NRL REPORT 3772

RESOLUTION CAPABILITIES OF CATHODE-RAY TUBES 10BP4, 10FP4, AND 16AP4

M. F. Hodges

November 30, 1950

Approved by:

R. B. Meyer, Head, Communications Branch
L. A. Gebhard, Superintendent, Radio Division II

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH

NAVAL RESEARCH LABORATORY
CAPTAIN F. R. FURTH, USN, DIRECTOR
WASHINGTON, D.C.

DISTRIBUTION

BuShips	
Attn: Code 832	10
ONR	
Attn: Code 470	1
Dir., USNEL	2
Supt., USNPGS	1
RDB	
Attn: Information Requirements Branch	2
Attn: Navy Secretary	1
Naval Res. Sec., Science Div., Library of Congress	
Attn: Mr. J. H. Heald	2
NRL Code 3910	2
NRL File	3

CONTENTS

ABSTRACT

The resolution capability of each of three types of c-r tubes, namely, types 10BP4, 10FP4, and 16AP4, has been determined by a simple technique to be in the order of 125 lines per inch. Factors influencing such determination including viewing distance, ambient lighting, tube operating potentials, and brightness contrast — are discussed. Light output comparisons for equal power and signal input to the three tubes show maximum light output from the type 10FP4.

PROBLEM STATUS

This is a final report on one phase of this problem. Work on other phases of the problem continues.

AUTHORIZATION

NRL Problem R01-11R

NE 021-402

RESOLUTION CAPABILITIES OF CATHODE-RAY TUBES 10BP4, 10FP4, AND 16AP4

I. INTRODUCTION

The military usefulness of a system for electrical transmission of graphic or visual information depends heavily on its resolution capability. It is well-recognized that system resolution is limited by available bandwidth, phase characteristics of amplifiers and transmission paths, signal-to-noise ratios, sweep linearity at pick-up and presentation locations, and the degree of synchronization between scanner and presentation signals. Individual units within a system, however, can impose further limitations on resolution. In a television system, one such component is the cathode-ray tube, and, accordingly, an investigation was undertaken of the resolution capability of three types of cathode-ray presentation tubes. Because black-white presentation of televised information is preferable for visual observation, attention was confined to tubes having P-4 phosphors. Attempts were made to ascertain the effect of tube operating parameters on resolution capability.[1]

II. SPOT-SIZE MEASURING TECHNIQUES

The size of a stationary fluorescent spot on the face of a c-r tube can be determined by several methods to any reasonable degree of accuracy depending upon a definition of what constitutes the spot. Only rarely, however, is a completely stationary spot useful in conveying information. Consequently, such a determination of spot size, although useful in evaluating electron-gun design, does not yield a representative figure of resolution capability during dynamic operation.

The "Shrinking Raster Method"[2] is one which permits establishing a figure of merit for dynamic resolution. For electrostatic focus and deflection c-r tubes, it is the present commercial practice, having also been adopted by the Joint Army-Navy Committee on Electron Tubes.

---

[1] At the time this work was started, only a small amount of data was available on the resolution capability of various common types of c-r tubes used for picture presentation. In 1948, however, an excellent book entitled "Cathode Ray Tube Displays", Soller, Theo, Starr, M.A. and Valley G.E. Jr. (Volume 22 of the Radiation Laboratory Series), was published by McGraw-Hill, New York. Although primarily covering c-r tubes used in radar applications, many fundamental aspects of c-r tube design are thoroughly discussed. In the latter phases of the present work, this book has been an invaluable guide.

[2] Soller, Theo, Starr, M. A. Valley, G.E. Jr. Cathode Ray Tube Displays McGraw-Hill Book Co. Inc. New York 1948 Page 594.

In this method a raster of a known number of lines is placed on the c-r tube, the brightness of which is adjusted for a representative average beam current at fixed first- and second-anode potentials. Focus voltage is adjusted for best line delineation at the center of the raster. The initial dimensions of the raster are noted, and then its height is reduced while the width is kept constant until the lines just merge. The final height of the raster, divided by the known number of lines, yields the nominal line width (actually height) and resolution capability of the tube under the given operating conditions. It is assumed and generally accepted that the resolution capability along the line is equal to the line height.

A second method, called the "Polka-Dot Method", evolved by R.C.A.[3] is similar to the "Shrinking Raster" technique. In it the raster, by modulation of the beam current, is presented in the form of small dots of light and is then shrunk until the spots merge; from the resulting raster size the resolution can be computed.

Reduction of raster size produces two major effects: first, it increases the apparent brightness of the resulting raster and, second, it reduces the contrast between traced and untraced areas within the boundaries of the raster. The reduction in contrast is due to the distribution of the light intensity from the line or spot. Secondary effects influencing the figure of merit for resolution are: (a) increased degradation of line or dot separation due to any loss of synchronism between horizontal and vertical sweep frequencies, and (b) slightly increased contrast between the raster and unscanned areas of the tube screen.

The method used in evaluating the three tubes studied represents a compromise between the polka-dot raster technique and circuit complexity. The desire to keep the number of variables at a minimum led to selecting low line- and field-sweep rates in order to use low grid-modulating frequencies. A line rate of 120 cycles per second and a field rate of 60 cycles per second produced a two-line raster which could be modulated by audio and low radio-frequency signal generators. The output of a Hewlett-Packard Model 200-C audio oscillator was used as a modulator after squaring in a H-P Model 210A Square Wave Generator. By means of Potter oscillator-frequency dividers, the modulating signal was used to synchronize the horizontal and vertical sweeps. This divider circuit provided just sufficient synchronization to hold the modulation pattern stable enough for examination and photographing.

---

[3] See Footnote 2, op. cit. Page 597

In order to reduce the effect of after-glow (phosphorescence) and possible jitter in the trace, the majority of photographs were taken for pulsed light output from the c-r tube.

A flat-topped pulse having approximately 10 milliseconds duration and a repetition rate of 4 per minute was used as an unblanking gate to permit recording slightly more than one line of the two-line raster. The c-r trace brightness was adjusted by cathode biasing the tube to the point where the pulse, when applied, would produce a brightness corresponding to a predetermined beam current. The beam current-brightness criteria is reproducible with reasonable consistency provided the first- and second-anode potentials are maintained constant.

It must be realized that, because of the method of establishing the tube ratings, the operating beam currents in this study were considerably lower than the published data for tubes for a given brightness. Published data on beam currents are based first on a 525-line raster and, second, on 15750-cycle-per-second horizontal and 60-cycle-per-second vertical sawtooth sweep frequencies. The use of slower sweeps requires a reduction in beam current so that the power input per unit area does not cause damage to the phosphor. In Appendix A, a current of 1 ua is shown to correspond to a nominal beam current of 200 ua for a standard raster operation. Although this 1-ua value is not a rigorous limitation on the beam current for the 120- 60-cycle raster, it represents a nominal working value.

III. MEASUREMENTS BY LOW-FREQUENCY GRID MODULATION

A. Type 10BP4 Characteristics

Figures 1 and 2 illustrate the degree of contrast and resolution obtainable with a beam current of 1 ua and a nominal 9.1-kilovolt second anode voltage. Dot modulation of 66 kc appears in Figure 1; in Figure 2, very slight indication of 70-kc modulation is evident.[4] As developed in Appendix B, these frequencies correspond to 165 and 175 lines per inch respectively. It is evident that in both cases these figures are marginal and represent the limit of possible usefulness if elaborate photographic techniques can be employed to emphasize the black-white nature of the signal. Both of these photographs were taken of a repetitive trace pattern using 4 x 5-inch Supper XX Panchromatic film at a lens opening of f 4.7 and a shutter speed of 1 second. Sweep nonlinearity is evident in both photographs.

The effects of progressive improvements in sweep linearity, squareness of gating pulses, and synchronization made during the investigation appear in later photographs. In each case, the major

---

[4] For viewing Figures 1 through 17 a magnifying glass is helpful in establishing the dot separation.

nonlinearity of the trace appears at one end, and between 60 and 80 percent of the trace appears reasonably linear. Calculations of resolution capability are based on the best portions of a trace and are therefore optimistic. The lines-per-inch figure can be reduced by an appropriate figure derived from a consideration of the characteristics of a parabolic- or exponential-trace wave-form. For either of these types of sweep, if the trace length and sweep time is maintained constant, the reduction in effective resolution is as described in Appendix C.

For example, a tube resolution capability of 165 lines per inch determined on a trace of which 60 percent appears linear would correspond, if the trace had been truly linear with time, to an actual resolution capability of 62 percent of 165 lines per inch, or 102 lines per inch. It should be noted, however, that a statement of tube resolution capability based on a 60-percent linear trace tends to be pessimistic. Obviously, the limiting factor under these conditions is the circuitry and not the c-r tube.

In Figure 3 a 60-kc signal appears as produced by a beam current of 20 ua at a 9.5-kv second-anode potential. Exposure time was 1/10 second at f 4.7. Even at this relatively high beam current, the modulation is discernable over about the first 40 percent of the trace.

Figure 4 shows a portion of a 70-kc trace produced by a 1.2-ua beam at 11.0 kv photographed in 1/100 sec. The difference in intensity between the two traces is attributable to a single sweep on the lighter- and a superimposed additional sweep on the more intense image.

Figure 5 is illustrative of the same conditions as in Figure 4, except that the exposure time was increased to 1/50 second.

Figure 6 shows 70-kc modulation of a 1-ua beam current at 11.5 kv taken in 1/50 second. The apparent improvement in resolution is not entirely attributable to the increased anode potential and decreased beam current. Some of the improvement is due to the good synchronism of the two repetitive patterns visible during the lens-open period.

Figure 7 is the first of a group of photographs which show the results obtained when the beam current of the cathode-ray tube was pulse gated from cut-off to some predetermined level. This technique minimized spot-size deterioration due to lack of sweep synchronization because the 10-millisecond pulse duration insured that only a portion of one complete raster was intensified. A pulse-repetition rate of approximately 4 per minute allowed the camera shutter to be manually opened or closed in the intervals between pulses.

Figure 8 shows 70-kc modulation of a gated 1-ua beam current at 11.2-kv second-anode potential. Very little evidence of modulation can be detected either in the negative or in the print. This may be due partly to the fact that the entire raster was included in this exposure, whereas for Figure 7 only a portion of the raster was photographed. Figure 9 is a photograph of 50-kv modulation of a gated 2-ua beam current at 11.8 kv. The modulation is quite apparent for most of the trace, despite an unequal intensity along the lines caused by a sloped-top gating pulse.

Briefly, then, Figures 1 through 9 show that the type 10BP4 c-r tube can reproduce, at low contrast ratios, up to 175 lines per inch and, at higher contrast ratios, up to 125 lines per inch--a resolution capability which would permit presentation of modulating signals as high as 21.9 megacycles on a 9 3/4 x 7 3/8-inch raster.[5] With proper restriction of contrast range, viewing distance, sweep stability, and other significant parameters, the type 10BP4 c-r tube is adequate for presenting information of appreciably higher detail than is the current practice in television systems, but it must be remembered that the data presented here are for essentially noise-free conditions. Even in the laboratory not all the variables were under absolute control.

B. Type 10FP4 Characteristics

The type 10FP4 c-r tube has an electron-gun structure slightly different from that in the type 10BP4 and, in addition, has an aluminum backing on the phosphor screen. Otherwise the tube has much the same operating characteristics. Figure 10 shows a group of three traces on this tube obtained at approximately six-second intervals for square-wave 60-kc modulation. The second anode voltage was 11.1 kv. Figure 11 shows a well-defined 50-kc modulation of a 1-ua, 10-kv beam. Figure 12 is an attempt to show 100-kc square-wave modulation of a 1-ua 9.8-kv beam. It is evident that this is not a useful modulation frequency, inasmuch as the line contrast is all but nonexistent. Figure 13 shows definite contrast in the 75-kc modulation for the same operating conditions as in Figure 12. Figure 14 is a photograph of 70-kc modulation of a 12.0-kv 1-ua beam. Figure 15 shows 50-kc modulation of a 11.5-kv 1-ua beam. The small dots visible in the retrace are due to ripple interference voltages produced primarily in the high-voltage supply.

C. Type 16AP4 Characteristics

Figure 16 shows 50-kc modulation of a 14-kv 1-ua beam, a single trace produced by the 10-millisecond gating pulse. Figure 17 shows 60-kc modulation of a 14-kv 1-ua beam, also a single trace.

IV. OPTICAL LINE-WIDTH MEASUREMENTS

Optical methods of line-width measurements generally yield figures of merit approximately half as good as the Shrinking Raster or

---

[5] See Appendix D.

Polka Dot techniques. However, for comparative purposes they can be made rapidly and, for the same observer, are fairly reproducible. A few such measurements made on the three tubes serve principally to show the dependence of spot size on tube operating potentials. In making these measurements, a small microscope having a reticle scale and a fixed magnification of 40 was mounted directly against the face of the c-r tube, and the width of the modulation spot (at right angles to the trace) was recorded for various beam currents and first- and second-anode potentials.

Spot-size variations with change of second-anode potential appear in Figures 18 and 19. With 100 volts on the first anode, the dimensions of the spot for a constant beam current of 1 ua are determined only with difficulty because the beam focus must be varied at each increment of second-anode potential and the beam current readjusted. Since the first anode acts as a combined limiting aperture and accelerator, increased potential reduces electron scattering, and consequently spot size improves. Moreover, since the first anode acts somewhat as a screen grid, the influence of the second-anode potential on spot size is quite small at any given first-anode potential. At a beam current of 1 ua, the maximum spread of line-width measurements for second-anode-potential variations of 2 to 1 was only 11 percent. At 5 ua, the spread was only 12 percent.

If the line width of the c-r trace is considered as a function of the ratio of second-anode potential, E_2, to first-anode potential, E_1, the desirability of keeping this ratio small becomes evident. Figure 20 represents a compilation of the various line-width data as a function of the E_2/E_1 relationship. There is considerable scatter in the measurements, but the trend shows increased line widths for increasing ratios. For large ratios, between 60 and 110, only a few measurements were made, so the apparent maximum in the curve may be erroneous. From a practical standpoint, tube operation at these high ratios is unsatisfactory. Internal flash-over, focusing problems, modulating-voltage requirements, and the better spot size obtainable at lower ratios make the higher ratios economically and operationally undesirable.

Line width decreases with increased first-anode potential for constant second-anode potential and beam current, as illustrated in Figure 21 for the three types of tubes, the 10BP4, 10FP5, and 16AP4. When the first-anode potential is increased from 200 to 400 volts, the spot size undergoes an 80-percent decrease in diameter. This percentage change decreases as the potential increases. The line width-anode relationship may be expressed as

$$\text{L.W.} = KE_1^{-n}$$

The values of K and n for the tubes studied are as indicated in Table 1.

Table 1

Tube	K	n
10BP4	1.00	0.70
10FP4	0.49	0.56
16AP4	2.10	0.76

The type 16AP4 tube has the same electron gun as the type 10BP4. On first consideration, it might be assumed that the larger tube having the same gun would permit a greater number of lines to be placed on the tube screen, in direct proportion to the diameter ratio. However, the gun position relative to the focus-coil position is different in the two tubes. This affects the geometrical magnification of the electron lens system and consequently the final image or spot size. The difference in second-anode potential (14 kv for the 16AP4, 10 kv for the 10BP4) also affects the line width by partially offsetting, by the increased E_2/E_1 ratio, the decreased spot size accompanying the higher second-anode potential. As seen in Figure 20, this increases the spot size.

The geometrical magnification of the type 10BP4 is about 5.5, that of the 16AP4 is 9.3; therefore the line width may be expected to increase by the ratio 9.3/5.5, or 1.7 times. In the measurements of the 16AP4 made at a value of E_2 of 14 kv, the trace length was increased over that used on smaller tubes by 1.4, the ratio of the two second-anode voltages. By this means, at a constant beam current, the energy delivered to the screen per unit area was equalized, although not necessarily exactly. The measured ratio of line widths varies between 1.5 and 1.4. Thus the total number of lines which can be placed on the tube is approximately the same as can be placed on the 10-inch tube with the same type gun.

V. LIGHT-OUTPUT MEASUREMENTS

The light output obtainable from a phosphor depends on the energy incident per unit area and is not linear with beam current. It increases approximately as the square of the total cathode-to-anode voltage for relatively low accelerating voltages, but ultimately a given type screen material reaches what is known as "sticking" potential. Above this potential there is only a slight increase in light output for further increase in anode voltage.

Light output measurements were made by placing a General Electric type DW-48 exposure meter, with hood removed, directly against the face of the c-r tube in such a way that the meter aperture spanned a portion of a single trace-and-retrace line of the 120-cycle unmodulated raster. The remainder of the tube face was masked with black paper to exclude outside light. No correction was made of the exposure meter readings for the different spectral characteristics of the phosphors. Figure 22 shows the variation in light output for changes in beam current for three different tubes.[6] The two curves for the 16AP4 also indicate the increase in the amount of light output obtainable at a given beam current by increasing the over-all accelerating potential. It is noteworthy that the light output for the type 10FP4, a tube having an aluminum layer on the gun side of the phosphor screen, has appreciably higher values than the type 10BP4 under the same operating conditions.

VI. DISCUSSION

A. "Resolution" Defined

We have been referring to the resolution capability of various tubes, and it is desirable that an understanding be reached of the restricted sense in which the term has been used. The resolution capability of a system is frequently determined by means of a chart utilizing line wedges or similar graphic symbols. When such a chart is used as a scanned test object, "resolution" is defined as the number of equal black and white lines per inch (perpendicular to the direction of scan) which will be reproduced as separate and distinct lines.[7] This definition, which has been the standard in evaluating the c-r tube resolution discussed in this report, neither restricts the system to a 1-to-1 transfer of picture contrast nor does it require that the areas of the reproduced black and white be equal.

B. Viewing Conditions

The conditions under which a c-r presentation is viewed materially influence the resolution capability of the system, or of the tube. The influence is partially subjective and partially objective, in that, for example, under relatively low ambient light conditions, a reduction in beam current will improve spot size. However, if photographs are to be made of the presentation, reduced beam current may require over-long exposure times, even when using the fastest available films. The inherently pulsed light from the c-r tube introduces a flicker phenomenon, which affects physiological perception and for low-intensity traces generally results, in the case of photographic materials, in a failure of the reciprocity law.[8]

---

[6] Dotted portions of these curves are extrapolated.

[7] Watt, A.D., "Determination of RC 120-B Facsimile Equipment Characteristics," NRL Report R-2885, 26 June 1946.

[8] Henney, K., and Dudley, B., "Handbook of Photography", Whittlesey House, Mc-Graw Hill, New York, 1939, p. 128.

A readily observable characteristic of c-r tube phosphors is the variation in color temperature with changes in beam current or anode voltage. This variation, together with the variation in spectral sensitivity of the eye, affects the determination of resolution capability. The visual acuity of the eye improves slightly[9] with distance from the test object, particularly for viewing distances between 1/2 and 2 1/2 meters if the size of the test object can be adjusted to subtend approximately the same visual angle. It is therefore probable that the optimum viewing distance for resolution determination varies with the observer and with the size of the object viewed, and the determination of resolution capability is thus dependent upon a number of variables not easily controlled or evaluated.

Some arbitrary, standard conditions are required. In the measurements here reported, photographs were made on 4 X 5-inch cut film, using a visually focussed camera located, in the majority of cases, approximately 12 inches from the face of the tube. The traces were also examined by means of a 9-power magnifying glass and viewed from various distances up to six feet. Occasionally, visual inspection indicated better resolution capability than did the photographic method because the low intensity at which such ultimate resolution could be observed was, except for very long exposures, below the threshold for most film.

C. Brightness Contrast

Determination of the line width of a c-r tube by the raster-shrinking, polka-dot, or low-frequency grid modulation techniques amounts basically to determining the presence of space between traces, which in turn becomes a problem of minimum contrast determination. The light intensity produced by a fluorescent spot on a c-r tube has generally been found to have a Gaussian distribution; it may be approximated mathematically by means of a cosine-squared function. Assuming linear addition of light output from two adjacent lines, and neglecting the presence of ambient and scattered light, a 50-percent overlap of the "skirts" of two spots or lines would produce zero contrast ratio and a "flat" field. No overlap between adjacent lines would provide 100-percent contrast ratio, and intermediate values of overlap would give proportionate percentages.

Luckiesh[10] has stated that, at a 50-percent brightness contrast and 10 foot-lamberts background level, the threshold size for normal observers is in the order of 1.3 minutes of arc. If the brightness contrast is reduced from 50 percent to 5 percent, all other conditions

---

[9] Luckiesh, M., and Moss, F.K., "The Dependence of Visual Acuity upon Stimulus Distance." J.O.S.A., 23, 25-29, 1933.

[10] Op. cit.

remaining constant, the minimum resolvable angle increases to 3.53 minutes. A standard 525-line television raster contains a minimum of 483 active bright lines, the remainder being blanked out during the vertical retrace time. Between the bright lines in such a raster there are dark spaces one less in number than the bright traces. The light from an 8 X 6-inch raster on a type 10BP4 ranges from one or two foot-lamberts to a highlight brightness of 20 foot-lamberts, possibly 10 foot-lamberts being a reasonable average. Assuming equal bright and dark line widths in an 8 X 6-inch raster, and a viewing distance of 12 inches, each line or space in a 525-line raster subtends at the observer's eye an angle of 1.8 minutes, which is very nearly at the limit of normal resolution. If such a raster were used to determine resolution capability by either the raster-shrinking or the polka-dot methods, the figure obtained would be adversely influenced by the reduced contrast which occurs when the traces are brought together.

It can be seen that any statement of resolution capability of a system or device should include a reference to the minimum acceptable contrast conditions, in order to make comparisons between systems or components.

D. Effects of Power-Supply Ripple and Radiation

In those figures in which sweep retrace is visible (specifically, Figures 14, 15, and 16) a small superimposed dot modulation of the desired grid modulation can be seen. This extraneous modulation is due to insufficiently filtered second-anode supply (usually an r-f type) and to the direct radiation of the oscillator used in that supply. Although various precautions were taken to exclude this signal, the interference persisted. Two- and three-stage R-C filters in the second-anode supply, and electrostatic shields around r-f portions of the supply, were tried. Of the two, the latter was the more effective. The power-supply oscillator frequency was approximately 200 kc, well above the limit of resolution of the various tubes investigated. Since it appears as an intensity modulation, it reduces the contrast between bright and dark lines. Attempts to synchronize the power-supply oscillator frequency with the desired modulation, in order to minimize the interference, were defeated by the instability of the oscillator with variations in load. The importance of thorough shielding and isolation of r-f type power supplies used in high-resolution systems cannot be over-emphasized, particularly since synchronization with the modulation frequencies is generally not feasible.

VII. CONCLUSIONS

The resolution capabilities of the three types of c-r tubes studied indicate a probable maximum of 125 lines per inch. Thus, assuming a vertical deflection of 7 3/8 inches, perfect synchronization, and low noise levels, an interlaced raster containing a nominal 1000 television lines would be obtainable. Light-output considerations favor the use of the 10FP4 if some compromise is acceptable in line-width requirements.

VIII. ACKNOWLEDGEMENT

For the enlarged photographs illustrating this report the writer is indebted to the Graphic Arts Branch of the Laboratory.

APPENDIX A

EQUIVALENT C-R TUBE BEAM CURRENT FOR SLOW-SPEED SWEEPS

The nominal input to a type 10BP4 c-r tube is 100 ua at 9000 volts, based on a line rate of 15750 cps and a field rate of 60 cps for an 8 x 6-inch raster. Then,

$$\text{Input} = 9000 \text{ v} \times 100 \times 10^{-6} = 0.9 \text{ watt}$$

Assuming equal traced and untraced areas within the raster, the active screen area per field is $8'' \times 6'' \times 2.54^2 \text{ (cm)} \times 1/2 = 155$ sq. cm.

In the normal television raster there are a minimum of 241 1/2 active lines per field, that is, lines actually used in conveying picture information. The remainder of the 262 1/2 lines are blanked out during the vertical retrace. Therefore the width of a line, W, can be computed on the basis of 483 lines completely filling the raster in a 6-inch vertical deflection. Thus,

$$W = \frac{6 \times 2.54}{483} = 0.03155 \text{ cm.}$$

In a 4-line raster (unblanked retrace) with a sweep length of 6 inches, the scanned area is

$$A = 4 \times 6 \times 2.54 \times 0.03155 = 1.923 \text{ sq. cm.}$$

On the basis of the nominal input to the 525-line raster, the permissible input now becomes

$$\frac{0.9 \text{ watt} \times 1.923 \text{ sq. cm}}{155 \text{ sq. cm.}} = 0.01116 \text{ watt}$$

At 10-kv second-anode voltage, the corresponding beam current, I_b, equals $0.01116 \text{ watt} \div 10^4 = 1.1116$ ua.

APPENDIX B

CORRELATION OF MODULATING FREQUENCY WITH LINES-PER-INCH RESOLUTION

In optical terminology both lines and spaces between lines are counted in arriving at a figure of lines per inch in a test chart. In television, there is frequent mention of the number of "lines" in a raster, considering only the bright traces as lines; the space between them, if any, is ignored. Thus 100 lines per inch in a television system, obtained by counting visible traces, is directly comparable to 200 lines per inch in an optical system. In this report the optical terminology has been used.

The time required for one cycle of sweep voltage at a rate of 120 cycles per second is

$$T_1 = 1/120 = 8.33 \times 10^{-3} \text{ second}$$

$$= 8.33 \text{ milliseconds}$$

For 50-kc modulating frequency, the time of one cycle of modulation is

$$T_2 = \frac{1}{50 \times 10^3} = 20.0 \times 10^{-6} \text{ second}$$

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

Each cycle of modulation produces two lines or dots, M. As the sweep circuit was designed, the trace time/retrace time ratio was 10:1. With this ratio, the actual trace time becomes

$$T' = 10/11 \times 8.33 \text{ milliseconds}$$

$$= 7.56 \text{ milliseconds}$$

From a consideration of these parameters, a formula for the equivalent lines-per-inch can be derived:

$$\text{Lines per inch} = \frac{T' \times M}{T_2 \times L}$$

where T' is the actual trace time, M is the number of lines per modulation cycle, T_2 is the time of one cycle of modulation, and L is the length of the trace in inches.

For 50-kc modulation frequency, the equivalent resolution, R, is

$$R = \frac{7.56 \times 10^{-3} \times 2}{20 \times 10^{-6} \times 6}$$

= 126.2 lines per inch.

For other modulating frequencies, the resolution increases directly as the frequency ratio, or as indicated in Table 2.

TABLE 2

Mod. Freq. Kc	Lines per Inch	
	Actual	Nominal
50	126.2	125
60	151.5	150
70	176.5	175
100	252.4	250

APPENDIX C

CORRECTION FACTOR
FOR
RESOLUTION CAPABILITY
DETERMINED FROM A NONLINEAR SWEEP

The sweep voltage used in deflecting the c-r beam across the tube face was generated by charging a capacitor through a high resistance, resulting in a rise in voltage across the capacitor with time. Although this rise is exponential, it may be approximated by a parabolic function. The voltage wave form is converted into an approximately equivalent current waveform for deflection of the c-r beam, but with deflection-tube distortion added in such fashion as to produce a distance-versus-time sweep characteristic with upward curvature.

A parabolic relationship for the deflection of a fixed 6-inch sweep length and a fixed sweep duration of 7.5 milliseconds may be expressed as $S = 0.107\ t^2$, where S is the linear distance along the trace and t is the time in milliseconds the trace is being produced. An exponential relationship for the same conditions may be expressed as $S = E^{0.260T} - 1$. These two curves may be compared with one for a truly linear trace, $S = 0.8t$ (Figure 23).

For a modulating frequency of 66 kc, 66 cycles or "dots" should appear per millisecond sweep time on a linear trace. This, in optical terminology, corresponds to 132 lines per millisecond. For a parabolic sweep and a constant modulation frequency of 66 kc, the upper curve of Figure 23 shows the number of lines produced per inch of deflection as a function of sweep time. Of course, during the first portion of the sweep the relatively high number of lines per inch produces a continuous-appearing trace, and during the latter portion of the trace the "spots" are visible. Commencing at the quasi-linear end of the trace and working toward the compressed end, average lines-per-inch figures can be computed for various percentages of quasi-linear trace distances. These have been plotted in Figure 24.

APPENDIX D

R-F BANDWIDTH REQUIREMENTS
FOR A 1000-LINE TELEVISION SYSTEM

Assuming that the vertical field rate for the 1000-line interlaced system remains the same as the present 525-line interlaced system, the horizontal trace time would be decreased as the number of lines increased. To produce a 1000-line raster in 6 inches vertical deflection (keeping the present standards of utilization), a tube resolution capability of

$$R = \frac{1000 \times 0.92}{6} = 153.7 \text{ lines per inch}$$

would be necessary. It is evident that in order to use a type 10BP4 c-r tube, with its resolution capability of 125 lines per inch, it will be necessary to increase the vertical sweep length W to

$$W = \frac{0.92 \times 1000}{125} = 7.35 \text{ inches.}$$

The corresponding horizontal sweep length would then become

$$L = 1.33 \times 7.35 = 9.78 \text{ inches,}$$

and appreciable rounding of the corners of the picture would occur.

Keeping the present trace time of 84 percent of the full horizontal sweep period the new horizontal trace time T would be

$$T = \frac{0.84 \times 525}{15750 \times 1000} = 28 \text{ microseconds.}$$

If we wish to have equal horizontal and vertical resolution, it will be necessary to have $920 \times 1.33 \times 1/2 = 613.3$ cycles of modulation occurring in one horizontal trace, since one cycle of modulation produces two "lines". One cycle of this modulation appears on the above trace for a time

$$T' = \frac{28.0 \times 10^{-6}}{613.3} = 0.04565 \times 10^{-6} \text{ second,}$$

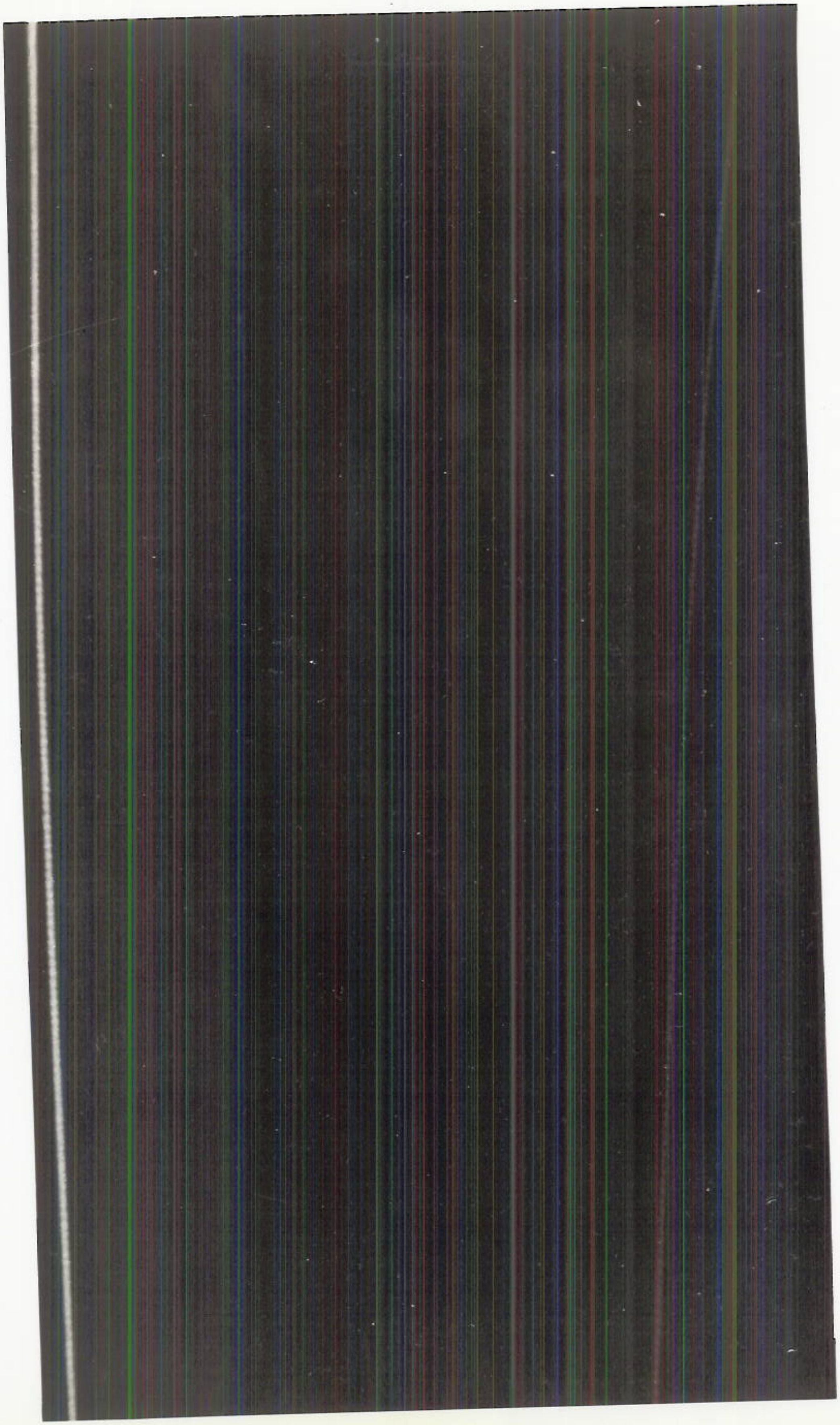
corresponding to a modulating frequency of 21.9 megacycles.

Type 10BP4 176 lines per inch

Figure 2

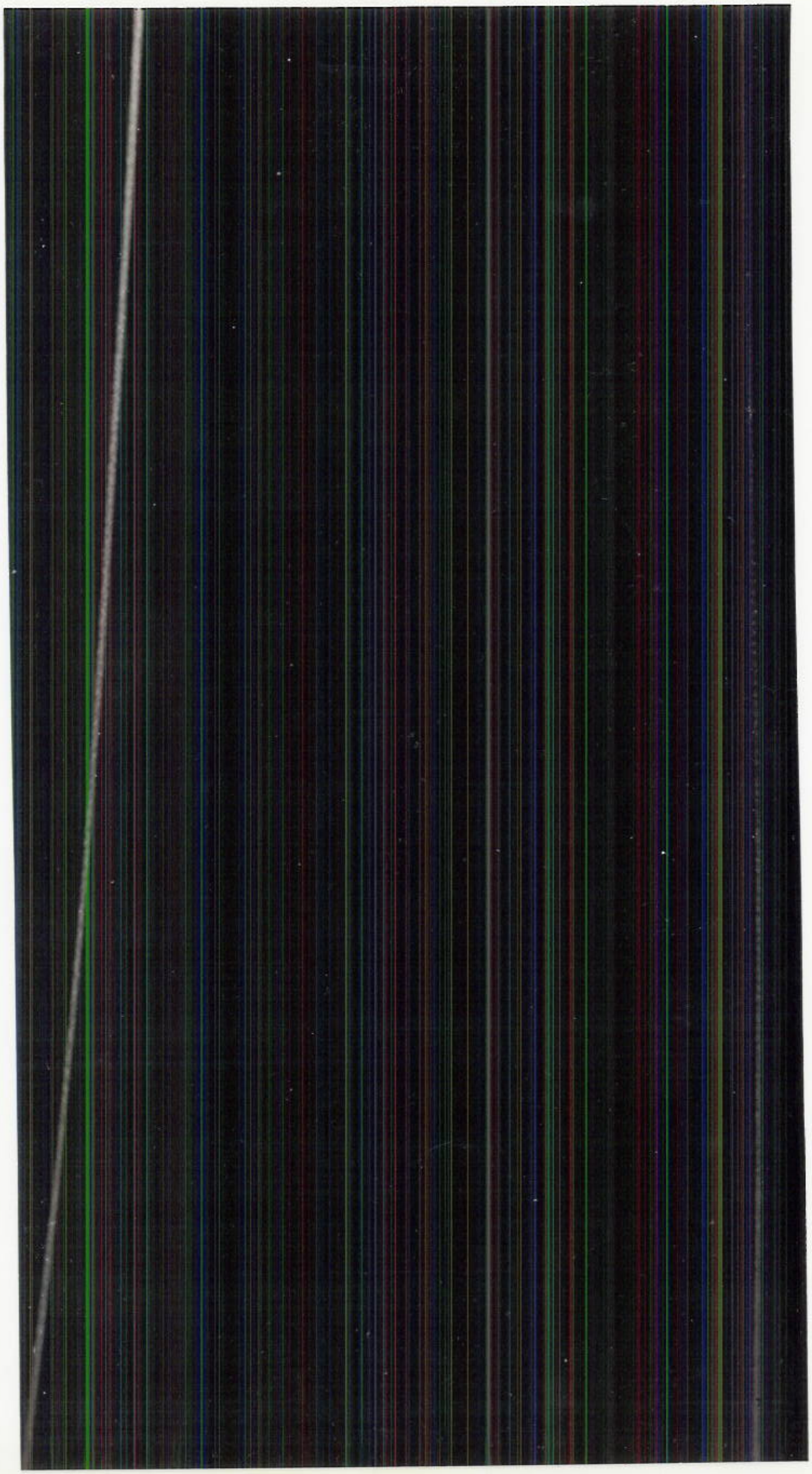
Type 10BP4 150 lines per inch 20 ua beam current

Figure 3



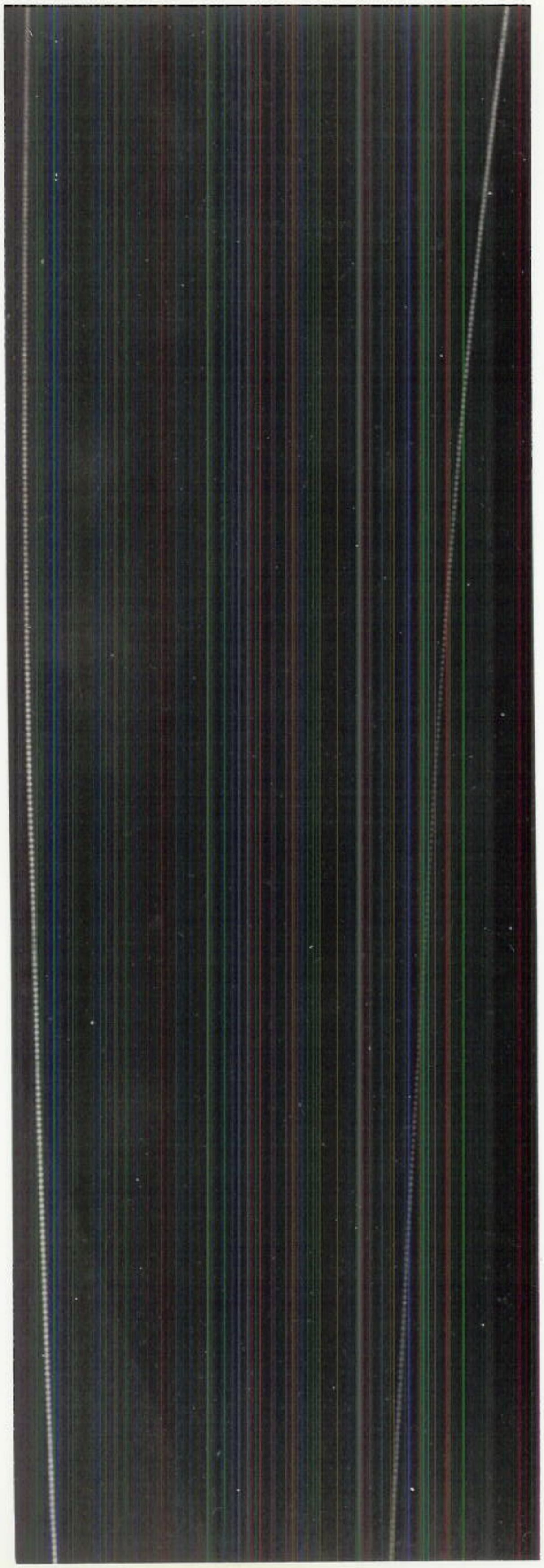
Type 10BP4 175 lines per inch 1.2 ua beam current

Figure 4



Type 10BF4 175 lines per inch 1.2 ua beam current

Figure 5

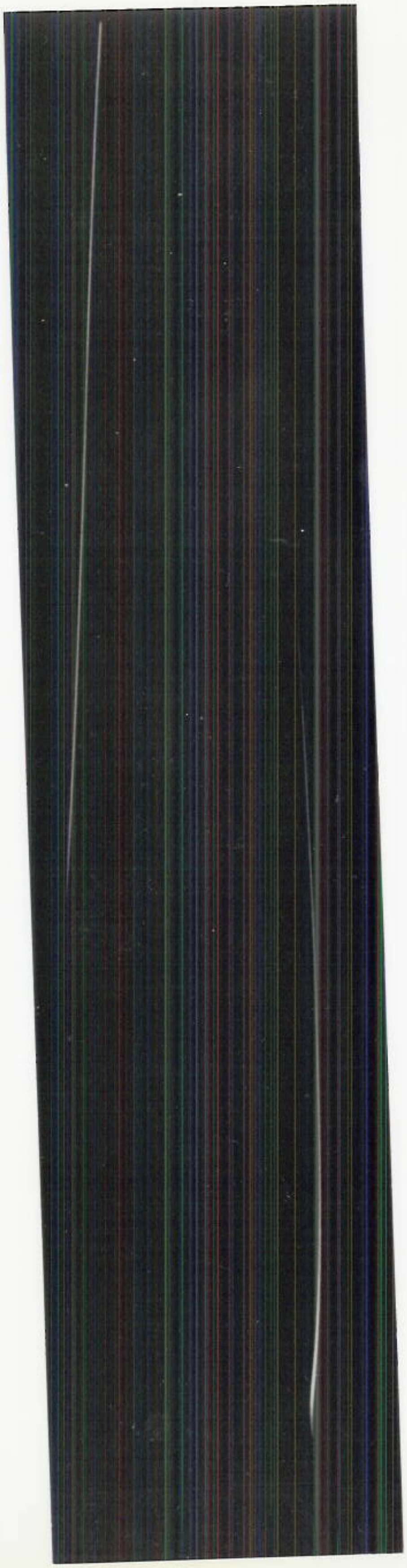


Type 10BP4 175 lines per inch 11.5 kv, 1 ua beam

Figure 6

Type 10BP4 Gated beam signal 175 lines per inch

Figure 7

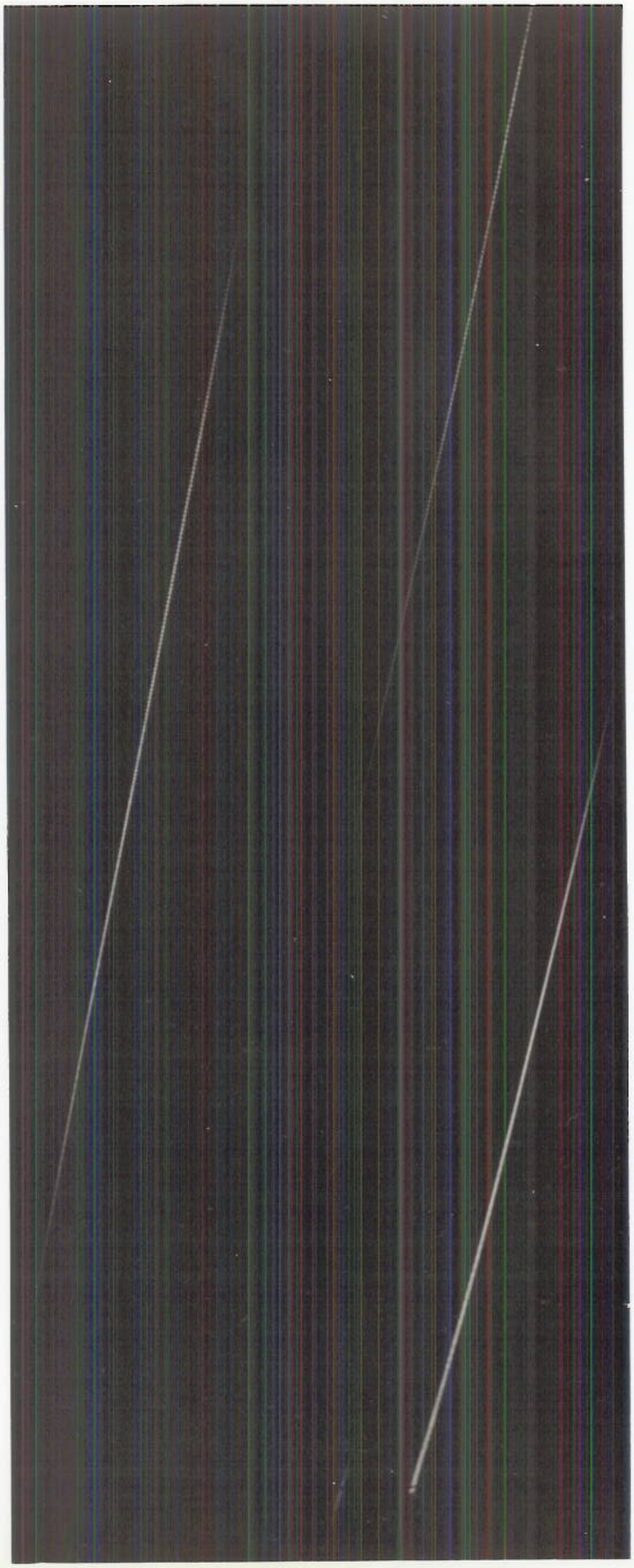


Type 10BP4 Gated beam signal, 175 lines per inch

Figure 8

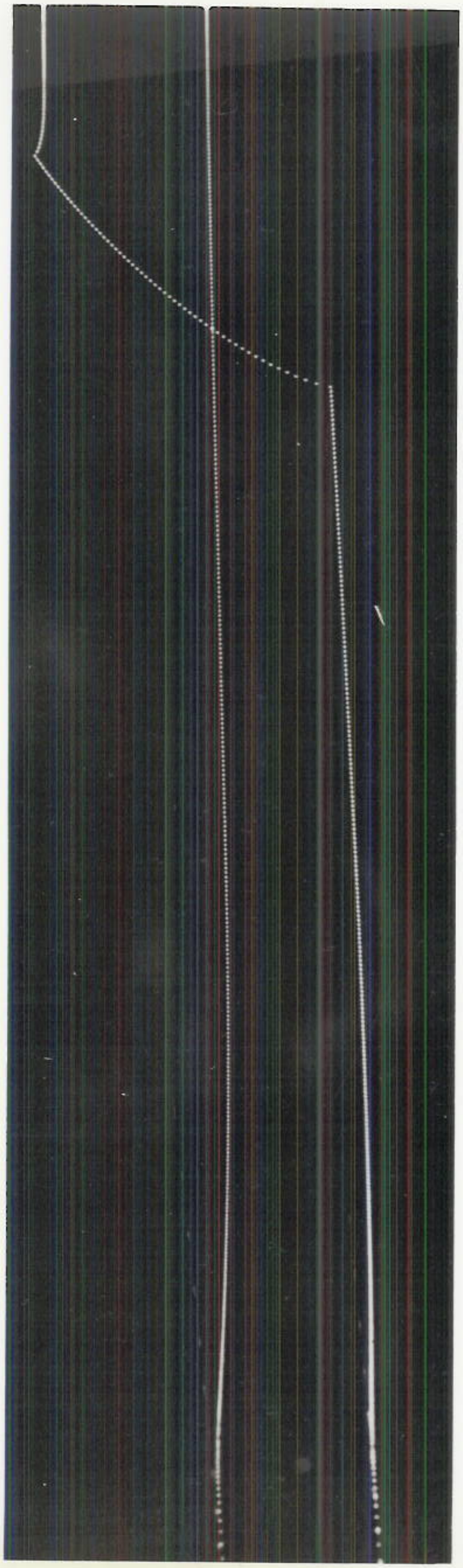
Type 10BP4 150 lines per inch

Figure 9



Type 10FP4 150 lines per inch

Figure 10

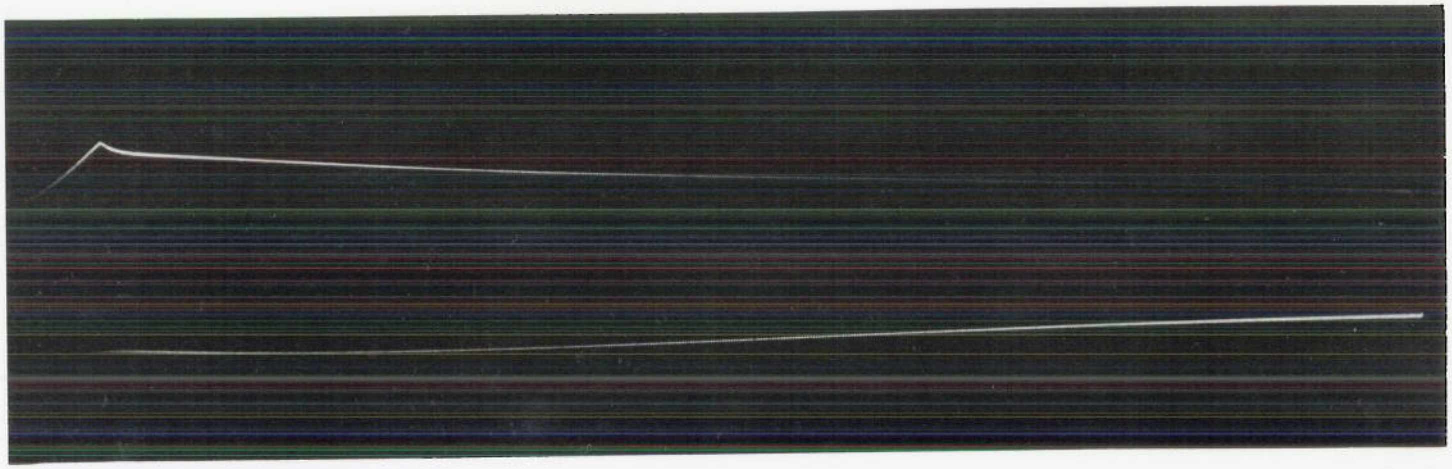


Type 10FP4 150 lines per inch

Figure 11

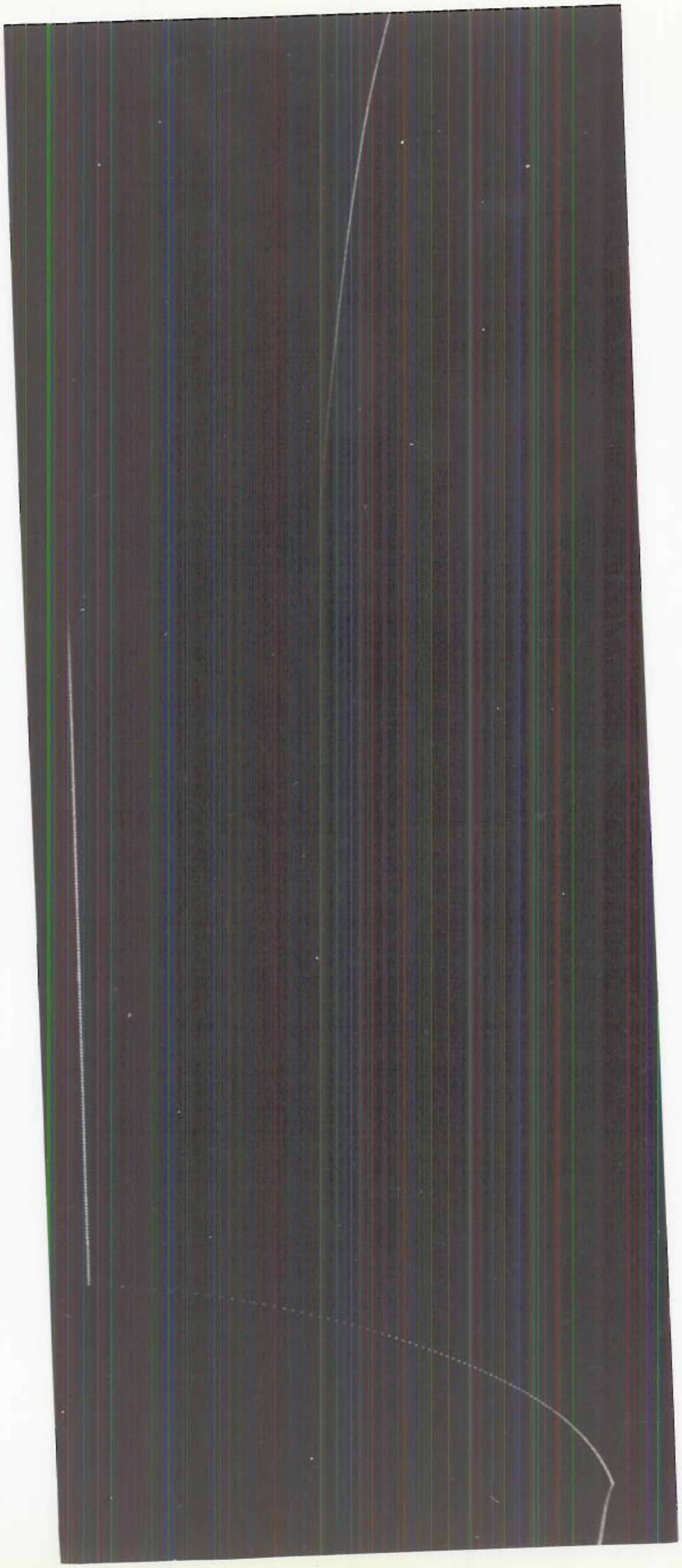
Type 10FP4 100 kilocycle intensity modulation
(Nominal 250 lines per inch)

Figure 12



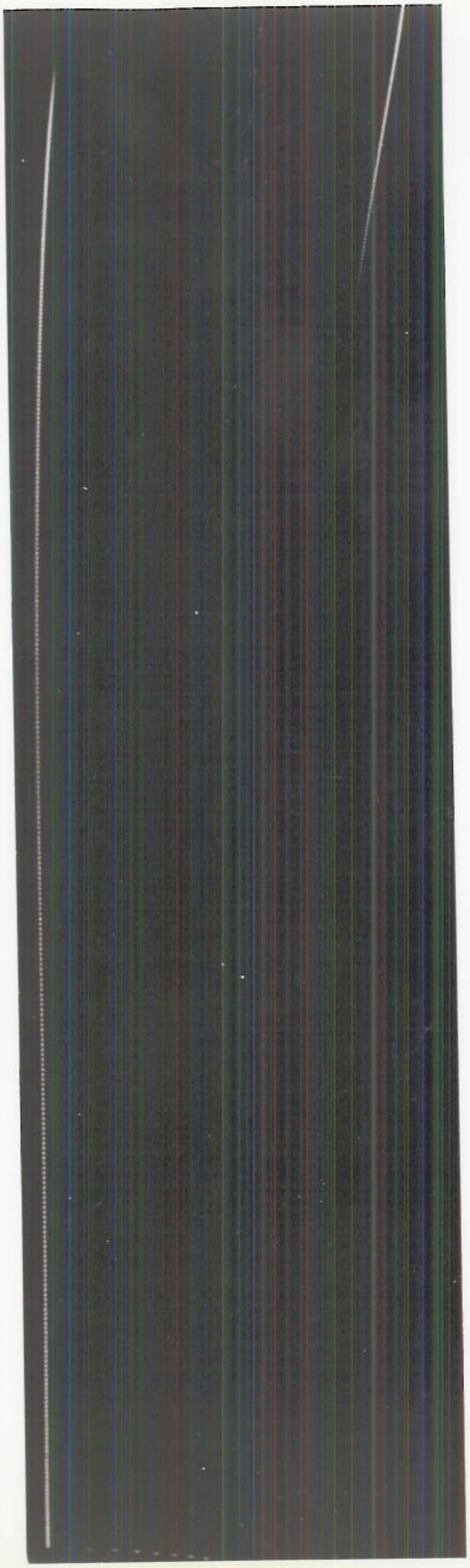
Type 10FP4 185 lines per inch

Figure 13



Type 10FP4 175 lines per inch

Figure 14

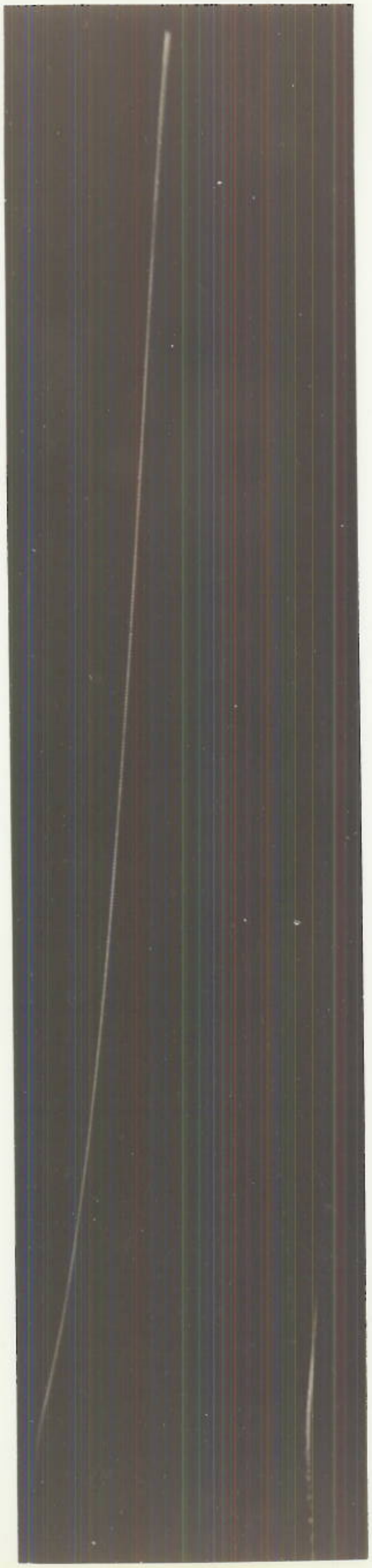


Type 10FP4 125 lines per inch

Figure 15

Type 16AP4 125 lines per inch

Figure 16



Type 16AP4 165 lines per inch

Figure 17

TYPE 10BP4 CHARACTERISTICS
LINE-WIDTH MEASUREMENTS
AT
CONSTANT BEAM CURRENT = 1 μa
AND
VARIOUS FIRST-ANODE POTENTIALS

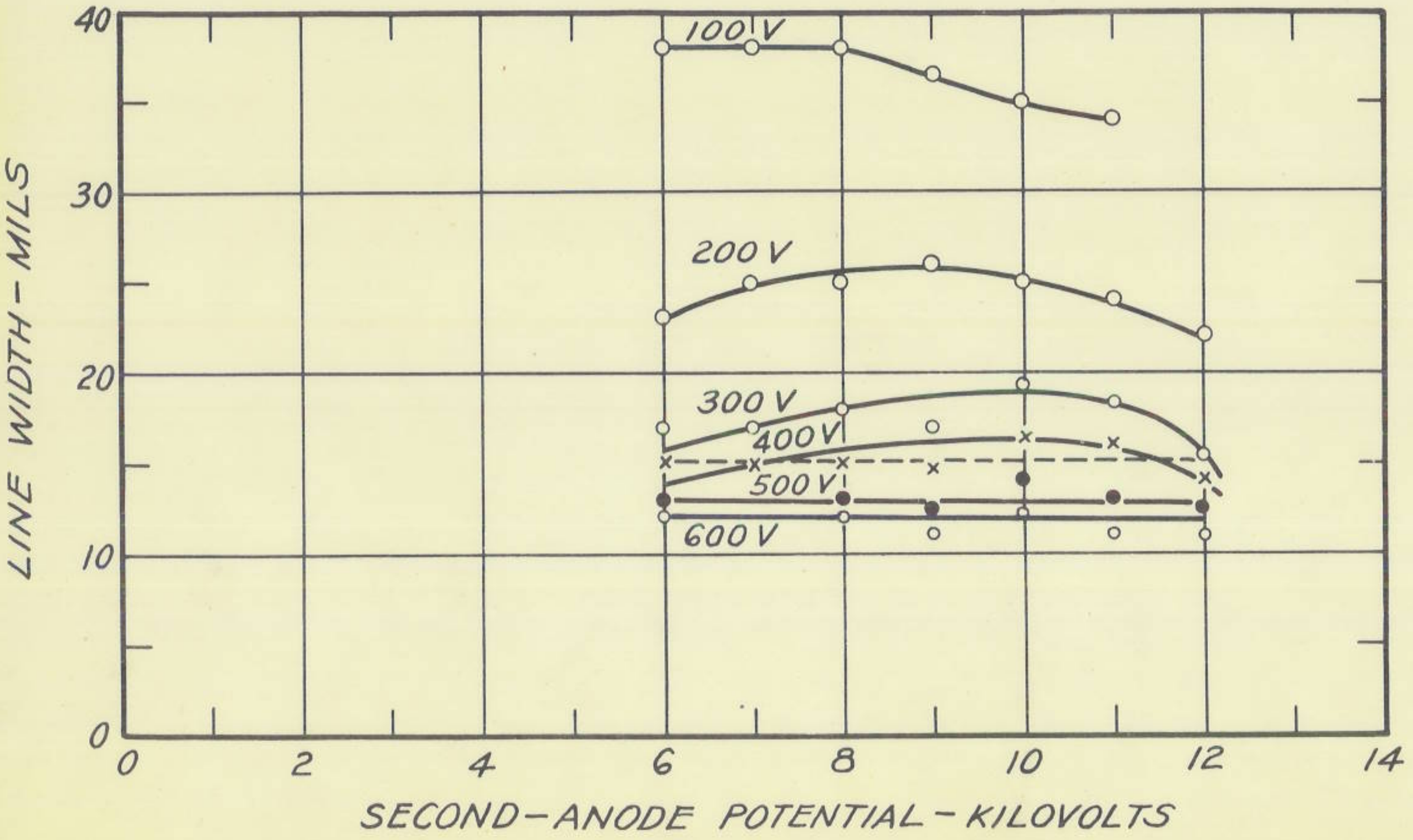


Figure 18

TYPE 10BP4 CHARACTERISTICS LINE-WIDTH MEASUREMENTS AT CONSTANT BEAM CURRENT = 5 μa AND VARIOUS FIRST-ANODE POTENTIALS

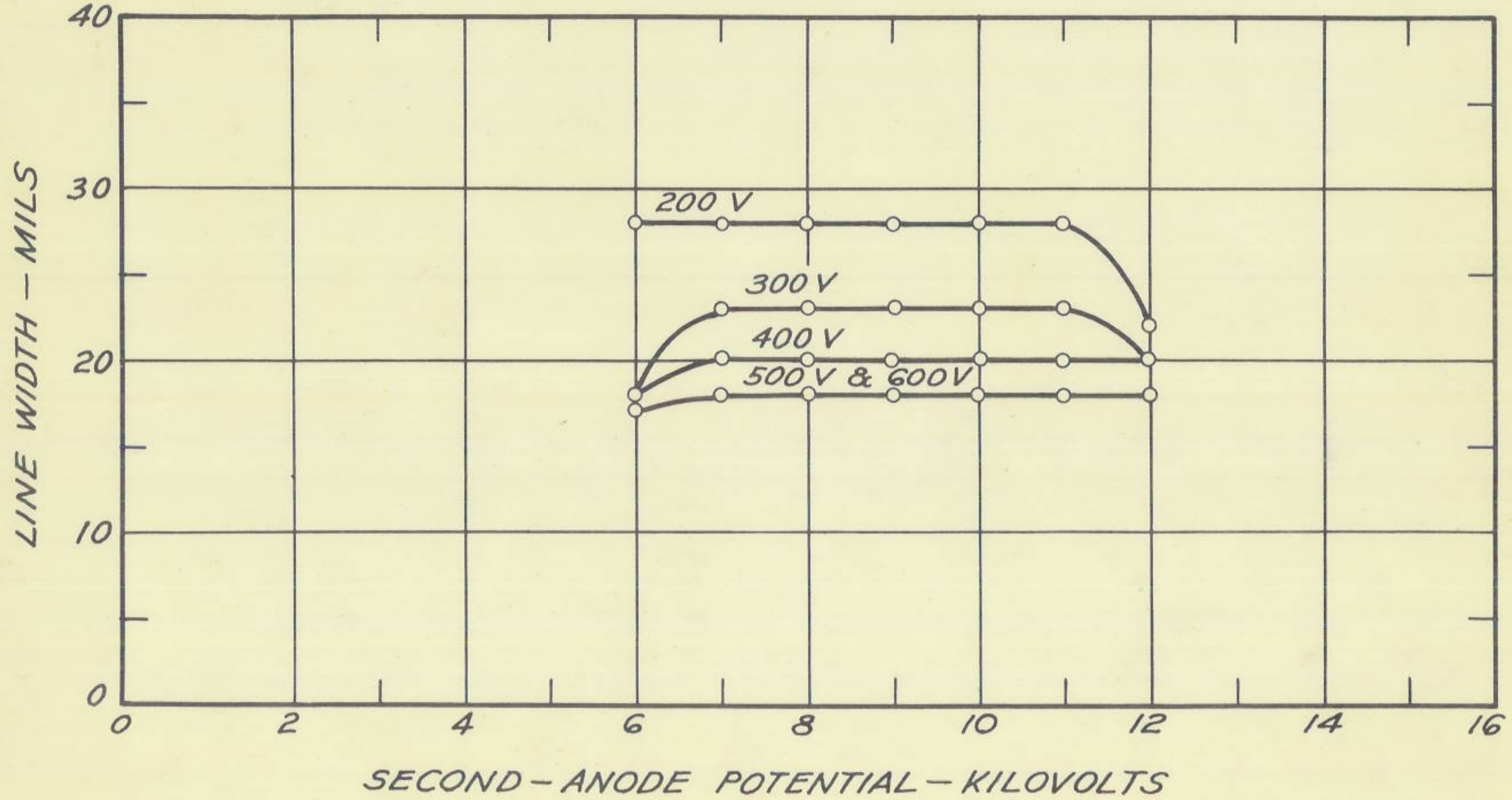


Figure 19

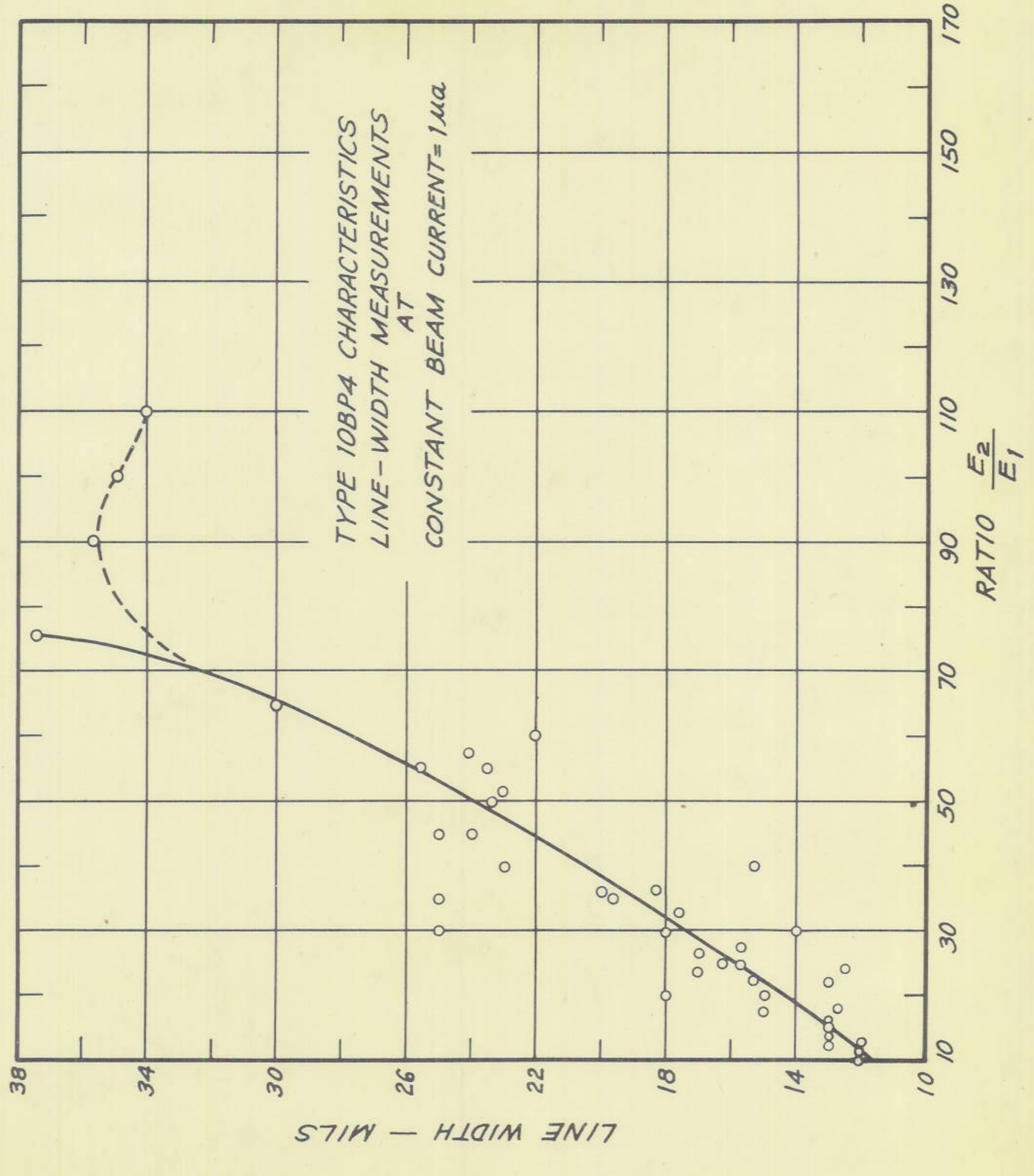

TYPE 10BP4 CHARACTERISTICS
LINE-WIDTH MEASUREMENTS
AT
CONSTANT BEAM CURRENT = 1 μa
LINE WIDTH — MILS
38
34
30
26
22
18
14
10
RATIO $\frac{E_2}{E_1}$
10
30
50
70
90
110
130
150
170

Figure 20

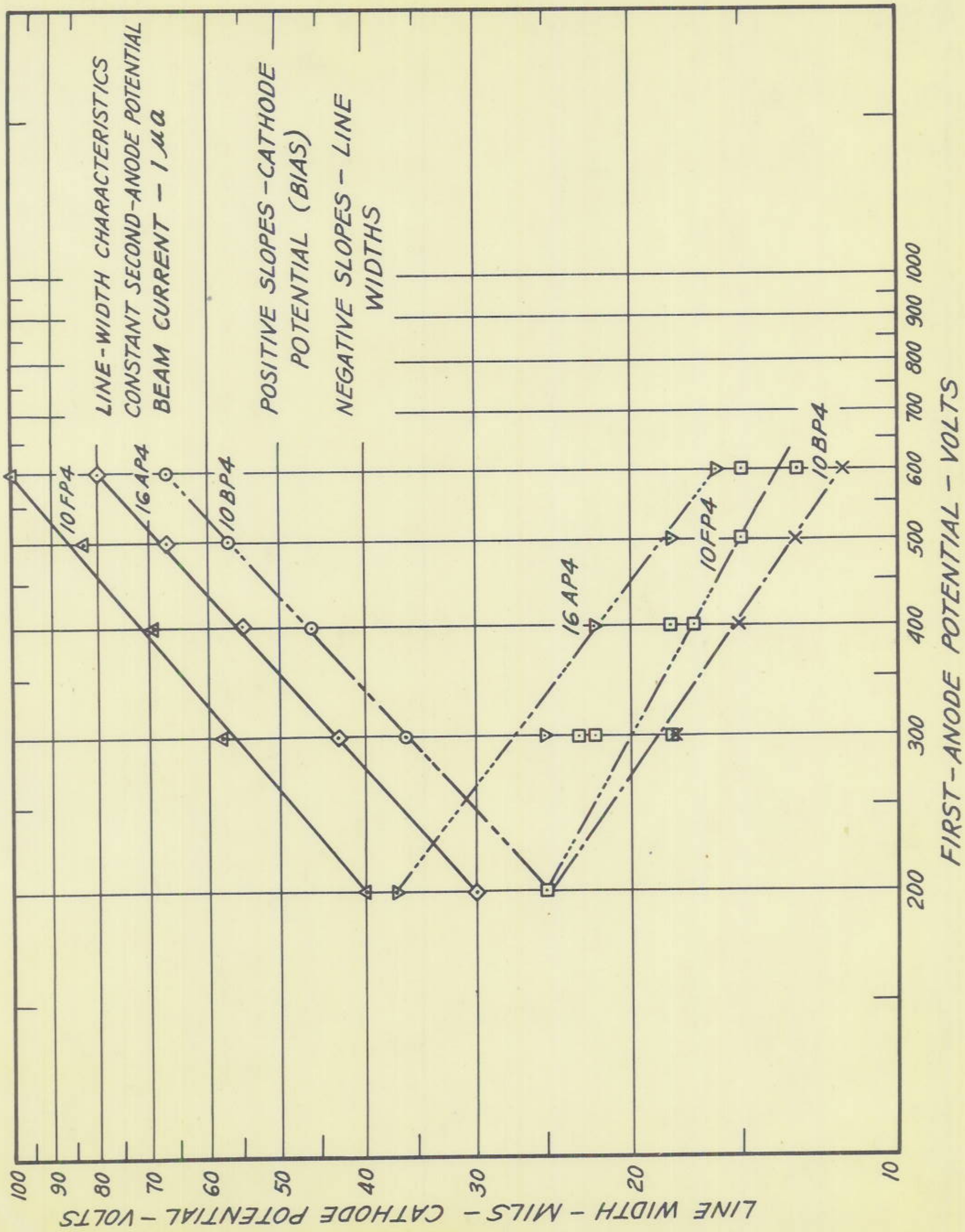

LINE-WIDTH CHARACTERISTICS
CONSTANT SECOND-ANODE POTENTIAL
BEAM CURRENT – 1 μa
POSITIVE SLOPES – CATHODE POTENTIAL (BIAS)
NEGATIVE SLOPES – LINE WIDTHS
10FP4
16AP4
10BP4
16AP4
10FP4
10BP4
100
90
80
70
60
50
40
30
20
10
LINE WIDTH – MILS – CATHODE POTENTIAL – VOLTS
200
300
400
500
600
700
800
900
1000
FIRST-ANODE POTENTIAL – VOLTS

Figure 21

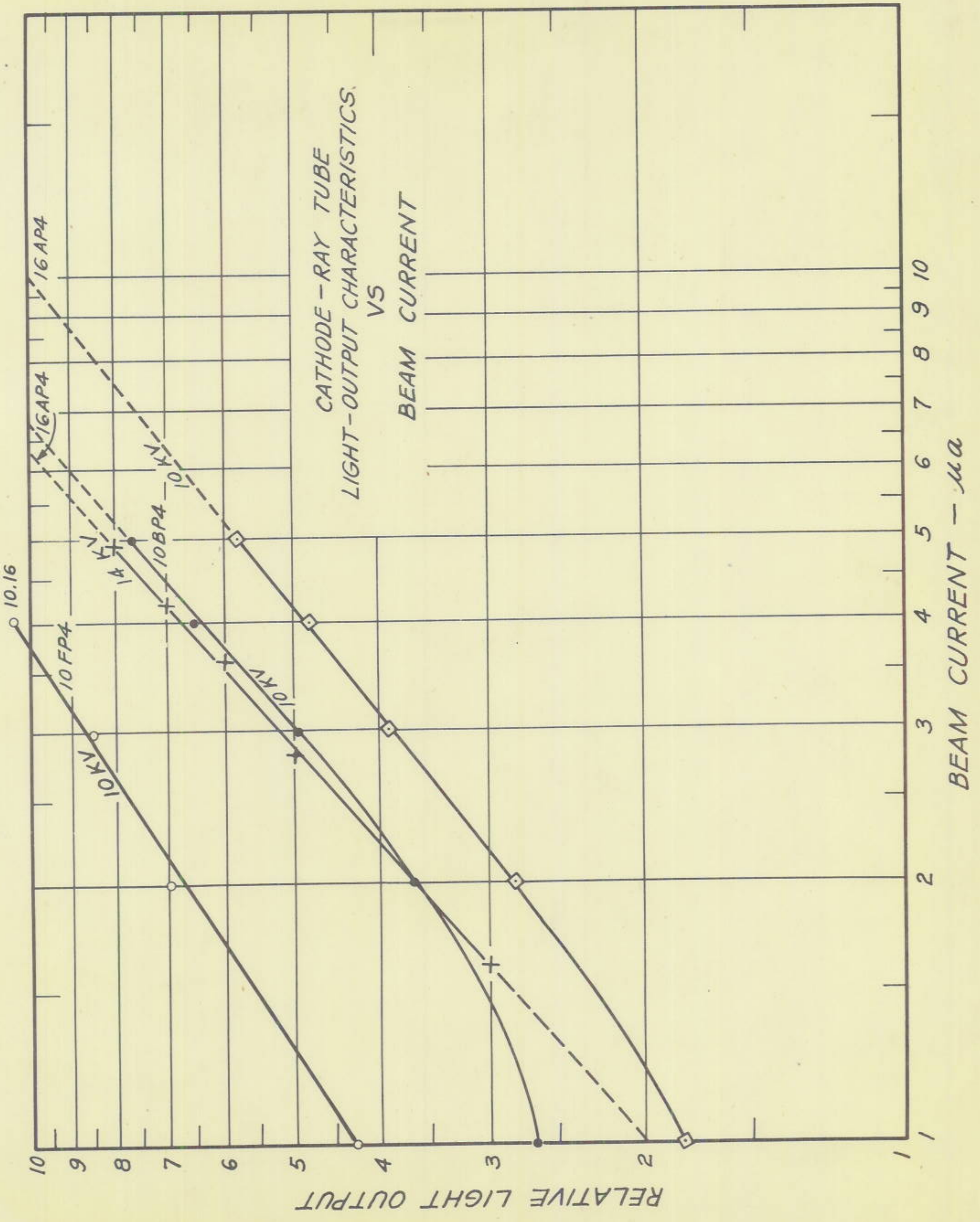

CATHODE-RAY TUBE
LIGHT-OUTPUT CHARACTERISTICS
VS
BEAM CURRENT
16AP4
16AP4
10KV
14KV
10BP4
10.16
10FP4
10KV
10KV
RELATIVE LIGHT OUTPUT
10
9
8
7
6
5
4
3
2
1
BEAM CURRENT – μa
1
2
3
4
5
6
7
8
9
10

Figure 22

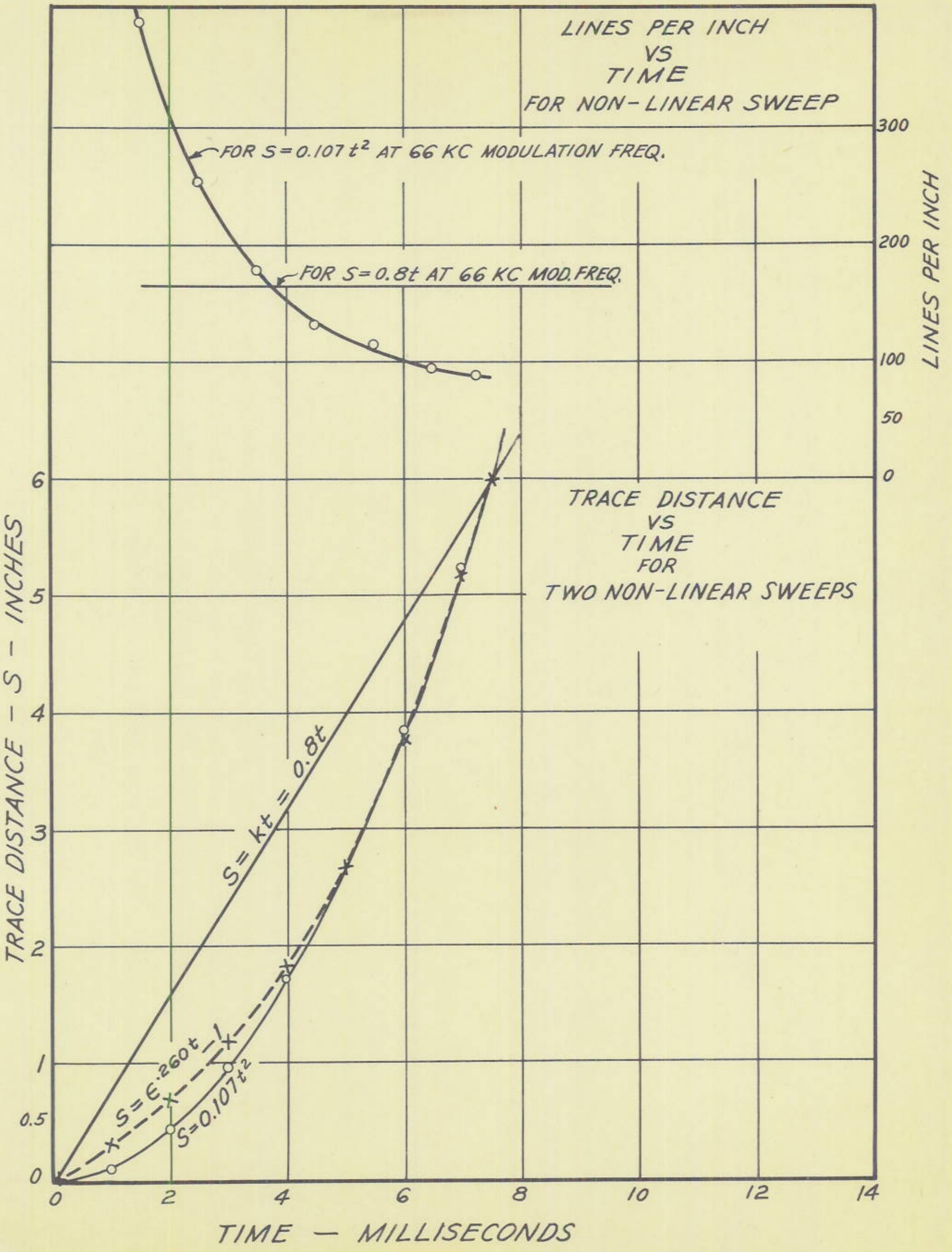

LINES PER INCH
VS
TIME
FOR NON-LINEAR SWEEP
FOR S=0.107 t² AT 66 KC MODULATION FREQ.
FOR S=0.8t AT 66 KC MOD. FREQ.
300
200
100
50
0
LINES PER INCH
TRACE DISTANCE
VS
TIME
FOR
TWO NON-LINEAR SWEEPS
S = kt = 0.8t
S=ε^.260t -1
S=0.107t²
TRACE DISTANCE - S - INCHES
0
0.5
1
2
3
4
5
6
0
2
4
6
8
10
12
14
TIME — MILLISECONDS

Figure 23

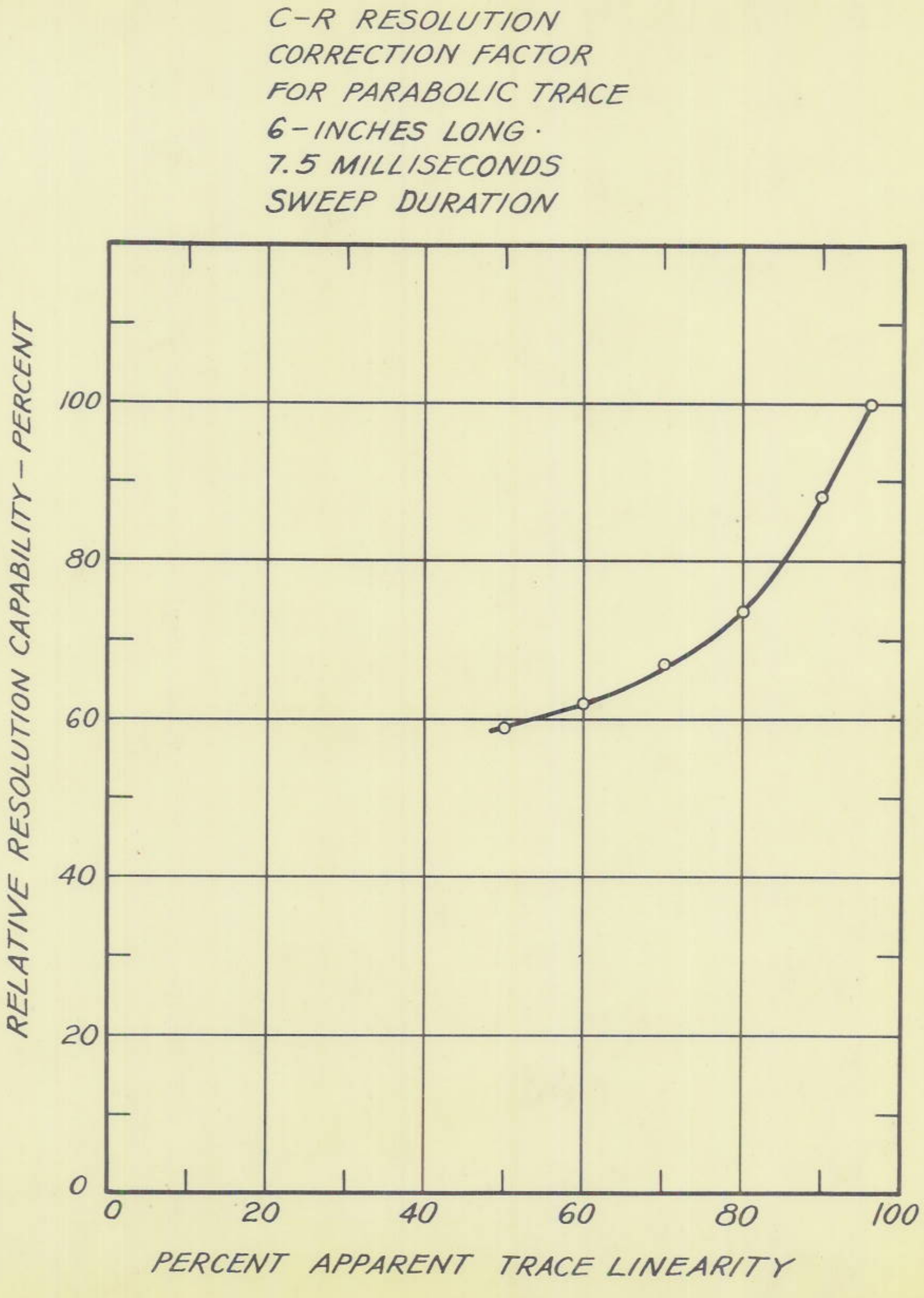

C-R RESOLUTION
CORRECTION FACTOR
FOR PARABOLIC TRACE
6-INCHES LONG ·
7.5 MILLISECONDS
SWEEP DURATION
RELATIVE RESOLUTION CAPABILITY - PERCENT
0
20
40
60
80
100
0
20
40
60
80
100
PERCENT APPARENT TRACE LINEARITY

Figure 24