THEORY OF SIGNAL RECEPTION IN TELETYPEWRITERS

CONTENTS

Drawings Attached

0. INTRODUCTION

This section, consisting of Bulletin 660 prepared by the Bell Telephone Laboratories, gives the general theory of the reception of signals in start-stop teletypewriters of the type now used in the Bell System. This theory is considered both from the point of view of using a teletypewriter in subscriber service and from the point of view of using it as a measuring tool for determining the quality of teletypewriter signals.

1. GENERAL

In considering the operation of two teletypewriters working together over a line circuit, it is convenient to consider the matter almost entirely from the viewpoint of a receiving machine in which the transmitted signals are recorded. The receiving mechanisms of all teletypewriters used in the Bell System are similar in principle, each having a selector magnet (or its equivalent), a start-stop distributor and a typing unit which is largely mechanical in its operation, with means provided for transferring the electrical impulses received from the line into selective mechanical motions. The theoretical discussion will be applied in particular to the receiving arrangements of the No. 14 teletypewriter. A more detailed description of the complete mechanism is given elsewhere.

The reception of an undistorted signal train corresponding to one character will now be described. Refer to Drawing 251-B-35 which shows schematically that part of the receiving mechanism which is of interest in explaining the theory. This includes a receiving selector magnet with its associated armature and armature extension, a locking lever, a stop latch and a selector cam which is driven by a friction clutch. Normally, i.e., before the first impulse of the character under consideration is received, the selector magnet is energized and the magnet armature and armature extension are in the position shown and the selector cam (which corresponds to a receiving distributor) is held from rotating by the stop latch. The first impulse of a character which is called the start impulse is spacing and this is followed by the five selecting impulses which may be either marking or spacing and then by the stop impulse which is marking. The start impulse allows the armature and armature extension to move to a position shown by the dotted lines and at the same time releases the stop latch. This latter operation permits the selector cam to start rotating. The speed of rotation and the starting position of the selector cam are normally so adjusted that the first depression (shown by A) will arrive at the locking lever at the time the middle of the first selecting impulse is being received. The locking lever will then fall into this depression and the locking wedge (B) will move toward the armature extension and lock it in the position it occupies at this instant. Immediately thereafter mechanical arrangements (not shown) will operate to store the impulse thus selected. This process will then be repeated for each of the other four selecting impulses. From this it is seen that the character selected is determined exclusively by the action of the selector cam, the locking lever and the armature extension, and the remainder of the mechanism merely serves to store and utilize the selected impulses.

After the five selecting impulses have been received the stop impulse is received which is normally a little less than one and one-half times as long as a selecting impulse. During the latter part of this impulse an arm on the receiving selector cam will strike the stop latch and the

cam will be held until the reception of the start impulse for the next character.

When a start impulse is received a small time will elapse before the selector cam can acquire full speed because of the inertia of moving parts, clutch slippage, etc. This is compensated for by making the distance between the starting position of the locking lever and the first selector cutting slightly less than would be required if the cam immediately attained full speed at starting. This displacement is indicated by the distance "X" and the corresponding time is shown at (t).

2. OPERATION OF ORIENTATION RANGE MECHANISM

An orientation device or range finder which changes the time at which selection occurs with respect to the beginning of the incoming impulses is provided on all Bell System teletypewriters. The range finder moves the stop position of the selector cam (and hence the start position) either forward or backward with respect to the direction of rotation. This range finder is provided with a pointer which moves along a scale, the scale being calibrated in per cent. of a unit signal impulse. In the No. 14 teletypewriters a movement of the range finder toward the lower numbers on the scale advances the time of selection toward the beginning of each selecting impulse. Likewise, a movement on the scale toward the higher numbers retards the time of selection toward the end of the impulses.

If a start-stop teletypewriter could be built with a selecting mechanism which responded instantaneously and if the teletypewriter were ideal in all other respects, the range finder, when perfect signals are being received, could be moved over a range of very nearly 100 per cent. and perfect copy would be typed. This condition is illustrated by case (a) of Drawing 251-B-35. The vertical solid lines are drawn through the centers of the five selecting impulses and the dotted lines joined thereto indicate the particular cam depression which is associated with each selecting impulse. Moving the orientation range finder in effect moves the solid lines with respect to the signal and in this case they can be moved by an amount corresponding to one unit impulse. In other words the time of selection can be moved by ± 50 per cent. without typing errors. (In an actual machine this range is less than this because of imperfections.)

3. RECEPTION OF DISTORTED SIGNALS

3.1 General

In the following discussions it will be assumed for purposes of illustration that only one type of distortion exists at one time. In the actual case several types of distortion usually exist at the same time and there is no simple relationship between the combinations of the various distortions and orientation range readings.

3.2 Effect of Bias

Bias consists of an increase or decrease in the duration of each marking impulse divided about equally between the ends of the impulse when the signal is received from the line. However, due to the fact that the distributor starts rotating at the beginning of the start impulse, the effect of bias is to shift all impulses forward or backward with respect to this time. The result of this is that there will be an addition or subtraction to the front of each marking impulse, with the rear of the impulses remaining unchanged.

In an ideal machine where selection would be made instantaneously the signal would be recorded correctly if it has the right condition (i.e., marking if it should be marking or vice versa) at the instant of selection. The particular times when the selections take place with the orientation setting at the middle of the range and with perfect signals are shown, as mentioned before, by the vertical solid lines numbered 1 to 5, inclusive, on Drawing 251-B-35. Referring to cases (b) and (d) it is seen that 25 per cent. bias will not cause errors. However, referring to cases (c) and (e) it is seen that 50 per cent. bias will just cause errors. In case (c) the second and fifth impulses will be falsely added and in case (e) the first and third impulses may at times be spacing instead of marking.

Actually, however, the maximum bias which can be tolerated in teletypewriters with the range finder set approximately in the middle of the orientation range is not the theoretical 50 per cent. but is in the order of 40 per cent.

Assume now that the incoming signals are biased to marking by 25 per cent., i.e., each marking impulse has 25 per cent. of the unit signal impulse added to it, as shown at (b) on Drawing 251-B-35. If an orientation range observation is made with signals as shown at (b), the lower limit will be unchanged and the upper limit will be shifted down by 25 per cent., i.e., failure will occur due to the fact that marks will be selected instead of spaces with the orientation pointer shifted upward by 25 per cent. with respect to its position with perfect signals. Likewise, spacing bias which effectively subtracts from the beginnings of marking impulses will cause the lower limit of orientation range to be moved upward by 25 per cent.

If signals biased by various amounts are received by the teletypewriter and if readings of orientation limits are obtained for each value of bias, the results for a perfect teletypewriter could be plotted as shown by the dotted lines of Fig. 1, Drawing 723-1145. In this chart bias is plot-

...ed horizontally and the orientation limits vertically. The ideal conditions assumed above are, of course, not present in an actual machine due to such factors as mechanical inaccuracies, electrical, mechanical, and magnetic characteristics, and variations in clutch slippage. A typical chart for an actual teletypewriter is shown by the solid lines of Fig. 1, which as will be noted, are shown solid out to about 50 per cent. marking and spacing bias. The parallelogram was completed with dotted lines to show what the complete characteristic would be if no new factors were introduced when there were very large amounts of bias. In an actual machine, that portion of the inner parallelogram, shown in dotted lines, would probably not be exactly as shown but would have some other shape due among other things to the fact that the magnet cannot properly respond to extremely short impulses.

If the teletypewriter itself has some bias due to such factors as improper line relay adjustments, magnet adjustments or improper mechanical adjustments, a graph like that shown in Fig. 2 may result. In this case, the teletypewriter has for purposes of illustration an internal marking bias of 10 per cent.

3.3 Effect of Distortion Other Than Bias

Several examples of the effect of distortion in the received signals other than bias are illustrated in cases (f), (g) and (h) of Drawing 251-B-35. Case (f) illustrates a shortening of the start impulse which is equivalent to the addition of 25 per cent. of a unit impulse on the end of the stop impulse. It will be noted that a 25 per cent. distortion of this one impulse is as difficult for the teletypewriter to handle as the 25 per cent. marking bias which occurs on all marking impulses as illustrated in case (b). It will also be noted that all of the selecting impulses have been shifted to the left, that is toward the start impulse. When an orientation range is taken, therefore, both the upper and lower limits will be shifted downward but the difference between the two limits will remain unchanged.

Case (g) illustrates the effect of the subtraction of 25 per cent. from the rear of the stop impulse. This shifts all of the selecting impulses in the opposite direction to that shown in case (f) and is as difficult for the printer to handle as 25 per cent. spacing bias, as illustrated at (d). Orientation range limits will be shifted upward and as in case (f) the difference between the two limits will remain unchanged. An example will now be given to illustrate this case. Suppose the range on perfect signals was 10 to 90. The range for case (g) will then be 35 to 115, each limit being shifted upward by 25 per cent.

Case (h) illustrates the effect of a 25 per cent. addition to the front of No. 1 impulse, a 25 per cent. subtraction from the front of No. 3 impulse and a 25 per cent. subtraction from the rear of No. 4 impulse. None of these effects will cause errors in typing with the range finder set in the middle of the range. When an orientation range is taken, failure will occur on the No. 3 impulse when the range finder is moved toward the lower end of the scale. When the range finder is moved toward the upper end of the scale failure will occur on the No. 4 impulse. Thus in this particular case a reduction in range will occur from both ends of the scale. Suppose the range on perfect signals was 10 to 90. The range for this case will then be 35 to 65, both limits being reduced by 25 per cent.

Marking distortion occurring on the beginning of No. 1 impulse has no effect because there is no selection during the start impulse.

3.4 Effect of Speed Variation

The effect of variations in distributor speeds on operating margins is illustrated on Drawing 251-B-35 by cases (i) and (j). Case (a) shows a perfect signal with the speeds properly adjusted which may be compared with cases (i) and (j).

Case (i) shows the result if the sending distributor is faster than the receiving distributor. It will be noted that in this case the most probable error is a false mark for the No. 5 impulse because a part of the stop impulse is received on No. 5 position. If perfect signals are assumed the speeds would have to be somewhat more than 7 per cent. different to cause errors of this kind in a normal teletypewriter with the range finder set in the middle of the range but if there is some signal distortion other than that due to speed discrepancies, such as marking bias, smaller differences of speed would be sufficient to cause errors. Case (j) illustrates the conditions when the sending distributor is slower than the receiving distributor. It will be observed in this case that the most probable error would also be in the No. 5 impulse due either to the No. 4 impulse being sufficiently prolonged to fall on the No. 5 selecting position or to the No. 5 impulse being so late in starting that it is not properly received on the No. 5 position.

If an orientation range observation were made with the sending machine faster than the receiving machine by the amount on the drawing, namely, 6.7 per cent., both upper and lower limits would be shifted downward and the shift of the upper limit would be about 37-1/2 per cent. and of the lower limit about 6.3 per cent. If the orientation range on perfect signals had been 10 to 90 the range with the above speed discrepancy present would be about 4 to 52. With the sending machine slower than the receiving both limits would be shifted upward. If the amount of speed

discrepancy were 5.9 per cent., as illustrated on the drawing, the shift in the lower limit would be about 31 per cent. and in the upper about 12 per cent. and the orientation range would now be about 41 to 102. It is seen that the effect is largely at one end of the range or the other depending upon whether the sending distributor is fast or slow.

In the above illustrations large speed discrepancies were used so that the shift of the signals could be shown readily on a drawing. In actual practice, the speed discrepancies would ordinarily, of course, be much less than this, perhaps of the order of 1/2 per cent. or less. A 1/2-per cent. discrepancy will cause about 3 per cent. shift in the upper limit if the sending machine is fast and about 2.5 per cent. shift in the lower limit if the sending machine is slow.

4. INTERPRETATION OF ORIENTATION READINGS

4.1 General

In the foregoing discussions the relations between orientation range readings and various types of signal distortion were considered. The purpose of this subdivision is to consider the teletypewriter as a testing tool in which orientation readings are made when receiving signals to be tested. When the orientation limits are known certain deductions may be made regarding the amount and nature of the distortion.

The orientation limits are determined by the combination of all the types of distortion present which may include bias, characteristic and fortuitous distortion together with distortion produced by speed discrepancies or by maladjustments or trouble conditions in the sending apparatus. It is impossible to determine from orientation readings the exact amount of each type of distortion present when more than one type is present. However, the maximum distorted signal that occurs during the period of observation is determinable, this being measured by the maximum change in either orientation limit. This figure gives a good indication of the quality of the teletypewriter signal. The manner in which printed errors occur in the neighborhood of the orientation limits may give some indication of the character of the distortion. If the limits are fairly definite, i.e., the copy changes from good to bad when the range finder is moved over only a small distance, some fixed distortion such as bias or distortion due to speed variation or faulty apparatus predominates. If there is a certain range at each limit over which certain characters are consistently in error, this is due to characteristic distortion. If the limits are not definite, i.e., if there is a range over which errors occur and the errors do not occur consistently on certain characters, this is due to fortuitous distortion.

4.2 Examples

A few orientation range readings will now be given along with their interpretation. It will be assumed for purposes of illustration that the orientation range on this particular machine with perfect signals is 10 to 90 and that the machine has been adjusted to remove internal bias. Other machines with equally good adjustment will give other ranges on perfect signals. The readings which would be obtained if the machine were equipped with end zero scales are also given below.

Readings on TTY without end zero scale		Readings on TTY with end zero scale		
Lower Limit	Upper Limit	Lower Limit	Upper Limit	
10	90	0	0	Signals are perfect.
30	90	-20	0	Lower limit raised 20%. Maximum distortion is 20%. The most probable condition is that there is a spacing bias of 20% although in certain cases this effect may be due to characteristic distortion.
10	70	0	+20	Upper limit lowered 20%. Maximum distortion is 20%. The most probable condition is that there is a marking bias of 20% although in certain cases this effect may be produced by characteristic distortion.
25	75	-15	+15	Lower limit raised 15% and upper limit lowered 15%. Maximum distortion is 15%. Signal probably contains no bias. Distortion probably consists mostly of fortuitous effects although in certain cases this effect may be produced by characteristic distortion.
40	70	-30	+20	Lower limit raised 30% and upper limit lowered 20%. Maximum distortion is 30%. Signals probably contain both bias and other distortions.

Readings on TTY without end zero scale		Readings on TTY with end zero scale			Readings on TTY without end zero scale		Readings on TTY with end zero scale		
Lower Limit	Upper Limit	Lower Limit	Upper Limit		Lower Limit	Upper Limit	Lower Limit	Upper Limit	
20	100	-10	*	Both limits raised 10%. Maximum distortion is 10%. Effect caused by distortion at beginning of start pulse. Possibly caused by trouble in sending distributor such as improper adjustment of 6th pulse contact of keyboard distributor.	41	102	-31	*	Lower limit raised 31% and upper limit raised 12%. Maximum distortion is 31%. Probably caused by sending machine being slower than receiving machine. If no other distortion were present the speed discrepancy would in this case be 5.9%.

* These readings are outside the range of the scale.

BELL TELEPHONE LABORATORIES INCORPORATED

TELETYPEWRITER EQUIPMENT

THEORY OF SIGNAL RECEPTION IN NOS. 14 & 15 TELETYPEWRITERS.

251-B-35
INFORMATION

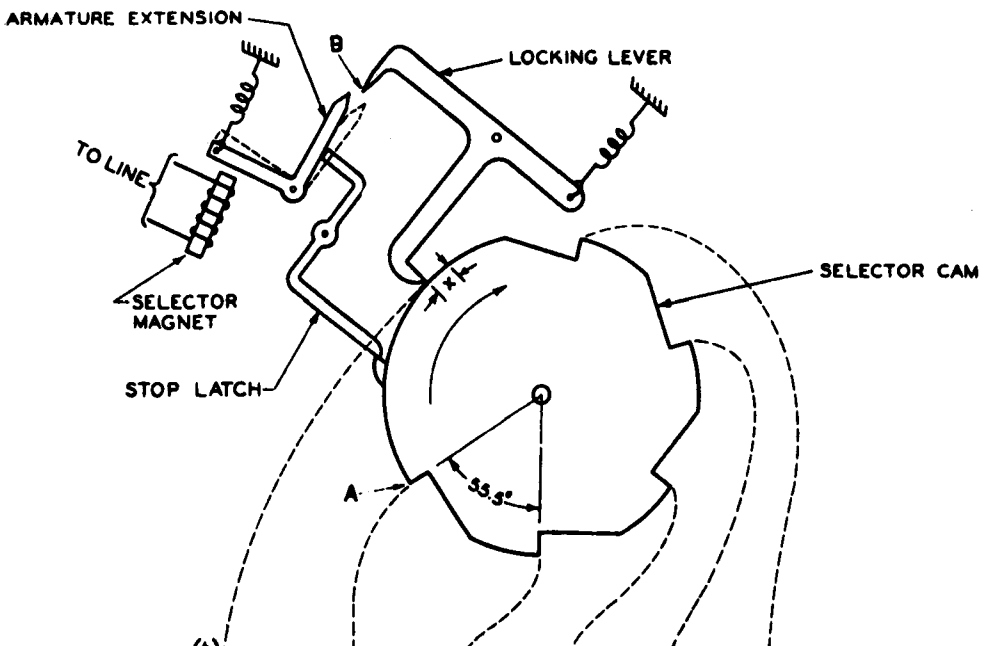
Engineer aw.
Draftsman
Checked by

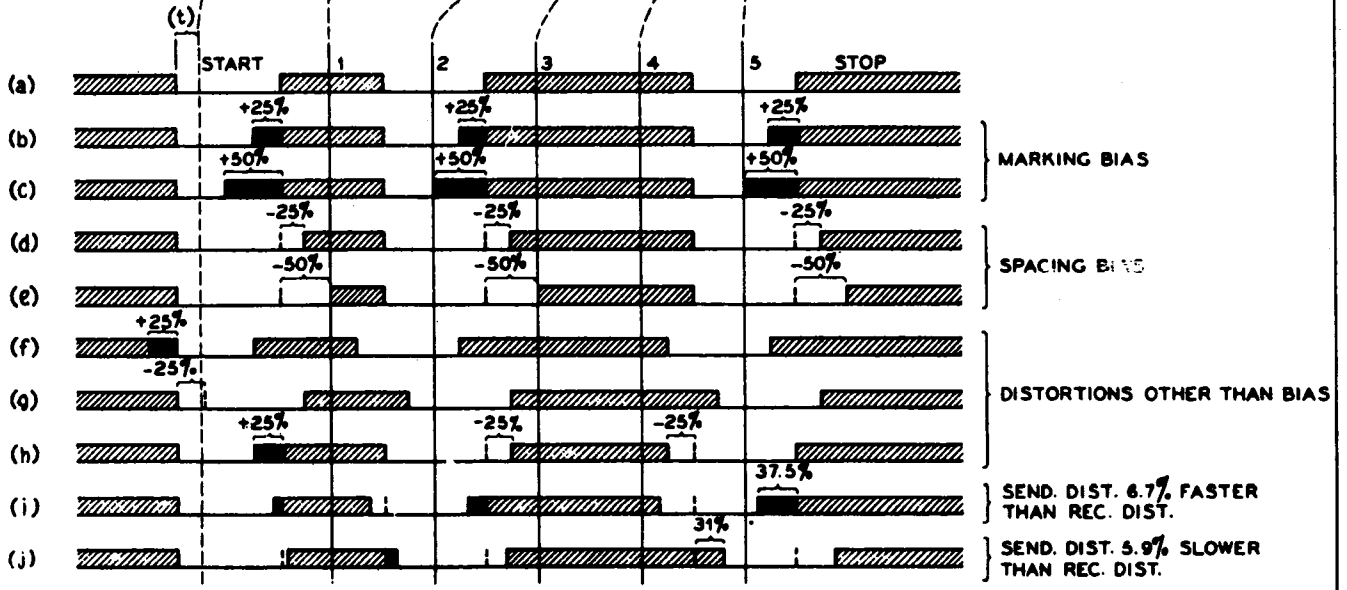
Log No. P-24111, 4.6, 33.
ISSUE 1

ADDED STOP LATCH.
LOG NO. P-24480 7-19-34
ISSUE 2 A.W.

ADDED SOLID LINE TO CAM.
LOG. NO. P-24588 1-10-35
ISSUE 3 A.W.

CHANGED (I) AND (J)
LOG NO P24609 3-21-35
ISSUE 4 A.W.





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TELETYPEWRITER EQUIPMENT
THEORETICAL MARGIN CHARTS

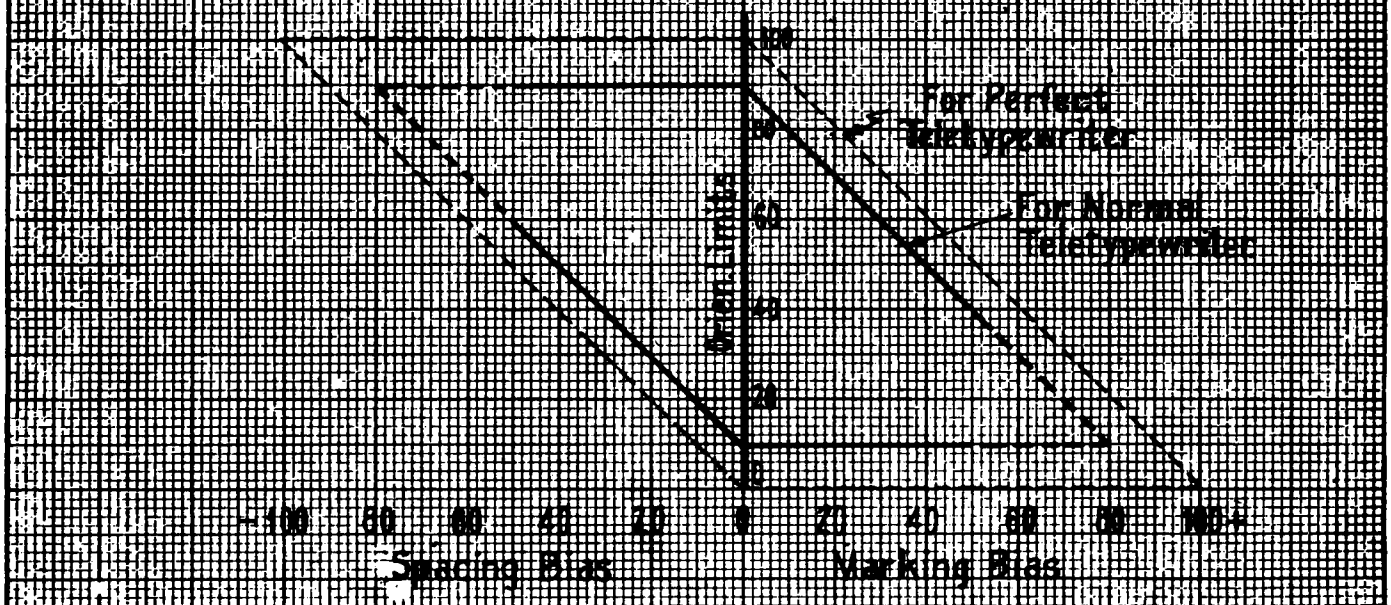

FIG. 1

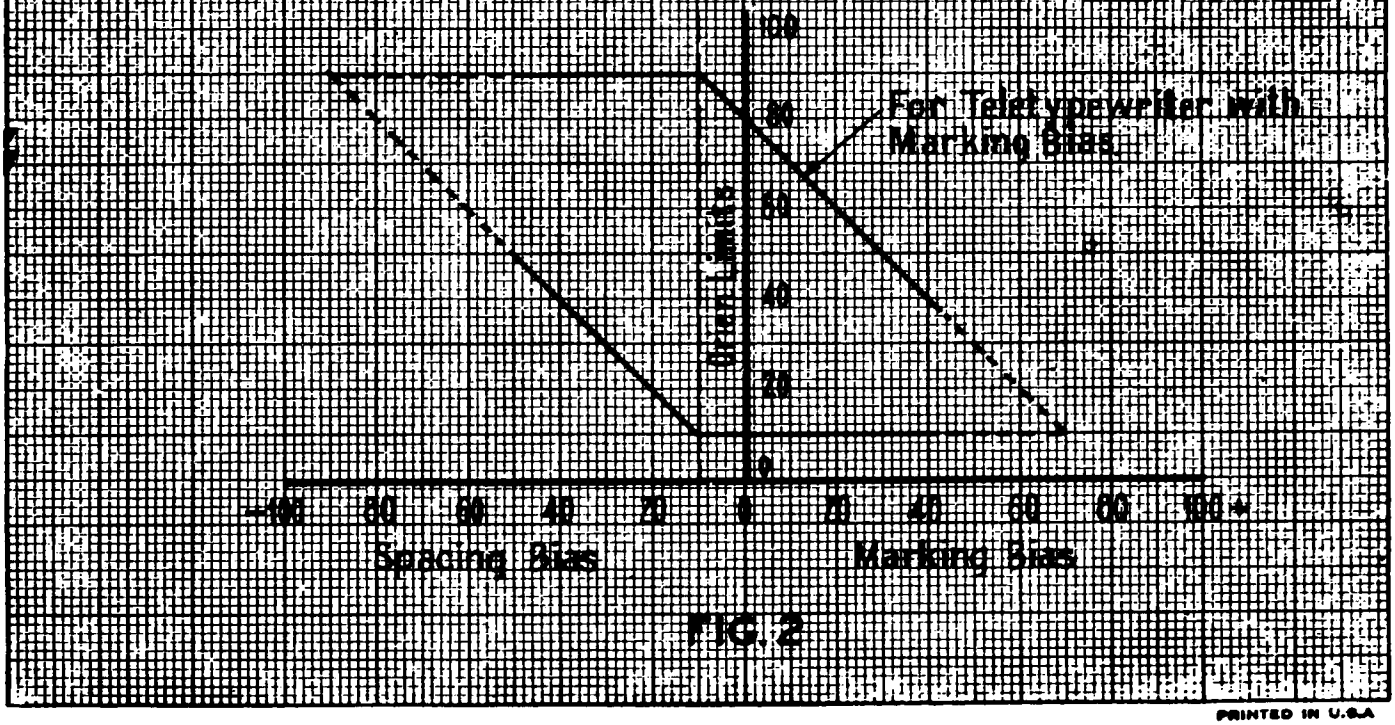

FIG. 2

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