

PICTURE TRANSMISSION RELATIONSHIP BETWEEN QUALITY, BANDWIDTH, AND TIME OF TRANSMISSION

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1. GENERAL

1.01 This practice provides fundamental background information for the engineering of closed circuit television circuits, including slow-scan systems. The relationships between picture resolution, bandwidth, and the time required to transmit a single picture are given.

1.02 The transmission of pictures in which motion is portrayed requires a very wide bandwidth, because of the necessity for transmitting many pictures in succession in a short time, each one differing only slightly from the preceding one. On the other hand, if a still picture is to be transmitted, the bandwidth may be very much less, providing the necessary time can be taken to transmit the various components of the picture. For some services a second or even several seconds might be used for transmission of a single picture and still effectively satisfy the viewer's needs.

1.03 An analysis of inquiries received by Operating Telephone Companies for closed circuit TV systems has shown that in many cases a less expensive system than the present 525 line U.S. Standard monochrome television system would meet requirements.

1.04 TV systems that employ fewer lines than the present 525 line RETMA standard, can be utilized to transmit intelligible information.

In general, a loss in sharpness and detail must be accepted. Efficient use of the scanned areas coupled with careful arrangement of the material to be transmitted, can overcome to a marked degree the shortcomings of the systems. If the demand is for very fast transmission and enough detail to handle a full page of single spaced pica typing, the present 525 line standard is adequate, with little margin, when properly used. If on the other hand a smaller amount of detail is handled per image or picture and this is coupled with a longer permissible frame time, slow-scan systems may be tailored to fit the needs of a large part of industry and enable transmission to be effected over circuits having much narrower bands than present broadcast TV circuits.

2. TRANSMISSION CONSIDERATIONS

2.01 Bandwidth, picture quality and transmission time (or frame period) are related quantities in a television system. The selection of two of these quantities leaves the third dependent. For instance, if picture quality and frame period are specified, the bandwidth is determined. The present monochrome systems specifies a picture of 525-line quality and a frame period of 1/30 second, and with these quantities specified, it can be shown that a bandwidth of about 4 mc will be needed. A mathematical derivation of this relationship is given in Part 4 of this practice. From the equations in Part 4, Tables I and II have been computed assuming base band transmission, and give the time necessary for the transmission of one picture over circuits having very good amplitude and phase responses from near zero frequency up through the pass band. If amplitude and phase responses are not held within close tolerances, then only a fraction of the band can be used and the time of transmission of one picture would be increased accordingly.

2.02 As regards the optimum picture quality attainable, the footnotes to Table I are indicative of what may be achieved. Table II indi-

cates that over short circuits a square picture having present broadcast television quality can be transmitted in about 21 seconds over a 5 kc phase and amplitude equalized circuit. If the quality is reduced to 200 lines per frame height, the picture can be transmitted in about 3 seconds.

2.03 Tables I and II have been computed on basis that horizontal and vertical resolution are equal. In a television system, however, this is seldom the case and horizontal and vertical resolution vary independently of one another. Vertical resolution is a function of the number of lines while horizontal resolution is a function of bandwidth. Distortions such as "pairing,"* therefore, adversely affect vertical resolution. Distortions affecting horizontal resolution are associated with bandwidth distortions and include line transmission distortions. Envelope delay, ringing, and other distortions associated with line transmission affect horizontal resolution only.

2.04 The product of horizontal and vertical resolutions approximates the number of picture elements in a picture. If this number remains constant, the fact that horizontal and vertical picture resolutions vary widely has been shown to have little noticeable effect on resolution.

2.05 It should be recognized that there are a number of factors in addition to resolution which affect an observer's opinion of televised picture material. These include brightness, contrast, flicker, aspect ratio, picture size, and shading. Further transmission distortions such as, streaking or ringing may nullify excellent resolution capabilities of a system. Because of these other facts the calculated performance of a system based on its resolution capabilities will not necessarily represent the subjective opinion of an observer as to its "picture quality."

2.06 Although many circuits, particularly program circuits, are well equalized for amplitude response down to sufficiently low frequencies that the amplitude factor is adequate for baseband picture transmission, none of our intercity program circuits have the required amount of phase equalization at low frequencies. Hence the figures given can be fully realized only on physically short circuits on which no transformers or

amplifiers are needed, and the amplitude equalization on such circuits must be of the type that does not adversely effect the low-frequency phase linearity.

2.07 On longer circuits requiring amplification, the phase equalization at extremely low frequencies is rather difficult to accomplish, and experience with telephoto and facsimile transmission has led to the use of carrier transmission and the inversion of the frequency band. If, for example, the baseband is inverted and a vestigial side band system is used with the line frequency near the upper edge of the band the necessary phase equalization may be accomplished more easily for the important frequency components in the signal. In such instances, however, the effective bandwidth in the terms used in the tables attached is reduced by a fraction of 0.7 — 0.8 or the time of transmission of a picture is increased from 1.2 to 1.4 times the values given. If a carrier in the middle of the available band is used together with double side band transmission, the time periods given in Tables I and II should be multiplied by two.

2.08 In the cases of telephoto and facsimile transmission over specially equalized long circuits, the carrier might, for example, be placed at approximately 2400 cps with a lower side band extending to about 1200 cps and a vestigial upper side band extending to about 2600 cps. In terms of the bandwidths given in Tables I and II this transmission is effectively 1000-cycle bandwidth transmission out of a 3000 cycle band. If similar methods were used for the other bandwidths listed in the first column, the times of transmission would be multiplied by a factor of 3.

2.09 Telephoto and facsimile transmission were developed to secure use of the best part of the voice band from the amplitude and phase standpoint for transmission, and also to avoid Kendall effect. This is the effect obtained when unwanted demodulation occurs due to the passage of the signal through nonlinear transmission elements, and this unwanted demodulation mixes with the wanted carrier signals at the detection point to produce further error products which degrade the quality of the detected signal.

2.10 Fig. 1 illustrates the Kendall effect in a double sideband carrier transmission system. At (a) is shown the carrier, and at (b) the

* "Pairing" is partial or complete failure of interlace in which the scanning lines of alternate fields do not fall exactly between one another but tend to fall (in pairs) one on top of the other.

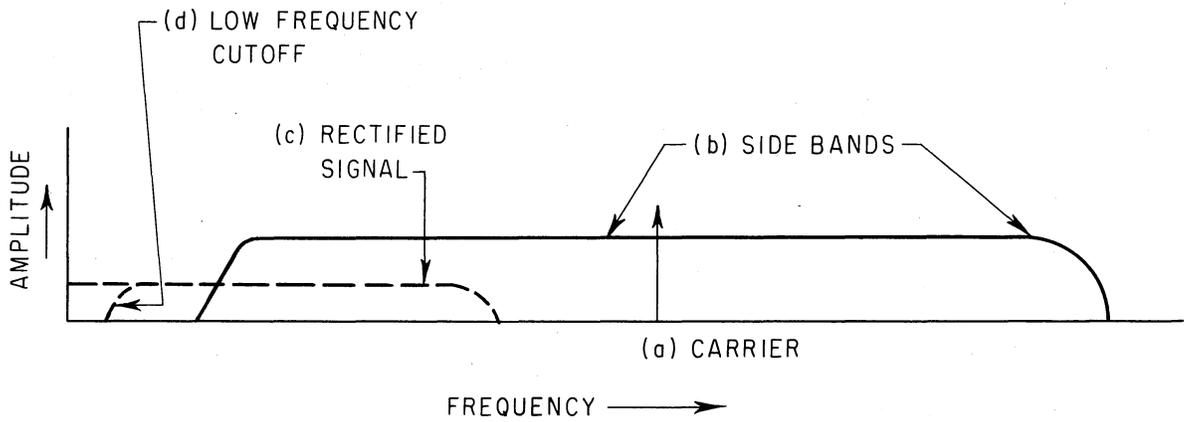


Fig. 1

EFFECT OF NONLINEARITY IN CARRIER SYSTEM

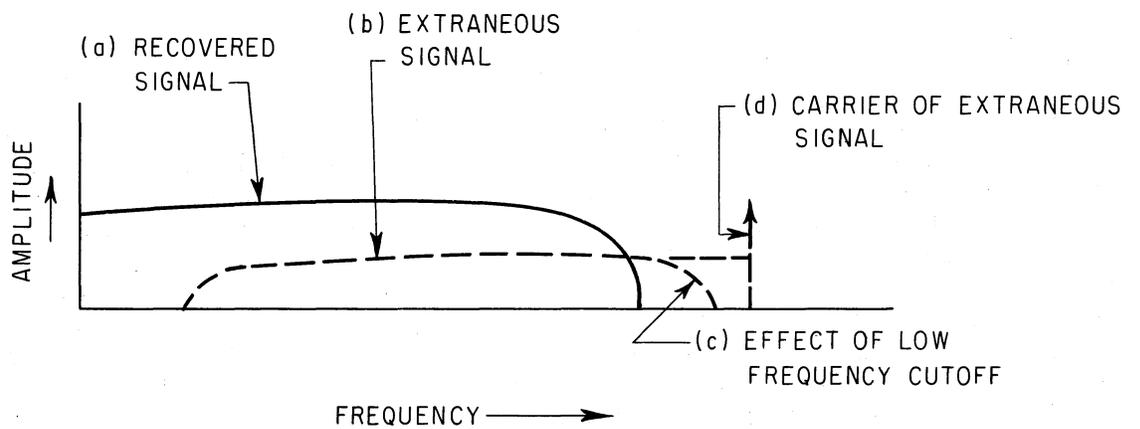


Fig. 2

RECEIVED SIGNAL IN NONLINEAR CARRIER SYSTEM

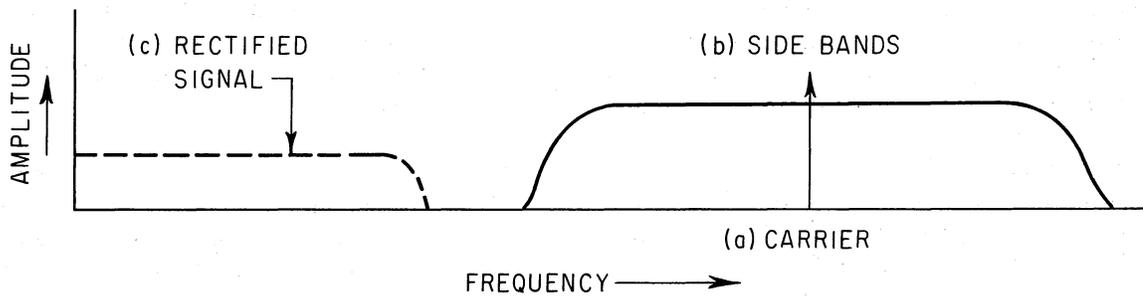


Fig. 3

FREQUENCY ALLOCATION TO AVOID RECTIFIED SIGNAL PATTERN

side bands. If the system is nonlinear, a partial rectification of the signal may be obtained. This rectification generates a small amplitude copy of the original video signal. This rectified signal is illustrated by the dotted band (c) in Fig. 1. It is transmitted along with the normal signal (from which it can not now be separated) through the remainder of the transmission path. The lower frequency end of the dotted band is usually cut off in the remainder of this path as indicated at (d). The ultimate recovered video signal is illustrated in Fig. 2. The two side bands are recovered as a video signal band (a). The extraneous rectified signal is recovered (b) as a duplicate, more or less of the original image but modulating a carrier (d) instead of direct current. The effect of the low-frequency cutoff is to suppress the portion of the band immediately near the carrier, as at (c).

2.11 In at least its simpler aspects, Kendall effect can be prevented by an allocation of frequency bands somewhat as shown in Fig. 3 such that there is margin left between the lower side band of the carrier signal and the band occupied by the extraneous rectified signal. In the case of facsimile and telephoto transmission the unwanted demodulation products fall in the range 0 to 1000 cycles and thus can be eliminated from the final detection by filtering. If they overlapped the wanted components, such as, for example, if the carrier were at 1000 cps and the vestigial band extended downward to 500 cps, they could not be filtered out without also removing important wanted components. Kendall effect is an important source of degradation on long distance circuits on which the signals pass through many amplifiers and thus accumulate large amplitudes of unwanted products before detection, and on shorter circuits when equipment is not adequately maintained.

2.12 Because of Kendall effect the evaluation of engineering tolerances upon the modulation characteristics of systems in which the bands overlap substantially is an exceedingly complex matter. In general, the tolerances upon the second and third harmonics run in the order of 60 to 70 db with respect to the fundamental. This compares with the tolerance for video circuits and a similar figure, of the order of 30 to 40 db, for cases where there is a good margin against overlap.

2.13 In review, for very short circuits, phase and amplitude equalized, the figures in Tables I and II can be realized while for longer circuits requiring amplification in addition to phase and amplitude equalizers, low-frequency phase equalization is very difficult to achieve and in general carrier methods should be employed. This effectively multiplies the figures in the tables by factors from 1.2 to 3 depending on the particular method used, and the conservatism employed in the system design.

3. ILLUSTRATIONS OF PICTURE QUALITY

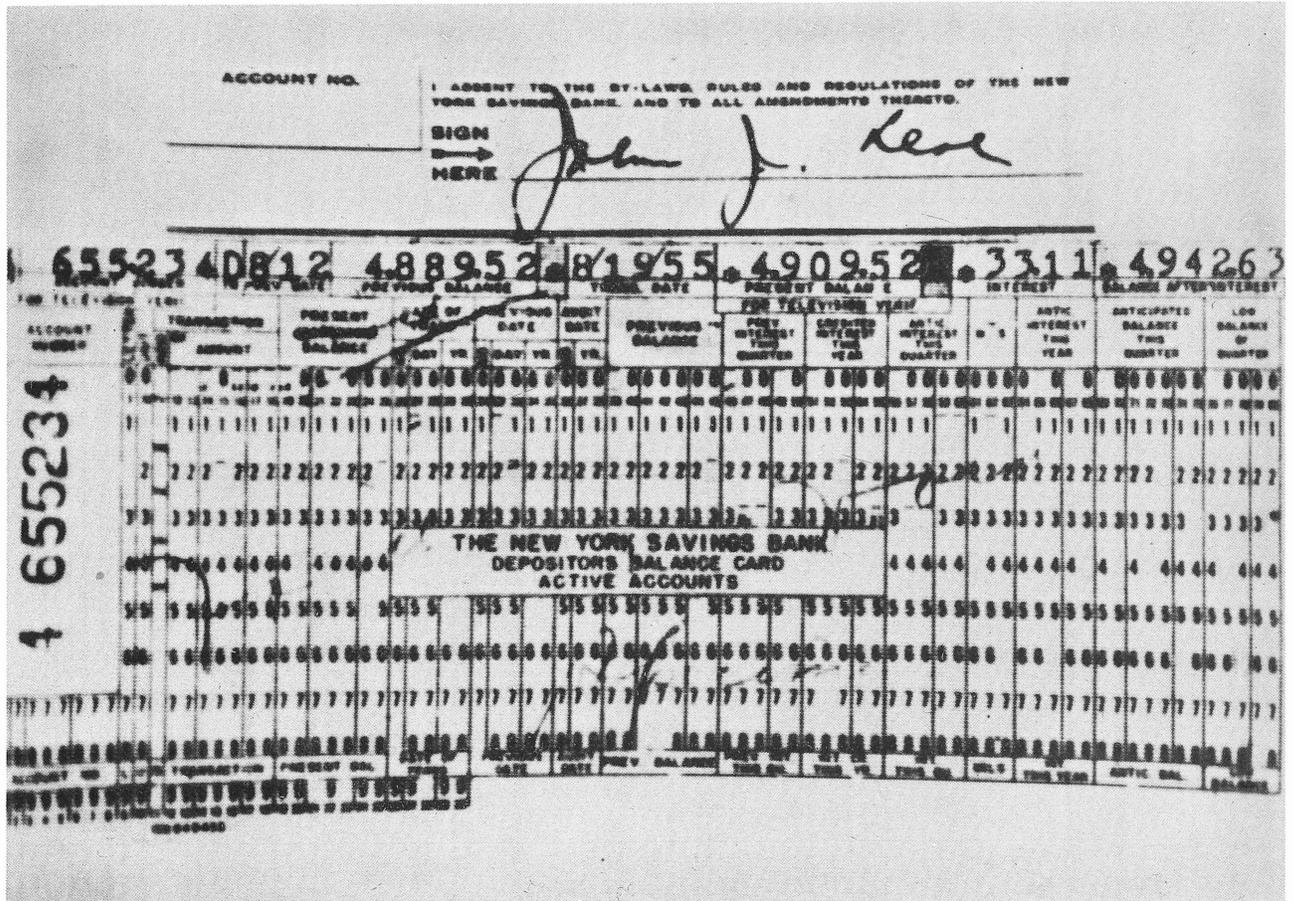
3.01 The illustrations have been prepared in order to form a partial basis for judgment as to the picture quality which should be provided in a slow-scan TV system.

3.02 Examples are given of pictures transmitted over television systems having 525, 328, 218 and 87.5 lines per frame height. The pictures have approximately equal horizontal and vertical resolutions and an aspect ratio of 4:3 (width: height). Also illustrated are (1) the advantage of using the raster area efficiently, and (2) the effect of picture size on the number of lines required for a given quality.

3.03 Fig. 4 is representative of a 525 line system. The transmitted material is that on a card showing the status of a bank account bearing the signature of the depositor—John J. Doe.

3.04 Fig. 5 shows a 2-inch section cut from Fig. 4 together with comparable sections from 328 and 218 line systems. Change in sharpness and visible detail can be noticed as the line structure becomes coarse. Direct comparison of the qualities provided by the systems can be made with this illustration. It is also apparent that if the system over which this information was transmitted was designed to rescan after scanning a fraction of the total lines per picture height, the transmitting time could be reduced proportionately.

3.05 Figs. 6 and 7 are a full size 8½ by 11 page of typed material. Two hundred eighteen line quality reproductions of this material were very badly blurred. In order to scan this material horizontally the long dimension of the typed page was made to fit the short dimension of the



SIGNATURE AND BOOK BALANCE INFORMATION

SCANNING : HORIZONTAL

SYSTEM : 525 LINE, BROADCAST QUALITY

RASTER

WIDTH : 4 UNITS, ALL USED

HEIGHT : 3 UNITS, ALL USED

LINES USED FOR IMAGE PORTRAYED 480

Fig. 4

Television - Bandwidth, Resolution and Frame Period Relationship - Case 18861 - File 16711-4

MEMORANDUM

The recent increase of interest in closed-circuit television and slow-scan picture transmission systems has raised a number of questions concerning required bandwidths, resolution, and time required to transmit a single picture. To make the answers to these questions more readily available, this memorandum presents a review of the fundamental relations between the above quantities, and derives formulae for practical calculations. Also included are two tables in which are entered the frame period required for certain representative bandwidths and numbers of scanning lines. The number of scanning lines can be regarded as a quality factor, i.e. the higher the number of scanning lines the greater the detail that can be shown in the picture. The first table applies to pictures having an aspect ratio of 4:3; (width to height), the other to pictures of 1:1 aspect ratio. In both tables it has been assumed that the time allotted to horizontal and vertical synchronizing and blanking is proportional to that used in current broadcast television practice.

It should be remembered that the bandwidths referred to in this memorandum are the "video" bands extending from near zero frequency (reciprocal of the frame period) upwards to a cut-off frequency numerically the same as the bandwidth figure. If transmit picture signals over telephone message facilities, which do not transmit frequencies much lower than a few hundred cps, and which have rather marked phase non-linearities except near the middle of the band, it may be necessary to modulate the signals on a subcarrier using either double or vestigial sidebands. In such cases, the bandwidths of the transmission path may have to be as much as 2-1/2 to 3 times that of the video bandwidth listed in the tables.

Bandwidth, Resolution and Frame Period Relationship

(Horizontal Scan Systems)

If no time were consumed in synchronizing television (or picture) signals or in blanking out return traces of the scanning spot, a horizontally scanned picture would exhibit a certain number, N_s , of scanning lines within the height of the

525 LINE BROADCAST TV QUALITY
SCANNING HORIZONTAL

THE QUALITY OF TRANSMISSION, TRANSMISSION AND TRANSMISSION SYSTEMS
STANDARD - CLASS 10000 - FILE 10000

CONCLUSION

The present increase of interest in direct current
transmission and high-voltage alternating current systems has
resulted in a number of questions concerning required bandwidth
specification, and this required to transmit a single channel
to meet the summary of these questions were readily available.
This memorandum presents a review of the fundamental relations
between the three variables, and further progress for prac-
tical calculations. Also included are the tables in which are
presented the frame period required for various representative
bandwidth and numbers of scanning lines. The number of scanning
lines can be regarded as a quality factor, i.e., the higher the
number of scanning lines the greater the detail that can be
shown in the picture. The first table applies to picture ser-
ving at aspect ratio of 4:3, picture is taller, the other is
picture of 1:1 aspect ratio. In both tables it has been
assumed that the line spacing is horizontal and vertical are
equalized and scanning is proportional to the area in picture
bandwidth utilization picture.

It should be remembered that the bandwidth referred
to in this memorandum and the "video" bands extending from zero
and frequency components of the frame period apply to a
cut-off frequency numerically the same as the bandwidth figure.
In present picture signals for telephone message facilities,
which in the present transmission work lower than a few hundred
cps, and which have rather narrow phase and linearity enough
that the number of the lines. It may be necessary to substitute the
signals as a substitute using either double or rectangular side-
bands. In such cases, the significance of the transmission will
may have to be as much as 1:1.7 to 1 times that of the video band
width limit in the video.

MINIMUM BANDWIDTH AND FRAME PERIOD REQUIREMENTS

Horizontal Line System

If an line were required in transmitting information
the picture signal or in scanning the picture lines of the
scanning area, a horizontally scanned picture with vertical
picture height, H_v , of scanning lines equals the height of the

328 LINE QUALITY
SCANNING HORIZONTAL

Fig. 7

scanner. This resulted in an inefficient use of the scanned area because only a portion of the scanned area contains intelligence. It is apparent that the quality produced by the 525 line system is the minimum usable quality.

3.06 Fig. 8 shows the improvement that can be made when the aspect ratio of the material to be transmitted is oriented so as to best fit the aspect ratio of the scanner. Comparing Fig. 6 with Fig. 8 it can be seen that Fig. 8, which was scanned vertically, is better. An improved fit of the material to the raster can, therefore, compensate for a poorer quality system. "Raster" is defined as the scanned (illuminated) area displayed on a picture tube.

3.07 It is obvious that the major reasons for the apparent improvement in the vertically scanned illustration is that each letter character occupies a relatively larger portion of the raster, when the material to be transmitted is well fitted to the raster. A minor reason for this improvement is that typed material contains more vertical than horizontal lines.

3.08 Fig. 9 is illustrative of half page typed material transmitted over a system with 525 lines. The material is made up of one-half of the full page used in the immediately preceding illustrations, and is well suited to the 3 by 4 aspect ratio of the scanned raster. Therefore, the available picture areas are used more efficiently. If the legibility of this series of illustrations is compared with that of the three preceding pictures, the importance of not crowding too much material or detail into a given area is made plain. Fig. 9 should be better than Fig. 6 and this is apparent by comparison.

3.09 Fig. 10 illustrates signatures that have been transmitted over four different systems as captioned. In this series of illustrations the lack of sharpness in pictures of 200 and 300 line quality does not mask the characteristics of the signature excessively. The impression given is that which would result if pens with progressively coarser nibs had been employed. It is also evident that if the 4 by 3 aspect ratio of broadcast TV had been used the scanned area would to a large degree be wasted.

3.10 Fig. 11 illustrates for comparison purposes a picture transmitted over four different systems. Here again, a reasonable likeness of the subject could have been transmitted using the 80 line system if, for example, the full 80 lines had been used to scan the *face area only*.

3.11 Fig. 12 was prepared to illustrate the effect of size on the apparent sharpness. The two pictures differ only in size and were transmitted over the same system.

3.12 Method Used to Simulate TV Systems. A commercial scanner was used which scans a 3 by 4 area of a gloss print and generates a standard 525 line RETMA signal. This equipment was used to generate all signals used in obtaining the foregoing illustrations. To simulate systems with smaller numbers of lines, gloss prints which only partially filled the 3 by 4 scanned area were employed.

3.13 The difference between the number of lines quoted for the system and the number of lines used for the picture represents the number of lines included in the blanking time. The proportions used correspond to the 525 line broadcast system.

3.14 The over-all bandwidth of the system was limited to 4.2 mc by means of a phase corrected low-pass filter, and the highlight picture brightness approximated 10 foot-candles.

4. MATHEMATICAL RELATIONSHIP OF BANDWIDTH, PICTURE QUALITY, AND TRANSMISSION TIME

4.01 This part presents a mathematical review of the fundamental relations between the above quantities for a horizontal scan system, and derives formulae for practical calculations. Tables I and II previously referred to list the frame period required for certain representative bandwidths and numbers of scanning lines. Assuming equal horizontal and vertical resolutions the number of scanning lines can be regarded as a quality factor, i.e., the higher the number of scanning lines the greater the detail that can be shown in the picture. Table I applies to pictures having an aspect ratio of 4:3; (width to height); Table II to pictures of 1:1 aspect ratio. In both tables it has been assumed that the time allotted to horizontal and vertical synchro-

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MEMORANDUM

The recent increase of interest in closed-circuit television and slow-scan picture transmission systems, has raised a number of questions concerning required bandwidths, resolution, and time required to transmit a single picture. To make the answers to these questions more readily available, this memorandum presents a review of the fundamental relations between the above quantities, and derives formulae for practical calculations. Also included are two tables in which are entered the frame period required for certain representative bandwidths and numbers of scanning lines. The number of scanning lines can be regarded as a quality factor, i.e. the higher the number of scanning lines the greater the detail that can be shown in the picture. The first table applies to pictures having an aspect ratio of 4:3; (width to height), the other to pictures of 1:1 aspect ratio. In both tables it has been assumed that the time allotted to horizontal and vertical synchronizing and blanking is proportional to that used in current broadcast television practice.

It should be remembered that the bandwidths referred to in this memorandum are the "video" bands extending from near zero frequency (reciprocal of the frame period) upwards to a cut-off frequency numerically the same as the bandwidth figure. To transmit picture signals over telephone message facilities, which do not transmit frequencies much lower than a few hundred cps, and which have rather marked phase non-linearities except near the middle of the band, it may be necessary to modulate the signals on a subcarrier using either double or vestigial sidebands. In such cases, the bandwidths of the transmission path may have to be as much as 2-1/2 to 3 times that of the video bandwidths listed in the tables.

Bandwidth, Resolution and Frame Period Relationship

(Horizontal Scan Systems)

If no time were consumed in synchronizing television (or picture) signals or in blanking out return traces of the scanning spot, a horizontally scanned picture would exhibit a

525 LINE BROADCAST TV QUALITY
SCANNING VERTICAL

MEMORANDUM

The recent increase of interest in closed-circuit television and slow-scan picture transmission systems has raised a number of questions concerning required bandwidths, resolution, and time required to transmit a single picture. To make the answers to these questions more readily available, this memorandum presents a review of the fundamental relations between the above quantities, and derives formulae for practical calculations. Also included are two tables in which are entered the frame period required for certain representative bandwidths and numbers of scanning lines. The number of scanning lines can be regarded as a quality factor, i.e. the higher the number of scanning lines the greater the detail that can be shown in the picture. The first table applies to pictures having an aspect ratio of 4:3; (width to height), the other to pictures of 1:1 aspect ratio. In both tables it has been assumed that the time allotted to horizontal and vertical synchronizing and blanking is proportional to that used in current broadcast television practice.

TYPED MATERIAL, $\frac{1}{2}$ OF $8\frac{1}{2}$ X 11 PAGE

SCANNING: HORIZONTAL

SYSTEM: 525 LINE, BROADCAST T.V. QUALITY

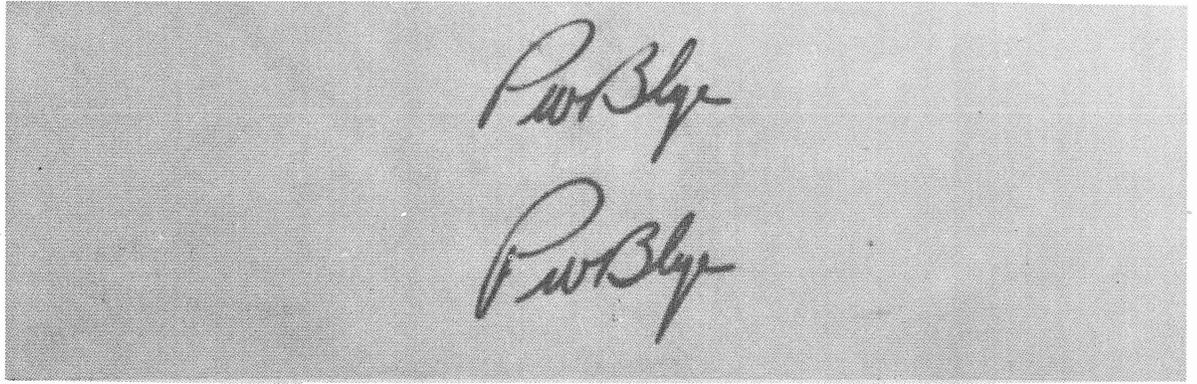
RASTER

WIDTH: 4 UNITS, ALL USED

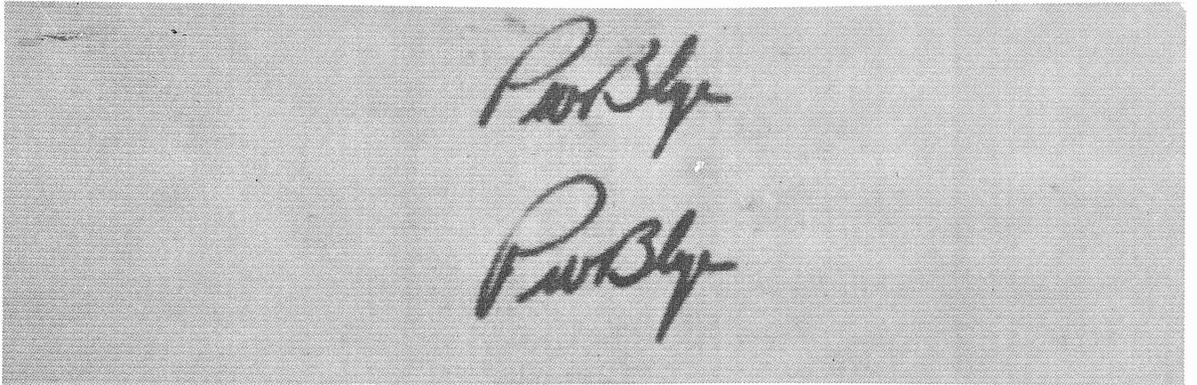
HEIGHT: 3 UNITS, ALL USED

LINES USED FOR IMAGE PORTRAYED 480

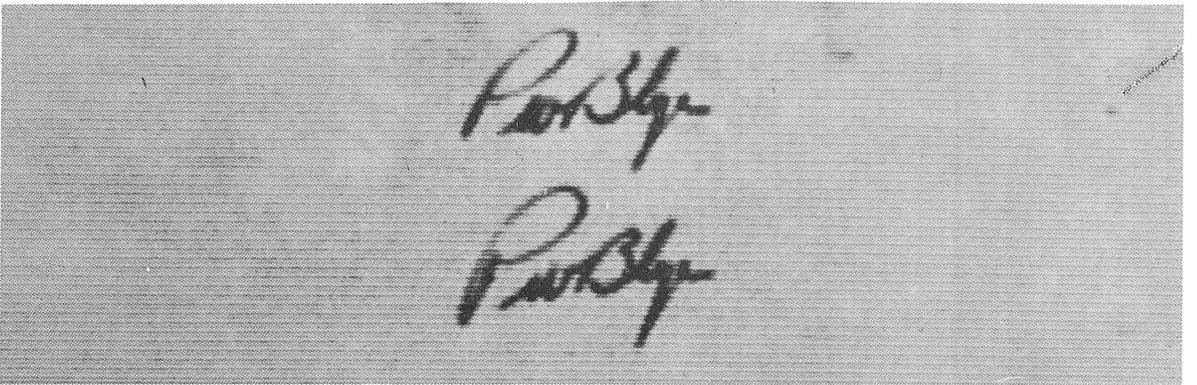
Fig. 9



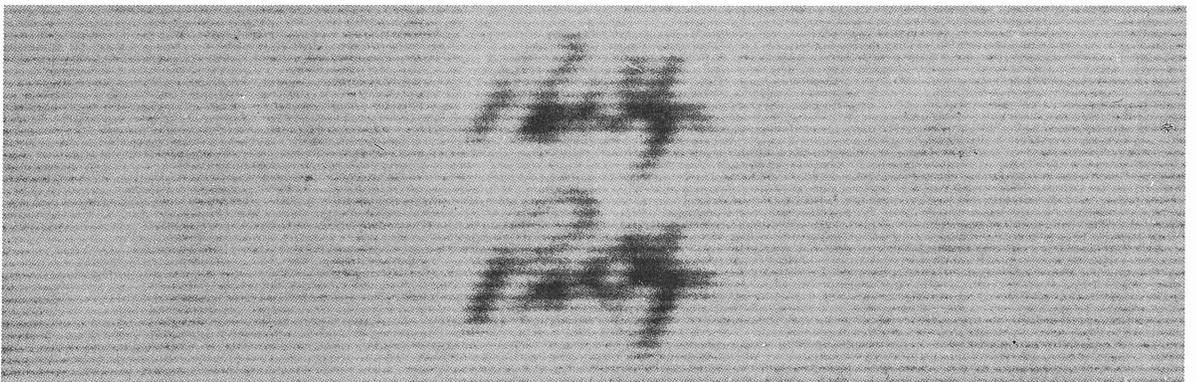
$\frac{2}{5}$ OF 480 LINE IMAGE



$\frac{2}{5}$ OF 300 LINE IMAGE



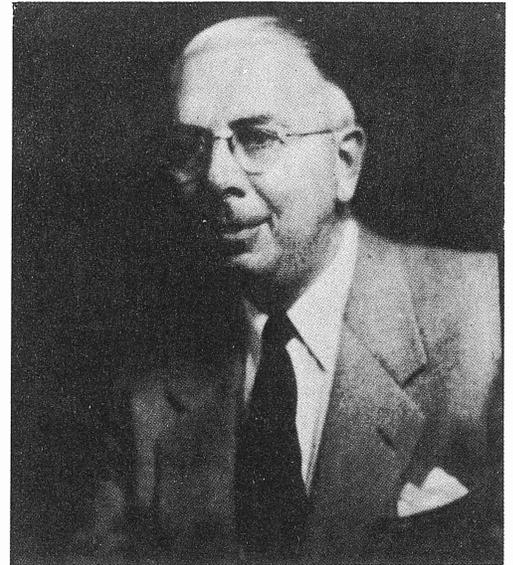
$\frac{2}{5}$ OF 200 LINE IMAGE



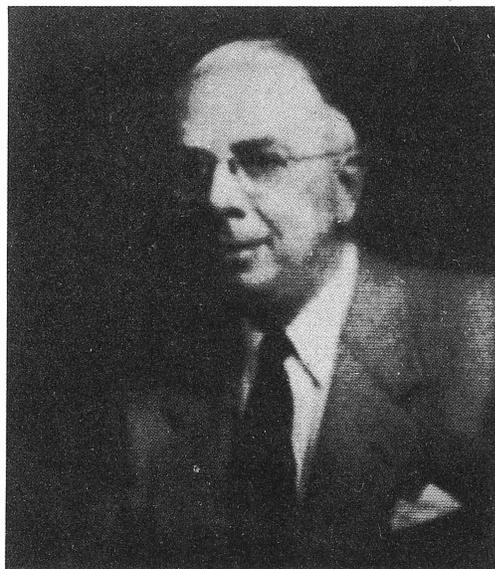
$\frac{2}{5}$ OF 80 LINE IMAGE

Fig. 10

THE PICTURES BELOW WERE SCANNED HORIZONTALLY EMPLOYING A RASTER AREA 3 UNITS HIGH AND 4 UNITS WIDE. IN EACH CASE THE PICTURE MATERIAL COMPLETELY FILLED THE VERTICAL HEIGHT (3 UNITS) BUT USED ONLY ABOUT 1/2 OF THE AVAILABLE WIDTH.



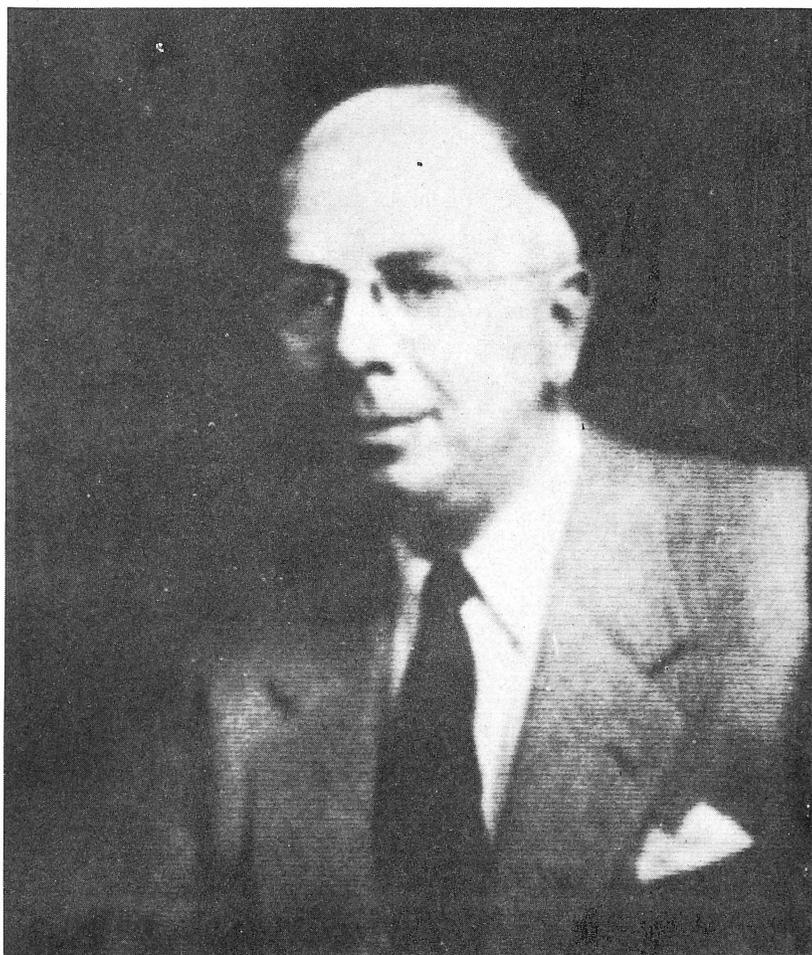
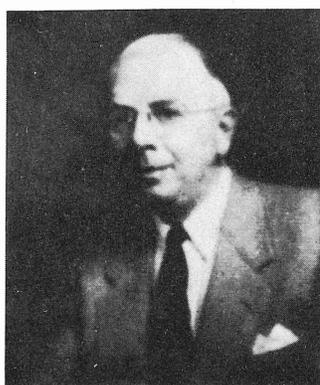
328 ← QUALITY → 525 LINES
 300 ← LINES USED FOR IMAGE → 480 LINES



218 ← QUALITY → $87\frac{1}{2}$ LINES
 200 ← LINES USED FOR IMAGE → 80 LINES

Fig. 11

THESE PICTURES ARE IDENTICAL,
EXCEPT FOR SIZE



SCANNING: HORIZONTAL

SYSTEM : 218 LINE

RASTER

WIDTH : 4 UNITS, ONLY 2 USED

HEIGHT : 3 UNITS, ALL USED

LINES USED FOR IMAGE PORTRAYED 200

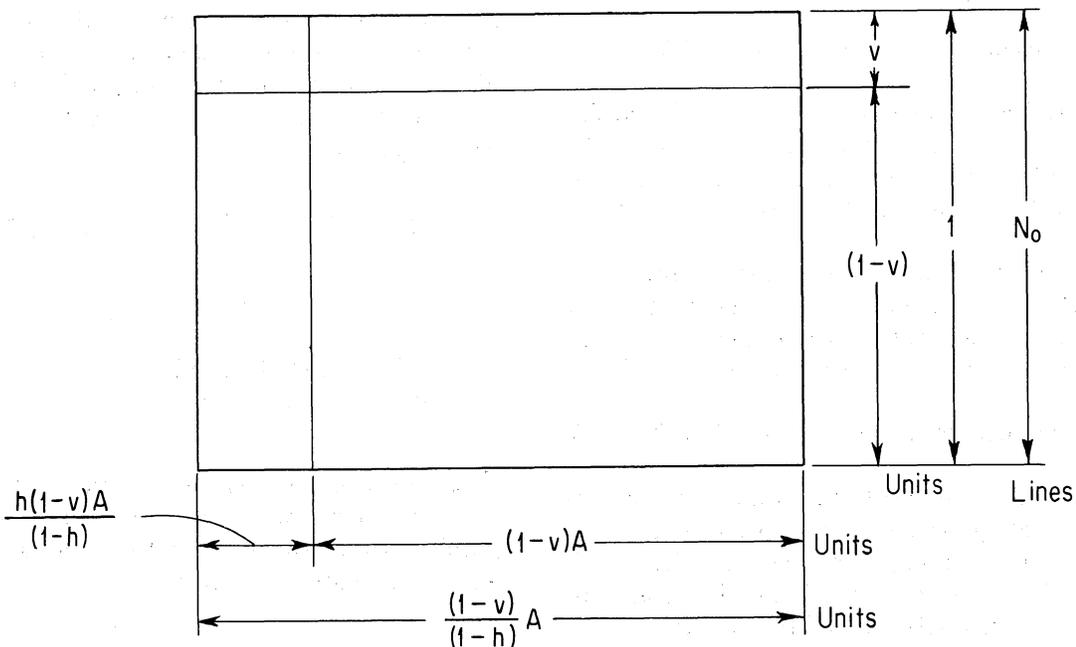
Fig. 12

nizing and blanking is proportional to that used in current broadcast television practice. (In broadcast television about 22 per cent of the time is devoted to horizontal and vertical blanking intervals.)

4.02 By bandwidths is meant the "video" bands extending from near zero frequency (reciprocal of the frame period) upwards to a cut-off frequency numerically the same as the bandwidth figure. To transmit picture signals over telephone message facilities, which do not transmit frequencies much lower than a few hundred cps, and which have rather marked phase nonlinearities except near the middle of the band, it may be necessary to modulate the signals on a subcarrier using either double or vestigial sidebands. In such cases, the bandwidths of the transmission path may have to be as much as $1\frac{1}{4}$ to

3 times that of the video bandwidths listed in the tables.

4.03 Fig. 13 geometrically illustrates the relationships in a horizontal scan system. If no time were consumed in synchronizing television (or picture) signals or in blanking out return traces of the scanning spot, a horizontally scanned picture would exhibit a certain number, N_o , of scanning lines within the height of the picture. This number, N_o lines per picture height, is sometimes referred to as the total (or nominal) number of lines by which the system is designated, as, for example, "a 525-line system," or "a 70-line system." Explicitly, N_o is defined as the ratio of the horizontal line rate to the frame rate. In broadcast television, the horizontal scanning rate is 15,750 lines per second and the frame rate is 30 per second; $N_o = 15,750 / 30 = 525$ lines per frame.



v = blanking fraction (vertical)

h = blanking fraction (horizontal)

N_o = lines per Frame

A = Aspect Ratio of picture (width \div height)

K = Kell factor

T = Time per Frame in Seconds

f_c = bandwidth (upper cut-off frequency) in cycles

Fig. 13

4.04 Because the horizontal scanning lines occupy fixed positions with respect to the frame of the picture, the resolution in the vertical direction is, on the average, somewhat less than that indicated by the actual number of scanning lines per unit distance (or picture height). The factor by which the actual number of scanning lines must be reduced to yield, on the average, resolvable lines is called the Kell factor and is designated below, by the letter K . Several attempts to evaluate the Kell factor by subjective tests have been made with resulting values of K lying between 0.53 and 0.85. A value of K of *about* 0.7 has become generally accepted. Kell factor is not usually involved in considerations of horizontal resolution because the scanning spot moves continuously along the horizontal scanning line.

4.05 With the foregoing in mind, the vertical resolution expressed in lines per picture height can be written as

$$\text{Vertical resolution} = N_o K (1 - v) \quad (1)$$

where N_o and K are as defined above and v is the fraction of vertical scanning time used for vertical blanking, during which the scanning spot moves from the bottom to the top of the picture.

4.06 For the horizontal resolution in lines per picture *width*, assuming same number of total lines, N_o , and same frame period, T , has been chosen, the expression would be

$$\text{Horizontal resolution} = 2f_c (1 - h) T/N_o \quad (2)$$

where f_c is the bandwidth (or upper cut-off frequency in cycles) and h is the fraction of total horizontal line scanning time use for the horizontal blanking period in which the scanning spot returns to the left side of the picture.

4.07 In this expression the factor 2 is used to indicate that both light and dark vertical lines are to be counted so that the maximum number of light and dark lines resolvable would be proportional to twice the number of complete cycles of the highest frequency passed by the system. It is obvious that for any bandwidth, f_c , the horizontal resolution would be proportional to frame period, T , and inversely proportional to the number of horizontal lines, N_o , employed in presenting the picture.

4.08 It has become customary to describe horizontal resolution in "lines per picture height" rather than lines per picture width, in order that the two expressions and their numerical evaluations can be directly compared, and thereby an assessment made in regard to the nearness to equality of the two quantities, vertical and horizontal resolution. To do this the expression for horizontal resolution needs to be modified by a factor derived from the aspect ratio, A , of the picture to be presented. When the aspect ratio (ratio of width to height) is 4:3 the expression for the horizontal resolution is

$$\begin{aligned} &\text{Horizontal resolution (lines per picture height)} \\ &= \frac{1}{A} \times 2f_c (1 - h) T/N_o \end{aligned} \quad (3)$$

4.09 If it is now desired to set up an expression for the relation between bandwidth, frame period, and number of horizontal lines, for a picture in which the resolution in lines per unit distance is equal, horizontally and vertically, the two equations derived above can be set equal to each other, or

$$KN_o (1 - v) = \frac{2}{A} f_c (1 - h) T/N_o$$

or

$$\frac{f_c T}{N_o^2} = \frac{AK (1 - v)}{2 (1 - h)} \quad (4)$$

4.10 In this expression v and h in the right-hand member are functions of the system employed and the Kell factor is a factor obtainable from subjective tests.

4.11 In current television practice, $h = 0.16$, $v = 0.07$, $A = 4/3$, and if $K = 0.7$ the right-hand member of (4) above equals $0.516 = 1/1.94$. If the left-hand member is evaluated with currently accepted constants for broadcast television, $f_c = 4.2$ mc, $T = 1/30$ sec and $N_o = 525$, its value of $0.508 = 1/1.97$. This is a good check on the accepted value for the Kell factor of 0.7, assuming equal horizontal and vertical resolutions. If the Kell factor is chosen to be about 0.69 the left- and right-hand numbers of formula (4) are exactly equal. This should not be interpreted to

mean that the Kell factor is in fact 0.69 since its determination is subjective. If an accurate determination were made, and it turned out to be say 0.8, this would indicate that in current broadcast television, vertical and horizontal resolution per unit distance are *not* equal.

4.12 Adopting, for TV systems having aspect ratios and blanking periods similar to broadcast television, the evaluation of 0.508 or 1/1.97 for the left-hand member of (4), the expression may be written as:

$$f_c = \frac{0.508 N_0^2}{T} \quad (5)$$

$$\text{or } T = \frac{0.508 N_0^2}{f_c}$$

$$\text{or } N_0 = (1.97 T f_c)^{1/2}$$

4.13 These are the relations which were originally sought. On the assumption that, in any system for picture transmission which may be devised for utilizing the various bandwidths available in the Bell System plant, approximately the same shrinkage from nominal lines to lines useful for picture delineation would occur as does occur in TV transmission, the frame periods given in the body of Table 1 were computed, using bandwidths as given in the left-hand ver-

tical column and nominal line numbers given in the top horizontal row.

4.14 For a square picture (aspect ratio, A, is unity) other expressions could be written for relating bandwidth, nominal lines and frame time, as follows:

$$KN_0 (1 - v) = 2f_c (1 - h) T/N_0 \quad (6)$$

$$\frac{f_c T}{N_0^2} = \frac{K (1 - v)}{2 (1 - h)}$$

$$\text{Using } K = .69 \\ v = 0.07 \\ h = 0.16$$

$$\frac{f_c T}{N_0^2} = 0.38$$

$$\text{and } f_c = \frac{.38 \times N_0^2}{T}$$

$$T = \frac{.38 \times N_0^2}{f_c}$$

$$N_0 = (2.63 T f_c)^{1/2} \quad (7)$$

The figures in Table II were computed using these formulae.

TABLE I
Frame Period for 4 x 3 Aspect Ratio Pictures

Lines per Picture } Height }	Bandwidth	925	702	525 ⁽¹⁾	360	200	80 ⁽²⁾
	7.5 mc	1/17.3 sec	1/30 sec	1/53.6 sec	1/114 sec	1/370 sec	1/2310 sec
4.2 mc	1/9.7 "	1/16.8 "	1/30 "	1/63.8 "	1/207 "	1/1290 "	
2.7 mc	1/6.22 "	1/10.8 "	1/19.3 "	1/41 "	1/133 "	1/831 "	
48 kc	9 "	5.2 "	2.9 "	1.4 "	1/2.4 "	1/14.8 "	
15 kc	29 "	16.7 "	9.3 "	4.4 "	1.4 "	1/ 4.6 "	
8 kc	54 "	31.2 "	17.5 "	8.2 "	2.5 "	1/ 2.5 "	
5 kc	87 "	50 "	28 "	13.1 "	4.1 "	1/ 1.5 "	
3.5 kc	124 "	71 "	40 "	18.8 "	5.8 "	1/ 1.1 "	
2.5 kc	174 "	100 "	56 "	26.3 "	8.1 "	1.3 "	
1.0 kc	435 "	250 "	140 "	65.8 "	20.3 "	3.3 "	

⁽¹⁾ U.S.A. standard Broadcast TV quality.

⁽²⁾ Suitable for identifying signatures, numbers and simple objects which fill up the picture screen.

TABLE II
Frame Periods for Square Pictures

Lines per Picture } Height }	<u>Bandwidth</u>	<u>925</u>	<u>702</u>	<u>525</u>	<u>360</u>	<u>200</u>	<u>80</u>
	7.5 mc	1/23 sec	1/40 sec	1/71.5 sec	1/152 sec	1/493 sec	1/3080 sec
	4.2 mc	1/12.9 "	1/22.4 "	1/40.2 "	1/85.2 "	1/276 "	1/1730 "
	2.7 mc	1/ 8.3 "	1/14.4 "	1/25.8 "	1/54.8 "	1/178 "	1/1110 "
	48 kc	6.8 "	3.9 "	2.18 "	1.03 "	1/3.2 "	1/19.8 "
	15 kc	21.7 "	12.5 "	7.0 "	3.3 "	1.0 "	1/ 6.2 "
	8 kc	40.6 "	23.4 "	13.1 "	6.2 "	1.9 "	1/ 3.3 "
	5 kc	65 "	37.5 "	21 "	9.8 "	3 "	1/ 2.06 "
	3.5 kc	93 "	53.2 "	29.9 "	14.1 "	4.3 "	1/ 1.44 "
	2.5 kc	130 "	75 "	42 "	19.7 "	6 "	1/ 1.03 "
	1.0 kc	325 "	188 "	105 "	49 "	15 "	2.4 "