Video Amplifier Performance Criteria for High Resolution Displays

by

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Abstract:

This paper uses theoretical and mathematical models and calculations to determine the optimum performance requirements for a video amplifier used in a CRT display. The VR295 and it's competition are used throughout for examples.

Competition & the Myth of JMHz & DPI:

There is a direct relationship between risetime and bandwidth. For a first order system, or one pole approximation, the bandwidth (-3 dB point) is given by

$$f = \frac{0.35}{(\text{risetime})}$$

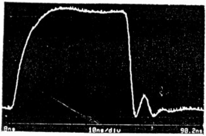
where risetime is from the 10% to 90% points.

The maximum bandwidth for a 3.5 ns risetime is 100 MHz. But, several Japanese manufacturers specify their products as follows:

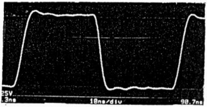
Monitor	risetime	bandwidth
Sony GDM1950	5 ns	100 MHz
Ikegami DM2010	3.5 ns	100 MHz
Matsushita TX2020	5 ns	140 MHz
Mitsubishi C8918	3.5 ns	110 MHz
Hitachi HM5219	3 ns	150 MHz

Only the Ikegami specs are possible, the others cannot be physically realized. This leads me to introduce a new unit of measurement, the Japanese Megahertz, JMHz.

Knowing that the JMHz is not real, it is necessary to test if the risetime specifications themselves are real. A Hitachi 4219 monitor with a specified risetime of 5.0 ns was measured and compared with a VR295. The photographs below tell the story.



Hitachi: tr = 3.5 ns, tf = 11 ns



VR295: tr = 4.5 ns, tf = 4.5 ns

Another misleading parameter is dots-per-inch, dpi. The VR295 can address 1280 pixels in 342 mm, or 95 dpi. However, the visual resolution is determined by the CRT spot size, which for the VR295 is 1.05 mm in the center, 1.8 mm at the corners. The minimum spacing required to resolve dots is 2 sigma (sigma is the standard deviation of a gaussian distribution), given by the shrinking raster method. The spot size is also 2 sigma. Therefore, the resolvable dpi is given by:

$$\text{dpi} = \frac{2 * 25.4}{(\text{spot size in mm})}$$

This gives 48 dpi in the center, 28 dpi in the corners.

This is where the resolution to addressability ratio comes in. It can be described:

$$R/A = \frac{(\text{spot size})}{(\text{pixel size})}$$

For the VR295, this is 3.9 center, 6.7 corners. This is the same as saying a single spot displayed is equal in diameter as 4 (or 7) pixels. For monochrome, a good R/A ratio would be 1. Reference [6] suggests a ratio of 0.8, to insure that individual lines and dots are visible. For color, however, due to the drawbacks of a shadow mask, reference [7] recommends a ratio somewhere between 1 and 2. Obviously, the CRT chosen for the VR295 is not optimal.

Prior Art:

There are several rules-of-thumb that have been used to design displays. For bandwidth, BW, reference [3] promotes that to resolve (the ability to separate) an on/off pixel pattern,

$$BW > \frac{1}{2T}$$

where T is the pixel time. For the VR295, this gives 56.64 MHz.

Reference [5] suggests the formula

$$BW = 0.7151 * \frac{wn^2N}{h}$$

where w/h = aspect ratio, n = number of lines, N = frame rate. For the VR295

$$BW = 0.7151 * \frac{(342)(1024)^2(66)}{(273)} = 62 \text{ MHz}$$

However, reference [5] also states "...for true high resolution about 25% more bandwidth ...is required." This would give 77.5 MHz.

As will be shown later, it is easier to determine the amplifiers' requirements in terms of risetime, not bandwidth.

The Second Order System:

It is necessary to review the response of a second order system. Given the transfer function

$$T(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

it can be derived that the unit step response in time is

$$y(t) = \left[1 + \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \cos(\omega_n \sqrt{1-\zeta^2}\, t + \theta)\right] u(t)$$

$$\theta = -(\cos^{-1}\sqrt{1-\zeta^2} + 180^\circ)$$

Figure 1 shows the step response plotted for different values of zeta, the damping coefficient.

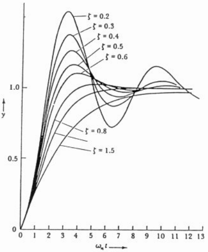


Figure 1.

The damped oscillation frequency is

$$\omega_d = \omega_n\sqrt{1 - \zeta^2}$$

a the settling time is

$$t_s = \frac{4}{\zeta\omega_n}$$

The percent overshoot, PO, can be calculated by

$$\begin{aligned}
PO &= \frac{\text{peak value} - \text{final value}}{\text{final value}} \times 100\% \\
&= [y(t_p) - 1] \times 100\% \\
&= \left[1 - \frac{1}{\sqrt{1 - \zeta^2}} e^{-\zeta\pi/\sqrt{1-\zeta^2}} \cos(\pi + \theta) - 1\right] \times 100\% \\
&= \left(e^{-\zeta\pi/\sqrt{1-\zeta^2}}\right) \times 100\%
\end{aligned}$$

and the risetime vs. bandwidth relationship, which is dependent upon zeta, can be determined using figure 2.

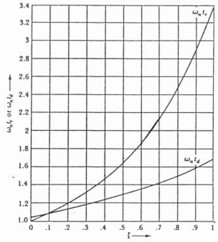


Figure 2.

Overshoot:

Before risetime can be calculated, zeta needs to be chosen. To do this, zeta is selected to give the best step response -- the least amount of error when compared to a perfect step. This is done by minimizing the integral of the absolute magnitude of error, IAE. Figure 3 shows a basic second order step response. Figure 4 shows the absolute magnitude of error. It is the area under this curve that needs to be minimized. The integral is given as

$$I_2 = \int_0^T |e(t)|\, dt.$$

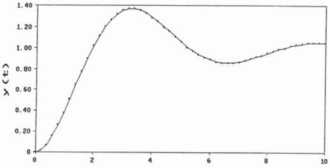


Figure 3.

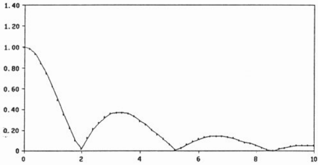


Figure 4.

Computer integrations were done for varying values of zeta. The minimum error was reached where zeta = 0.667. Figure 5 is a plot of the IAE.

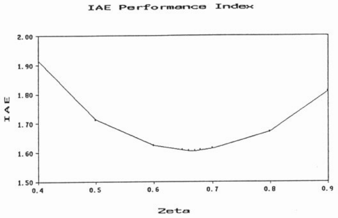


Figure 5.

The percent overshoot can then be calculated and is 6.0%.

Spot Distribution:

A displayed spot is not a replica of the video waveform. Actually, the shape of the video waveform is relatively unimportant -- anomolies are somewhat filtered out. The displayed spot is a convolution of a non-deflected spot shape, which very closely approximates a gaussian, and the video signal.

Since the Fourier analysis of this problem is rather involved, a computer program was written to do numerical convolutions in time. Figure 6 shows the results of different pulse widths (pixel sizes) for a given spot size. These correspond to A/R ratios of 0.33, 0.8, and 2.0, the latter being the smallest.

It can be seen that to reach the equivalent highlight luminance of a horizontal line, a pulse width of 6 sigma (A/R = 0.33) is required. This results in a displayed spot twice as wide as the horizontal line. Therefore, for "square" pixels, it is impossible to make a vertical line as bright as a horizontal line. With an A/R of 2.0, the vertical line is only 38% as bright as a horizontal one.

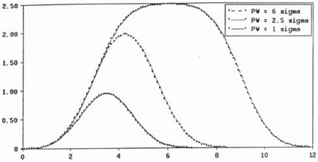


Figure 6.

To determine what risetime is required for a given A/R ratio, a triangle waveform was compared to the pulse waveform where each had equal area under the curve. The triangle waveform represents the theoretical lower limit for risetime. Figure 7 shows the two waveforms.

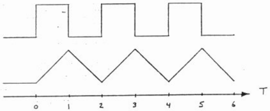


Figure 7.

Figure 8 plots the results of the two convolutions using an A/R of 2.0. Note the spot shapes are nearly identical, one just delayed in time. There is only a 1.6% difference in highlight luminance between the two. That is, infinite bandwidth is only 1.6% better than the very slow triangle waveform.

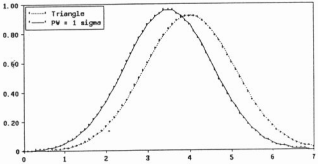


Figure 8.

Figure 9 plots the comparison for an A/R of 0.8. A trapezoid waveform was also included. The spread in highlight luminance is 10.8%. Obviously, for a smaller A/R ratio, a faster risetime is desirable. For the VR295 with an A/R ratio of at least 4, the slow triangle waveform is perfectly adequate.

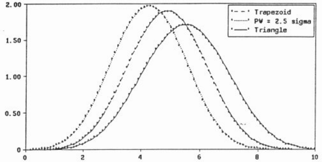


Figure 9.

Risetime:

Knowing that a triangular waveform is acceptable, a second order response needs to be found which also has an area under it equal to 1. Since there is approximate symmetry involved, only the first half of the function needs to be integrated; the solution being when the area is 0.5.

Using a zeta of 0.667 the following function is integrated for different values of omega, w, from 0 to T, where T is normalized to 1.

$$y(t) = 1 + 1.342 * e^{-0.667wt} * \cos(0.745wt - 3.872)$$

Figure 10 is a plot of the results. For an area of 0.5, omega = 2.92. However, y(2.92) = 0.98, so this function would not quite reach final value. To insure margin, omega * T = 3.0 will be used. Using figure 2, it can be seen that for a zeta of 0.667, omega * risetime = 2.0. Combining these two equations the required risetime can be calculated.

$$tr = 2/3 * T$$

For the VR295, this results in 6.0 ns. Bandwidth cannot easily be determined. Omega is the natural frequency, in this case 53 MHz, and is a little less than the upper -3 dB frequency.

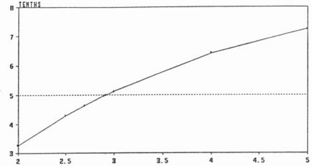


Figure 10.

References:

[1] "Signals, Systems, and Controls", B.P. Lathi, Harper & Row, 1974.

"Modern Control Systems", Richard C. Dorf, Addison Wesley, 1981.

[3] "Information Transmission, Modulation, and Noise", Misha Schwartz, McGraw Hill, 1980.

[4] "Digital Image Processing", Rafael C. Gonzalez/Paul Wintz, Addison Wesley, 1987.

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[6] "CRT Applications and Reference Notes #001", Frederick G. Oess, Clinton Electronics Corporation, 1980.

[7] "Understanding and Evaluating a Computer Graphics Display", Larry Virgin, "Information Display", 1987.