Optimum spot size for raster-scanned monochrome CRT displays

Jim Hagerman

Abstract — It is generally regarded that the optimum 50% spot width is equal to the raster line spacing for CRT displays. This paper presents a mathematical analysis to determine the optimum spot width. The analysis indicates the optimum spot width is slightly less than 0.9 times the line spacing.

Keywords — *CRT spot size, monochrome CRTs, raster-scanned CRT.*

1 Introduction

The optimum picture in a raster-scanned CRT display is a compromise between resolution and the ability to smooth out a full-field condition. In order to obtain a so-called smooth raster, the raster scan lines must be close enough to each other to meld together and form a solid image. On the other hand, to achieve good resolution, the scan lines must be far enough apart so that if every other scan line were on, a high level of modulation would exist. Since line spacing is not usually variable but fixed in most designs, spot width becomes the variable and must be chosen accordingly. A longstanding rule of thumb has been to set the 50% spot width equal to the line spacing. In fact, to prevent too small a spot, the latest ANSI HFS/100 standard recommends a spot width greater than 0.5 times the line spacing.

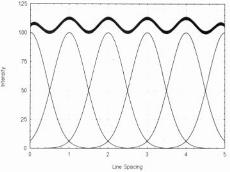

FIGURE 1 — Individual raster lines and resulting total for $s_{50} = 1.0$.

A previous analysis (calculated by different means[1]) showed that the optimum picture was obtained when the 5% spot width was 2.21 times the line spacing. This equates to a 50% spot width of 0.94 times the line spacing.

$$s_{50} = 0.94\lambda, \tag{1}$$

where s_{50} is the 50% spot width and λ is the line spacing. This is very close to the above rule-of-thumb law.

A new kind of analysis is presented here which arrives at a very similar result.

2 Raster

At reasonable beam current levels, the spot intensity can be approximated by a Gaussian. This is given by

$$g(x) = e^{-[(x-\mu)^2/2\sigma^2]}. \tag{2}$$

A raster is formed by overlapping many scan lines side by side. A computer program was written to generate several Gaussians, each spaced 1λ (1 line) apart using spot width as the variable. The program would calculate the sum of these Gaussians (Fig. 1). The sum is the equivalent luminance response of the raster, a cross section of what you would see if you were looking at the displayed image.

Equation 2 has two variables, μ and σ. The former is used by the program to generate the centers of each Gaussian. The latter is the standard deviation and determines the width of each Gaussian. It does not, however, equal the 50% spot width. The 50% spot width s_{50} must be related to σ. Equation 2 is rearranged and solved for σ:

$$\sigma = \frac{s_{50}}{2\sqrt{-2\ln(g)}}. \tag{3}$$

The amplitude of the Gaussian g is set to 0.5. This results in

$$\sigma = 0.425\, s_{50}. \tag{4}$$

The amount of smoothness in the raster is the modulation between the maximum and minimum amplitudes. This modulation is defined by

$$\text{Modulation} = \left(\frac{\max - \min}{\max + \min}\right). \tag{5}$$

The modulation for several values of s_{50} per line spacing is plotted in Fig. 2.

3 Performance

The optimum performance of a display is achieved if there is no modulation when every line is on (full field), and 100% modulation when every other line is on (half-field). This condition is not possible with CRT displays. A compromise must be reached. It is suggested here that the best compromise occurs when each of these parameters suffers equally; *i.e.*, the modulation at full field is some percentage less than 100%, while the modulation at half-field is the same percentage greater than 0%. The point at which there is equal

---

*Member, SID.

Received 11/27/92; accepted 8/11/93.

The author is with Hughes-JVC Technology Corp., 2310 Camino Vida Roble, Carlsbad, CA 92009; telephone 619/929-5312, fax -5708.

0734-1768/93/0103-0367$1.00

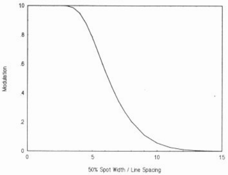

FIGURE 2 — Raster modulation as a function of s_{50}/λ.

modulation loss for both cases occurs at a spot-width to line-spacing ratio of 0.894. Here, the raster has 11.7% modulation and alternating on/off lines have 88.3% (or 100% − 11.7%) modulation. This is the optimum spot size:

$$s_{50} = 0.894\lambda. \tag{6}$$

This analysis has focused on the performance of a raster. It is interesting to note how well our optimum spot size performs along a scan line rather than across one. In this case, the Gaussian spot is convolved with a sine wave (beam-current function) instead of an impulse function. Assuming infinite bandwidth in the video amplifier, it has been shown[5,8] that the modulation can be given by

$$\text{Modulation}_{\text{sine wave}} = e^{-[(\pi^2/4\ln 2)\,(s_{50}\nu)^2]}, \tag{7}$$

where ν is the spatial frequency. If we look at spatial frequency which is one-half the line spacing, we get the equivalent of an on/off raster condition, but in the scanned direction, *i.e.*, vertical lines rather than horizontal lines. Here, we set

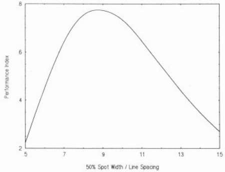

FIGURE 3 — Display performance, from Ref. 9.

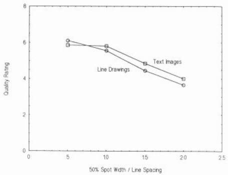

FIGURE 4 — Display quality, from Knox (Ref. 6).

$$\nu = \frac{1}{2\lambda}. \tag{8}$$

Combining Eqs. (6)–(8), we get a modulation at this frequency of 49.1%. Although coincidental, this is surprisingly close to 50% – a modulation which seems very natural.

It is also interesting to see how critical the optimum spot width is. This will help determine the allowable tolerance on spot width. A performance figure of merit that gives equal weight to both the full-field and half-field conditions can be given by

$$\text{Performance} = M_{\text{half}}/(1 - M_{\text{full}}), \tag{9}$$

where M_{half} and M_{full} are the modulation of the half-field and full-field conditions, respectively. This equation is an empirical description of the optimal criteria as previously given. Although mathematically sound, this function will later be found to be somewhat in error. Equation (9) is plotted in Fig. 3. The peak is not very sharp, giving a range of values for s_{50} that maintains a high value of performance, including the unity rule of thumb.

4 Experimental data

Several years ago experiments were performed by Knox[6] to measure the display quality for different spot-width to line-spacing ratios. These data are shown in Fig. 4 using a quality rating from 0 to 8, 8 being the highest. The images used were mechanical line drawings and text images. The image quality reaches a maximum at a ratio of about 1.0 and remains constant as the ratio decreases.

It can be seen that the shape of this curve is not the same as predicted above in Fig. 3. Apparently, the results of Eq. (9) are exaggerated and do not reflect actual experimental data, except that they agree that the optimum ratio is less than 1.0.

5 Conclusion

A mathematical approach to finding the optimum spot-width to line-spacing ratio is given. The optimum ratio is 0.894. This correlates well with earlier work, experimental data, and a longstanding rule of thumb.

Acknowledgments

The author wishes to thank Dr. Carlo Infante for his reviews and comments of previous drafts and to the management of Hughes-JVC Technology for encouraging this analysis.

References

1 P G J Barten, "Optical Performance of CRT Displays," *Proc 1st Intl Display Research Conf*, 160-165 (Sept. 1981).

2 G M Murch and L Virgin, "Resolution and Addressability: How Much is Enough?" *SID Intl Symp Digest Tech Papers*, 101-103 (1985). G M Murch, L Virgin, *et al*, "Resolution and addressability: how much is enough?" *Proc SID* **26**, 305-308 (1985).

3 C Infante, "All You Ever Wanted to Know About CRTs and Monitors but Were Afraid to Ask," (private communication, Digital Equipment Corp., March 1989).

4 L Virgin, "Understanding and Evaluating a Computer Graphics Display," *Information Display*, 17-19 (December 1987).

5 P G J Barten, "Evaluation of CRT Displays with the SQRI Method," *SID Intl Symp Digest Tech Papers*, 445-448 (1988).

6 S Knox, "Resolution and Addressability Requirements for Digital CRTs," *SID Intl Symp Digest Tech Papers*, 26-29 (1987).

7 C Infante, "Introduction to CRT Systems," *SID Seminar Lecture Notes*, Vol. I, p. xx (1986).

8 C Infante, "On the Resolution of Raster-Scanned CRT Displays," *Proc SID*, **26**, 23-36 (1985).

P G J Barten, "Resolution of data display tubes, *Proc SID* **25**, 35-42 (1984).

G M Murch and R J Beaton, "Matching display resolution and addressability to human visual capacity," *Displays* **9**, 23-26 (Jan. 1988).