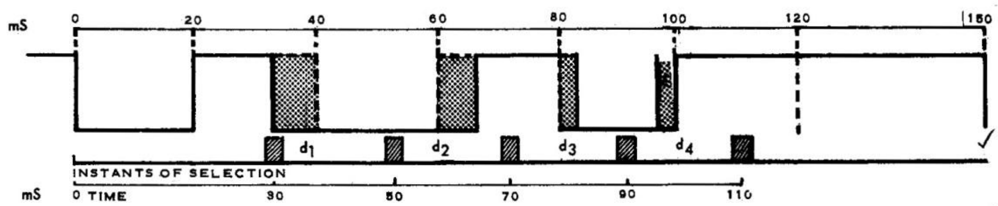


FIG. 3. EFFECTS OF DISTORTION ON SELECTION.

Assuming that 20% of a unit interval is necessary for the receiver to decide whether the code element is a mark or a space, d2, d3 and d4 are correctly selected.
The 45% distortion to d1, however, is excessive, and a spacing condition is selected instead of a mark.

The code combination for the letter "Y" (SMSMSMM) now appears to the selecting mechanism as the code for the letter~"H" (SSSMSMM), and the machine prints an incorrect character.

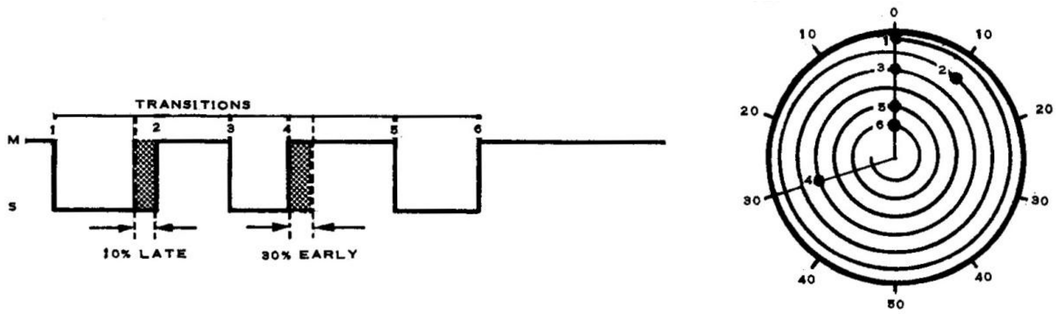
2.5 Measuring start-stop distortion. One type of telegraph distortion measuring set (T.D.M.S.) uses an oscilloscope with a spiral sweep as an indicator (Fig. 4b). When the start element begins, a bright spot appears at the top centre of the screen. When all the transitions in the character occur at precisely the correct time there is a bright spot for each transition on each spiral, on a vertical line from the beginning spot to the centre of the screen.

The outer circumference of the screen is calibrated in percentage distortion.

When a transition occurs early the bright spot appears to the left of the line.

When a transition occurs late the bright spot appears to the right of the line.

Fig. 4b shows the placing on the spiral trace of the bright spots due to the transitions in the signal depicted in Fig. 4a.



(a) (b

FIG. 4. MEASURING START-STOP DISTORTION.

(i) The transition from the previous stop element to the start element. (1 in Fig. 4a) produces a bright spot at the top of the screen (1 in Fig. 4b).

(ii) Transition 2 is 10% late, and the spot occurs to the right of the vertical line (2).

(iii) Transition 3 is normal, and the spot appears on the line (3).

(iv) Transition 4 is early, and the spot is displaced to the left of the line (4).

(v) Transition 5 and 6 are normal, and appear on the line.

The maximum individual displacement of the transitions in Fig. 4 is 30%, and this value indicates the distortion in terms of its effect on the margin of the machine.

2.6 The degree of start-stop distortion, therefore, can be defined as the maximum of the individual transition displacements from their correct instants, as timed from the beginning of the start signal.

The ratio of this value to the unit interval is expressed as a percentage.

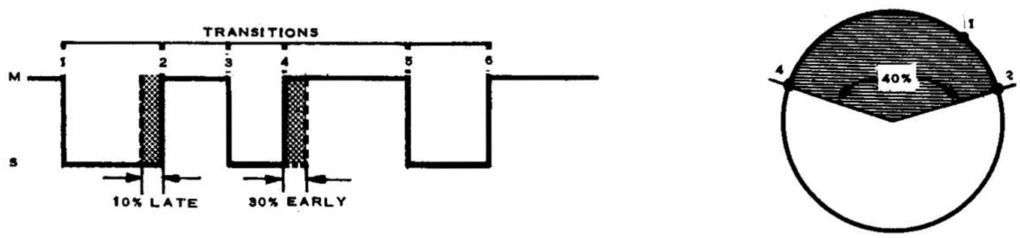
2.7 Isochronous distortion. Isochronous signals, that is, signals which are of unit length or multiples of unit length, and which do not contain start-stop elements, are generally used to test the A.C. intermediate stages in the telegraph network. When these signals are checked using start-Stop measuring equipment, as in Fig. 4, the transitions are examined separately and the distortion expressed as the maximum displacement of an individual transition, in the same way as start-stop distortion.

When signals are measured isochronously, the distortion measuring instrument is designed to 'hook" at continuous signals which are of unit length or multiples of unit length, and which do not contain a reference point from which transitions can be related as occurring early or late.

2.8 Measuring isochronous distortion. One type of isochronous distortion measuring instrument uses an oscilloscope with a circular trace arranged to make one revolution in the same time period as the signal unit interval. Each transition causes a bright spot to appear on the trace, and for an undistorted signal the position of the spots should coincide.

When distortion is present, the spots appear over a segment of the circular trace, the position of the spot corresponding to the first transition occurring at random.

Fig. 5 shows the display on the circular trace due to the same signal which was measured in the start-stop mode in Fig. 4.



(a) (b

FIG. 5. MEASURING ISOCHRONOUSLY.

(i) Assume that transition 1 in Fig. 5a appears as a bright spot on the screen in the position indicated. (1 in Fig. 5b).

(ii) Transition 2 is 10% late, and the spot is displaced to the right of-spot 1. (Spot 2 in Fig. 5b).

(iii) Transition 3 is normal and spot 3 coincides with spot 1.

(iv) Transition 4 is 30% early, and spot is displaced to the left of spot 1 by 30%. (Spot 4 in Fig. 5b).

(v) The spots due to transitions 5 and 6 coincide with spot 1.

In Fig. 5b the distortion is expressed as 40% (30% early plus 10% late). The displacement of the transitions is measured with respect to each other, as compared to the start-stop method of using a common reference point.

Isochronous distortion, therefore, indicates the total spread of the displacement of the transitions.

2.9 The degree of isochronous distortion can be defined as the maximum difference between the actual and theoretical intervals separating any 2 transitions.

The ratio of this value to the unit interval is expressed as a percentage.

2.10 Comparison of measuring techniques. The end-to-end quality of a telegraph network is determined by using start-stop signals and measuring techniques, but the quality of the A.C. intermediate stage is determined by using isochronous test signals and measuring techniques.

As shown in Figs 5 and 6, the results produced by start-stop and isochronous measurements on a given signal are not necessarily the same, and the difference between measuring the total spread (isochronous), and the maximum individual displacement (start-stop), should be fully appreciated in order to avoid misinterpretation of results.

3. MACHINE MARGIN.

3.1 The margin of a telegraph machine is the maximum distortion which the incoming signals can suffer before errors in translation occur. It is usually expressed as a percentage of the unit interval.

A telegraph machine is said to have a margin of 40% when the incoming signal transitions can be displaced up to 40% early or late before errors occur.

Tolerance to distortion is achieved by the machine design, which arranges for selection to be effected during a short period in the middle of each code element when undistorted signals are being received; this ensures that the margins for receiving early and late signals are equal.

3.2 The theoretical maximum margin is achieved in the ideal case when selection occurs in negligible time precisely in the centre of the code element. This condition would produce a margin of ±50%.

In practice the amount by which the margin of a machine departs from the theoretical maximum is dependent upon the following factors:-

(i) Machine design and adjustment.

(ii) Motor speed.

(iii) Orientation.

3.3 Machine design and adjustment. Telegraph machines require a finite time in which to correctly identify an element condition as being marking or spacing. As the time required for selection increases, the margin of tolerance to distortion decreases.

Selecting periods required by machines of different manufacture vary about an approximate time of 4 milliseconds, which is 20% of a 20mS unit length.

When undistorted signals are received, the middle of the first selection period occurs in the centre of the first code element, that is, 30mS after the commencement of the start signal.

The commencement of the start signal triggers a mechanical action which allows the receive cam to revolve, and the 30mS timing is affected by mechanical wear or maladjustment. Any variation in the timing affects the equality of the margin to early and late transitions.

3.4 Motor Speed. The relative speeds of the send and receive cams, and the effect of incorrect speeds on machine margin, are discussed in "Telegraph Machine Principles". In the following paragraphs the maximum speed variations which can exist before distortion occurs are discussed.

The figures given relate to machines designed to send and receive 7½ units at a signalling speed of 50 bauds.

3.5 Percent Speed Error. The number of revolutions per minute (R.P.M.) at which a motor revolves determines the time taken by the send and receive cams to complete one revolution. In the case of the send cam, this determines the duration of the signal elements transmitted. In the case of the receive cam, this determines the timing of the selected instants.

The percentage speed error, therefore, can be expressed in relation to either R.P.M. or cam time.

When quoting speed error values, however, it is necessary to state whether the values relate to the R.P.M. or cam time. The percentage of speed error (R.P.M.) which produces a certain distortion differs from the percentage speed error (cam) time.) which produces the same amount of distortion.

For example, a cam revolving at 400 R.P.M. completes one revolution in 150mS.

Due to a speed error, the cam revolves at 500 R.P.M., completing one revolution in 120mS.

Problem:- Express the speed difference as a percentage.

Solution. 1. Relating speed error to R.P.M.

Speed error = 500 R.P.M. – 400 R.P.M.

= 100 R.P.M.

Expressed as a % of correct speed = $\frac{100}{400} \times \frac{100}{1}$

Percentage Speed Error (R.P.M.) = 25%.

Solution 2. Relating speed error to cam time.

Time difference for one revolution = 150 – 120

= 30mS.

Expressed as a % of correct time = $\frac{30}{150} \times \frac{100}{1}$

Percentage Speed Error (cam time) = 20%.

Solution 1 properly relates speed in terms of distance and time. Solution 2 relates speed in terms of time only, but because telegraph distortion is concerned with time intervals during a revolution of a cam, this method considerably simplifies later calculations without reducing accuracy.

In this paper, therefore, the percentage of speed error relates to the time taken by a cam in completing one revolution, compared to the standard time.

3.6 Speed error and margin. Fig. 6 shows the theoretical time-intervals of signal elements in relation to the instants of selection. The selecting period is assumed to be of 4mS duration.

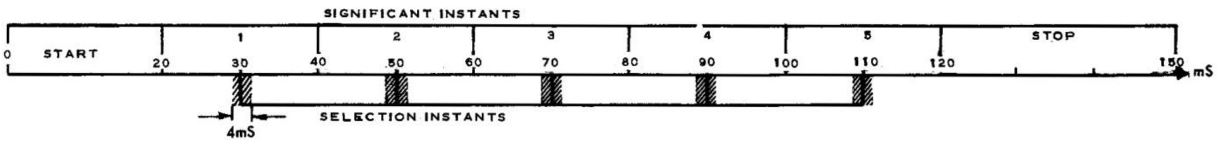


FIG. 6. IDEAL TIME INSTANTS.

The early and late margins are of 8mS duration, that is, 40% of the unit interval of 20mS.

3.7 Transmitter fast. When the transmitter speed is correct, the send cam completes a revolution in 150mS, and this is the length of each character transmitted.

The unit interval is calculated by:-

$$\text{Unit interval} = \frac{\text{character length}}{\text{No. of units}}$$

$$= \frac{150\text{mS}}{7\frac{1}{2}}$$

$$= 20\text{mS.}$$

When the transmitter is 1% fast, the send cam completes a revolution in less than 150mS, and the character length is calculated by:-

$$\text{Character length} = 150\text{mS} - (1\% \text{ of } 150\text{mS})$$

$$= 150 - 1.5$$

$$= 148.5\text{mS.}$$

$$\text{and the new unit interval} = \frac{148.5}{7\frac{1}{2}}$$

$$= 19.8\text{mS.}$$

Fig. 7 shows the time relationships based on a unit interval of 19.8mS, when the transmitter is 1% fast.

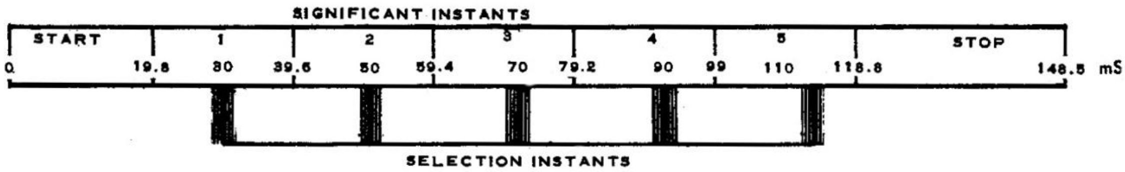


FIG. 8. TRANSMITTER 1% FAST.

Fig. 7 shows that when the send cam completes a revolution 1% faster than the standard time:-

(i) The unit interval is reduced by 1%.

(ii) The transitions are advanced by 1% from their theoretical instants, and the margins are reduced proportionately.

(iii) The greatest reduction of margin occurs in the 5th code element, where the transition which should occur at 120mS is advanced by 1.2mS, that is, 1% of 120mS.

3.8 Speed error and distortion. The loss of margin in milliseconds is expressed as a distortion percentage by relating the milliseconds displacement to the unit interval.

When the transmitter is 1% fast the distortion to the 5th element is calculated by:-

$$\text{Distortion} = \frac{1.2}{20} \times \frac{100}{1} = 6\%.$$

3.9 The calculations presented in paras. 3.7 and 3.8 are included for purposes of explanation. The value of distortion due to speed error is more easily found by directly relating the percentage speed error to the particular element instant under consideration. The milliseconds displacement is then expressed as a percentage of unit length. Expressed as a formula:-

$$\% \text{ Distortion} = \frac{\% \text{ (speed error) of theoretical instant}}{\text{Unit length}} \times 100.$$

When the transmitter is 1% fast, and the theoretical instant under consideration occurs at 120mS.

$$\begin{array}{l}\% \text{ distortion} \\ \text{(transmitter 1\% fast)}\end{array} = \frac{1\% \text{ of } 120}{20} \times 100$$

$$= \frac{1.2}{20} \times 100$$

$$= 6\%.$$

3.10 When the milliseconds displacement is known, the % speed error is found by relating the time displacement to the theoretical instant. Expressed as a formula:-

$$\% \text{ Speed error} = \frac{\text{displacement of theoretical instant}}{\text{theoretical instant}} \times 100$$

and using the previously given values:-

$$\% \text{ speed error} = \frac{1.2}{120} \times \frac{100}{1}$$

$$= 1\%.$$

3.11 The maximum amount by which the transmitter can be fast before errors occur is calculated by the application of the formula given in para. 3.10.

Fig. 8 shows that the limit is reached when the 5th element is advanced to the point where the instant beginning the stop element coincides with the end of the 5th selecting period.

Fig. 8 shows the instant beginning the stop element occurring at 112mS instead of 120mS, an advance of 8mS.

Applying the formula from .para. 3.10:-

$$\text{Maximum } \% \text{ speed error} = \frac{8}{120} \times \frac{100}{1}$$

$$= 6.6\%$$

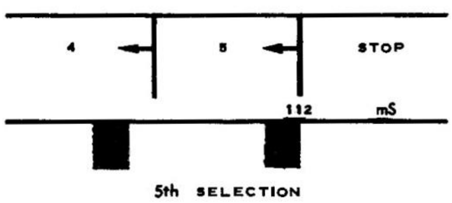


FIG. 8. MAXIMUM SPEED ERROR.
(TRANSMITTER FAST).

3.12 Transmitter slow. When the transmitter takes longer than the standard time to complete a revolution, the unit intervals are longer, and the transitions occur later than their theoretical instants.

When the transmitter is 1% slow, each significant instant is 1% late, with the maximum displacement occurring at the beginning of the 5th code element, that is, at 100mS. The distortion to the 5th element is calculated by applying the formula presented in para. 3.9.

$$\begin{aligned} \text{\% distortion (Transmitter 1\% slow)} &= \frac{\text{1\% of } 100}{20} \times \frac{100}{1} \\ &= \frac{1}{20} \times \frac{100}{1} \\ &= 5\%. \end{aligned}$$

3.13 The limit to the amount by which the transmitter can be slow before errors occur is reached when the beginning of the 5th code element coincides with the beginning of the 5th selecting period, as shown in Fig. 9.

The significant instant is delayed by 8mS, from 100mS to 108mS, and the speed error under these conditions is calculated by:-

$$\begin{aligned} \text{Maximum \% speed error} &= \frac{8}{100} \times 100. \\ &= 8\%. \end{aligned}$$

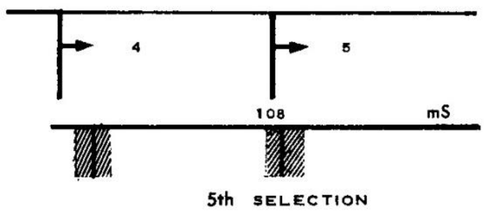


FIG. 9. MAXIMUM SPEED ERROR. (TRANSMITTER SLOW).

3.14 Receiver speed error causes the timing of the selecting instants to be early when the receive motor is fast and late when the receive motor is slow.

When the receiver speed is correct the receive cam completes a revolution in 130mS, that is, 6½ unit intervals, with the selecting instants occurring at the times shown in Fig. 6.

3.15 Receiver 1% fast. When the receive cam completes a revolution in 1% less than the standard time, all instants of selection are advanced by 1%, with the greatest time displacement being suffered by the 5th instant of selection.

The start of the 5th instant of selection, which should occur at 108mS, moves closer to the start of the 5th code element.

Calculating the distortion:-

$$\begin{aligned} \text{\% distortion (Receiver 1\% fast)} &= \frac{\text{1\% of } 108}{20} \times 100 \\ &= \frac{1.08}{20} \times 100 \\ &= 5.4\%. \end{aligned}$$

3.16 The limit to the amount by which the receiver can be fast before errors occur is reached when the start of the 5th selecting period coincides with the start of the 5th code element, as shown in Fig. 10.

The start of the selecting period is advanced by 8mS, from 108mS to 100mS.

$$\text{Maximum speed error (Receiver fast)} = \frac{8}{108} \times 100$$

$$= 7.4\%.$$

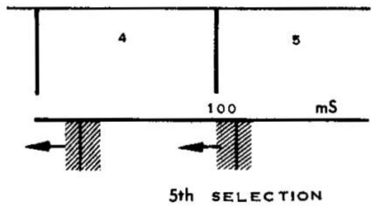


FIG. 10. MAXIMUM SPEED ERROR. (RECEIVE FAST).

3.17 Receiver 1% slow. In this condition the end of the 5th selecting period is displaced toward the start of the stop element by 1% of its correct time.

The end of the 5th selecting period should occur at 112mS, and the distortion is:-

$$\text{\% distortion (Receiver 1\% slow)} = \frac{1\% \text{ of } 112}{20} \times 100$$

$$= \frac{1.12}{20} \times 100$$

$$= 5.6\%.$$

3.18 The limit to the amount by which the receiver can be slow before errors occur is reached when the end of the 5th selecting period coincides with the start of the stop element, as shown in Fig. 11.

The end of the selecting period is delayed by 8mS, from 112mS to 120mS, and the speed error is:-

$$\text{Maximum speed error} = \frac{8}{112} \times 100$$

$$= 7.1\%.$$

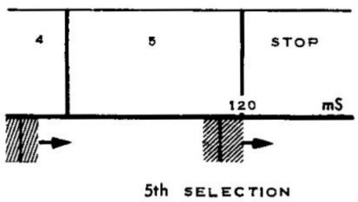


FIG. 11. MAXIMUM SPEED ERROR. (RECEIVER SLOW).

3.19 Errors in Printing due to speed differences are generally characterised by distortion to the 5th code element, that is, a mark is selected instead of a space ("extras"), or a space instead of a mark ("dropouts"). Any inaccuracy of speed results in a loss of receiver margin, reducing the ability of the receive mechanism to cope with distortion from other sources.

3.20 Orientation. The receiving cam unit generally includes a facility by which the instants at which selection takes place can be varied with relation to the commencement of the start element.

This allows the selecting mechanism to be correctly phased so that the margins for receiving early and late transitions are equal.

Incorrect setting of the orientation device (range-finder) results in a loss of margin.

4. TYPES OF DISTORTION.

4.1 Sources of Distortion. The preceding paragraphs show that speed differences between machines result in a loss of margin to distortion from other sources.

The sources of distortion in a telegraph network, in general terms, are:-

(i) Wear and maladjustment of mechanical devices, such as machines and relays.

(ii) Transition delays produced by reactive components associated with resistors. (The production of transition delays are discussed in the paper "Telegraph Transmission").

(iii) Interference to the telegraph signals from adjacent circuits.

4.2 Start-stop measuring devices show the displacement of the individual transitions with reference to the start signal, and the maximum individual displacement is the degree of start-stop distortion; the distortion is expressed in terms of its effect upon the receive machine.

Observations of an oscilloscope display of the transitions show that some displacements occur in a random fashion, and others follow a repeated pattern.

This systematic repetition of displacements enables telegraph distortion to be divided into types, and recognition of these types provides a clue to the source.

4.3 The main types of telegraph distortion are:-

(i) Bias distortion, when all the marking or all the spacing elements are consistently lengthened.

(ii) Characteristic distortion, when the shortest elements (mark or space) of a particular combination are consistently changed in length.

(iii) Fortuitous distortion, which occurs in a random manner; it is non-systematic and non-repetitive.

4.4 Distortion due to causes such as speed deviations, faulty individual transmitter contacts and interference from alternating currents, is called "Cyclic" distortion.

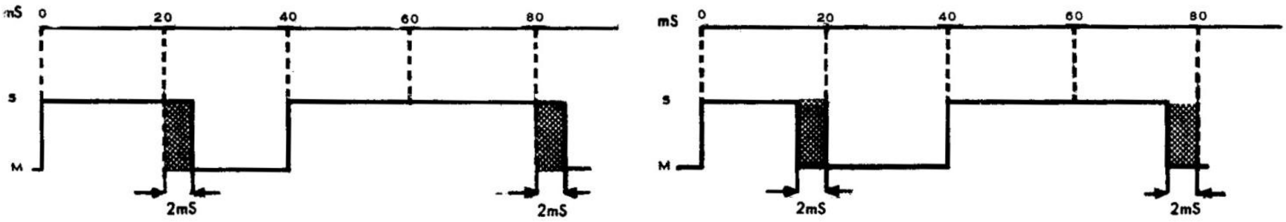
In practice, cyclic distortion is regarded as being fortuitous, because, although it is periodic in nature, it varies from machine to machine, and in the case of interference from A.C., from signal to signal.

5. BIAS DISTORTION IN DIRECT CURRENT TRANSMISSION.

5.1 There are two types of bias distortion:-

(i) Marking bias, in which all marking elements are lengthened and all spacing elements are correspondingly shortened (Fig. 12b).

(ii) Spacing bias, in which all spacing elements are lengthened and all marking elements are correspondingly shortened (Fig. 12a).



(a) Spacing Bias

(b) Marking Bias

FIG. 12. BIAS DISTORTION.

The amount of bias is the lengthening expressed as a percentage of the unit interval.

For example, when the unit interval is 20mS, a marking bias of 10% indicates that all marking elements are lengthened by 2mS (10% of 20mS), as shown in Fig. 12.

5.2 Bias in Double Current is due to:-

(i) Non-neutral positioning of the send device.

(ii) Unequal battery potentials.

(iii) Non-neutral receive relay.

5.3 Non-neutral positioning of the Send Device. When the Send Device is a tongue which pivots between 2 contacts, equal mechanical pressures should be required to move the tongue from either contact. When the pressures are not equal, the tongue is in transit for less time in one direction, and biased signals are produced.

5.4 Unequal Battery Potentials produce marking and spacing conditions which are represented by unequal values of steady state current.

Assuming the element time-intervals to be correct, the amount of bias produced by unequal maximum values of current is dependent upon the shape of the signal elements. Fig. 13 shows square-topped equal length elements of unequal current values applied to a neutrally adjusted receive relay. In this paper relay transit time is not shown. The relay operates at points 0_1 and 0_2 for time intervals t_1 (mark) and t_2 (space), which in the example are equal; there is no distortion.

For square-topped elements the only amplitude requirement for correct reproduction of the time intervals is that the mark and space currents reach the relay operate point (0_1 and 0_2 in Fig. 13).

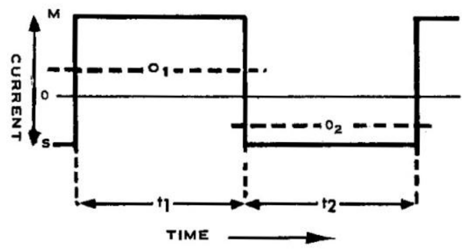
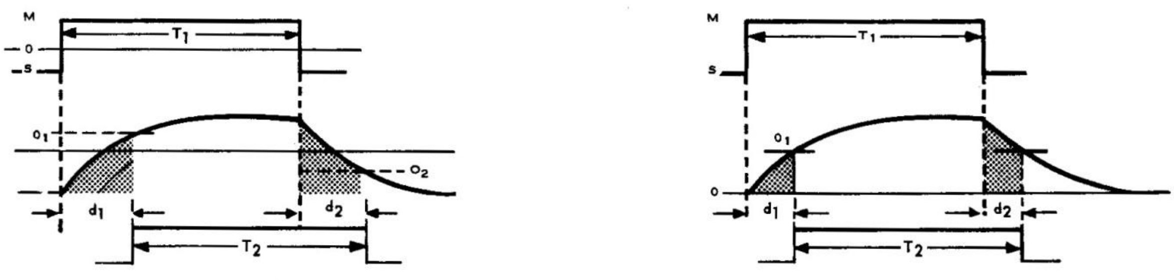


FIG. 13. BIAS AND SQUARE WAVE SHAPE.

In practice, there is a transition delay due to the reactive circuit components associated with resistance, as discussed in the paper "Telegraph Transmission".

When the elements require a finite time to reach a steady value, the restitution is delayed by a time equalling the interval between the commencement of the transition and the point at which the receive relay operates. This interval (d_1 and d_2 in Figs. 14a and b), is the "restitution time", and is defined as the time interval between an instant of modulation and the corresponding instant of restitution (Fig. 14).



(a) Double Current. (b) Single Current.

FIG. 14. RESTITUTION TIME.

In the double current case, the operate points (01 and 02) refer to a polarised relay. "Restitution time" is also applicable to single current, and in Fig. 14b the operate point (0_1) refers to a single current receive device which is mechanically or electrically "biased" in a spacing direction.

T_1 and T_2 are the original and restituted time intervals, respectively, d_1 is the restitution time of the space-to-mark transition; d_2 is the restitution time of the mark-to-space transition. When d_1 and d_2 are equal, there is no distortion.

Fig. 15 depicts a signal in which the maximum marking current is substantially greater than the maximum spacing current, and in which the changes from one condition to another are not instantaneous.

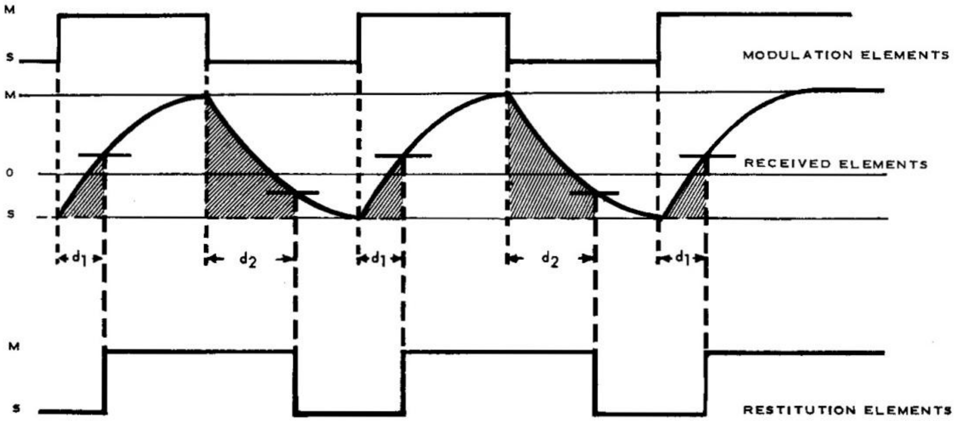


FIG. 15. BIAS AND TRANSITION DELAY.

Because of the unequal current values, d_1 is less than d_2, and the time intervals for which the relay is operated to each condition differ from the original time intervals; the elements now possess a marking bias.

A comparison between Fig. 13 and Fig. 15 indicates that bias distortion due to unequal battery potentials is zero when the elements retain their original square shape.

5.5 When the Receive Relay is not neutral, the operate points 0_1 and 0_2 in Fig. 14a are not equally spaced in time from the zero line, d1 and d2 are not equal, and bias is produced.

5.6 Bias in Single Current Working is due to:-

(i) Incorrect timing of the make/break action of the send contacts.

(ii) Incorrect relationship between element amplitude and the operate point of the receive relay.

(iii) Changes to the element wave shape.

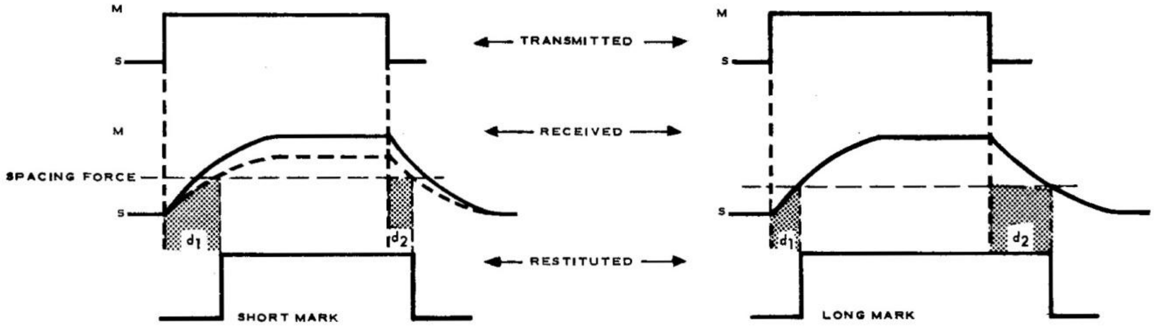
5.7 Incorrect Timing. The forming of the code elements is achieved by the opening or closing of the send contacts for unit intervals or multiples of unit intervals.

When all code elements are formed by the same contacts, any variation from standard make/break timing results in bias distortion.

5.8 Incorrect Level Relationship. The single current receive device operates to a marking condition when current is received, and to a spacing condition when no current is received. In the absence of current the device is mechanically or electrically restored to the spacing condition.

The device operates to a mark when the magnetic force due to the incoming current overcomes the permanent spacing force, and returns to the spacing condition when the spacing force again predominates.

Fig. 16 shows the relationship between the steady state value of the received element and the relay operate points, and the variations of this relationship which produce bias distortion.



(a) Variation in Amplitude. (b) Variation in Spacing Force.

FIG. 16. AMPLITUDE AND RELAY OPERATE POINTS.

In Fig. 16a the correct steady state value of current (full line) is decreased to the value indicated by the dotted line. Restitution times d_1 and d_2 now are unequal; all spaces are lengthened and spacing bias exists. The reduction in current value may be due to variations in leakage, especially in open wire lines, or a change in the circuit resistance or applied potential.

In Fig. 16b the spacing force, due to maladjustment, is decreased. Restitution times d_1 and d_2 again are unequal; all marks are lengthened and marking bias exists.

5.9 Changes in Waveshape. Previous graphical descriptions of single current signals show the transitions from mark to space and space to mark as being similar in shape and time.

As stated in the paper "Telegraph Transmission", variations from these descriptions occur in practical circuits. Fig. 17 shows a single current circuit which includes a short loop of negligible capacitance, a spark quench capacitor (C_1) across the transmitter contacts, a current limiting resistor, and a receiver which is inductive and resistive.

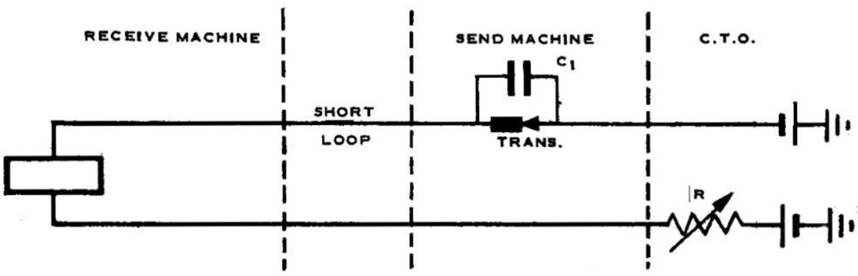
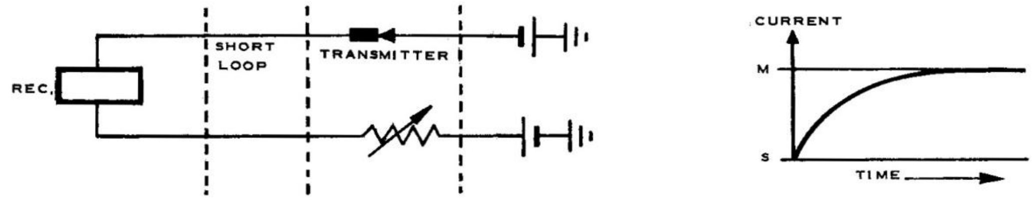


FIG. 17. SINGLE CURRENT CIRCUIT - SHORT LOOP.

The circuit follows the standard practice of dividing the applied E.M.F., thus reducing the circuit potential with respect to earth, and consequently safeguarding the line insulation resistance.

Fig. 18a and b show respectively the equivalent circuit when the transmitter contacts close, and the space-to-mark transition of the received signal element.

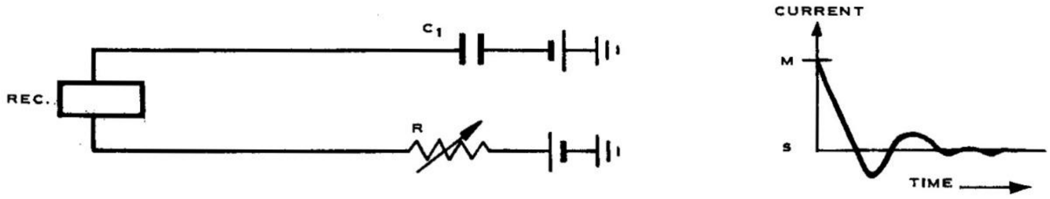


(a) Contacts Close. (b) Space-to-Mark Transition.

FIG. 18. EQUIVALENT CIRCUIT FOR A MARK.

The transmitter contacts short circuit the spark quench capacitor C_1, and the transition delay (Fig. 18b) is dependent upon L and R, the short loop contributing negligible capacitance.

Fig. 19a and b show respectively the equivalent circuit when the transmitter contacts open, and the mark-to-space transition of the received signal element.



(a) Contacts Close. (b) Mark-to-Space Transition.

FIG. 19. EQUIVALENT CIRCUIT FOR A SPACE.

The opening of the transmitter contacts places the spark quench capacitor C_1 in series with the machine inductance, changing the circuit conditions for the mark-to-space transition. Capacitor C_1 eventually charges to the signalling potential, but the initial charging potential is a combination of the large back E.M.F. produced by the machine inductance, plus the signalling potential.

The spark quench capacitor, therefore, is initially overcharged, and the subsequent oscillatory action between L and C produces the waveshape shown in Fig. 19b.

5.10 Condition for Zero Distortion. Fig. 20 shows the receive device operate points, as determined by the fixed spacing force, required for zero distortion.

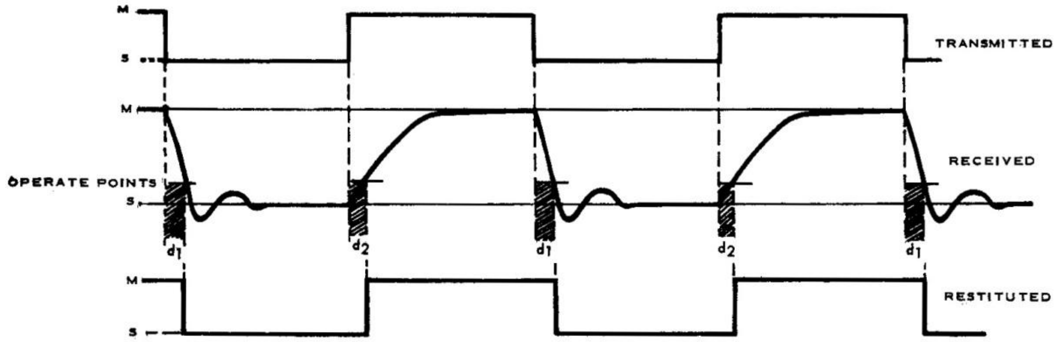


FIG. 20. SINGLE CURRENT WAVESHAPES - SHORT LOOP.

In Fig. 20 the relay operate points are such that the restitution delay times d_1 and d_2 are equal; the time intervals are correctly reproduced by the relay, and there is zero distortion.

Any charge in the relationship between the spacing force and the element waveshape will produce bias distortion.

5.11 Effect of Additional Machine. Fig. 18 shows that the space-to-mark transition delay is determined by the circuit L and R. Additional machines in the circuit increase L, which increases the transition delay time, as shown by the dotted lines in Fig. 21.

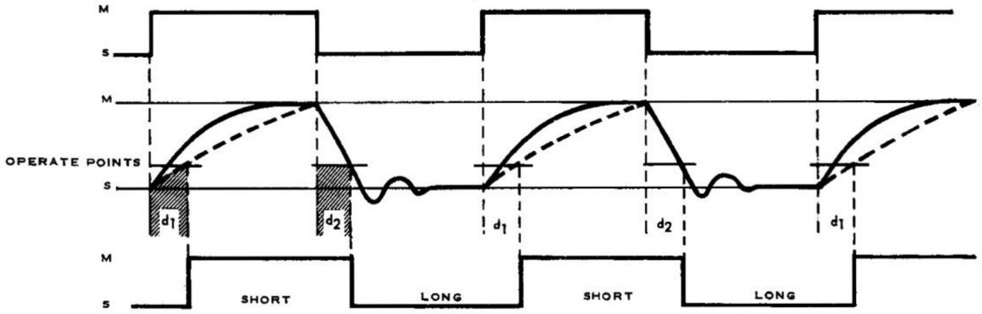


FIG. 21. EFFECT OF INCREASED L.

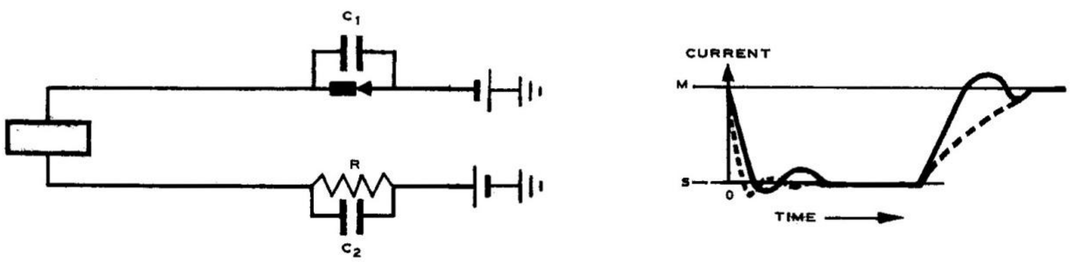
The transition delay to the spacing condition is determined primarily by the value of C_1, as shown in Fig. 19. The additional inductance increases d_1 without substantially affecting d_2; d_1 and d_2 are unequal, and distortion exists.

As all spacing elements are lengthened, spacing bias has been introduced to the circuit.

5.12 Signal Shapers. In practice, single current short loop circuits can include a component known as a signal shaper, which sharpens the space-to-mark transition.

In Fig. 22a the signal shaper is represented by C_2, and the resultant waveshape is shown in Fig. 22b.

The dotted lines represent the transitions without C_2, and Fig. 22b shows that the beginning of the spacing element is affected by only a small amount, representing a change in the total capacitance when the contacts open (C_1 + C_2). When the contacts close, however, the beginning of the mark element is changed considerable, because the circuit contains capacitance (C2) in addition to the usual L and R.



(a) Signal Shaper. (b) Single Current Waveshape.

FIG. 22. SIGNAL SHAPER IN SHORT LOOP.

The duration of the spacing elements and the time constants of C_1 and C_2 are such that at the instant of closing the contacts C_2 is in a discharged condition, and the resistance R is effectively short circuited.

At this instant there is no voltage dropped across R, and a higher voltage is applied to the receiver inductance, thus increasing the rate of growth of current.

When C_2 is sufficiently large, its interaction with the inductance produces a current with an initial peak value in excess of the steady state value, as shown in Fig. 22b.

5.13 Single Current - Long Loop. When the loop length is increased the line capacitance becomes an added component which further modifies the element waveshape. Fig. 23 depicts a single current long loop, in which the line capacitance C_2 is greater than the spark quench capacitor C_1.

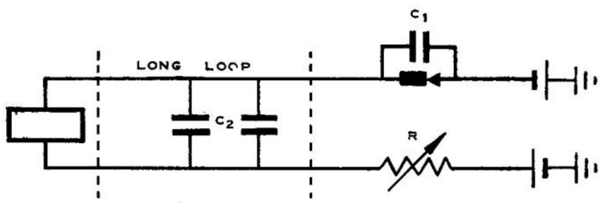
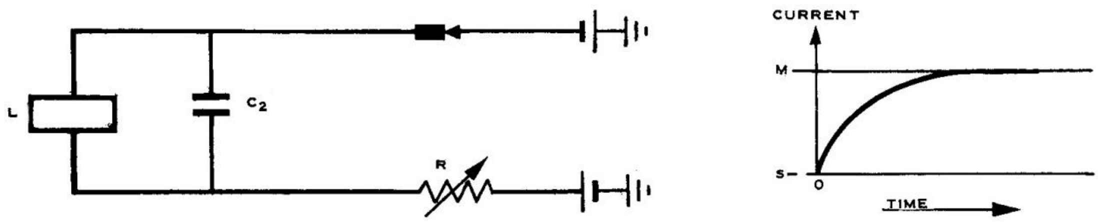


FIG. 23. SINGLE CURRENT - LONG LOOP.

The equivalent circuit when the contacts close in the marking condition is shown in Fig. 24a, and the space-to-mark transition is shown in Fig. 24b.

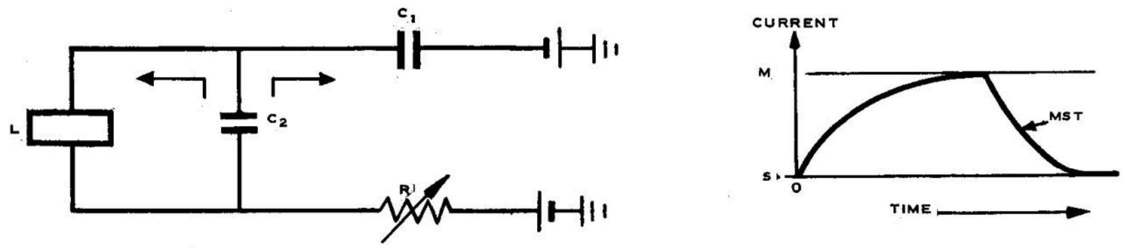


(a) Contacts Close. (b) Space-to-Mark Transition.

FIG. 24. MARKING CONDITION.

In this condition C_1 is shorted out by the transmitting contacts, and the combination of C_2, L and R delays the growth of current to the maximum value.

The equivalent circuit when the contacts open in the spacing condition is shown in Fig. 25a, and the mark-to-space transition is shown in Fig. 25b.



(a) Contact Open. (b) Mark-to-Space Transition.

FIG. 25. MARKING CONDITION.

When the contacts open, the line capacitance discharges in the directions indicated by the arrows in Fig. 25a. The discharge current at the receiving end is in the same direction as the original marking current, and the mark-to-space transition is delayed considerably more than in the case of the short loop.

The waveshapes in long loops are determined largely by C_2 and R, and as these components are in the circuit during both transitions, the resultant waveshapes approach a double current form, as indicated in Fig. 25b.

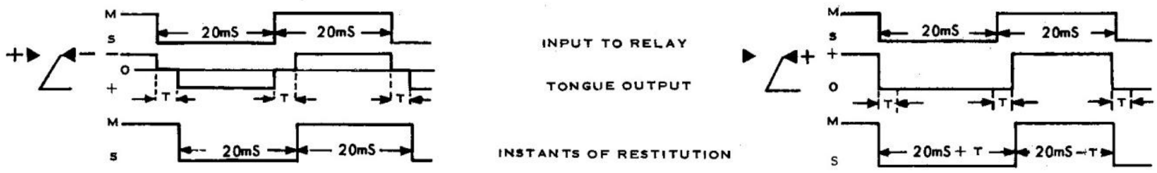
Long Loops and Bias Distortion. As in short loops, long loop signal elements are subject to bias distortion due to changes in the relationship between the amplitude of the received element and the relay spacing force. However, bias distortion due to changes in waveshape is minimised by the dominancy of the line capacitance over machine inductances and spark quenches.

5.14 Relay Transit time and Distortion. In previous paras, it is assumed that relay transit times are equal for mark-to-space and space-to-mark transitions, and do not contribute, therefore, to distortion.

This is true for double current signals, in which battery of opposite potentials are connected to the relay contacts, and the new signalling condition is not applied to the line until the relay tongue has completed its travel (Fig. 26a). Under these conditions the transit time (T) is added to the last condition, and its effect is cancelled.

In single current signalling, however, where battery is applied to one contact only, the "no-current" condition is transmitted whenever the tongue is not making on the battery-connected contact (Fig. 26b), and this applies during the transit time (T) of the relay tongue.

In this case, therefore, it is important to ensure that the transit time is a minimum, in order to reduce the bias inherent in this type of circuit.



(a) Double Current. (b) Single Current.

FIG. 26. TRANSIT TIME AND DISTORTION.

6. CHARACTERISTIC DISTORTION IN DIRECT CURRENT TRANSMISSION.

6.1 Characteristic distortion exists in a circuit when the transition delay time is affected by the transmission characteristics of the circuit (R, L, and C), such that the steady state value is not achieved in the unit interval.

6.2 Types. Characteristic distortion can be considered as being of two types:-

(i) Negative, when the shortest elements of a particular combination are consistently shortened (Fig. 29). The term "negative" indicates a reduction from the ideal interval.

(ii) Positive, when the shortest element of a particular combination are consistently lengthened (Fig. 31). The term "positive" indicates an addition to the ideal interval.

6.3 Negative Characteristic Distortion occurs when the elements require a longer period than the unit interval, in which to reach the steady value of current. Not all the elements of a particular combination, therefore, are of sufficient duration to reach the maximum value before the transition to the next condition occurs.

Thus the transitions commence at a value of current which is determined by the duration of the preceding element.

In Fig. 27 the elements require 1½ unit lengths (at 50 bauds) in which to reach the maximum value. A transition occurring at 20mS (point A) commences at a lower value of current than a transition occurring at 40mS (point B).

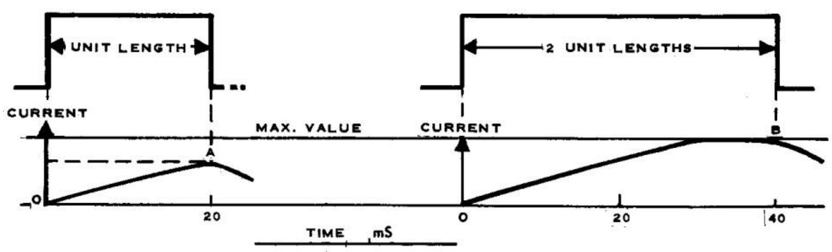


FIG. 27. CURRENT VALUE AND ELEMENT LENGTH.

The operate points of a relay (0_1) are included in Fig. 28a and b. Restitution time d represents the delay periods between the start of the transitions (points A and B) and the relay response.

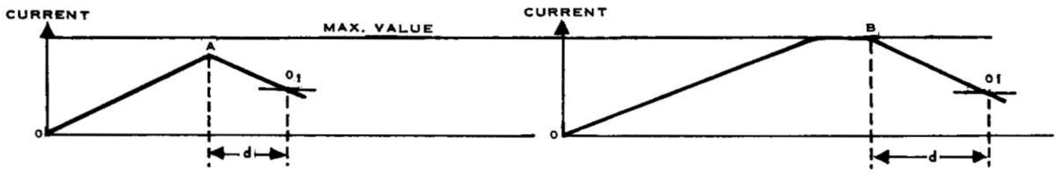


FIG. 28. RESTITUTION DELAY AND ELEMENT LENGTH.

The restitution time (d) in Fig. 28a is less than the restitution time (d) in Fig. 28b, because transition A in Fig. 28a commenced at a lower value of current than transition B in Fig. 28b. This indicates the, under these conditions, the restitution delay time is determined by the duration of the preceding element.

Fig. 29 shows a telegraph signal in which the elements do not reach their steady state value within the unit length period, mainly due to line capacitance. The operation of the relay is delayed less after a short element than after a long element. For convenience, double current operation is assumed, with the relay changing over at zero current.

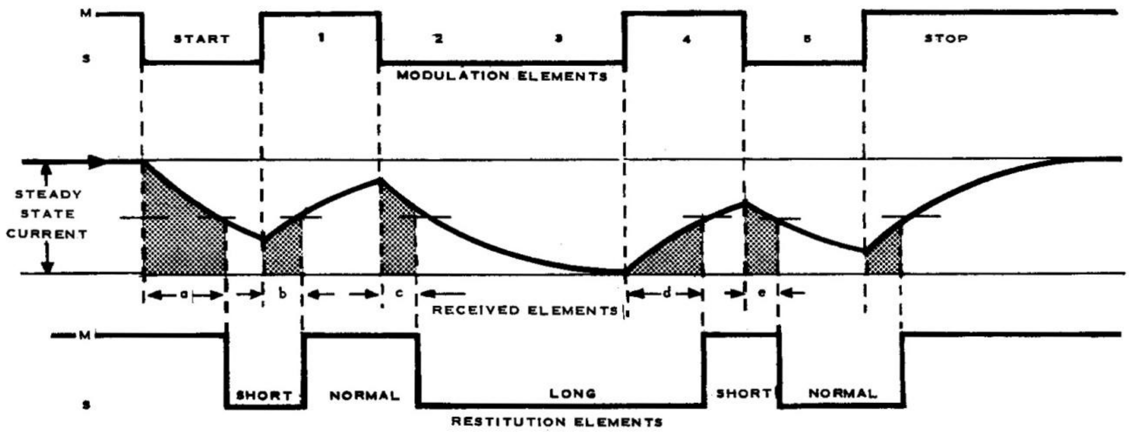


FIG. 29. NEGATIVE CHARACTERISTIC DISTORTION.

(i) The previous stop signal is of sufficient duration to allow the current to reach the steady state value.

(ii) The restitution delay (a) on the first transition is a maximum.

(iii) The start element does not reach the steady state value and the restitution delay (b) is less than (a).

(iv) The transition to the first code element, therefore, is advanced, and the start element is correspondingly shortened.

(v) The first code element is of unit length and does not reach the steady state value. Restitution delay (c) is equal to (b), and there is zero distortion.

(vi) The fourth code element is preceded by an element which is of sufficient duration to reach the steady state value; (d) is a maximum and (e) is less than the maximum, and the fourth code element is correspondingly shortened.

(vii) The start element (space) and the fourth code element (mark) suffer from negative characteristic distortion because they are preceded by elements which reach the steady state value; the beginning and the end transitions of the distorted elements occur at different values of current.

(viii) The first and fifth code elements are undistorted because they are preceded by elements of similar length; the beginning and the end transitions of the first and fifth code elements occur at the same value of current.

6.4 Negative characteristic distortion is dependent upon:-

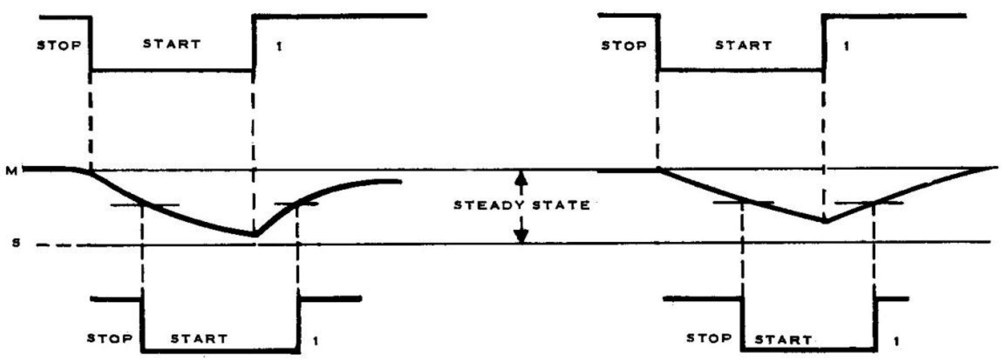
(i) The relationship between the build-up time of an element and the unit interval. In direct current transmission, this means the relationship between the line capacitance and signalling speed.

(ii) The signal combination being transmitted. Negative characteristic distortion does not occur in those combinations in which all transitions occur at the same value of current. For example, when the build-up time is between one and two unit intervals duration, those combinations in which all elements are two or more unit intervals long are unaffected.

When alternate marks and spaces (reversals) are transmitted the elements do not necessarily reach maximum value. This type of signal, however, does not suffer from negative characteristic distortion, because all transitions occur at the same value of current.

6.5 Negative characteristic distortion increases with an increase in the slope, or build-up time, of an element. The system becomes unworkable when the current does not reach the relay operate point during the unit interval.

Fig. 30 shows the amount of distortion increasing with element build-up time.



(a) (b)

FIG. 30. AMOUNT OF DISTORTION.

In Fig. 30a and b the stop element reaches a steady value, and the start element is shortened by an amount which depends upon the build-up time of an element.

A comparison of Fig. 30a and b shows:-

(i) The build-up times are such that the transition to the first code element in Fig. 30a commences at a value of current which is closer to the steady state value than the similar transition in Fig. 30b.

(ii) The start element in Fig. 29a is shortened less than the start element in Fig. 29b.

6.6 Positive Characteristic Distortion occurs when the interaction of capacitance and inductive causes the current to build up to a value in excess of the steady state value, and the current fails to return to the steady state value within the period of the unit interval.

The operation of a relay is delayed more after a short element than after a long element, as shown in Fig. 31.

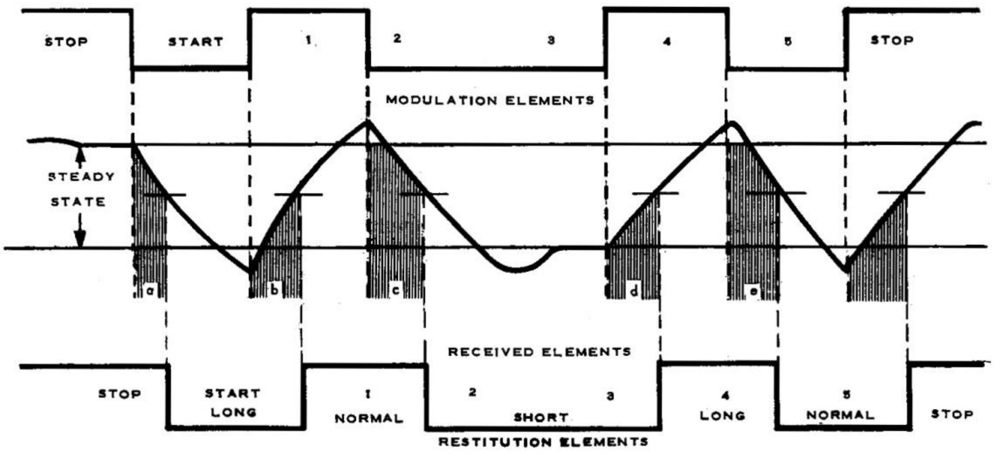


FIG. 31. POSITIVE CHARACTERISTIC DISTORTION.

(i) The stop signal is long enough to allow the current to return to a steady state condition.

(ii) The first transition commences at a steady state value of current, producing restitution time (a).

(iii) The transition to the first code element commences at a value of current which is in excess of the steady value, producing restitution time (b). The start signal is prolonged by an amount equal to the difference in restitution times (a) and (b).

(iv) The transition at the end of the first code element commences at a value in excess of the steady state, similar to the preceding transition. Restitution times (b) and (c) are equal, and there is no distortion.

(v) The transition to the fourth code element is preceded by an element long enough to allow the current to return to the steady value, producing restitution time (d).

(vi) The transition to the fifth code element is preceded by an element of unit length, and occurs at a value in excess of the steady state. Restitution time (e) is greater than (d) and the fourth code element is lengthened.

(vii) The start element (space) and the fourth code element (mark) suffer from positive characteristic distortion because they are preceded by elements which reach the steady state value of current; the beginning and end transitions of the distorted elements occur at different values of current.

(viii) The first and fifth code elements are undistorted because they are preceded by elements of similar length; their beginning and end transitions occur at the same value of current.

6.7 Positive Characteristic Distortion does not occur in those combinations in which the transitions occur at the same value of current. This includes those combinations in which the elements are of sufficient duration to allow the current to return to a steady condition, and reversals.

7. FORTUITOUS DISTORTION.

7.1 Fortuitous Distortion arises from random influences upon the circuit or equipment and the amount and direction of the displacement of the transitions do not follow a pattern.

The main sources of fortuitous distortion are the interfering currents which result from electromagnetic or electrostatic induction into the telegraph circuit.

The sources of interference are adjacent telegraph circuits, particularly in long underground cables, and, in the case of open wire lines, induction from power lines.

In telegraph terminology the induction of undesirable currents into a circuit is called "crossfire".

7.2 The effect of crossfire currents is to aid or oppose the element current according to their phase relationship. The amount of distortion produced by a given magnitude of crossfire increases as the build-up time of an element increases.

Fig. 32 shows the effect of a change in the slope of an element due to crossfire, when the change occurs close to the relay operate point.

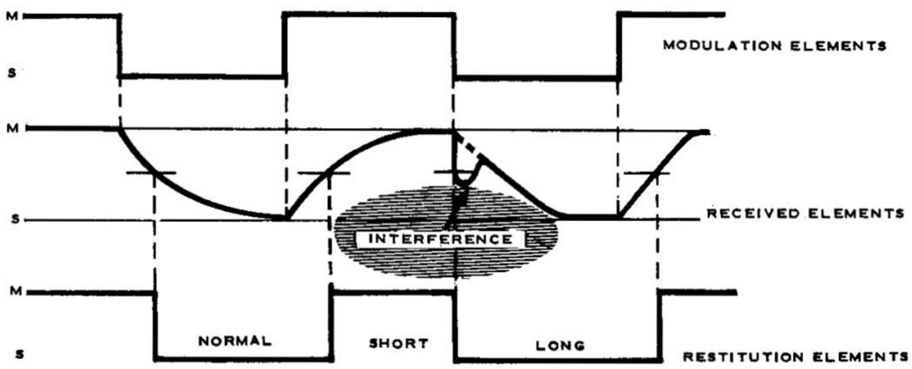


FIG. 30. FORTUITOUS DISTORTION.

In Fig. 32 the waveshape is modified by the interfering current, and the transition is advanced, thus shortening the affected element.

8. DISTORTION IN A.C. TELEGRAPHY.

8.1 Types of A.C. Signalling. We saw in the paper "Telegraph Transmission" that the two types of A.C. signalling used in Australia are:-

(i) Amplitude modulation (A.M.), in which the A.C. is changed in amplitude from maximum for a marking condition, to zero for a spacing condition.

(ii) Frequency modulation (F.M.), in which a nominal mean frequency is shifted to a lower frequency for a marking condition, and to a higher frequency for a spacing condition.

Because the frequencies used in both types are within the voice frequency range (300c/s to 3.4kc/s), A.C. operation is referred to as "voice frequency telegraphs", or simply "V.F.T".

The principles of signal distortion in A.C. signalling are discussed in this paper, and detailed information as applied to individual items of equipment is presented in other papers of this course.

8.2 Bias Distortion in A.M.V.F.T. When a mark is transmitted, an A.C. is applied to the receiver, where it is converted to D.C. to operate a polarised relay to the marking condition.

When a space is transmitted, no A.C. is received, and the relay is electrically "biased" to return to the spacing condition.

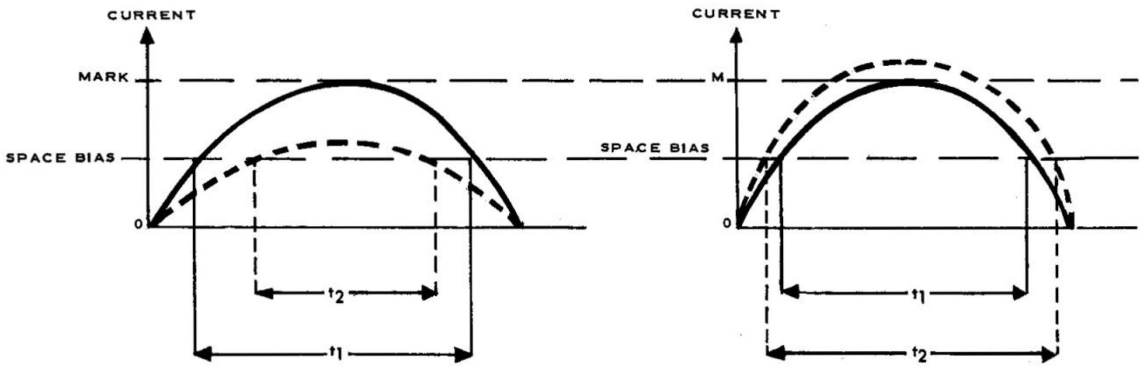
A.M.V.F.T. therefore, is essentially the same as that explained in Section 5 for single current operation, with the same basic causes of bias distortion. These are:-

(i) A change in the relative amplitude of the received element current and the spacing bias current (Fig. 33).

(ii) Non-neutrality of the receive relay. The principles of relay neutrality are explained in the paper "Polarised Telegraph Relays".

Fig. 33 shows that, due to the frequency restriction of filters, the rectified element is not a square shape.

The relative magnitudes of the marking current and the spacing bias current are adjusted so that the relay operations reproduce the original transmitter operations. The correct duration of a marking condition of unit length is represented by t_1.



(a) Spacing Bias. (b) Marking Bias.

FIG. 33. RELATIVE AMPLITUDES IN A.M.

The dotted line in Fig. 33a represents a reduction in marking current amplitude, which produces the reduced relay marking condition t_2. All marks are decreased in length and spacing bias exists.

The dotted line in Fig. 33b represents an increase in marking current amplitude, producing the increased relay marking condition of t_2. All marks are increased in length and marking bias exists.

Similarly, an increase or decrease of the spacing bias from its correct value produces bias distortion.

8.3 Bias Distortion in F.M.V.F.T. At the receive end of the F.M. signalling stage the marking and spacing frequencies are applied to two tuned circuits, one resonant below and the other above the rest frequency. The A.C. output from each tuned circuit is rectified and applied to a differentially wound polarised relay.

The mean, or "carrier" , frequency (fc), is generally decreased by 30c/s for a mark (fc-30), and increased by 30c/s for a space (fc+30).

Fig. 34 shows the basic circuit components at the receive end of an F.M.V.F.T. system.

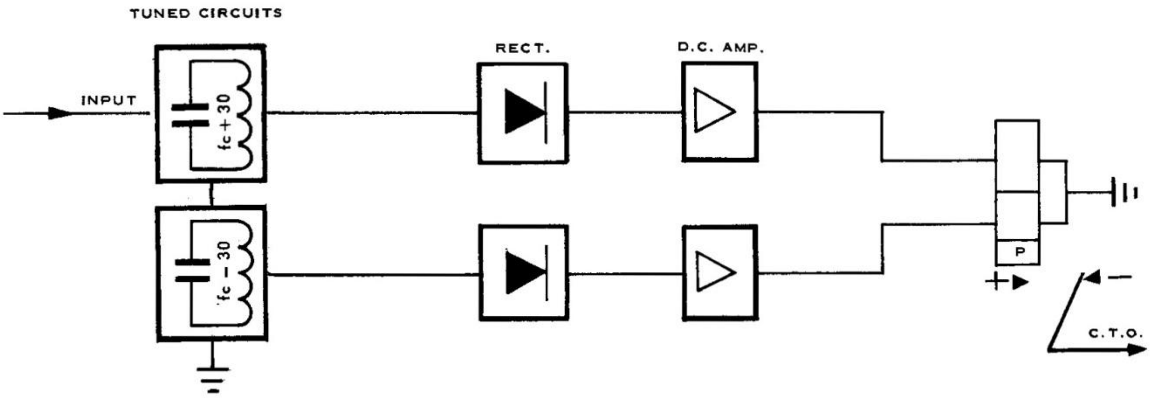


FIG. 34. BASIC F.M. RECEIVER.

(i) The tuned circuits' voltage output is a maximum at fc + 30 or fc - 30.

(ii) The output is rectified and amplified, and D.C. is applied through the coils of a polarised relay, in one direction for a space, and in the other direction for a mark.

(iii) The tongue of the relay applies positive or negative potential to the line.

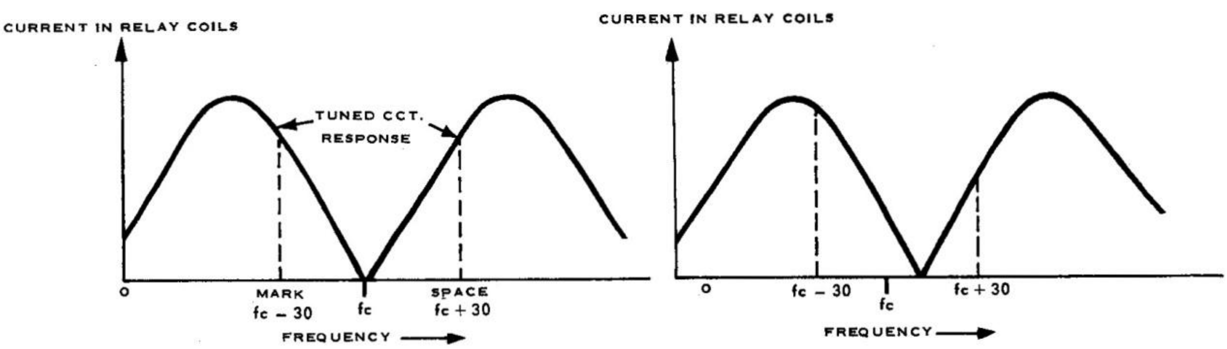
F.M.V.F.T., therefore, is essentially double current operation, with the same basic causes of bias distortion. These are:-

(i) Unequal amplitudes of the mark and space element current.

(ii) Non-neutrality of the receive relay.

The output of a tuned circuit varies with the applied frequency, and any change in the marking and spacing frequencies from the standard results in a change in the amplitude of the mark and space currents applied to the relay.

Fig. 35 plots frequency against the amplitude of the element current through the relay coils.



(a) Correct frequency. (b) Incorrect frequency.

FIG. 35. CURRENT VERSUS FREQUENCY.

Fig. 35a shows that when the frequencies are correctly related to the tuned circuits response, the mark and space currents are equal in amplitude.

Fig. 35b shows that when this relationship is upset due to frequency error, one element amplitude is decreased and the other is increased.

In F.M. transmission, therefore, frequency error produces mark and space elements of unequal amplitude, causing bias distortion, as discussed in para. 5.4, and shown in Fig. 15.

8.4 Characteristic Distortion in A.M. and F.M. The frequencies produced in amplitude and frequency modulation, due to a flat-topped element input, are discussed in the paper "Telegraph Transmission".

When these frequencies are restricted by filters, the rectified elements at the receive end lose their abrupt wave-shape, and require a finite time to reach the steady state current value.

Characteristic distortion is produced when the frequency restriction is such that the rectified current requires longer than the unit interval to reach value, as explained in para. 6.3 and shown in Fig. 29.

8.5 A further cause of characteristic distortion in A.M.V.F.T. is the automatic gain control (A.G.C.) arrangement in the receiver amplifier-detector. The A.G.C. is designed to maintain the rectified marking current at a constant amplitude, and features a grid-leak bias capacitor which is charged during the incoming marking frequency.

During the spacing (no frequency input) intervals the bias voltage tends to decrease, and after a prolonged spacing interval the gain of the amplifier can be greater than normal.

During this condition the first space-to-mark transition occurs early, as shown in Fig. 36.

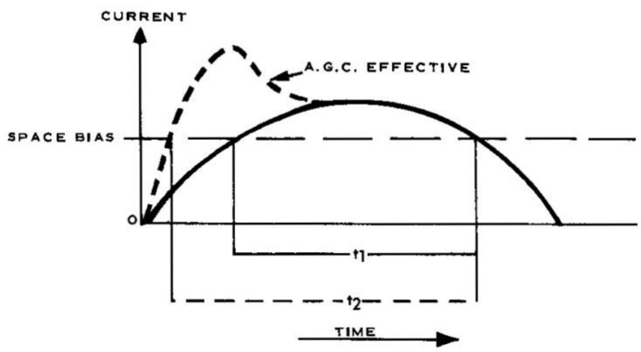


FIG. 36. A.G.C. Action.

In Fig. 36 the heavy line represents the rectified marking current of correct amplitude, causing the relay to mark for time t_1.

The dotted line represents the first space-to-mark transition which occurs after a prolonged spacing interval.

The initial increased amplitude, due to increased amplifier gain results in an advance in the relay operation to the mark condition.

The element current returns to the normal amplitude as the A.G.C. becomes effective and the relay marks for time t_2.

The lengthening of the mark following the long spacing interval is termed characteristic distortion, because the build-up time of the marking element is dependent upon the state of charge of the A.G.C. capacitor, that is, the duration of the preceding element. Distortion from this particular cause does not occur in F.M.V.F.T., in which the receiver is sensitive to frequency rather than amplitude changes.

8.6 Fortuitous Distortion in A.M. and F.M.V.F.T., is due to the presence of unwanted frequencies which are acceptable to the receive filters, and produce random effects on the telegraph signal transitions.

The principles of the way in which interfering currents affect the transitions are explained in para. 7.2 and shown in Fig. 32.

9. DISTORTION AND ORIENTATION LIMITS.

9.1 Telegraph machine receive mechanisms generally include an orientation facility, by which the instants of selection can be varied with relation to the commencement of the start signal.

The total variation which can be effected without incorrect translation is known as the orientation "range" of the receiver.

The limits of a receivers' range are read on the orientation scale, which is calibrated in per cent of a unit element length. A pointer indicates the amount of displacement to the one side or the other of the ideal condition.

Fig. 37 shows a typical relationship between the instants of selection and the scale calibrations.

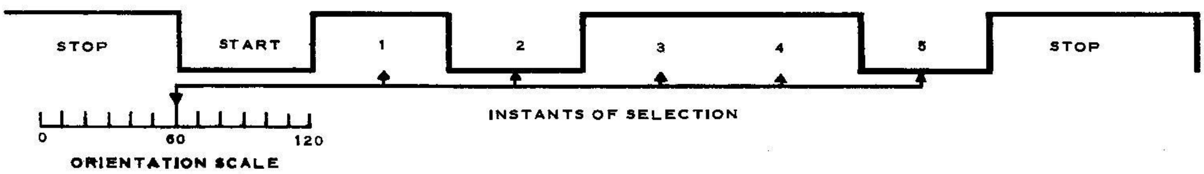


FIG. 37. ORIENTATION SCALE AND SELECTION.

In the example shown in Fig. 37 the pointer is set on mid-scale (60), and the instants of selection occur in the centre of undistorted elements. In the ideal case the instants of selection can be shifted in either direction by 40% of a unit interval (to points 20 and 100 on the scale), before mistranslation occurs.

Under these conditions the receiver is said to have a range of 20 to 100, with 20 as the lower limit, and 100 as the upper limit.

The orientation device on a maximum margin receiver can be used to measure the distortion present in incoming signals. The orientation scale readings indicate the reduction in range due to distortion, and the direction of the shift in limits indicates the type of distortion.

The relative directions of movement of the scale pointer and the instants of selection vary in machines of different manufacture. This paper assumes the relationship indicated in Fig. 37, where a movement of the pointer towards zero results in the instants of selection being moved closer to the start element. Conversely, a movement of the pointer towards 120 results in the instants of selection being moved closer to the stop element.

9.2 Effect of Marking Bias on Limits. Fig. 38 shows a signal in which all the marking elements are lengthened, and the spacing elements are correspondingly shortened. The orientation pointer is set on mid-scale; the instants of selection in this receiver are centered with respect to an undistorted signal element. The receivers' range to undistorted signals is assumed to be 20 to 100, and the receiver is assumed to be free from internal distortion, which, in practice can modify the following results.

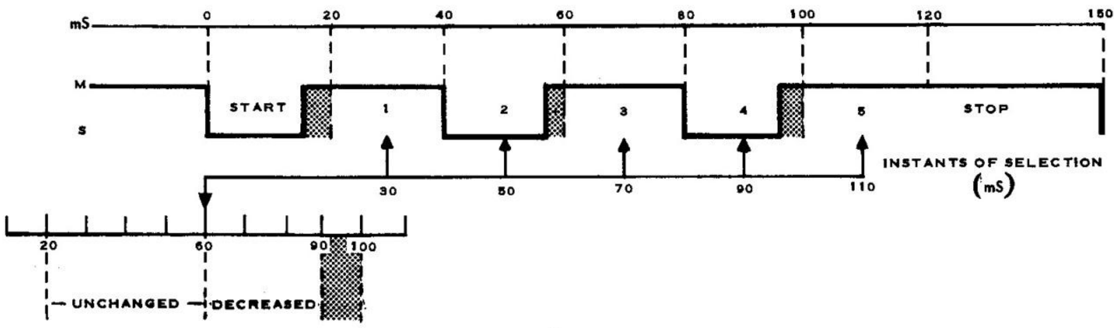


FIG. 38. MARKING BIAS.

Start-stop transitions, when distortion is present, occur early or late with respect to the commencement of the start signal.

The mark-to-space transition to the start signal is the reference point, and marking bias causes all space-to-mark transitions to occur early, as shown in Fig. 37.

The numerical upper limit to the range is determined by the maximum amount by which a transition occurs early, and the lower limit is determined by the maximum amount by which a transition occurs late.

In the example given in Fig. 38, because there are no transitions occurring late, the instants of selection can be shifted to the left by 40% (40 points on the scale), before mistranslation occurs; the lower range limit is unchanged at 20 on the scale. Because all space-to-mark transitions occur early, however, the instants of selection can be shifted to the right by a reduced amount; the upper range limit is reduced, and assuming 10% marking bias, mistranslation occurs at 10 points lower than the ideal upper limit, that is, at 90 on the scale.

Marking bias, therefore, reduces the numerical value of the upper limit of the range, and leaves the lower limit unchanged.

9.3 Effect of Spacing Bias on Limits. Fig. 39 shows a signal in which all the spacing elements are lengthened, and the marking elements are correspondingly shortened.

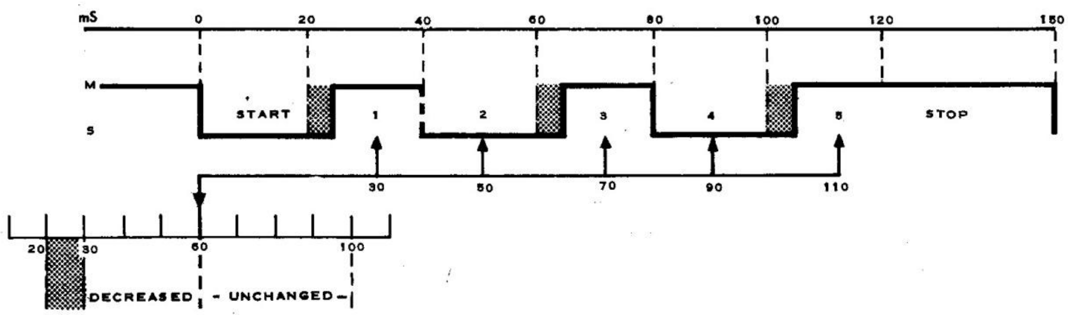


FIG. 39. SPACING BIAS.

Spacing bias causes all space-to-mark transitions to occur late, and the instants of selection can be shifted to the left by a reduced amount before mistranslation occurs; the pointer can be moved to the left of mid-scale by fewer points before mistranslation occurs.

When the spacing bias is 10%, errors occur at 30 on the scale instead of 20, that is, the numerical value of the lower limit of the range is increased.

Spacing bias, therefore, increases the numerical value of the lower limit of the range and leaves the upper limit unchanged.

9.4 The Effect of Negative Characteristic Distortion on Limits differs with the particular combination which is being received. Fig. 40 shows the code combination for the letter "Y" with the received elements requiring 1.5 unit lengths in which to reach a steady state value of current.

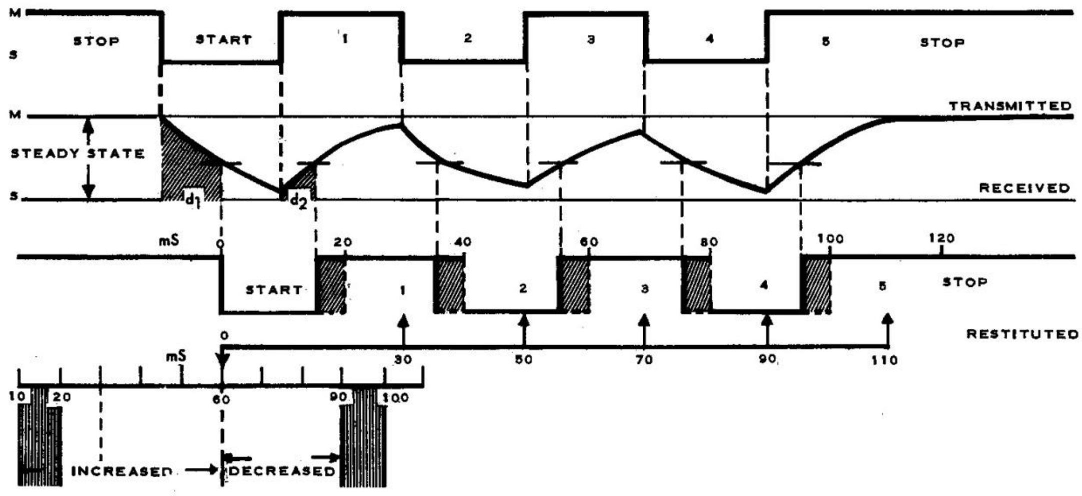


FIG. 40. NEGATIVE CHARACTERISTIC DISTORTION - CHARACTER "Y".

(i) Because the rise time is 1.5 unit intervals, the previous stop element reaches maximum current value, and the restitution delay (d1) to the commencement of the start signal is a maximum (Fig. 40).

(ii) The start element does not have sufficient time to reach the steady current value; the restitution delay (d2) to the first code element is short, and the start element is shortened.

(iii) The signal combination is such that the transitions at the beginning and end of the code elements commence at the same value of current; the restitution delays are equal, and the restituted code elements are undistorted.

(iv) Because only the start element is shortened, all succeeding significant instants of restitution occur early with respect to the beginning of the start element (Fig. 40).

(v) In Fig. 40 the instants of selection are shown occurring at their correct intervals after the commencement of the start signal, and relating these instants to the significant instants of restitution show that the upper margin is reduced, and the lower margin is improved.

In this particular example, therefore, the effect of negative characteristic distortion is to shift the upper and lower orientation limits in the same direction.

The numerical values of the upper and lower range limits are reduced.

9.5 Fig. 41 shows the effect on the orientation limits when the code combination for the letter "B" suffers from negative characteristic distortion. The element rise time is 1.5 unit intervals.

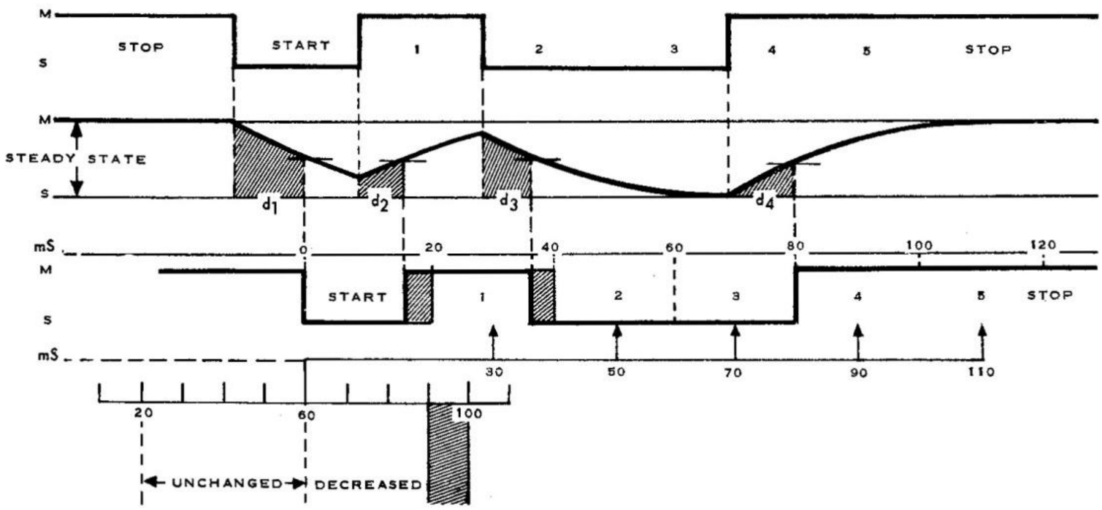


FIG. 41. NEGATIVE CHARACTERISTIC DISTORTION - CHARACTER "B".

(i) Because the rise time is 1.5 unit intervals, the previous stop element reaches a steady state current value, and the restitution delay (d_1) to the commencement of the start signal is a maximum.

(ii) The start element does not have sufficient time to reach the steady current value, and the restitution delay (d_2) to the first code element is short; the start element is shortened.

(iii) The transitions at the beginning and end of the first code element (d_2 and d_3) commence at the same value of current; the restitution delays are equal, and the restituted first code element is of correct length.

Because of the short start element, the significant instants of restitution occur early with respect to the start element, and the advance of that significant instant which should occur at 40mS reduces the upper limit, as shown in Fig. 41.

(iv) The spacing condition preceding the fourth element is of such a duration that the current reaches the steady value, and the restitution delay (d_4) is a maximum.

Restitution time d4 delays the succeeding significant instant by the same amount by which the start element is shortened, and the instant occurs at 80mS, which is correct.

Consequently, the margin between this instant and the fourth instant of selection is normal, and the lower orientation limit is unchanged.

In this particular example, therefore, the effect of negative characteristic distortion is to reduce the numerical value of the upper range limit, and to leave the lower range limit unchanged.

In general terms, negative characteristic distortion reduces the upper range limit, and the effect on the lower limit depends upon the signal combination which is being received.

9.6 The Effect of Positive Characteristic Distortion on Limits also differs with the signal combination which is being received. Fig. 42 shows the code combination for the letter "Y", in which the element current requires 1.5 unit intervals in which to return to the steady state value from an excess value.

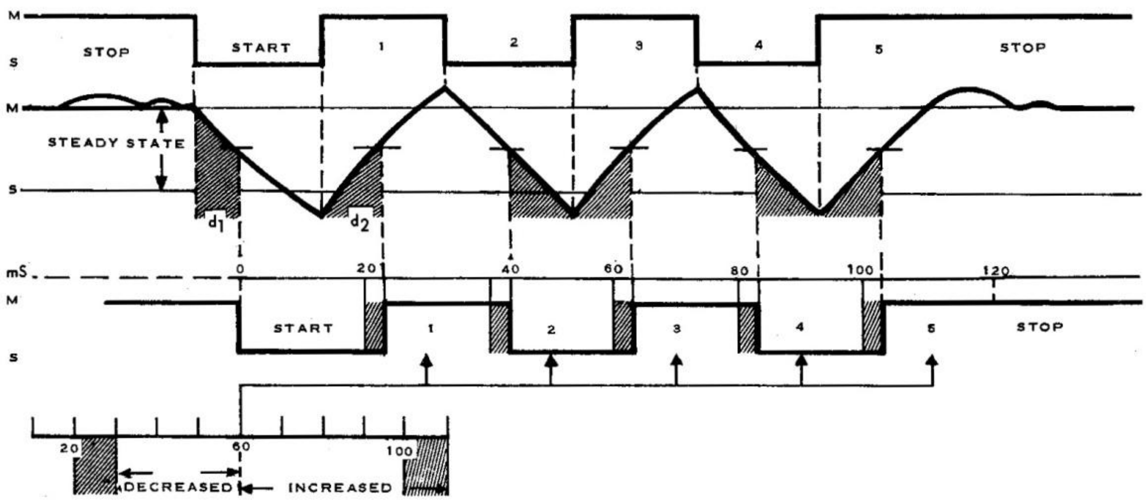


FIG. 42. POSITIVE CHARACTERISTIC DISTORTION - CHARACTER "Y".

(i) The transition to the start element commences at a steady state value of current, with the restitution delay d_1.

(ii) The transition to the first code element commences at an excess value of current, and restitution time d2 is longer than d1; the start element is lengthened.

(iii) All succeeding transitions commence at the same value of current; the restitution delays are equal, and there is no distortion to the code elements,

(iv) Because the start element is long, the significant instants of restitution occur late with respect to the commencement of the start signal, resulting in a reduction to the lower range limit, and an improvement in the upper range limit.

In this particular example, therefore, the effect of positive characteristic distortion is to shift the upper and lower limits in the same direction.

The numerical values of the upper and lower range limits are increased.

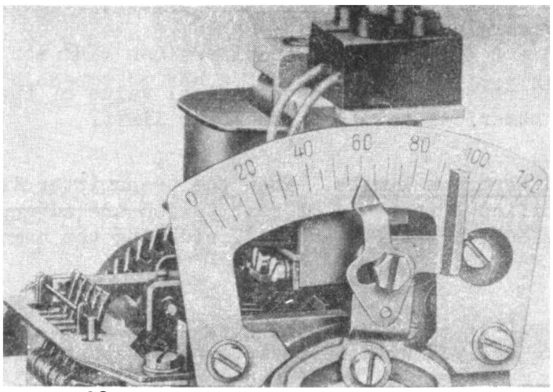


FIG. 43. TYPICAL ORIENTATION DEVICE.

9.7 Fig. 44 shows the effect on the orientation limits when the code combination for the letter "A" suffers from positive characteristic distortion. The element current requires 1.5 unit intervals in which to attain a steady state value.

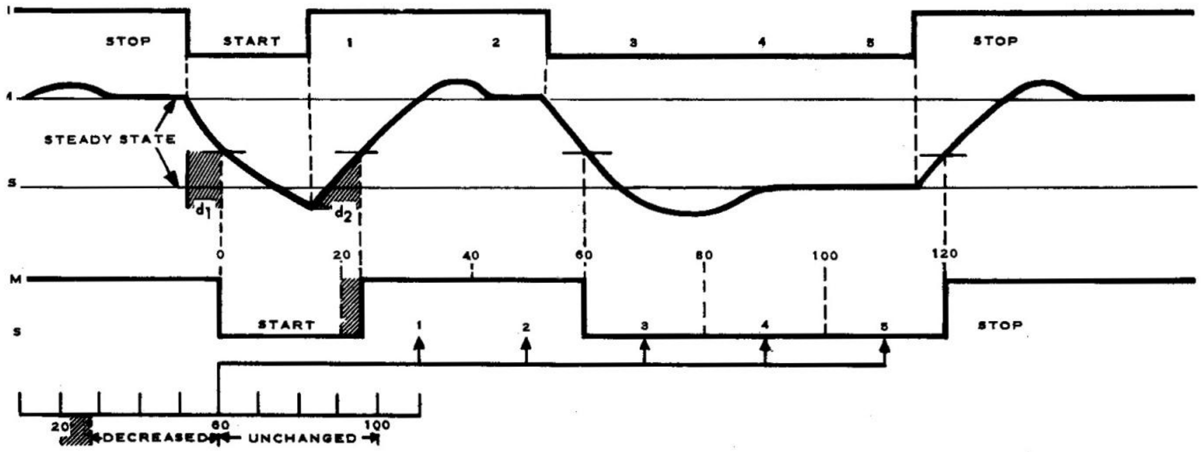


FIG. 44. POSITIVE CHARACTERISTIC DISTORTION - CHARACTER "A".

(i) Restitution time d2 is greater than dl, and the start element is lengthened.

(ii) The significant instant which should occur at 20mS is late, reducing the lower margin.

(iii) All other significant instants occur at their correct times, and the upper margin is unchanged.

In this example, therefore, the effect of positive characteristic distortion is to increase the numerical value of the lower limit, and to leave the upper limit unchanged.

In general terms, positive characteristic distortion increases the numerical value of the lower orientation limit, and the effect on the upper limit depends upon the signal combination which is being received.

9.8 Effect of Fortuitous Distortion on Limits. Because of the random effect on the transition, some significant instants of restitution occur early and some late with respect to the commencement of the start signal, resulting in a reduction in both early and late margins.

Fortuitous distortion reduces the numerical value of the upper range limit, and increases the numerical value of the lower limit.

9.9 Effect of Speed Error on Limits. When the transmitter is fast or the receiver is slow, the significant instants of restitution are advanced with respect to the instants of selection (Fig. 8 and 11), reducing the numerical value of the upper and lower limits.

When the transmitter is slow or the receiver is fast, 'the significant instants of restitution are delayed with respect to the instants of selection (Fig. 9 and 10), increasing the numerical value of the upper and lower limits.

10. TESTING SIGNALS.

10.1 The received telegraph signals can include the effects of all types of distortion, including speed deviations. Separating the total distortion into its various component types is effected by the use of test signals which are susceptible to a particular type of distortion.

10.2 Speed Deviations. The degree of start-stop distortion can be measured under two conditions:-

(i) When the distortion includes the effect of a speed difference between the transmitter and measuring device. This is called the degree of "gross" start-stop distortion.

(ii) When the speed difference has been eliminated. This is called "synchronous" start-stop distortion.

When the transmitter and measuring device are start-stop machines, speed differences are eliminated by the appropriate adjustments prior to the transmission of testing signals.

Measuring devices which use an oscilloscope display have a facility which allows the frequency of the time-base oscillator to be adjusted to the speed of the incoming start-stop signals. When this facility is used the device then measures the degree of synchronous start-stop distortion.

This fact should be appreciated when referring to E.Is. which indicate the limit of the degree of gross start-stop distortion.

10.2 Testing for Bias. The signal combinations in which all transitions commence at the same value of current do not suffer from characteristic distortion. These signals include the start-stop characters "O" (SSSSMMM') and "M" (SSSMMMM), and the isochronous 1 : 1 and 2 : 2 reversals.

The bias component can be isolated by observing on an oscilloscope measuring set the display caused by recurring signals of this type.

10.3 Testing for Characteristic Distortion. Measurement of those signals which suffer from characteristic distortion give an amount of distortion from which the degree of bias can be subtracted, the remainder being the degree of characteristic distortion.

Suitable signals include "RY" and the isochronous signals 1 : 5 and 5 : 1.

Characteristic distortion due to the A.G.C. reaction to long spacing elements in A.M.V.F.T. also can be checked with the start-stop characters "Blank"(SSSSSSM), and "T" (SSSSSMM).

10.4 Testing for Fortuitous Distortion. When a recurring signal is received, the indication of the degree of bias and characteristic distortion should be steady. Variations from the average steady value indicate the degree of fortuitous distortion.

The limits of distortion and the standard testing procedure are given in the relevant E.Is.

11. TEST QUESTIONS.

1. What is telegraph distortion?
2. Sketch a telegraph signal in which a transition occurs 9mS late, and another is 4mS early.
3. Express the displacement of the transitions in the above signal as a percentage, when the modulation rate is:-

   (i) 50 bauds.

   (ii) 75 bauds.
4. To what reference point are these transitions early or late, and why is this reference point used?
5. Why is the displacement of transitions expressed individually?
6. With the aid of a diagram, show the timing relationship between the significant instants of restitution and the selection instants.
7. Define the "degree of start-stop distortion".
8. What is the main difference between a distortion measuring device designed to measure start-stop distortion, and one designed to measure isochronous distortion?
9. Define the "degree of isochronous distortion".
10. When a telegraph machine transmits 7½ units at 50 bauds, calculate the distortion to the fifth code element when:-

    (i) The transmitter is 1% fast.

    (ii) The transmitter is 1% slow.

    (iii) The receiver is 1% fast.

    (iv) The receiver is 1% slow.
11. State 3 types of telegraph distortion, and state their effect on the signal time-intervals.
12. With the aid of diagrams show the effect on a telegraph signal of the 2 types of bias distortion.
13. What are the main causes of bias distortion in double current signalling?
14. Define "restitution time", and illustrate your answer with a sketch showing:-

    (l) The transmitted element.

    (ii) The received element.

    (iii) The element of restitution.
15. What are the main causes of bias in single current signalling.
16. Illustrate with a sketch the relationship between the steady state value of marking current and the relay operate points, and the variations of this relationship which produce bias distortion.
17. Sketch a typical single current circuit, showing a transmitter with spark quench capacitor, a short loop, a receiver, and a limiting resistor and battery.
18. Draw the equivalent circuit when the transmitter marks, and the received space-to-mark transition wave-shape. Give reasons for the wave-shape.
19. Draw the equivalent circuit when the transmitter spaces, and the received mark-to-space transition wave-shape. Give reasons for the waveshape.
20. What is the effect on the element wave-shape when an additional machine is added to the circuit? What type of bias distortion is produced?

21. With the aid of a simple circuit explain the operation of a signal shaper.

22. Use sketches to compare the received element wave shapes in a short loop with those in a long loop, and give reasons for your answer.

23. What considerations determine the type of signalling used for a particular length of line?

24. What is the affect on the element time-intervals of:-

    (i) Negative characteristic distortion?

    (ii) Positive characteristic distortion?

25. What causes negative characteristic distortion? Show with the aid of a sketch how this type of distortion affects a telegraph signal,

26. What causes positive characteristic distortion? Show with the aid of a sketch how this type of distortion affects a telegraph signal.

27. What type of signal combination is unaffected by characteristic distortion?

28. What is the effect on signal elements of fortuitous distortion? Illustrate your answer wtth a sketch.

29. What are the main causes of bias, characteristic and fortuitous distortion in:-

    (i) A.M.V.F.T.?

    (ii) F.M.V.F.T.?

30. Show by a sketch the relationship between a telegraph signal, instants of selection, and a typical orientation scale.

31. When a machine has the above relationship, what is the effect on the orientation limits off-

    (I) Speed error?

    (ii) Marking bias?

    (iii) Sparing bias?

    (iv) Characteristic distortion?

    (v) Fortuitous distortion?

32. What is the difference between "gross" and "synchronous" distortion?

33. How could a total degree of start-stop distortion be separated into degrees of bias, characteristic and fortuitous distortion?

End of Paper.

NOTES