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***for***  
**FACSIMILE**

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## FOREWORD

These test procedures are to bring up to date the IRE "Standards on Facsimile—Temporary Test Standards—1943" (43 IRE 9.S1). In part there has been new experience and technological advance since then. But it has also been noted that that document could, to advantage, be made more complete and cover a wider range of tests. An important objective has therefore been to make the new test procedures more comprehensive, to cover tests for determining most of the measurable quantities that were defined in IRE Standards on Facsimile: Definitions of Terms (56 IRE 9.S1, ASA C16.30-1957) now IEEE No. 168. The scope, in part, has been derived from facsimile equipment designed to operate over a telephone frequency bandwidth, but the tests are described in a general way, to make them utilizable over wider bandwidths as far as possible.

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# Test Procedure for FACSIMILE

## INTRODUCTION

Facsimile is defined as the process, or the result of the process, by which fixed graphic material including pictures or images is scanned and the information converted into signal waves which are used either locally or remotely to produce, in record form, a likeness (facsimile) of the subject copy.

The purpose of this Test Procedure is to specify uniform methods of measuring performance characteristics of facsimile systems. Underlying theory is generally omitted as this material is available from other sources, but a brief discussion is given of the principles involved for each measurement. Where possible the measurements call for the use of the IEEE Facsimile Test Chart, which provides a convenient high-quality testing tool. The CCITT has also developed a test chart which is in use in many countries throughout the world. The general measuring procedures are outlined here and the factors which affect the accuracy of the results are discussed along with methods of presenting the results. Not all of the tests described will be significant for all types of facsimile equipment. The user must select the tests which are relevant for the type of equipment used and the intended application.

The facsimile art differs from most others in that a permanent graphic record is made of each transmission. In part, for this reason, there has not always been great urgency to develop precise measuring methods. Even where an exact measuring procedure is available, in actual use the frequent technique is apt to be a mere examination and visual estimate of the final received copy. This is quite advantageous in regard to the time taken for the tests. It does suffer, of course, from not being as reproducible as an objective test.

In the procedures which are outlined herewith, there are occasions where it is deemed desirable to describe both procedures. A good illustration of this lies in the testing for Noise (section 3.4). The more usual test for this is by visual inspection of a picture—in a more specialized case, a flat “screen” transmission may be used. This is described. However, on occasion a more objective test, also described, is available using a meter. Not all observers will agree on the visual test, especially with the general picture, but the meter reading will be independent of the operator. Parallels to this situation occur often.

In order to make clear, where several possible

tests are described, which is to be considered the fundamental one, this has been designated “BASIC TEST.” In most cases this uses the most objective procedure. There are, however, a few situations where a more subjective test is so much more significant that it has been selected. The basic test is not necessarily the most common one used in the art, nor even the most desirable in any given case, for the same types of reasons that in physical measurements one only very rarely has recourse to a primary standard. Therefore, in order not to give a wrong impression, the term “preferred test” has been avoided. The order of presentation of alternative tests has been chosen for most apt description, and no effort has been made to place the basic test in any uniform location.

Throughout, the testing procedures have been based as far as possible upon the definitions for the quantities being measured, as set forth in the 1956 IRE standard, “IRE Standards on Facsimile: Definitions of Terms, 1956” (IEEE 168). However there are cases where the definition is so idealized that the measurement would not be significant. In such cases a practical interpretation has been given to the terms, to conform to current usage. A typical example of this occurs in the test for Maximum Modulating Frequency (1.5.3). In other cases it has been found desirable to extend the definitions, as in the tests for Scanner—Overlap and Underlap Y (2.2.1).

It is recognized that in some cases a concept can lose some of its exact significance and even become meaningless if the component quantities upon which the concept is based do not permit it or are too irregular. This is somewhat analogous to asking, “What is the width of the Atlantic Ocean?” In such cases the procedure has been selected and described in a fashion to be utilizable as far as, and sometimes even somewhat beyond, the point where the quantity being measured has physical meaning. However no tortuous efforts have been made to push a mathematical concept to an extreme logical end. An illustration is given in the test procedures for measuring Recorded Spot X Dimension (1.2.1.2.1).

The simplest complete facsimile system consists of a transmitter, a communications facility or path, and a receiver. There are many occasions where essentially the same property is to be tested in the three places. An example of this is for the Halftone Characteristics (1.4). In such cases it is desirable, when making a measurement, to state specifically where, in the whole

system, the input is considered to be, and where the measurement is being made. The units of measurement are necessarily different for the graphic material at the two ends and for the electric signal in the middle. These units therefore need in each case to be specified explicitly. Subsidiary cases of this problem occur when measuring either the transmitter or receiver, because the signal can undergo many electric transformations between the line and the graphic material.

The facsimile art is growing in many directions, such as toward use of wider frequency bands and toward use in satellite systems. An effort has been made to choose testing methods which are as general as possible so that they will remain applicable with advances in the state of the art. However, one must be resigned to the likelihood of cases where any given procedure can become obsolete for some newly developing system, and to the need for reviewing the testing methods from time to time.

## 1. EQUIPMENT SPECIFICATIONS

### 1.1 Dimensional and Speed Specification of Copy

#### 1.1.1 Scanning Line Length

If the scanner is of the rotating-drum type, the scanning line length is the circumference of the drum including the effect of thickness of copy.

**BASIC TEST:** If the scanning process is linear, that is, if the scanning spot speed is constant over the subject copy, the scanning line length may be measured by transmitting a portion of the IEEE test chart.

The receiver is de-phased so that the edges of the subject copy image appear in the middle of the record sheet. The reproduction of pattern 19 of the IEEE test chart, including its horizontal line, is observed, the point (a) at which the horizontal line starts just after the dead sector or clamp bar interval, is noted; as well as the point (b) at which the line ends, just before the dead sector (see Figure 1).

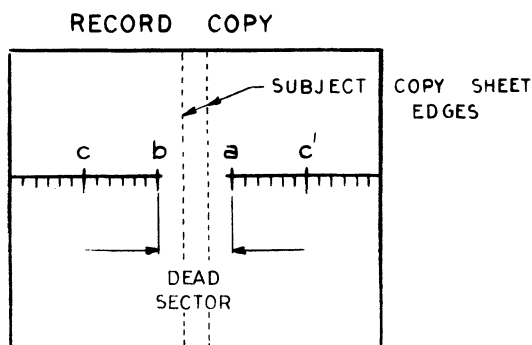


FIGURE 1

A third point (c) is marked on the line at a distance (a-b) back from (b) and its position on the line is noted (or a point (c') is marked a distance (a-b) forward from (a), and its position noted).

The points (a, b, and c or c') are transferred back to the chart being used as subject copy, as in Figure 2. Point (d) is marked on an extension of the line at a distance (c-b) beyond

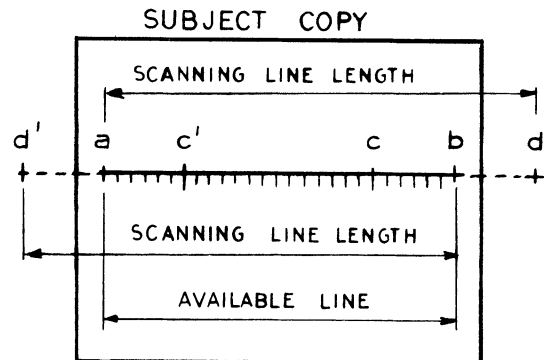


FIGURE 2

(b) (this may end off the sheet, which necessitates pasting an adjacent sheet). Or point (d') may be marked on an extension in the reverse direction, at a distance (a-c') ahead of (a). Then the distance (a-d), or (d'-b) on the subject copy is the scanning line length. If both points (d and d') are transferred, and (a-d) does not equal (d'-b), this is an indication of nonlinearity in the scanning.

**BASIC TEST:** For a measurement of the corresponding recorder line length, a second transmission is made, not de-phased. The points from the first recording are transferred to this second recording instead of to the subject copy. The distances (a-d) and (d'-b) will be the recording line length.

Where the scanning is not linear the scanning line length loses some of its meaning, but a scanning line duration may be obtained from a suitable time representation of the electric signal on a linear time base oscilloscope. The scanner is set up to scan the horizontal line of

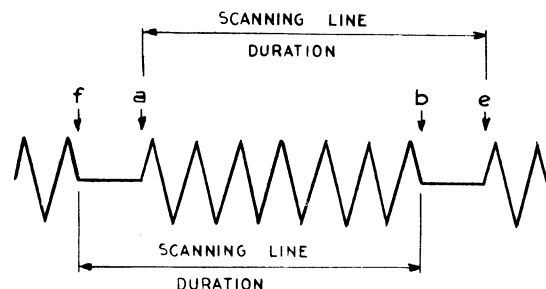


FIGURE 3

pattern 19 on the chart continuously. The amplitude-modulated signal appears as shown in Figure 3. The distance (a-e) or (f-b) is proportional to the scanning line duration. This measurement can be obtained from a calibration of the oscilloscope trace.

### 1.1.2 Available Line—Useful Line

#### 1.1.2.1 Scanner

**BASIC TEST:** The available line of the scanner may be measured by substantially the same process as the Scanning Line Length (see 1.1.1). The receiver is dephased so that the edges of the subject copy image appear in the middle of the record sheet (as in Figure 1). The reproduction of pattern 19 on the chart, including its horizontal line, is observed. The point at which the horizontal line starts just after the dead sector is noted, as well as the point at which the line ends, just before the dead sector.

These points (a) and (b) are transferred back to the chart being used as subject copy. The distance between them is the available line of the scanner (see Figure 2).

#### 1.1.2.2 Recorder

**BASIC TEST:** The available line of the recorder may be measured by recording a steady signal on the record sheet of the recorder in question. The measured length of the horizontal lines on the record sheet is the available line of the recorder.

**NOTE 1:** The actual useful copy width is the maximum width of copy which can be handled by a facsimile system. In a system which does not incorporate reduction or enlargement the shorter available line length (as limited by scanner or recorder) minus the phasing deviation and skew equals the actual useful copy width.

**NOTE 2:** The subject copy sheet width usually is larger than the useful copy width. In some equipments (i.e. clamp bar-drum type scanners), the sheet width dimension must be held to a fairly close tolerance while in others there is only a maximum width limitation.

### 1.1.3 Usable Length of Copy in Noncontinuous Components

There are two distinct quantities which this measurement covers:

(a) Maximum and minimum length of subject copy accepted by the scanner and record sheet by the recorder.

(b) Maximum length of intelligence on the subject copy, which can be scanned at the

transmitter; or on the record sheet, which can be recorded at the receiver.

**BASIC TEST (a):** The maximum and minimum lengths of subject copy and the maximum length of record sheet may be determined merely by placing sheets of these limiting dimensions into the machines, then measuring them.

In the simpler cases the maximum length of intelligence on the subject copy can be determined by placing a subject copy in the transmitter and noting the first and last points at which picture signals are produced, then measuring the distance between them on the subject copy.

Also, in the simpler cases the maximum length of intelligence on the record sheet may be determined by noting the first and last points at which picture signals can be recorded, then measuring the distance between them on the record sheet.

Where these operations are not feasible, or where the measurement is desired over a complete system, the following procedure may be used:

**BASIC TEST (b):** Place into the transmitter subject copy with message information extending to or beyond the expected scanning limits of the transmitter. Record a copy, examine it and note starting and ending limits of the recorded copy on the subject copy.

In certain cases it may be necessary to send the subject copy out of frame, at the top and again at the bottom, in order to distinguish the limitations imposed individually by the transmitter or the receiver. The specific method required to accomplish this will depend upon the individual system. The net length may be measured after transferring the critical points on the appropriate copy.

#### 1.1.4 Stroke Speed

The measurement of stroke speed takes on quite different aspects according to the use to be made of the results. For successful compatible operation, free of skew, the stroke speeds of scanner and recorder must match to quite a high degree of accuracy (see 1.7 Compatibility between Transmitter and Receiver, and 2.3.1 Skew, where an accuracy figure of 1 part in  $10^5$  is mentioned illustratively; and higher accuracy may be needed in more exacting applications).

In some systems the apparatus alone need meet only a nominal figure of stroke speed, and the exact speed during operation is set by some kind of transmitted signal. Such signals can be a line start pulse (as used in broadcast

television), or a single-frequency synchronizing wave which can be multiplexed on the picture signal or sent separately (a case of which is the use of a common 60-cycle-per-second power wave between sender and receiver), or other signals linking the two locations. In such cases the measurement of stroke speed on scanner and recorder separately need only be approximate, and within the tolerance range over which the equipment can be driven by the signal.

In other systems the scanner and recorder are driven by independent local clocks (or constant-frequency oscillators), and the two keep in step by virtue of the constancy of these oscillators.

If the speed at which a machine is designed to be driven is unknown, it can be tried with a variable-frequency oscillator drive to find the range of speeds at which it can respond. Or, if it can run free at its approximate design speed without its clock, this speed can be measured in the nominal fashion mentioned above.

However, scanners and recorders, each with and operated by their individual drive clocks, need to have their stroke speeds measured to a very much higher standard of accuracy if it is then expected that they will be shipped out to the field and made to work compatibly on the basis of the measurements. The accuracy that is required in this case then follows the usual principle that it must be illustratively something like an order of magnitude better than the performance requirement for the machines in operation.

Since the measurement is one of frequency it involves essentially a comparison of the unknown with a standard frequency. For some years a standard of frequency has been maintained by the National Bureau of Standards at Boulder, Colorado (USFS).<sup>1</sup> This has been broadcast by radio stations WWV (Greenbelt, Md.) and WWVH (Maui, Hawaii), also by WWVB and WWVL. Other reference standards are broadcast by NBA, NPG, NPM, NSS, and several other countries.

These are broadcast with high accuracy (in the case of WWV to something like 150 parts in  $10^{10}$ ) but reception is impaired by motions of reflecting layers of the ionosphere. Thus among other precautions it is necessary to select quiet periods for the ionosphere, when this motion is known to be small. Low-frequency stations transmitting at frequencies below about 25 kilocycles per second are generally free of doppler effect due to ionospheric shift.

The problem is under continuing study, and recommendations are subject to regularly announced notices by the National Bureau of

Standards in appropriate technical publications such as the Proceedings of the IEEE.<sup>2</sup>

Some commercial organizations manufacture equipment to make the comparison convenient.<sup>3</sup> Also in recent years commercial standard oscillators have become available whose frequencies are likely to be more stable than standard frequency transmissions received via the ionosphere.

There are essentially two types of measurement which can be made. One is a measurement of the frequency of the local facsimile oscillator which is used with the system. This is translated into the stroke speed, with a knowledge of the number of poles in the drive motor, the ratio of any gearing between the motor and scanner or recorder head, the number of scanner or recorder heads, and possibly other pertinent facts, according to the mechanism.

The other type of measurement is one of the time interval between successive scanning or recording strokes. This is the reciprocal of the stroke frequency or speed. For the accurate measurement of stroke frequency, this is in general the most convenient, and it is the recommended method. There are various possible procedures which can be used, depending upon the apparatus available and what part of the standard frequency signal is used.

Possibly the simplest, and the recommended, procedure is to use the pulse modulation of the standard, at one second (or other) intervals and record these on a facsimile receiver together with stroke indicating pulses from the apparatus under test.

An alternative is to use the continuous wave modulation of the standard signal and count cycles with an electronic counter, over intervals gated by stroke indicating pulses.

The applications to facsimile transmitters and receivers, respectively for tests, are described in somewhat more detail later.

#### 1.1.4.1 Scanning-Line Frequency

For a conventional rotary drum transmitter this is equal to the drum speed in revolutions per minute. It can therefore be measured by the use of a suitable tachometer on the drum shaft. In most cases this will have only sufficient accuracy for a nominal measurement as discussed in the preceding section.

It is also possible, again as mentioned in the preceding section (and where the operation is not start-stop), to determine the scanning-line frequency from the input drive frequency to the motor, with a knowledge of the number of pole pieces, gear geometry,

etc. The accuracy obtained here depends upon the accuracy with which the drive frequency is known or determined. General methods for measurement of such a frequency, in comparison with a standard, have been described in the literature,<sup>4, 5, 6</sup> and will not be repeated here.

**BASIC TEST:** Where the high accuracy is required, to apply the recommended method which uses standard one-second (or other) pulses, a receiver and its recorder are needed which can record the standard WWV or other signals. This would require a radio receiver giving a signal in the audio output which can be accepted by the facsimile receiver. On the transmitter scanner to be tested is placed subject copy with a single sharp line perpendicular to the scanning line (the scanner feed may also be disabled), and the output signal is superposed on that from the standard source.

With continued reception the record shows two or more lines crossing the scanning lines, one set of lines from the standard and another from the machine under test. For example, if the machine has 90 strokes per minute (and the recorder also) this would give  $1\frac{1}{2}$  strokes per WWV one-second pulse and that record would appear as two dotted lines. The deviation from parallelism between the standard lines and the test lines gives a measure of the scanner timing deviation from that of the standard.

The longer the duration of the record the higher can be the accuracy of measurement. For highest accuracy the recording and line feed processes of the receiver can be stopped after an initial recording, and resumed after a considerable length of time (for example an hour). This greatly enhances the displacement which results from lack of parallelism, and improves the ease and accuracy of measurement.

The detailed application of the test requires a numerical calculation of the significance of a lack of parallelism between the traces. This will naturally vary with the specific speeds and standard signals involved. But it is assumed that when the traces come out parallel, the stroke speed can be exactly determined from the standard signal used. The problem is then to compute, for the cases where the traces are not parallel, the numerical correction to this stroke speed, indicated by a measured departure from parallelism. In a general way it can be said that with

$M$  = scanning lines per minute

$N$  = standard timing pulses per minute

and, if the relationship holds that

$$m/M = n/N \quad (1)$$

where  $m$  and  $n$  are the smallest integers for which this holds, then the timing signal produces a pattern of  $n$  dotted lines on the record sheet, the dots being  $m$  scanning lines apart.

The pattern appearance is subjective, and it will appear to the eye as described, only if  $m$  and  $n$  are small. If the actual ratio of  $M$  to  $N$  differs only slightly from such a simple case, the simple pattern will still show, but it will be skewed. The skewed pattern can be exactly represented by

$$(m + e)/(M + u) = n/N \quad (2)$$

Here the small change in  $M$  from the simple case is expressed by  $M + u$ , and the corresponding small change in  $m$  to maintain the equality is expressed by  $m + e$ . For the subjective impression to remain  $u$  must be small compared to  $M$ , and  $e$  must be significantly smaller than  $\frac{1}{2}$ .

From equation (2) the quantity  $u$ , which is the departure of the scanning line frequency from  $M$  (that gives the simple non-skewed pattern) is

$$u = (mN - Mn + eN)/n \quad (3)$$

From equation (1)  $mN = Mn$

$$\text{Thus } u = eN/n \quad (4)$$

The quantity  $e$  may be measured from the relative slope  $S$  of the timing pulse record with respect to the record of the signal from the scanner under test. From this  $e$  is computed as

$$e = SmW/L \quad (5)$$

where  $W$  = nominal scanning line width (see 1.2.2)

$L$  = scanning line length (see 1.1.1)

From these one obtains the frequency departure  $u$  as

$$u = SN (m/n) (W/L) \quad (6)$$

An illustrative case (noted several paragraphs previously) is shown in Figure 4. The records of the scanner signal  $A$  and timing signal  $B$  are for the case where

$M$  = 90 lines per minute (scanner and recorder)

$N$  = 60 pulses per minute

$m$  = 3

$n$  = 2

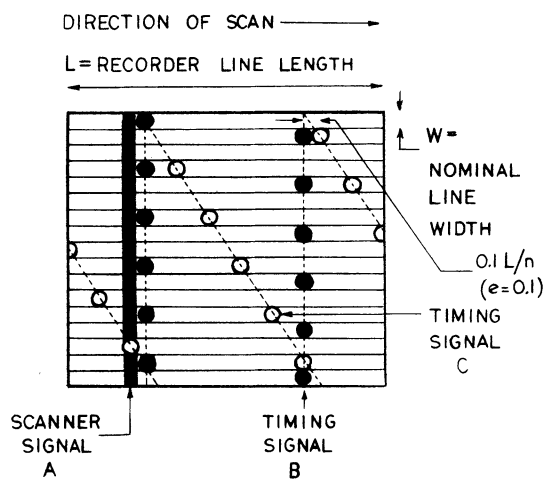


FIGURE 4

Here the scanner signal records as a single solid line perpendicular to the scanning lines. The timing pulses record as two dotted lines with the dots coming every 3 scanning lines. The dotted lines are parallel to the solid line, namely  $e = 0$ , and  $M$  is exactly 90 lines per minute.

The case is also shown where the timing signal  $C$  (in hollow dots) forms lines which are slanted with respect to the scanner signal. The case illustrated shows a relative slope of  $\frac{1}{2}$  scanning line length per 15 scanning line widths, namely

$$S = (1/30)(L/W) \quad (7)$$

In this case, from equation (5)

$$e = 1/30 (L/W)(3)(W/L) = 1/10 \quad (8)$$

In this case, from equation (6), the frequency difference  $u$  (from  $M$ ) is

$$u = 1/30 (L/W)(60)(3/2)(W/L) = 3 \text{ lines per minute} \quad (9)$$

This illustration then shows the scanner (and also the recorder) operating at 93 lines per minute, as measured from a timing pulse of one per second (or 60 per minute). If the recorder operated at another speed than the 93 lines per minute of the scanner, both sets of lines  $A$  and  $C$  would be slanted somewhat differently, but the relative slope  $S$  between  $A$  and  $C$  would remain the same.

The alternative procedure which has been mentioned may be applied by using the same subject copy described above for the transmitter under test, and arranging for the successive output pulses (one stroke duration apart) alternatively to open and close

a gate. The standard frequency signal cycles go through the gate, and a counter counts their number passing through, to measure the stroke duration. Repeated operation can give an average figure, with higher accuracy than the single test. Commercial apparatus is available for this operation.

#### 1.1.4.2 Recording-Line Frequency

For a drum-type or helix-type machine, this can be measured with a tachometer as in the case of the scanner. For a multistyle belt-type recorder a tachometer on the drive pulley shaft will give a reading which may be multiplied by the ratio of the circumference of the pulley to the scanning line length to determine the recording-line frequency. In most motor-driven recorders the frequency of the motor power input may also be used to determine the Recording-Line Frequency as in 1.1.4.1 Scanning-Line Frequency.

**BASIC TEST:** Where high accuracy is required, the recommended method using standard one-second (or other) pulses can be applied much as described previously for the transmitter scanner. With the recorder under test separate from the one on which the pulses are being recorded, it is necessary to obtain from it in some way a sharp pulse marking each stroke. If no simpler arrangement is available, this can be accomplished by using a transmitter locked with the receiver under test. The transmitter scans a single line copy as if it were itself under test, and puts out the desired signal. The record of this signal pulse, superimposed on the standard signal pulse, is obtained and the stroke timing compared with the standard in the same way as for the transmitter scanner test.

As an alternative the test can be simplified by using the recorder to be tested for recording the signals. In this case it is not always necessary to use a separate signal pulse from the recorder. Instead the parallelism of the line from the standard pulse may be measured to the edge of the sheet.

The further alternative using the counter requires a signal pulse per stroke from the recorder under test, successively to open and close a gate as in the test for the transmitter scanner. The stroke duration is again measured by the number of standard frequency cycles passing through the gate.

#### 1.1.5 Spot Speed

The spot speed, assuming linear scanning, is equal to the total scanning line length (see section 1.1.1) multiplied by the stroke speed

(see section 1.1.4). Since the spot speed is usually measured in linear units per second, and the stroke speed in strokes per minute the figure obtained must in general be divided by 60.

#### 1.1.6 Reproduction Speed

Reproduction speed is a measure of the rate at which a facsimile system will reproduce an area of subject copy.

If the useful line length, stroke speed and number of scanning lines per unit length are known, the reproduction speed may be obtained by multiplying useful line length by stroke speed and dividing by lines per unit length. This will provide a figure for the area recorded per unit time.

**BASIC TEST:** An alternative direct measurement (when these figures are not immediately available) is to determine by stop watch, or other means, the time to record a length of copy. Measure the area (on the subject copy) of the amount of material actually recorded. Dividing the measured area by the recording time provides the reproduction speed. This should obviously agree, to the order of accuracy of the figures, with the computation in the previous paragraph.

It is also possible to base reproduction speed on the area of recorded copy. This will vary from that based on subject copy where there is either enlargement or reduction in the process. Where figures are given they should state the basis to which they refer.

### 1.2 Fine Structure of Copy

#### 1.2.1 Spot Dimensions

Neither a scanning nor a recorded spot is likely to be a sharply defined figure of uniform illumination or density. Consequently it is necessary to provide a definition that in some way averages the uneven or irregular nature of the spot to give a sharp specific dimension that can characterize its size.

There are two criteria that have been used to formulate the sharp dimension. One of these is related to the signal spectrum and effective resolving power of the spot, and this is described in section 1.2.1.1.1 and used in several other sections. It is specifically used where the resolving power of the spot is of particular importance in the test.

The second criterion is related to the reproduction of a flat field in the recorded copy, in areas where the subject copy shows a flat field. This is described in section 1.2.1.2.1, and also used in several other sections. It is used particularly where the tests involve dimensions which are critical in determining the presence

of scanning line structure in the recorded copy. Thus there is generally no conflict between the uses of the two criteria.

The two criteria are not usually the same, but lead generally to figures which approach each other as the spot configurations become more perfect and well-defined.

#### 1.2.1.1 Scanning Spot

##### 1.2.1.1.1 X Dimension

There are two concepts involved in the dimensions. One of these is the purely geometrical concept. Where the spot has sharp boundaries, a given geometrical dimension can be measured directly, say with a microscope. The second concept involves the electric characteristics together with the geometric spot. For example, a given scanning spot may have a very small geometric X dimension (along the scanning line). But if the scanning process is dominated by a narrow pass-band filter, the *effective* spot size may be conceived of as broadened by the action of the filter.

The combined concept is that used in the 1956 Definitions of Terms, in linking the definitions of maximum keying frequency and scanning spot X dimension. (*Maximum Keying Frequency:* The frequency in cycles per second numerically equal to the Spot Speed divided by twice the Scanning Spot X Dimension. *Scanning Spot X Dimension:* The effective scanning spot dimension measured in the direction of the scanning line on the Subject Copy.) The definitions do not, however, give a precise meaning for "effective." It is necessary, in addition, when using the combined concept, to state where in the system, with respect to band-limiting filters, the electric signal is being taken.

As noted there is a close correlation between what can be characterized as the "effective" scanning spot size and the frequency band of the generated signal. Thus, the criterion used for "effectiveness" must be one that, as far as reasonably possible, establishes equality both of resolution capability in the spot and spectral distribution in the signal over a variety of configurations in the spot and in the signal band.<sup>7</sup>

A simple spectral distribution in the signal baseband consists of equal component magnitudes, with no phase distortion, from zero frequency up to a cutoff frequency  $F$ , as illustrated in Figure 5 at

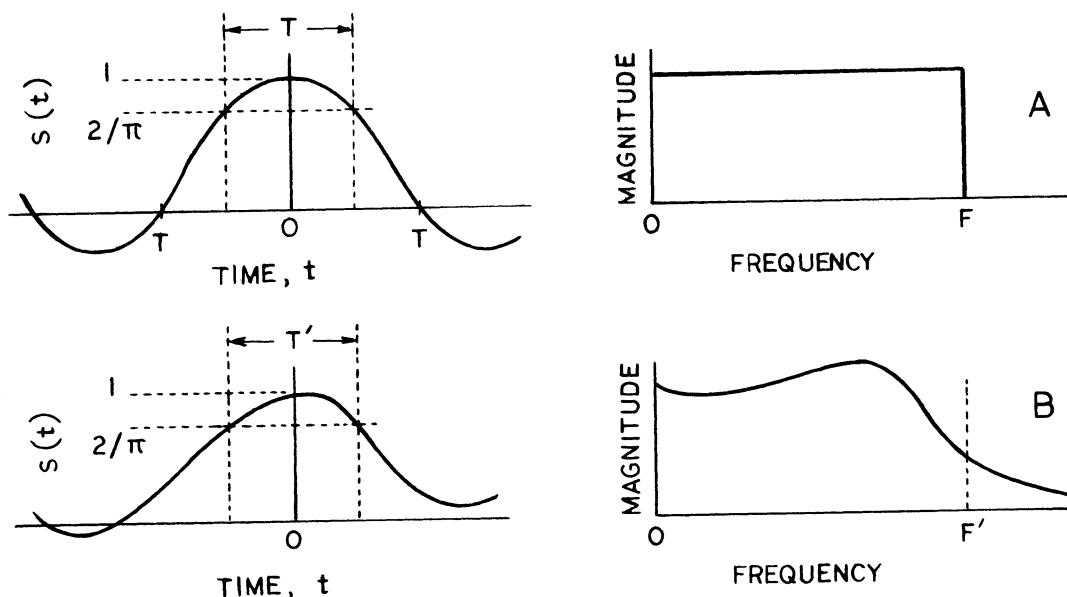


FIGURE 5

A, with zero magnitude beyond  $F$ . As indicated by Nyquist,<sup>8</sup> this transforms to a signal which goes to zero magnitude at  $-T$  and  $T$  (and also at integral odd multiples of these), where  $T = 1/(2F)$ , and where

$$S = [1/(2\pi tF)] \sin(2\pi tF) \quad (10)$$

Here

$S$  = normalized signal voltage (or current)

$t$  = time, in same units as  $T$  (or  $1/F$ )

The time  $T$  is called the "Nyquist interval." Within a Nyquist interval element centered on zero time, the useful signal extends from  $-T/2$  to  $T/2$ . At zero time itself,  $S = 1$ . At the edges of the Nyquist interval element,  $t = \pm 1/(4F)$ , and

$$S = (2/\pi) \sin(\pi/2) = 2/\pi \quad (11)$$

A criterion of the resolving capabilities of the spot must lie in the signal configuration near zero, say in the Nyquist interval element centered about zero. A simple quantitative measure of this configuration is the drop in magnitude from the center to the edges of the Nyquist interval, namely to  $2/\pi$  of the peak.

Then if one has an arbitrary spot which leads to a signal as illustrated at B in Figure 5 (for some specific modulation arrangements, the negative portion of the signal may be folded up above the zero

line), a criterion of its resolving capabilities can be taken as indicated by the time  $T'$  measured between the points at which the drop in voltage (or current) is to  $2/\pi$  times the peak value. It is clear, of course, that if the spot is too irregular, or distorted, the idea of equivalence in resolving capabilities becomes meaningless.

If then  $T'$  is taken as the "effective" Nyquist interval, half the reciprocal, or  $F' = 1/(2T')$  can be considered as the "effective" frequency band of the spectrum that transforms to the arbitrary spot configuration. This is illustrated at the left of Figure 5 B.

The above procedure is a sensitive method, therefore, of measuring the effective frequency band where the cutoff is not sharp. It is also a basis for defining the scanning spot  $X$  dimension.

**BASIC TEST:** The subject copy is taken as a fine line of known width across the direction of scanning. The electric signal is measured at the point which has been chosen in the system. If the signal is amplitude modulated, its instantaneous magnitude (or instantaneous carrier amplitude) is measured, say on an oscillograph. If it is frequency modulated, the instantaneous frequency can be converted into an instantaneous magnitude by a discriminator which is so chosen, for the measurement, as not to introduce signal distortion. For other types of modulation suitable arrangements may be devised.

On the oscillograph the points are

noted, on each side of the peak, at which the signal drops to  $2/\pi$  of the peak value (measured to the steady background signal as a reference zero). The distance between the points, translated to the value on the subject copy itself, is taken as the provisional Scanning Spot  $X$  Dimension.

The exact broadening effect of the subject copy line width is complicated. However, when it is small it adds approximately in quadrature to the spot dimension.<sup>9</sup> Thus the corrected spot  $X$  dimension is

$$X = \sqrt{x^2 + w^2} \quad (12)$$

where  $X$  = corrected spot dimension

$x$  = provisional spot dimension

$w$  = subject copy line width

If one desires to use the pure geometric concept for measuring the  $X$  dimension, and the spot edges happen to be diffuse, the same technique can be used, except that the electrical point chosen in the system must be one prior to any filtering (this provided that the photocell transducer itself is not limiting the band).

There are alternatives in procedure that may be used in special cases where convenient.

(*Alternative a*) Frequently, the pass band of the facsimile transmitter is sufficiently wide not to be the limiting factor in the transmission of the facsimile signals. Under such circumstances, and where the actual physical aperture is sharp, and is projected sharply on the subject copy, purely geometric measurements may be made. For example, the actual aperture used to form the scanning spot

can be calculated using the lens formula:

$$X = vU/u \quad (13)$$

where  $X$  = spot dimension

$u$  = lens to aperture distance

$v$  = lens to subject copy distance

$U$  = aperture dimension

$F$  = focal length of projection lens

and where,

$$\frac{1}{F} = \frac{1}{u} + \frac{1}{v},$$

or finally

$$X = U \left( \frac{v}{F} - 1 \right) \quad (14)$$

Here  $u$  and  $v$ , in a thick or compound lens, are measured to the appropriate principal planes.

(*Alternative b*) The geometric measurement may also be made by perpendicularly scanning very slowly a narrow line of known width, and by measuring both the displacement of the scanning spot with respect to the subject copy line and the carrier amplitude of the signal emitted by the transmitter. A gauge may be mounted on the device used to move the line and the distance moved measured in thousandths or even ten-thousandths of an inch (or hundredths or thousandths of a millimeter). The actual measurement consists of a series of static readings of displacement and amplitude. The scanning spot  $X$  dimension may be found from a plot of the readings as in Figure 6. If the aperture is round, the

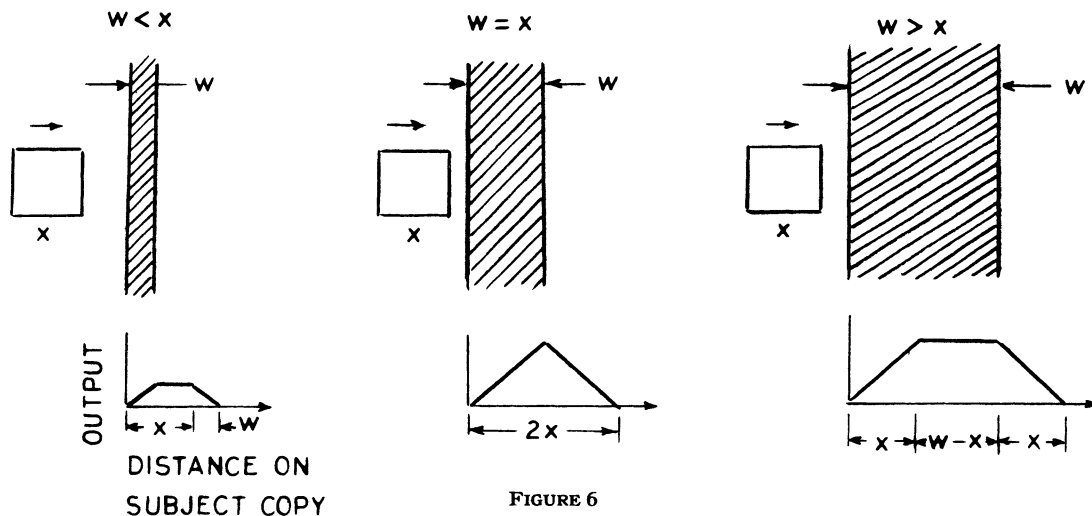


FIGURE 6

amplitude rise will not be linear but will approach maximum and minimum values of the amplitude tangentially, making it necessary to estimate where the curves reach maximum and zero. Figure 7 shows

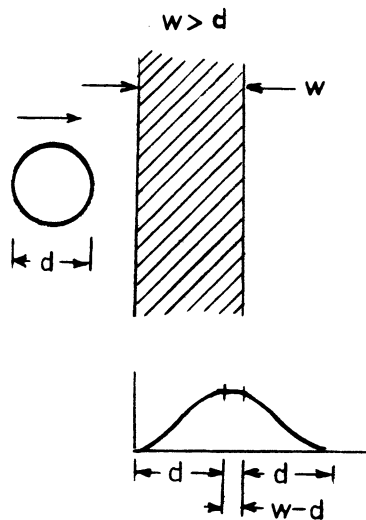


FIGURE 7

the value for the diameter  $d$ . The effective scanning spot  $X$  dimension will be somewhat less than  $d$  (for a sharp aperture it will be  $d\sqrt{1-(2/\pi)^2} = 0.771d$ ). It can be measured directly from the  $2/\pi$  points in Figure 7 by subtracting  $w$  in quadrature (as in equation (12)) from this separation.

(Alternative c) A special technique may be used for sharp rectangular apertures in which alternate black and white lines are scanned rapidly or slowly. If the width of these black lines and white lines are each equal to one half the scanning spot  $X$  dimension, the output will be a constant (Figure 8). Pattern 13 of the IEEE Test Chart may be used. The technique is actually usable for other spot shapes if they are not too irregular.

#### 1.2.1.1.2 Y Dimension

In this dimension (perpendicular to the direction of scanning) the geometrical and combined concepts in general agree. This is because it would take a very special type of electric comb filter (and one not likely to be used) to influence the scanning process in this respect.

**BASIC TEST:** The general method of measuring the  $Y$  dimension consists in scanning a subject copy containing a fine line of known width  $w$ , at a very small

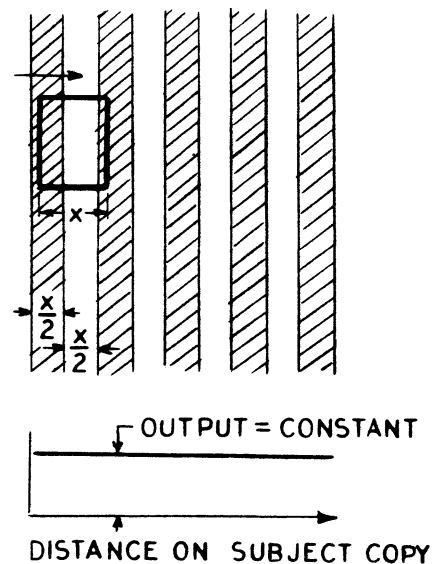


FIGURE 8

angle to the scanning lines, so that it crosses only a very few scanning lines in the entire length (not just available length) of the scanning lines. The exact number of the scanning lines spanned is measured from the jogs appearing in the recorded copy, (with an allowance to extrapolate from the available lines to the entire lines), and is called  $m$ . Then as the spot advances along the  $x$  direction of the copy, it samples the fine line at different parts of its own  $y$  coordinate (see A of Figure 9). Thus the output, viewed in an oscilloscope or oscillograph, will be as at B of Figure 9. The output may

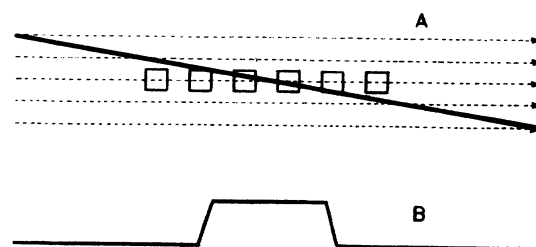


FIGURE 9

be repeated by disabling the scanner motion in the  $y$  direction. This output is entirely analogous to Figure 6, and correction may be made to the reading for the width of the subject copy line in exactly the same way, namely by subtracting  $w$  in quadrature (as in equation (12)), from the separation of the  $2/\pi$  points.

It is necessary, however, to convert the time dimension  $t$  on the oscilloscope into a  $y$  coordinate. The  $y$  coordinate is

$$y = tmFA \quad (15)$$

where  $F$  = scanning line frequency (see 1.1.4.1)

$A$  = nominal line width (see 1.2.2)

The various alternatives in 1.2.1.1.1 may also be adapted to measuring the  $Y$  dimension.

#### 1.2.1.2 Recorded Spot

##### 1.2.1.2.1 $X$ Dimension

The recorded spots are apt to be irregular in density, shape, or size, or sometimes to be made up of a cluster of smaller spots. Nevertheless the  $X$  dimension has been defined in the 1956 Definitions of Terms as the largest center-to-center spacing between recorded spots which gives minimum peak-to-peak variation of density of the recorded line.

**BASIC TEST:** It can be measured by feeding the recorder with a signal of the type schematically indicated on line A of Figure 10. It consists of short pulses

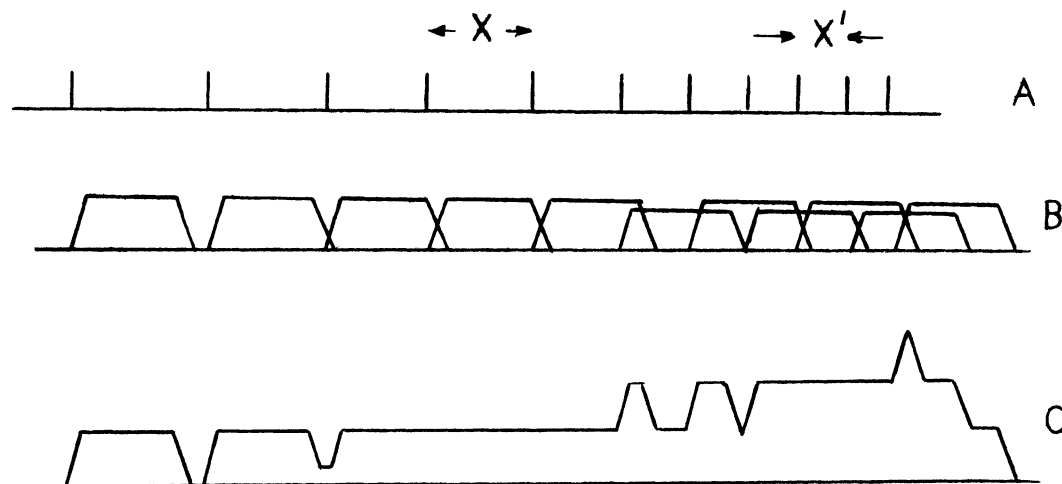


FIGURE 10

(short, that is, compared with the order of the expected  $X$  dimension) emitted at gradually decreasing intervals. Basically it can be obtained from a pulse generator arranged for a gradual variation of the pulse repetition frequency.

It is understood that in practice the signal would be modulated to fit the modulated signal used by the recorder. The simplest results are obtained by inserting the signal at baseband at the point in the recorder where the normal signal is also at baseband, but this may not always be possible, and some other arrangement needed.

The individual recorded spots are schematically indicated in line B. The individual spots cumulate to the final recording in line C. This shows variations of density along the scanning line which reach a minimum at the two pulse spacings  $X$  and  $X'$ . The spacing  $X$ , being the larger, gives the recorded spot  $X$  dimension, after translation from the signal time

scale to the distance scale along the record copy.

It is clear that this procedure will not work with all modulation and demodulation systems, and indeed that the definition itself of the dimension is not meaningful for all such systems. This is indicated by Note 2 to the definition, which limits it to equipment giving a succession of discrete record spots in response to a constant density in the subject copy. The test which has been described has a somewhat larger range of validity than expressed in the note, but it can break down for example where the spot is too irregular. The variety of possibilities, however, is too great to warrant a detailed analysis.

Precautions must be observed when the measurements are influenced by special characteristics of the receiver. For example the size and possibly the configuration of the recorded spot may change with intensity of recording. Generally, the recording spot gets larger as the in-