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RECEIVING SELECTORS - OPERATION, FAULTS AND MARGINS

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ABSTRACT

A review of start-stop electromechanical selector operation, including signal distortion, internal faults, response to distorted signals, and resultant operating margins.

Frequently a need arises for a receiving unit to operate at other than established bit rates, requiring the engineer to design anew or otherwise modify existing equipment. Various areas of the selector and the manner in which they contribute to internal distortion are covered herein to indicate what design changes may mean in terms of selector operation, and to serve as a guide in predicting operating margins.

SELECTOR OPERATION, FAULTS AND MARGINS

The primary requirement of a teletypewriter receiving selector is to sample each incoming signal element to determine its state-marking or spacing. Were all telegraph signals presented to a receiving unit, of ideal shape, the receiving selector would need not be a precision device. In practice, however, signals are rarely received undistorted and it becomes a requirement of the receiver to select only a small portion of the time of each signal impulse to make the determination whether the signal is marking or spacing. The degree to which that required portion of the signal can be reduced and effectively converted into a mechanical representation is indicative of the quality of the selector.

Since the performance of the receiving unit is largely gauged by its response to the incoming signal, an analysis of selector operation may well begin with a review of the telegraph signal-receiver relationship.

SIGNAL-RECEIVER RELATIONSHIP

To simplify explanation, the subject review will begin with the ideal. Accordingly, Figure 1 is provided to depict a perfect telegraph signal-receiver relationship. Fig. 1B represents a telegraph signal pictured in the conventional rectangular wave shape form consisting of a start element, eight code elements and a double stop element conforming to 8-level, 11.0 unit code recently adopted by the Bell System.

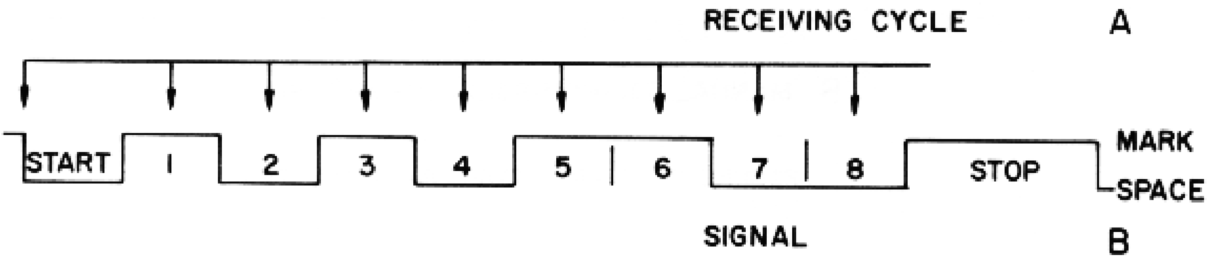
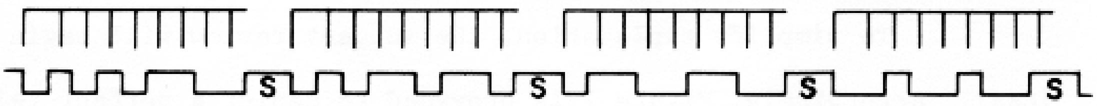


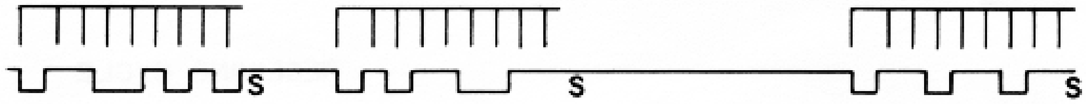
FIGURE 1, SIGNAL RECEIVER RELATIONSHIP

Fig. 1A represents the receiving cycle in which sampling of the respective signal elements occurs at intervals precisely spaced to the duration of a unit signal element. The cycle commences with the mark to space transition at the beginning of start element of the telegraph signal.

In start-stop teletypewriter operation each receiving cycle is initiated by this start transition at the beginning of the received signal. To maintain synchronization with the sender the speed of the receiver must be such that it arrives at its stop position during the stop element of the same character. Since the receiver remains at rest until re-started by the next mark to space transition, synchronization is maintained on a character to character basis, and speed differences are prevented from cumulating beyond one character duration. The send-receive relationship illustrated in Fig. 2A is for automatic transmission. An example of manual keyboard transmission with the usual delay period between subsequent characters is shown in Fig. 2B. In either case the receiving cycle is initiated by the first (start) transition following the stop element(s).



A. CONTINUOUS TRANSMISSION (READER)

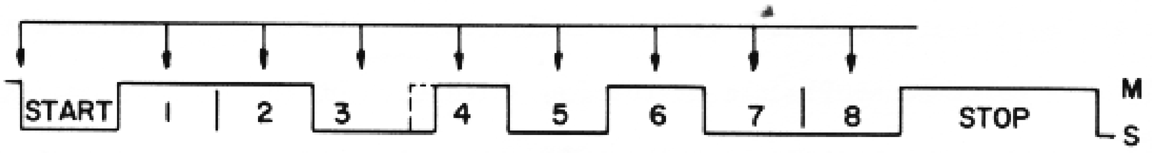


B. MANUAL TRANSMISSION (KEYBOARD)

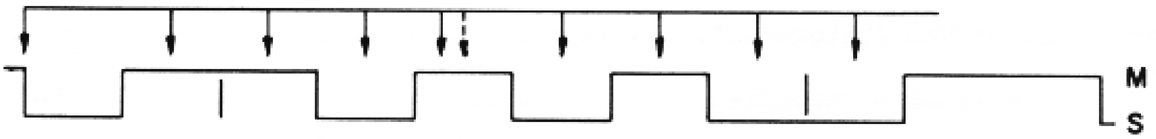
FIGURE 2, START-STOP TRANSMISSION

DEVIATIONS FROM THE IDEAL

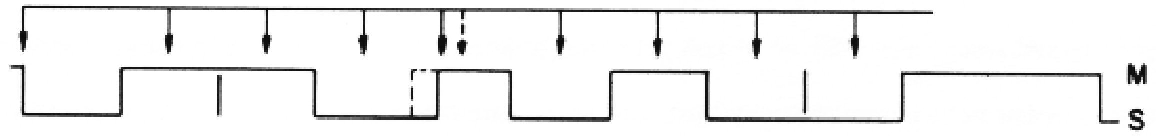
In practice, departures from a perfect system occur in both the selector and in the signal as presented to it. Fig. 3A illustrates a change from the perfect signal, in which the space to mark transition of the No. 4 signal element is considerably delayed. It can be observed



A SIGNAL DEVIATION



B SAMPLING DEVIATION



C COMBINED DEVIATIONS

FIGURE 3, SIGNAL - SAMPLING DEVIATIONS

that sampling instant for that signal element could, however, still detect its respective signal element as being in the marking condition. It is also apparent that the signal could be detected as intended with further delay of the signal transition of up to 50% of the unit signal element. A displacement of a sampling instant is shown in Fig. 3B. Here sampling is advanced without mishap and like the signal distortion a displacement of up to 50% of a unit signal element can be tolerated. Likewise, displacements in both the signal transition and sampling instant in which the total of the two does not exceed 50% (Fig. 3C) are also acceptable. The same reasoning applies to delays in sampling instants and corresponding advances in the trailing end of the signal element.

Deviations from the exact sampling intervals are chiefly the result of irregularities in the operation of the selector. There are also deviations from nominal design values because of manufacturing tolerances and in some cases to suit design and manufacturing routines. These are faults within the selector which when consolidated for the complete receiving cycle may be equated to signal distortion and referred to as internal distortion.

To limit the distortion to that which the telegraph system can tolerate (50%), the distortion which each of the various components within the system might contribute is restricted. In the case of the Model 35 Receiving Selector 12% has, in effect, been determined as the allowable internal distortion[1]. It is rarely expressed in this manner but rather in terms of signal distortion which it must be capable of tolerating - in this case 38%. This is the tolerance associated with the beginning of the signal elements. There is also a tolerance associated with the end of the signal elements - 35% - which although appearing at first glance as a relaxation in requirements may not be so, since this tolerance is normally specified under conditions optimum for the beginning of the signal element.

To attach significance to the preceding tolerance figures, the selector designer must have some appreciation of the telegraph signal as seen by the selector and consequently a familiarity with the nature of signal distortion is of value.

SIGNAL DISTORTION

A perfect telegraph circuit reproduces signals at the receiving end exactly as they are impressed at the sending end as regards lengths of the component elements and any change in these lengths during the transmission may be considered as a lowering of the signal quality and is called distortion. In practice the sources of distortion are not limited to the transmission line. Typically, the opportunity for signal distortion begins with the sending unit, increases considerably with the transmission line and often terminates with some contribution from the receiving unit itself. Although the causes of distortion are many, it is the effect on the signal element as presented to the receiving unit which is of prime importance in selector operation.

As indicated in previous illustrations the same start transition that serves as a reference in the receiving cycle also serves as a reference for all subsequent transitions in the signal cycle. It is the timing of these signal transitions rather than the duration of the signal elements that is of primary importance, and distortion has the effect of displacing these subsequent transitions from their normal position. Departures from perfect transition timing are known as transition displacements.

TRANSITION DISPLACEMENTS

Four types of transition displacements are possible. These are identified with their generally accepted notations[2] as follows:

1. Marking beginning displacement (MB) which is an advance of the space to mark transition relative to the start transition. This displacement would tend to increase the length of a marking signal element by adding to the beginning of the element (conversely, the trailing end of the preceding spacing signal element would be shortened by the same amount).
2. Spacing beginning displacement (SB) which is a delay in the space to mark transition relative to the start transition and tends to decrease the length of a marking signal element by subtracting from the beginning of the element.
3. Spacing end displacement (SE) which is an advance of the mark to space transition, and tends to shorten the marking signal element by subtracting from the ending of the element.
4. Marking end displacement (ME) which is a delay in the mark to space transition and tends to lengthen the marking signal element by adding to the trailing end of the element.

A signal exhibiting all four types of displacements is illustrated in Fig. 4, the heavy solid line representing a perfect signal display, and the respective displacements indicated by the broken lines.

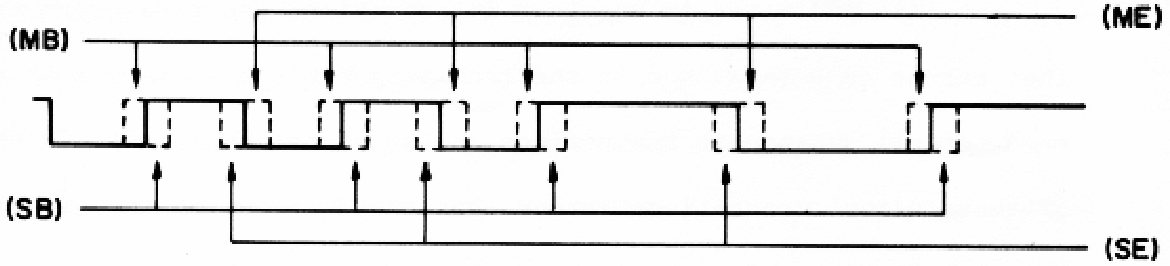


FIGURE 4, TRANSITION DISPLACEMENTS

Signal distortion may involve any one or more of the displacements in varying degrees for any or all of the respective signal elements and as such can produce an infinite number of displacement effects. It is, however, possible to classify these as one or some combination of three general categories of distortion - bias, characteristic distortion and fortuitous distortion.

In addition to the transition displacements which the receiver sees and must cope with, the cause of distortion is also of interest in that the behavior of the selector magnet-armature assembly is similar to that of D.C. telegraph circuit components (relaying devices, etc.) and in this respect capable of producing locally within the selector, a distortion condition analagous to that occuring in transmission lines. Although bias distortion is usually the most prevalent, all three types of distortion are usually present and play increasingly significant roles in selector design as operating speeds are increased.

BIAS

Bias is that distortion causing a uniform displacement of like signal transitions resulting in uniform lengthening or shortening of all marking signal elements or groups of elements. This condition is illustrated in Fig. 5. A perfect transmitted signal is illustrated in Fig. 5A, while Fig. 5B shows the signal wave shape at a relay point some distance from the transmitter, modified by the presence of the line capacitance and inductance. The relay operating level, from marking to spacing and spacing to marking, is so indicated. The wave is unsymmetrical in a manner which causes the transient from mark to space to be more rapid than that from space to mark, and results in a relayed signal with shortened marking signal elements - as pictured in Fig. 5C.

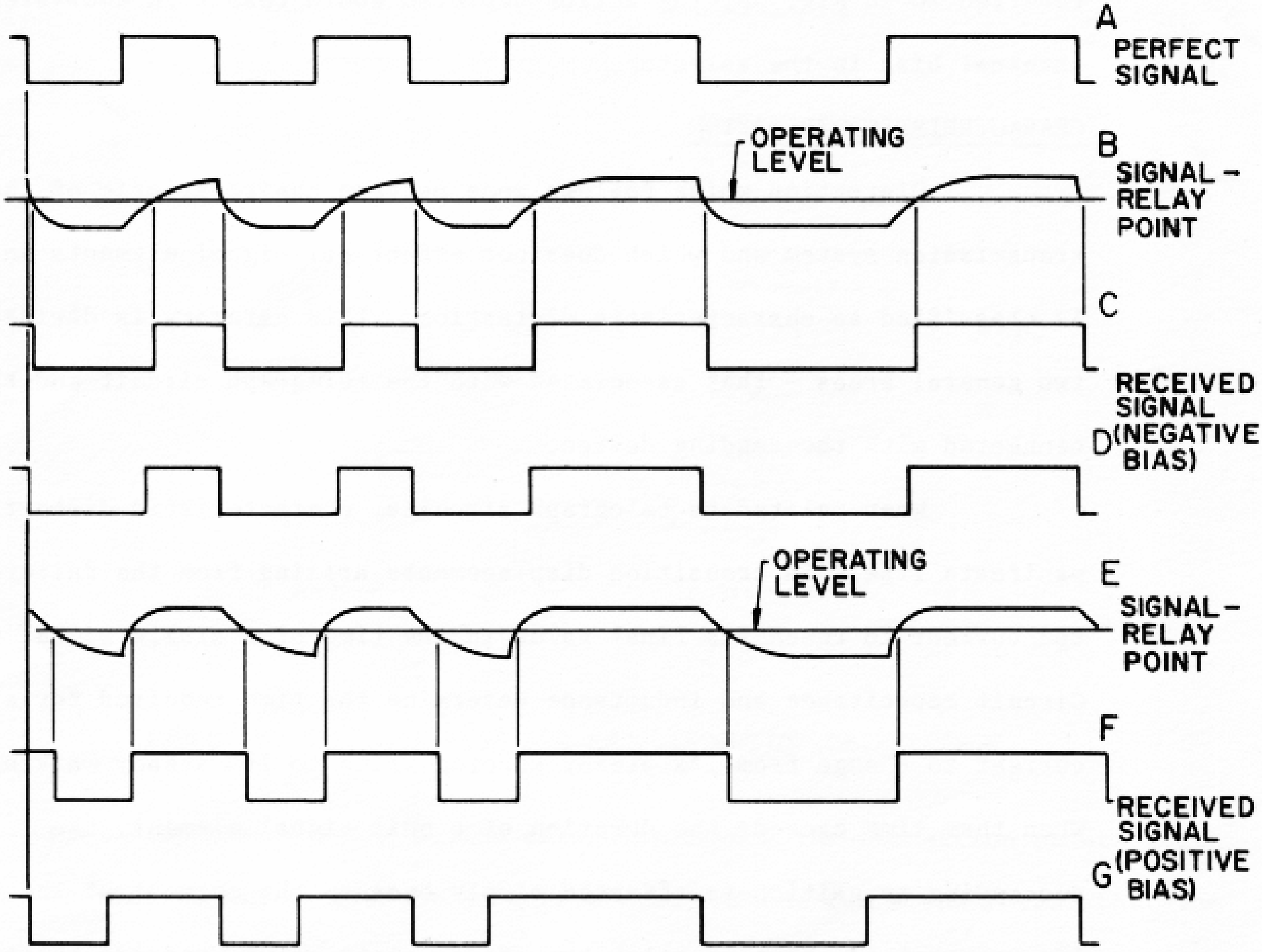


FIGURE 5, SIGNAL BIAS GENERATION

Although the distortion may effect either the beginning or the end of the signal element, the start transition is shifted a like amount and the result is the equivalent of advancing or retarding the beginning of each marking signal element. Fig. 5D represents the signal with the start transition aligned with the common reference and shows the spacing beginning displacements peculiar to spacing bias distortion.

Bias which shortens the marking signal elements is negative or spacing bias and conversely that which lengthens the marking signal elements is positive or marking bias. Figs. 5E, F, and G correspond to Figs. 5B, C, and D and depict the results of distortion producing positive or marking bias.

Were a selector magnet-armature assembly substituted for the relay referred to in Fig. 5B, the action depicted would result in equivalent internal bias in the selector.

CHARACTERISTIC DISTORTION

Distortion which follows some pattern characteristic of the transmission system and which does not effect all signal elements uniformly is classified as characteristic distortion. This category is divided into two general areas - that associated with the telegraph circuit and that connected with the sending device.

When related to telegraph circuits, characteristic distortion manifests itself in transition displacements arising from the failure of the current to reach its final value in the time of a single signal element. Circuit capacitance and inductance determine the time required for a current to change from its steady spacing value to its steady marking value. When that time exceeds the duration of a unit signal element, the succeeding transition is affected simply because the current at the time of its reversal is above or below the steady state value, and can therefore reach a relay (or selector armature) operating value later or earlier than it would from the intended steady state value. These delays or advances result in different transition displacements for a single, or groups of successive signal elements of the same state.

It is also in this area that the receiving units contribution to distortion appears. When present, it is usually in the form of additional inductance imposed upon the transmission line, which may introduce or further aggravate a bias or characteristic distortion condition. Selector magnets, however, are normally isolated from the signal line by means of special relays which contribute far less inductance to the circuit than that of selector magnets. Further, recent developments in the selector magnet driver area have substantially eliminated the receiver as a source of line inductance.

Signals generated by teletypewriter keyboards and tape readers are seldom ideal as they are impressed upon the telegraph circuit. Practical manufacturing tolerances for the mechanical operating components are for the most part responsible for the transition displacements resulting therefrom. These, however, are usually "fixed" and related to specific signal elements. Similarly an "off speed" transmitter will produce "fixed" transition displacements. The permissible tolerance, i.e., transition displacements relative to the start transition, associated with the signal as generated is ±5%[1].

Unlike the characteristic distortion of the telegraph circuit there is little or no effect on relaying devices and selector armature behavior as regards single or groups of like signal elements. These distortions, appearing in the line signal are characteristic of the transmitter, and are illustrated in Figs. 6A and 6C respectively. The "slow" transmitter depicted in Fig. 6C produces spacing beginning (SB)

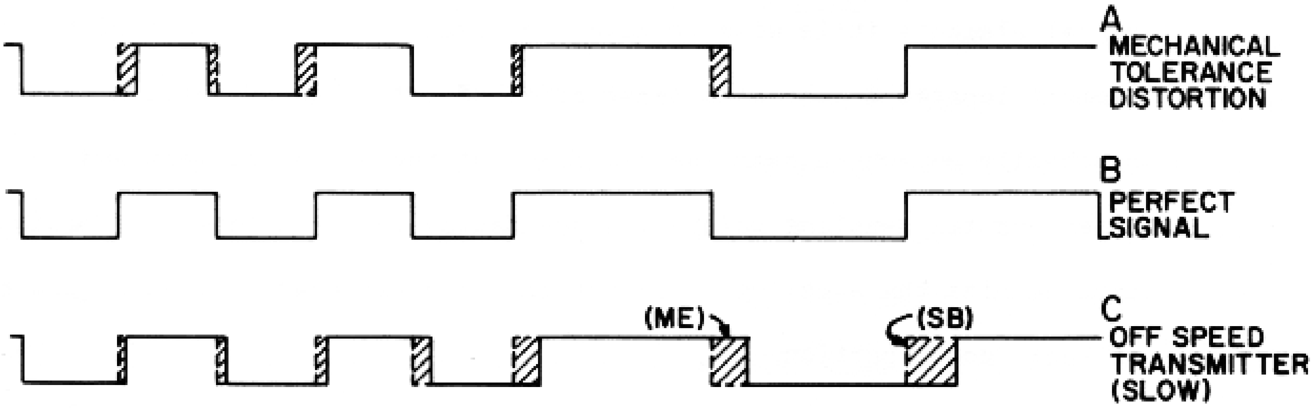


FIGURE 6, CHARACTERISTIC DISTORTION (MECHANICAL) and marking end (ME) displacements of increasing size for each successive signal element in a direction away from the start transition. A "fast" transmitter would produce marking beginning (MB) and spacing end (SE) displacements in the same manner.

FORTUITOUS DISTORTION

Distortion which occurs at random and follows no natural law is classified as fortuitous distortion. It is unpredictable and can affect any of the signal components in varying degrees. When the start transition is affected, the receiving cycle is either advanced or delayed thus the signal-sampling relationship of all signal elements is affected in a manner similar to that of bias. Although no compensation can be made for this type of distortion small degrees can be absorbed to the extent of available signal and selector operating margins.

SAMPLING DISTORTED SIGNALS

The selector does not have the capability of distinguishing between types of distortion or combinations thereof. It is, however, provided with a means for allowing the sampling instants to be shifted or oriented relative to the start transition and subsequent signal elements so that optimum sampling may be approached. Since distortion normally effects the beginning and/or end of each signal element or groups of signal elements it is wise to have the "used" or sampled part of the signal element located in the area least affected. The "good" portion is ordinarily somewhere near the mid-point of the signal element and by orienting the sampling points its boundaries can be determined. This in turn permits the sampling to be set to occur reasonably close to the center of that "good" portion.

A range scale calibrated in "points" (percents of a unit signal element) is part of the orientation mechanism and serves as a reference for the sampling instants. The mid-point of the range scale is arranged to coincide closely with the mid-point of the unit signal element.

Figure 7 illustrates the sampling associated with a distorted line signal. A perfect receiver is assumed and for reference a perfect signal is provided in Fig. 7A. Sampling occurs at the mid-points of the respective signal elements permitting shifting of the sampling instants up to 50 points to the right or left (low or high end of range scale) without impairing proper signal reception.

A distorted signal is introduced for the remaining illustrations. The bold line represents the signal as received and the cross-hatched section represents the transition displacements for the respective signal elements as follows:

Signal Element	Transition Displacement	
1	10% (SB)	8% (SE)
3	10% (MB)	
5	30% (SB)	
6	5% (ME)	
(Stop)	20% (SB)	

With reference to Fig. 7B, it is evident that the amount the sampling instants can be shifted is considerably less than the 50 points available with a perfect signal. Examination shows that signal element No. 5 is the most critical as regards the beginning of the element and signal element No. 2 as regards the end of the element. In effect then, were 20% additional spacing bias (or 20% additional SB displacement, regardless of cause) applied to the signal,the tolerance in the No. 5 element would be reduced to the point of failure. Any additional spacing bias at that point would cause the No. 5 element to be sampled as spacing rather than the marking intended, with no harmful effect on the remaining samplings. Conversely the sampling instants could be shifted to the left 20 points before an error would occur (Fig. 7C).

In orienting the sampling instants to the right (Fig. 7D) we find that a shift just in excess of 40% points will cause the No. 2 sampling instant to interpert the (MB) displacement of No. 3 signal element as a marking condition for the No. 2 signal element. Further shifting of

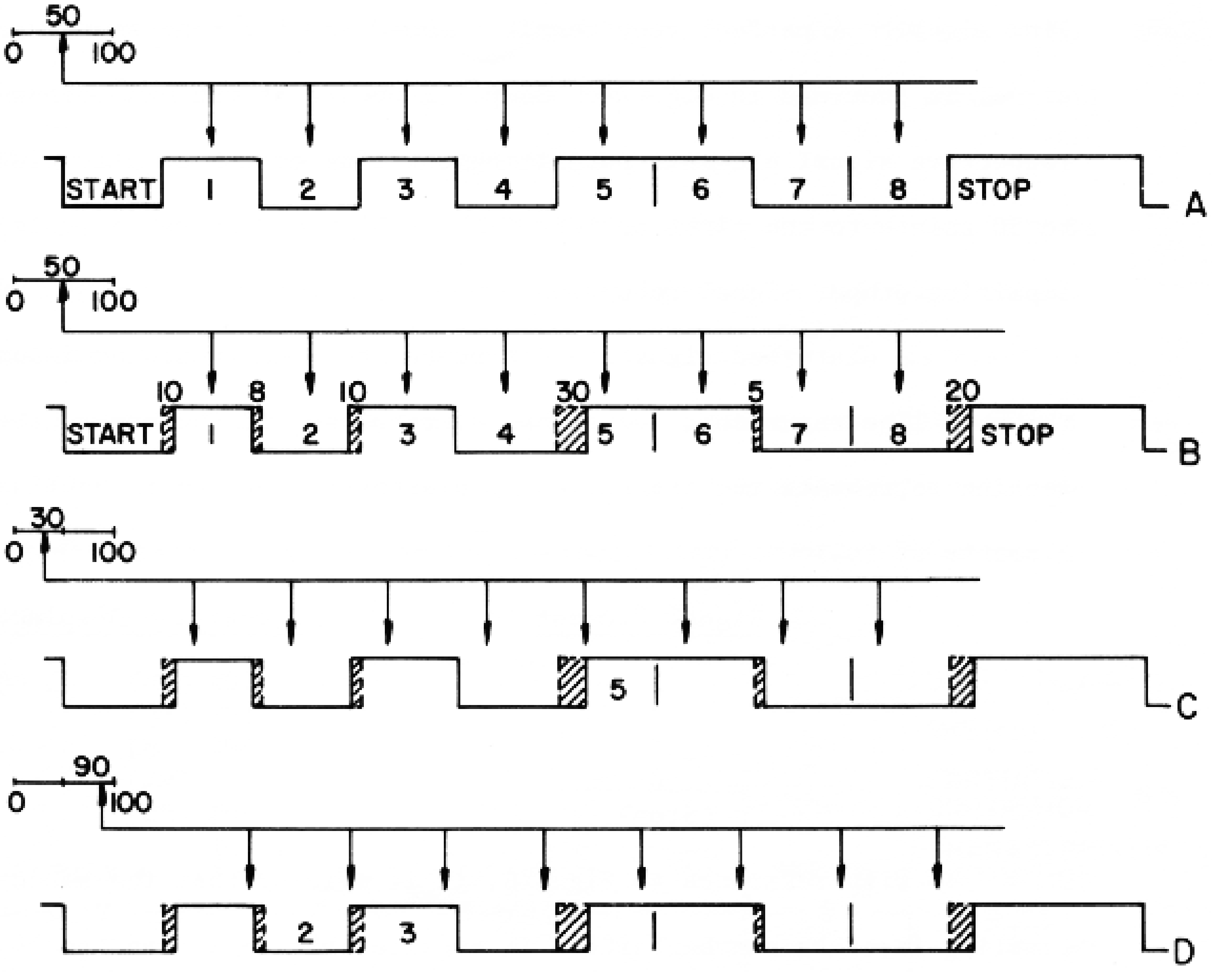


FIGURE 7, SAMPLING DISTORTED SIGNALS

2 points to the right would cause the (SE) displacement of the No. 1 signal element to be sampled as spacing instead of the intended marking, however, failure had already occurred as a result of element No. 2 being the critical element, and the upper orientation limit remains at the 90 point position on the range scale (shift of 40 points).

Since No. 5 and No. 2 elements are the critical elements, they in effect serve as the reference for the optimum sampling position. These elements are not equally critical as No. 5 can tolerate 20% additional distortion while No. 2 is capable of accepting 40%.

Assume now that the circuit was subject to additional fortuitous distortion. Inasmuch as this form of distortion is unpredictable, the resulting transition displacements could occur anywhere in the signal -

including the beginning of the start element. As such the signal can safely accept only a 20% additional distortion. However, were the sampling instants shifted 10 points to the right (60 point range scale setting), the tolerance of the No. 5 element would be increased to 30% with a corresponding decrease of 10% in tolerance associated with the No. 2 element. This "balancing out" yields a tolerance of 30% in either direction and means that any of the four possible types of transition displacements could be increased up to 30% without affecting the reception.

Although the operating range remained unchanged during these procedures, the capability of the unit was increased to accept 10% additional distortion over that for the initial range scale setting.

The 20% (SB) displacement for the stop element has no effect on sampling. Were this displacement excessive it is possible that the receiver would fail to synchronize with the line signal, however, misselections of the signal elements would occur prior to this point.

INTERNAL DISTORTION

Illustrations of signal element sampling to this point assumed a perfect receiving unit, i.e., sampling was instantaneous and occurred at exact intervals conforming to unit signal elements. Although these conditions may be approached with electronic receiving selectors, the electro-mechanical unit, burdened with those problems characteristic of mechanical operating components - mass, inertia, clearances and piece part tolerances - departs somewhat from the ideal arrangement. As a result sampling not only deviates from the exact intervals associated with successive signal elements but may also vary for respective signal elements in successive signal cycles. As such we can no longer treat sampling as instantaneous but rather as a spread of sampling instants or a sampling period.

Since, for continued proper selection, the entire sampling period must occur between successive signal transitions, the degree to which the signal transitions can be displaced (50% under ideal sampling conditions) is reduced accordingly. This reduction in tolerance to signal distortion, due to faults within the selector is in effect the internal distortion of the selector.

Like signal distortion the selector internal distortion can be classified as one or some combination of three general categories of faults - internal bias, internal characteristic faults and internal fortuitous faults.

INTERNAL BIAS

Sampling instants as depicted in preceding illustrations were with respect to the line signal proper. In electro-mechanical selector operation signal element sampling is not performed on the signal as delivered to the receiving unit but rather on the interpretation of this signal by the receiving selector magnet-armature assembly. This action provides further opportunity for distortion of the signal. As indicated earlier the selector magnet-armature assembly can behave in much the same manner as a signal line relay as regards a source of distortion. This is due chiefly to the armature transit time as determined by the magnet's attractive force and the armature retraction spring. The signal transition as now seen by the sampling members is no longer instantaneous and hence susceptible to bias, particularly when the transit time is "long." The distortion introduced at this point is not considered as signal line distortion, but rather internal distortion and in this respect chargeable against the total distortion permitted the receiving unit.

As such this fault cannot appear as signal distortion in the conventional signal - receiving cycle diagram, but must be expressed in terms of an equivalent sampling period. The determination of equivalent

Re-examination of Figs. 8A and 8B will reveal that the introduction of negative distortion (either bias or end distortion) to the line signal will compensate for an equivalent degree of internal bias. Consequently a positively biased selector has greater tolerance, to the extent of twice the internal bias, towards negatively distorted signals than towards undistorted or positively distorted signals.

As a result, the equivalent sampling period for internal bias does not treat all line signals equally and must, therefore, carry some identification to indicate those signals (of opposite distortion) which are treated more favorably. The plus and minus sign have been selected as identifiers for positive and negative internal bias respectively.

Positive bias (B+) is indicated in Fig. 8E. Although the illustration shows the sampling period extending to the right of the sampling reference, it is the sign which determines the treatment with respect to distorted signals.

Fortunately bias can be kept to a minimum and very often eliminated by proper adjustment of armature clearances, travel, and spring tension. The procedures associated with these adjustments, particularly the balancing of the magnets attractive force with the armature retraction spring tension, is commonly referred to as "biasing" the selector.

INTERNAL CHARACTERISTIC FAULTS

In electro-mechanical selector operation, mechanical sampling is accomplished by a lock lever (or levers) sensing the position of the armature. As indicated earlier the armature interprets the received signal by responding to the current impressed on the associated magnet coils.

Inasmuch as the movement of a number of mechanical members is involved in achieving a selection, the armature must be retained in the sampled position for a period of time sufficient to permit the positioning of those members and provide a mechanical representation of the corresponding signal element. In effect then, the armature is locked in its sampled position - marking or spacing - until that signal element is mechanically recorded and stored; and is free to change its position only during the unlocked periods. Should the current condition change during the locked period, the armature would be restrained in its locked position and would change its position upon withdrawal of the locking member.

Figure 9 represents the lock lever action in a selector mechanism. Although the piece part configuration varies with different selectors, the principle of operation in this respect is essentially the same. As illustrated, the sampling timing (intervals) is under control of the lock cam. Any deviation in the angular displacements of the respective cam lobes of the cam or rates at which the cam actuates the lock levers is reflected back into the sampling instants with a corresponding departure from the perfect sampling interval.

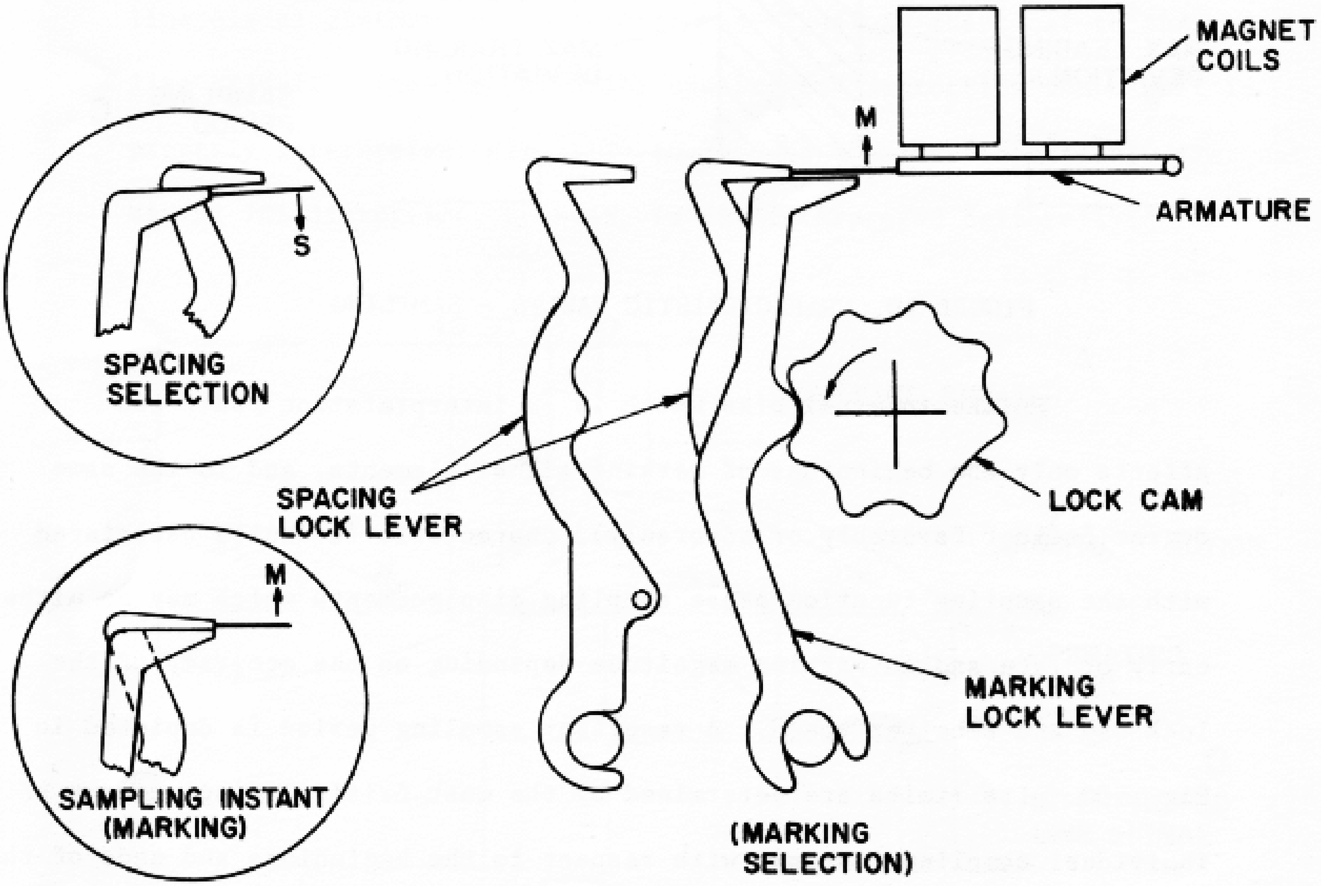


FIGURE 9, SELECTOR LOCK LEVER ACTION

This displacement from the sampling reference is a type of characteristic fault. Figure 10A illustrates the sampling displacements resulting from irregularities in camming intervals, and Fig. 10 shows the effect of an "off speed" receiver. The progressive shifting of the sampling instants to the left is indicative of a fast receiver. The overall effect here is similar to that caused by a slow transmitter, but, in this case the resulting distortion is chargeable to the receiver.

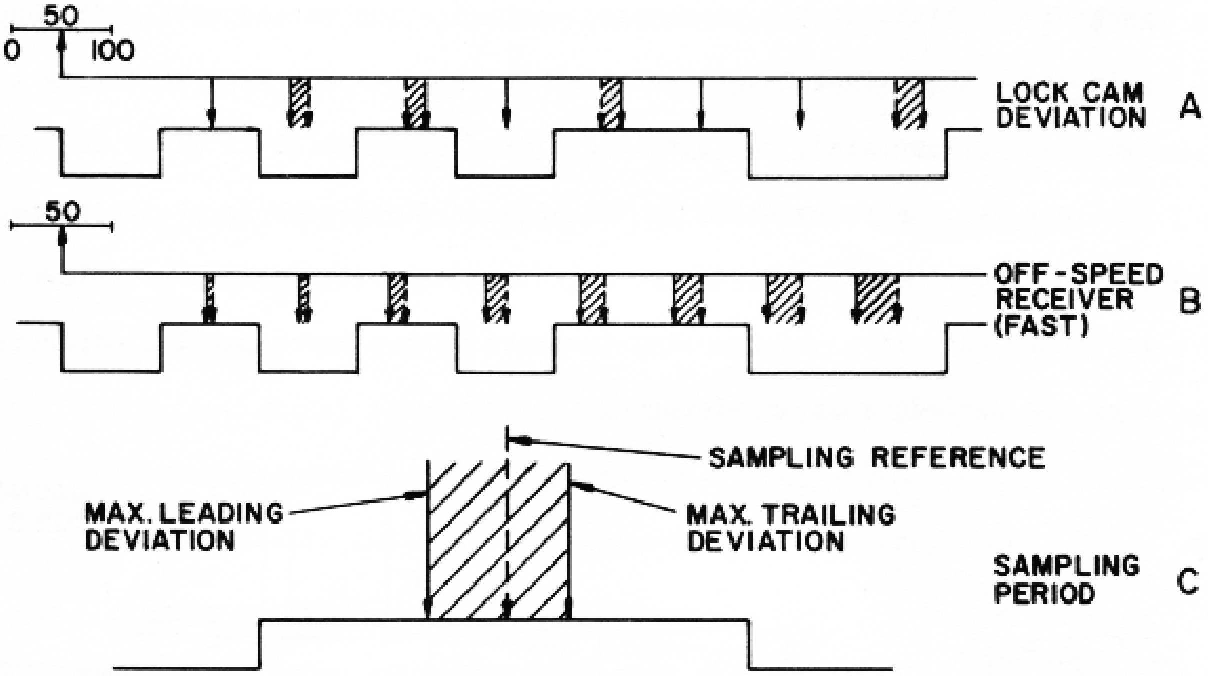


FIGURE 10, CHARACTERISTIC FAULTS - SAMPLING

Unlike internal bias which is an interpretation fault and affects only the beginnings of marking signal elements, and to the same degree (either favorably or adversely), characteristic faults associated with the sampling function cause sampling displacements which may be either early or late and in varying magnitude depending on the accuracy of the lock cam and receiver speed. A resultant sampling period is depicted in Fig. 10C. Its limits are determined by the most critical displacement of the individual sampling instants with respect to the beginnings and ends of the signal element. Although the leading and trailing critical displacements may vary in magnitude, at the optimum orientation setting the sampling reference in effect shifts to the center of the sampling period so that the overall distortion is divided equally between the beginning and end of the signal, and the distortion applicable to either is equivalent to one-half the sampling period.

There also exists a type of characteristic fault which affects signal interpretation. Like characteristic distortion in telegraph circuits, faults associated with the armature action, such as a failure to reach a fully attracted position prior to a signal reversal, affect the trailing end of the interpreted signal. The internal distortion developed here is illustrated in Fig. 11. A line signal with varying degrees of negative distortion (Fig. 11A) results in corresponding armature action as shown in Fig. 11B. The long armature transit time does not in all cases permit completion of the armature travel prior to the signal reversal. With no line signal distortion the interpreted signal is identical to that of the line signal. Likewise, with 10% spacing end distortion the signal is properly interpreted (Fig. 11C) to produce the 10% distortion. A signal having 20% distortion, however, is not interpreted faithfully. The

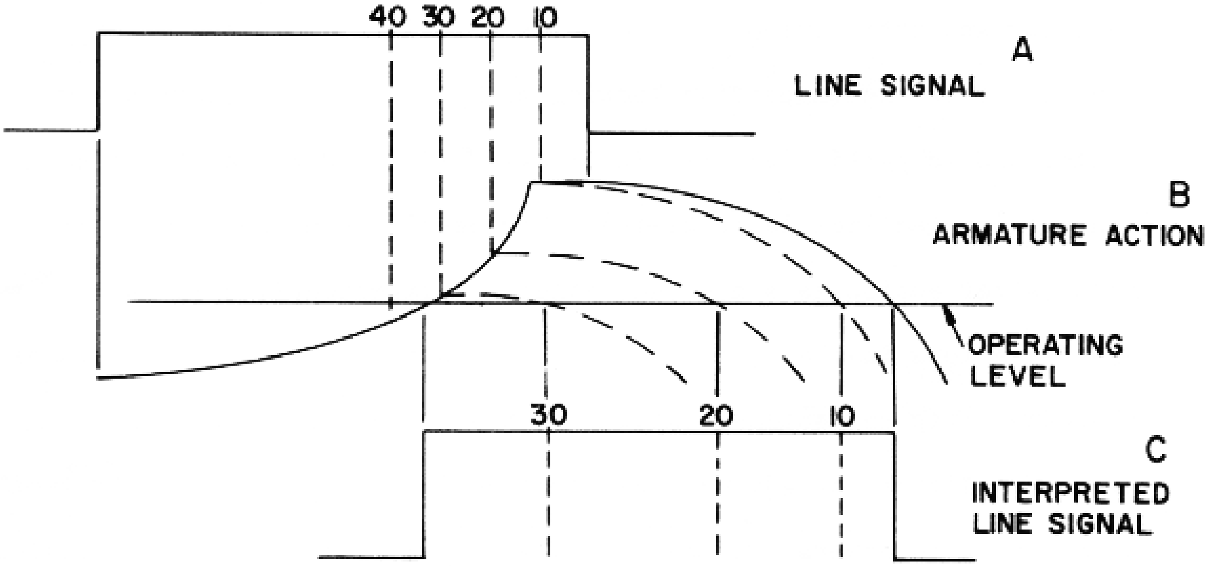


FIGURE 11, CHARACTERISTIC FAULTS - INTERPRETATION failure of the armature to complete its travel prior to the signal reversal has caused it to begin retraction earlier than from the fully traveled position and as a result the interpreted signal has much more than 20% end distortion. The same condition holds true for 30% signal distortion. Were 40% distortion applied, the armature would not reach its operating level prior to reversal and complete mis-interpretation would occur.

Obviously, had the signal been preceded by a marking signal, a steady state condition would have been reached prior to any of the signal reversals and no distortion would have occurred in the interpretations.

The armature transit time shown in Fig. 11B was exaggerated to illustrate this form of internal characteristic fault. As a rule the distortion is small, however, as indicated, it is non-linear with respect to the degree of signal distortion inducing it, varys in occurrence with different signal combinations and is not readily distinguishable from fortuitous distortion with conventional test equipment; and consequently it is generally included in the fortuitous classification.

INTERNAL FORTUITOUS FAULTS

These are random in nature and are rarely associated with a specific sampling instant. Causes are many - variations in armature behavior and that period of indecision associated with the movement of the armature past the respective locking members, improper lubrication, foreign matter and in particular erratic behavior in the chain of those components controlling the lock lever timing. Frequently referred to as "jitter", this latter action is a combined effect of imperfections in the cam surface and deviations in the rotation of the cam attributed to such items as clutches, trip mechanisms, external loads and drive arrangements.

Jitter may advance the sampling instants in some cycles while delaying it in others, and cannot normally be associated with any specific sampling instant. However, within a fixed time - generally accepted as the equivalent of line of copy (72 characters) - it is likely that all the internal fortuitous faults will have had an opportunity to affect all sampling instants.

Since internal fortuitous distortion may randomly advance or delay the sampling instants in subsequent cycles the resulting sampling period may, because of the many characters included in the determination of fortuitous faults, be pictured as extending in equal amounts from both sides of the sampling reference.

SKEW

Although all internal distortion is classified in the three aforementioned categories, certain conditions may exist which treat the beginning of the signal element differently than the end. This condition is known as skew and is the result of an inequality in the irregularities associated with the beginnings and ends of marking signal elements. It is normally caused by the effect of internal faults on the difference in armature movement rates at the beginnings and the ends of marking signals because of improper armature travel with respect to the lock or sampling points.

An example of this condition is provided in Fig. 12. Assume a magnet armature relationship in which the armature clearance and travel are not properly adjusted. Bias exists because armature travel is greater on the spacing side of the armature lock than that for marking. Proper procedure is to realign the lock point and armature travel, however, the difference in travel can be compensated for by oppositely biasing the armature retractive spring to produce the armature action shown in Fig. 12B. Although this results in asymmetrical armature transitions, the line signal is faithfully interpreted by the selector magnet-armature assembly (Fig. 12C).

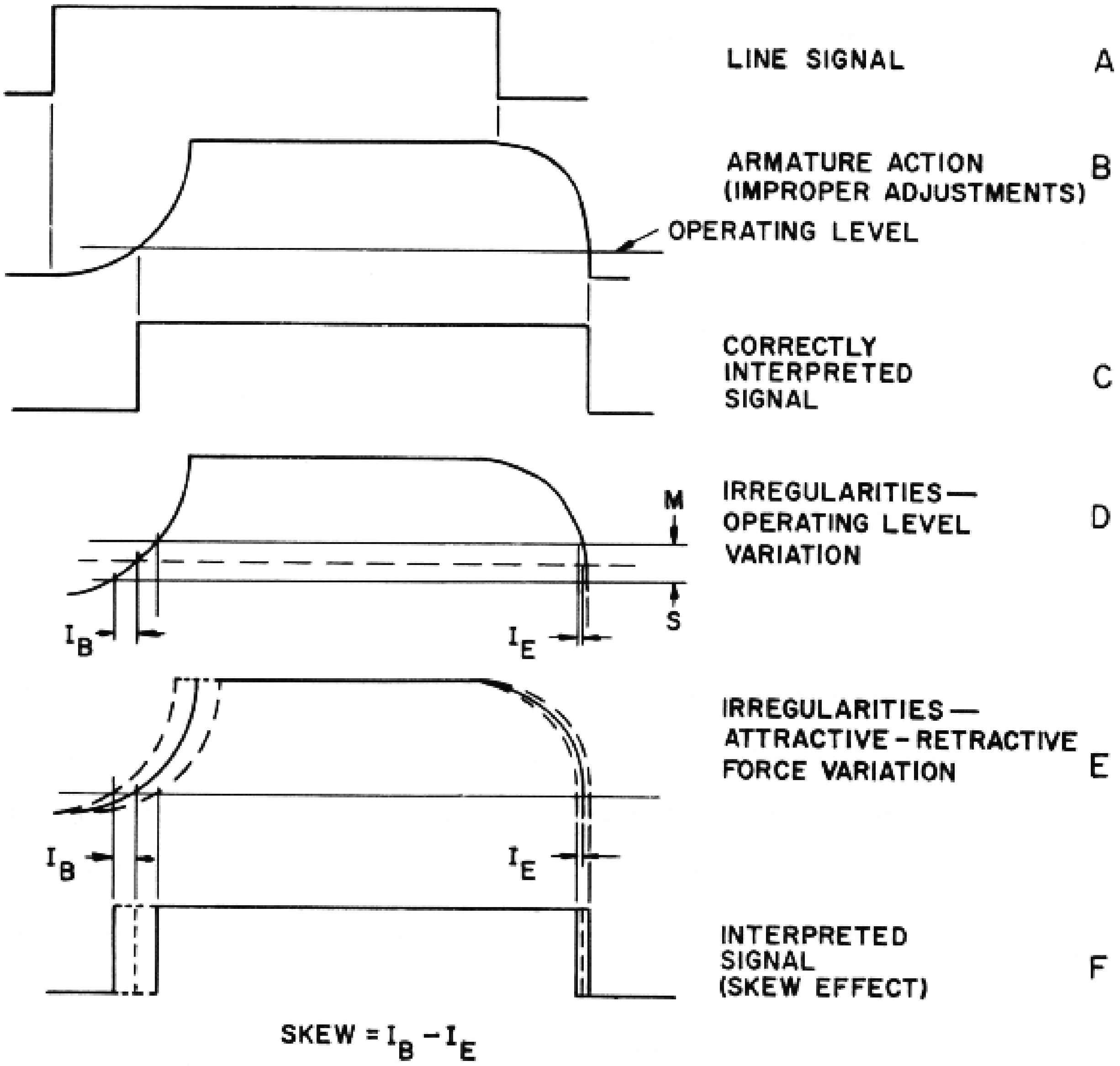


FIGURE 12, SKEW GENERATION

Now assume the selector has additional faults. In Fig. 12D, the operating levels of the lock levers are not identical and as a result the sampling of spacing elements occurs earlier in the armature rise than that for marking. Because the curve representing the armature movement is far more sloping at the beginning of the signal, the time displacement or irregularity at the beginning (I_B) is greater than that for the end of the signal (I_E). The difference in the respective irregularities is equivalent to the skew.

Skew can also occur simply because the operation of the armature is more irregular at the beginning of the signal as a result of the comparably low attractive force (Fig. 12E), and consequently its displacement relative to the signal transition is largely fortuitous.

The example illustrates positive skew. Were conditions reversed to produce opposite asymmetry, negative skew would have resulted. Erratic armature release is a common cause of skew.

As indicated it is the difference in the irregularities that is important. The smaller irregularity represents that degree of distortion common to both the beginning and end of the signal and is typical of the fortuitous distortion caused by variations in armature behavior. Erratic armature action affects the interpretation of the stop element as well as the signal elements and as a result the start transition can behave in a manner to produce "jitter" in the sampling cycle.

The effect of skew differs from that of bias. Whereas internal bias affects the beginnings of marking signals and compensate for signals having opposite distortion, skew affects the beginnings or the ends of signal elements to decrease tolerance. As indicated in Fig. 12F, positive skew reduces tolerances much in the same manner as if both positive and negative bias were concurrently present. Positive skew reduces tolerance at the beginning of marking signals while negative skew affects the end. Like bias, skew must be identified to indicate its effect. (S_B) and (S_E) have been selected to identify positive (beginning) and negative (ending) skew respectively.

TOTAL INTERNAL DISTORTION

The total internal distortion is a summation of the internal faults affecting both the interpretation and the sampling function and is depicted in Fig. 13A as an equivalent sampling period. What was the sampling instant for a perfect receiver now serves only as a sampling reference for selector orientation.

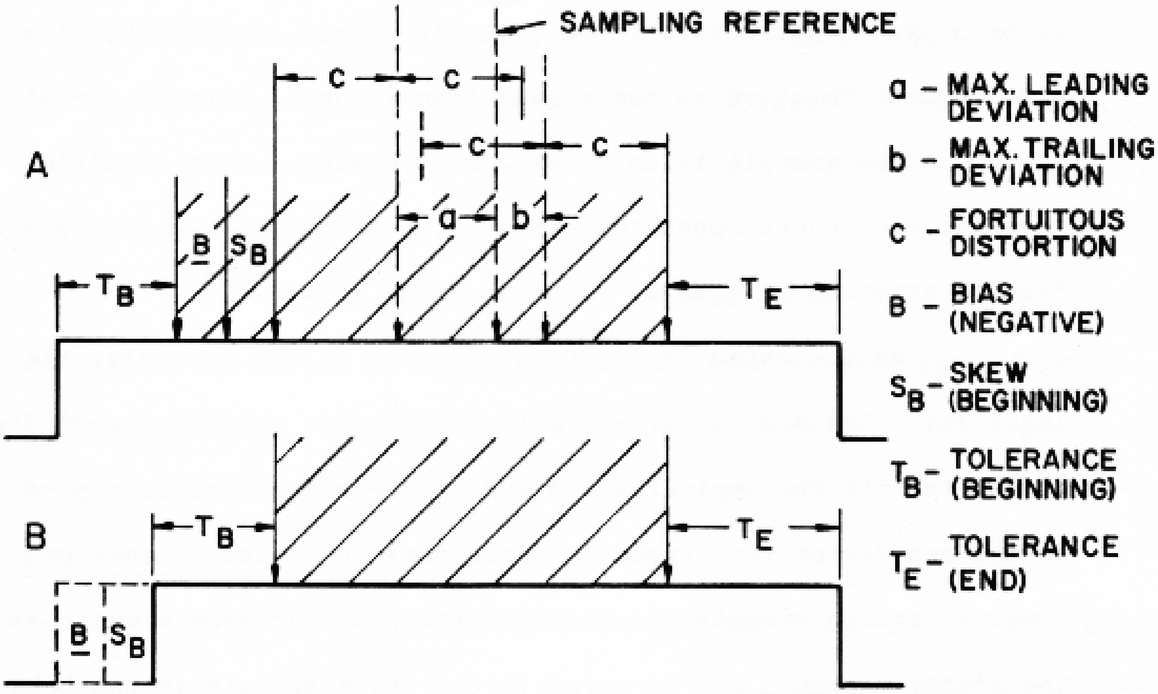


FIGURE 13, EQUIVALENT SAMPLING PERIOD

The equivalent sampling period, in order to equate to the internal distortion of the selector, must of course represent a consolidation of interpretation faults and sampling periods associated with each the signal elements comprising the signal and has its limits determined by the most critical of the individual sampling periods as relating to the beginning and end of the signal element respectively.

Although the equivalent sampling period serves as a convenient means for illustrating receiver distortion with respect to the line signal, the handling of interpretation faults makes it unwieldy when analyzing the selectors response to distorted line signals. A preferred manner of illustrating the selector faults is shown in Fig. 13B. The combined effect of bias and skew is shown in the interpreted signal and the sampling period consists of those faults only related to the sampling function. So long as the entire sampling period remains within successive signal transitions (as interpreted), proper selection will occur with operating margins with respect to the beginning and the end of the signal element as indicated by T_B and T_E.

This latter approach permits more ready association of bias and skew with distorted signals and identifies the internal distortion with its source - sampling or interpretation.

DETERMINATION OF SELECTOR OPERATING MARGINS

Previous examples matched specific signal elements and corresponding sampling periods to illustrate the manner in which a mis-selection occurs. These do not, however, present a true picture of the operating margin of the selector inasmuch as it is possible to have a signal element distorted in a manner which would complement its corresponding sampling displacement to provide greater operating margin than that obtainable with a perfect signal element, and as a result may mask a selector irregularity.

Considering the varied combinations of sending units and transmission lines, any of the signal elements presented to a receiver may at any time have the maximum distortion in that signal. Consequently a valid margin check of the selector requires that all signal elements have the maximum distortion.

Specific procedures have been established and test equipment developed for determining the operating margins of selectors[3]. Means are provided for applying the four possible signal displacements in predetermined amounts equally to all the signal elements comprising the received signal. Those displacements associated with the beginning of the signal element (SB and MB) are introduced in the form of pure bias, while those associated with the end (SE and ME) are introduced through what is termed end distortion, an artificial characteristic distortion in which the ends of all signal elements, with the exception of the stop element, are shortened or lenghtened.

Under these test conditions, selector failure is determined by the most critical of the equivalent sampling periods with respect to both bias and end distortion and consequently the optimum selector setting and distortion tolerance can be determined for each.

In practice the quality of the selector is unknown, and is determined by its failing points when subjected to different signal transition displacements. From these failing points it is possible to determine the respective internal faults. However, to illustrate the manner in which internal distortion faults affects the selector's response to input signals, assumed values for the various internal faults have been chosen (Fig. 14).

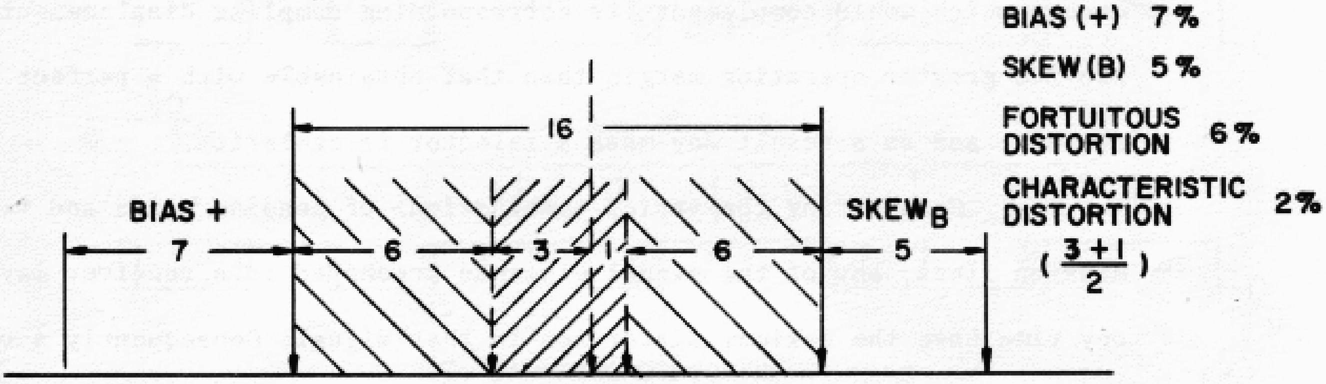


FIGURE 14, EXAMPLE - SELECTOR FAULTS

The routine for determining selector receiving margins is represented by Figures 15 and 16. Since the equivalent sampling period is known and the same degree of signal transition displacement is applied to all signal elements comprising the signal, only two opposite elements are required for the illustration of selector response to bias and end distortion, and for range determination.

RANGE

To establish the overall range, a near perfect signal (within the capabilities of the distortion test set - maximum distortion .75%) is delivered to the selector. The signal as interpreted, is distorted due to the presence of positive bias and positive skew which effect the beginnings of marking signals as indicated. The sampling period is oriented to the right and left (high and low) until the boundaries of the respective signal elements as interpreted are reached. Orientation to the right (Fig.15A) is limited by

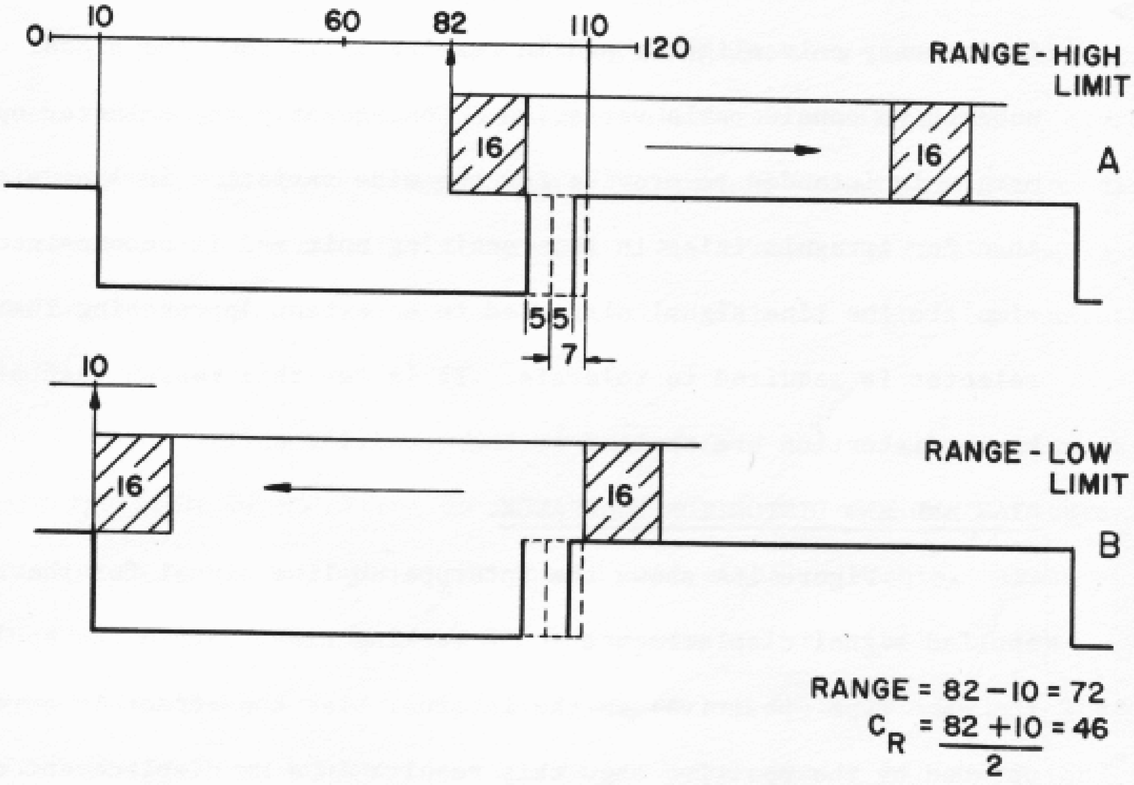


FIGURE 15, SELECTOR RANGE ORIENTATION

the sampling period for the spacing signal element, reaching the following signal element (marking) at a corresponding range scale setting of 82. Any further movement to the right may cause a sampling of that following element and subsequently a marking selection instead of the intended spacing. The lower limit (Fig. 15B) is determined by the same sampling period reaching the preceding signal element. The marking signal element sampling is non-critical for although positive skew is present, the greater marking bias shifts the interpreted signal transition an amount sufficient to provide a 2 point margin in this area. As indicated the lower orientation limit is 10, yielding a range of 72 points and a center of range scale setting of 46.

This step, while indicating the mechanical limitation of the mechanism, does not provide a complete picture of the selector quality. With the exception of suffering damage from external causes, the selector characteristics vary only slightly and in reality it is the line signal which is subject to considerable variation. Consequently the selector operating margin is intended to provide for the wide variation in line signals rather than for irregularities in the receiving unit and it becomes necessary to simulate the line signal distorted to an extent approaching that which the selector is required to tolerate. It is for this reason that signals of known distortion are applied to the receiving unit.

BIAS AND END DISTORTION TOLERANCE

Figure 16A shows the interpreted line signal for the first of the applied signal displacements - 35% marking bias. Since the applied bias is the same type (positive) as the internal bias the effect is adverse. Compounded by the positive skew this results in a MB displacement of 47%, and places the upper orient limit at 47. Again, further movement will cause the sampling period to detect the following signal element. (Examination will reveal that the determination of the lower limit under this signal condition would reveal nothing, since the limit remains unchanged from that for a perfect signal.)

Spacing bias (35%) is now applied to the signal. The opposite internal bias compensates for 7% of the bias, however the positive skew adversely effects the beginning of the marking signal resulting in an SB displacement of 33%. The sampling period is shifted to the left (Fig. 16B) and failure is encountered as the setting is shifted below the 43 point,

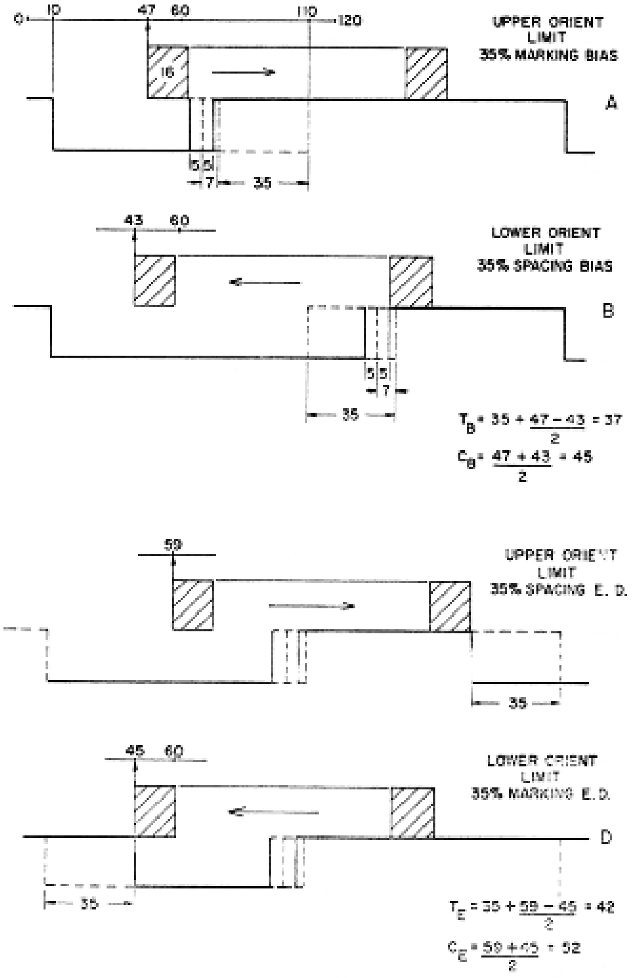


FIGURE 16, SELECTOR BIAS AND END DISTORTION ORIENTATION

caused by the sampling period extending beyond the transition point of its respective signal element as interpreted. These two steps reveal that the receiver will tolerate maximum bias at a range scale setting of 45.

The same procedures are repeated for end distortion as indicated in Figs. 16C and 16D with a resulting tolerance to end distortion of 42% at a setting of 52.

OPTIMUM ORIENTATION SETTINGS

In addition to the optimum settings for maximum bias and end distortion tolerances, there is also an optimum setting for fortuitous distortion. This latter setting provides the greatest tolerance when any of the four types of signal transition displacements are equally likely.

In practice, however, the optimum setting with respect to bias is preferred since most transmission circuits suffer some bias, to use up some of the receiver's bias tolerance but little if any of its end distortion tolerance. The three optimum orientation settings are illustrated in Fig. 17 to indicate their respective tolerances. The variations in tolerances are caused by the treatment accorded the beginnings and ends of signal elements, arising from interpretation faults and as a result the optimum settings do not necessarily coincide with the mid-point of the orientation range.

It is interesting to note that reasonable amounts of internal bias do not affect the selector tolerance to bias provided the center of bias tolerance setting is maintained. This may be seen in Fig. 17A. A shift in the sampling period corresponding to additional displacement in the marking signal element will maintain the bias tolerance with a corresponding change in end distortion tolerance. If the shift is in the direction of reducing the internal bias, the end distortion tolerance is increased.

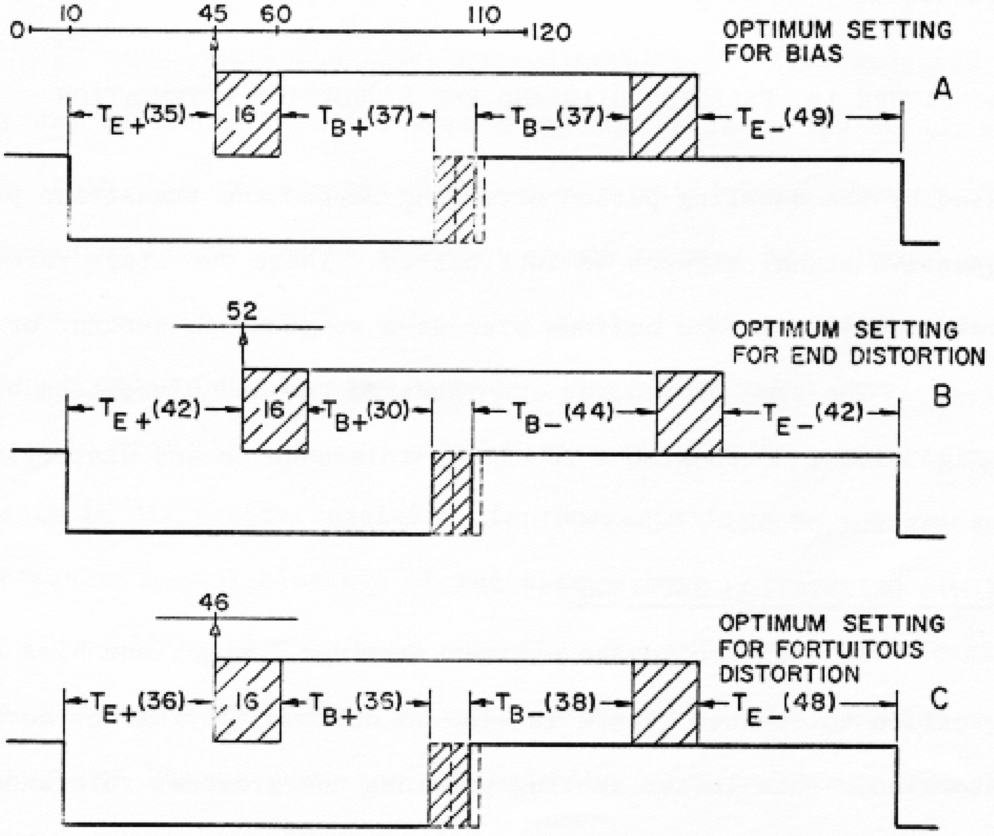


FIGURE 17, OPTIMUM ORIENTATION SETTINGS

The positive skew present is undesirable in that it further reduces the selector's tolerance to bias. Negative skew, affecting the trailing end of marking signal elements, has no affect on bias but does reduce the tolerance to end distortion. Since skew is the difference in fortuitous effects at the beginnings and ends of marking signal elements it may be eliminated by decreasing the larger effect or increasing the smaller. The former is obviously preferred since removal of skew in the latter manner reduces the overall tolerance by having the distortion affect both ends of the marking signal element. This move in effect converts the skew to plain fortuitous distortion and would appear in the illustrations as a widening of the sampling period.

SELECTOR OPERATING CHARACTERISTICS

The developed test procedures provide a relatively simple means of determining the selector's characteristics when subjected to signals containing fairly large displacements. The internal bias is determined by the difference in the optimum settings for bias and end distortion. Using the values from Fig. 17, Bias = $C_E-C_B= 52-45=+7$ indicating 7% marking bias.

Skew is the difference in tolerance to end distortion and bias. Skew = $T_E-T_B=42-37=+5$ indicating 5% positive skew (beginnings of marking signals affected).

Other distortion (chiefly fortuitous with possible presence of some mechanical characteristic distortion) is the difference between the maximum tolerance possible (50%) and the tolerance to bias or end distortion whichever is greater. D "other"= 50%-42%=8%. This conforms to half of the sampling spread in the illustration. Although this "other" distortion is composed of fortuitous distortion and characteristic distortion, a dimensional analysis of the lock cams and associated parts can predict the degree of characteristic distortion attributable to sampling deviation. As indicated earlier, that characteristic distortion due to armature action is difficult to determine with conventional test equipment and for all practical purposes is treated as fortuitous distortion.

To provide a complete picture of the selector operating characteristics, it is necessary to follow somewhat the same procedures as for the standard test except to apply the signal distortion in small increments and plot the respective failing points.

Such a plot is shown in Fig. 18 and illustrates the selector's characteristics under all signal conditions. The area formed by the intersecting parallelograms represents the working area and is determined by the operating margins of the selector under various selector orientation settings

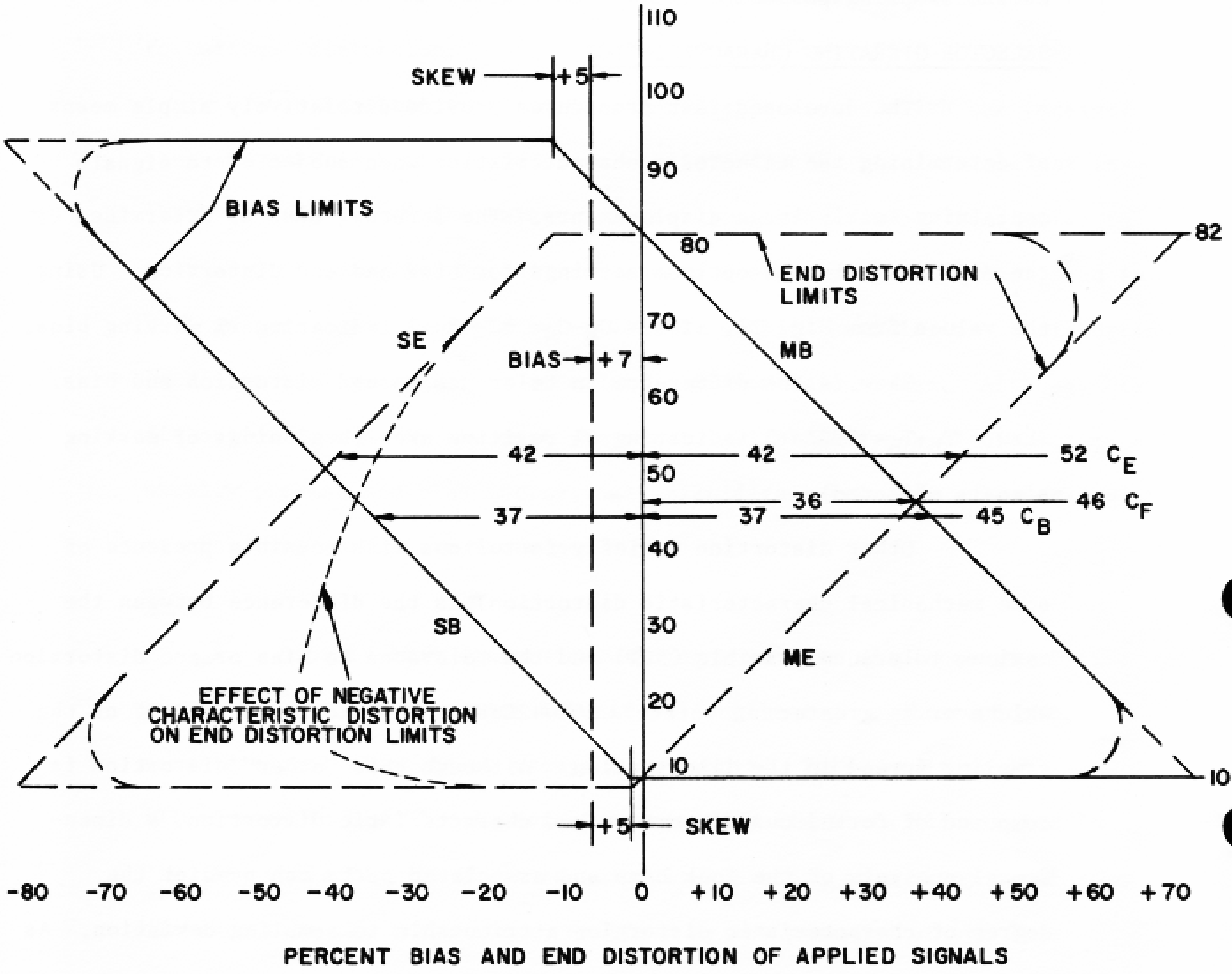


FIGURE 18, SELECTOR CHARACTERISTIC PARALLELOGRAM and input signal displacements. The working area is reduced from the ideal by the presence of internal distortion. The effect of skew and bias are indicated.

Because armature transit times are not instantaneous, true parallelograms will never be formed and the corners as illustrated, are modified accordingly. When transit times are comparatively long and the distortion of the resulting parallelograms extends into the working area, the armature action type of internal characteristic distortion affects reception. The boundaries of the working area in the example assume an absence of this type of internal characteristic distortion however, when present, it can result in a reduction in margin greater than the signal displacement causing it. The effect is illustrated by the curved broken (SE) line. The curvature indicates the armature fails to reach its fully attracted position when the spacing end distortion input signal reaches 25%; and for larger distortions the relation between transition displacement and reduction in margin in the signal as interpreted is no longer linear. The horizontal variations between the two respective boundaries is an indication of the internal characteristic distortion (interpretation) for respective (SE) input displacements.

Although other variations are possible, the illustration takes into account only SE signal displacements to show the resulting decrease in tolerance to end distortion with no appreciable reduction in overall range. This variation further indicates the fallacy of relying on the orientation range measurement with undistorted signals for determining selector operating margins. By applying line signals distorted in an amount approximating that which the selector is required to tolerate, the internal characteristic distortion is taken into account during operating margins checks.

SUMMARY

Because of distortion of the telegraph signals presented to the receiving unit, the selector must be capable of operating on only a small part of each of the signal impulses comprising the signal. The limit to which that portion of the signal can be reduced conforms to the equivalent sampling period of the selector and determines the operating margins. Normally termed internal distortion, the equivalent sampling period is a consolidation of faults within the selector, some responding differently to beginnings of signals as compared to the ends, and consequently selector operating margins are usually expressed as tolerances to signal distortion with respect to both the beginnings and ends of signal elements.

Internal distortion falls into two general and fairly unrelated categories - signal interpretation and sampling. Distortion - bias characteristic distortion and including skew - arising from improper signal interpretation has as its source an asymmetry with respect to marking and spacing signals, normally caused by incorrect armature travel and transit times. Sampling faults are a result of departures from correct sampling intervals with respect to the incoming signal, which in turn are caused by deviations (from the ideal) in parts dimensions, receiver shaft speed variations, and inconsistent starts for the receiving cycle. In addition to variations in clutch and clutch trip behavior erratic armature action can contribute to the latter cause.

By way of example, present selectors operating at 110 Baud, very often have armature transit times in excess of one-third of the signal element, requiring that tolerances of other parts and adjustments which might contribute to improper signal interpretation be exceptionally stringent. A reduction of transit time does much to minimize these effects. In sampling, the manner of dimensioning component parts in these same selectors permits around three percent distortion of which half might be related to the allowable manufacturing tolerances. Experiences with selector shaft speeds have shown that variations because of "sloppy" belt drives, "soft" shaft couplings, or underpowered motors, without any appreciable outward appearance, produce rotational displacements as high as eight degrees from the nominal. This seemingly small amount translates into an intolerable 21% sampling distortion.

Finally, design and manufacturing excellence, if achieved, would be for nought unless proper orientation for the application is maintained. Internal interpretation faults require that the selector be subjected to distorted signals approximating those expected in service, in order to determine the optimum orientation setting. Selection of the mid-point of the orientation range is not sufficient for this purpose as variations of up to 5 percent with respect to the optimum setting are not unusual.

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