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A Survey of Data-Display CRT Resolution Measurement Techniques

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A SURVEY OF DATA-DISPLAY CRT RESOLUTION MEASUREMENT TECHNIQUES

Summary

The recent rapid growth of data displays having color and/or higher information densities has caused a corresponding increased emphasis on improved measurement of their resolution capabilities. Much disagreement results when comparing displays measured with different techniques or expressed in different terms. This paper describes many of the methods currently used to measure the resolution of data displays. Comparisons, disadvantages, and advantages of the various techniques are presented.

This survey was prepared as background material for the Electronics Industries Association JT20.3 Task Group on Spot Profile and MTF. It was presented as a seminar at the 1984 Society for Information Display International Symposium at San Francisco on June 6, 1984

A SURVEY OF DATA-DISPLAY CRT RESOLUTION MEASUREMENT TECHNIQUES

Introduction

Information density in displays is increasing rapidly with the phenomenal growth of data and graphics displays. The introduction of color to data and avionics displays has required improvement of the shadow-mask CRT, which heretofore had only limited resolution demands placed on it, mostly for television use. The color shadow-mask CRT requires special considerations when measuring resolution to avoid anomalies caused by the physical structure of the screen. All of this has renewed interest in display resolution and resolution measurement.

The resolution of data displays and data-display cathode-ray tubes is a most difficult parameter to characterize accurately. Large differences in resolution measurements are often observed, due to the diversity of display formats, such as raster scan and stroke writing, alphanumerics and graphics. The large diversity of measurement techniques also produces differing results. Differences in test operator perception and skills add to the problem. Resolution data should therefore be used with caution. Figure 1 shows some of the major sources of resolution measurement error.

When comparing displays or CRTs, the display engineer must be sure that resolution data are comparable. A display from manufacturer A specified as having 20-mil resolution at the half-amplitude points with 200-microampere beam current may actually have better resolution than a display from manufacturer B specified as having 10-mil spot size measured with the shrinking-raster technique at 100 microamperes. It's the age-old "apples-and-oranges" problem again.

The resolution of a CRT display may be expressed in any of several ways, including:

- spot size
- line width
- number of TV lines
- modulation depth at a specified spatial frequency
- MTF curve

Each of these measurements has differing connotations and is not usually directly comparable to the others, especially if drive or duty-cycle differences are considered.

Resolution may be measured in an even greater number of ways, as shown in Figure 2. It is the purpose of this paper to present information on as many techniques as possible.

Spot Characteristics

The profile of the current distribution in a typical undeflected electron beam is usually near Gaussian. When the electron beam strikes the phosphor screen, the light-output distribution can differ from the beam-current distribution in several ways, as shown in Figure 3: (1) The light output of an undeflected beam may be nonlinear due to phosphor saturation at high current densities, thus rounding the peak. (2) Reflections within the CRT faceplate glass may

cause spurious light at points well away from the center peak. (3) Phosphor graininess or "noise" causes a more jagged profile shape. (4) Etched glare-reduction panels broaden the profile by scattering of the light from the spot. (5) Screen structure such as phosphor dots for shadow-mask tubes and target patterns for storage tubes may cause gross features that limit resolution, as shown in Figure 4. The spot may not be symmetrical in the x, y, or intermediate planes. Astigmatism, coma, and other aberrations may be present that require more than a simple, single-axis profile to properly analyze.

In addition to the above stationary beam problems, deflecting the beam adds coma, astigmatism, and focus aberrations to the spot. In some cases it is even desirable to have an elliptical spot to compensate for video bandwidth limitations. Further, magnetic fields, power-supply ripple, and vibration externally influence resolution and its measurement. All these factors are important as they determine the ultimate, useful resolution of the display. They must be eliminated to properly characterize the CRT alone, but need to be considered in determining the resolution of a complete display system such as a terminal.

Ways of Expressing Resolution

Resolution can be expressed several ways: (1) as spot size, typically spot width at the 50%-luminance points; (2) as line width, at either 50%-amplitude width or 60.7% if measured by the shrinking raster method; (3) as trace width, the width at approximately the 5% amplitude, which is the trace limit as seen by the eye and measured with a microscope (there have been some indications that the visual trace width may correspond more closely to the 1% amplitude under some viewing conditions); (4) as the number of TV lines as judged from merging of tapered alternate black and white bars on a video test pattern; and (5) as MTF (in cycles/unit distance for a specified modulation depth), which is a measure of the spatial frequency response of a display. For a Gaussian spot such as that shown in Figure 5, these measures are related as follows:

Height	Correction Factor
60.7%	1.0
50%	1.18
10%	2.15
5%	2.45
1%	3.03

The correction factor for other heights may be calculated using the equation:

$$CF = \sqrt{-2 \log_e (h/100)} \quad (1)$$

where h is the height at which the trace is measured in percent.

While the 50% and 60.7% amplitudes are most commonly specified for resolution, they may not be the most realistic amplitudes to use as a measure of spot quality. A spot having a small core may, through CRT design compromises or manufacturing defect, have low-level haze which will be objectionable particularly for alphanumeric displays. For characters such as an "0", the center will tend to fill in due to overlapping and consequent additions of light from the skirts of the spot when it is in the several close locations necessary to form the character. It would be difficult for the industry to change from the "small" (50 to 60.7%) spot sizes presently quoted to a more realistic but larger 5 to 10% figure. A possible compromise might be to express resolution at both levels. For example, a spot size might be quoted as 7.8/13.5 mils for 50/5% levels or better yet it could be quoted as 7.8 mils at 50% with a 50/5% ratio of 0.58. This ratio would be useful as a figure of merit - the best spot characteristics would be exhibited by a small 50% spot size and a figure of merit as close to 1.0 as possible.

It is also recommended that as many operating parameters as possible be stated when specifying resolution to assure similar test conditions between manufacturers and users. (Ref. 1-8)

Visual Methods

Microscope Trace-Width Measurement

The simplest visual measurement method utilizes a microscope or magnifier with calibrated reticle to measure trace width. This method is subjective and results in a width measurement at the 1% to 5% level of the spot profile; this level varies considerably with ambient light and trace luminance. A single line, expanded raster, or circular trace may be used depending on the ultimate application. (Ref. 9-11)

Shrinking-Raster Method

The shrinking-raster method is widely used because it requires minimal instrumentation and is more accurate than the microscope method described above. It also produces "comfortingly" small spot-size numbers since the width is effectively measured at the 60.7% amplitude. With this method, a raster of usually 10 or 100 lines is first expanded until the lines are easily resolvable. Then the raster is shrunk until the individual lines are just barely discernible, as shown in Figure 6. To obtain line width, the just-resolved raster's total vertical size is divided by the number of lines.

Among the drawbacks of the shrinking-raster technique is the subjectivity of judging when the lines merge; ± 20 to 25% variation between observers is not uncommon. It is also difficult to apply it to structured screens such as those used in shadow-mask color tubes. A low-frequency signal applied to one axis of the raster may be used to help eliminate effects of the screen structure by allowing the eye to integrate the raster and phosphor-dot pattern. (Ref. 1-3, 5, 6, 9-14)

Vernier Line Method

This less known method is said to have the advantage of measuring the total width of the visible trace with greater repeatability than the microscope method while still requiring minimal instrumentation. With the vernier line method, the amplitude of a small-amplitude square wave is adjusted until the top of one segment is coplanar with the bottom of the next on the CRT, as shown in Figure 7. At this point, the visual trace width is obtained by measuring the amplitude of the square-wave input to the display and comparing it to the deflection factor for the display. The deflection factor may be obtained by applying a known DC voltage to the input and dividing by the distance the trace shifts. This method is most useful for oscilloscope displays since the ability to apply a square wave on the vertical axis and a time base to the horizontal exists within the instrument. The measured line width is at the 1% to 5% amplitude, as in the microscope method. An advantage of the method lies in using the eye only for adjustment of the square-wave amplitude and not for the actual measurement of line width with a reticle. (Ref. 15)

Photographic Method

The photographic method is simple, provides qualitative indication of astigmatism, coma, and halation and is especially useful for comparing the effects of gun design, alignment, focus voltage, beam current, etc. It is less useful for quantifying spot size due to differences in the sensitivity thresholds and gamma (linearity) characteristics of film and the eye which preclude spot-size measurements from the photograph. With this technique, a series of photographs

using a constant exposure are taken of the spot (pulsed to avoid phosphor damage or saturation) at various currents or focus voltages, as shown in Figure 8. The film is moved slightly for each exposure so that an entire series of exposures appears on one print. (Ref. 16, 17)

Television Camera Method

This method is similar to the photographic method, except that a television camera is used to display a highly magnified image of the spot or trace on a monitor. While being easier to view, it is generally not very useful for quantitative measurements due to limited dynamic range, and because TV system gamma and threshold sensitivities differ greatly from those of the eye. (Recently, some work using a television camera, frame storage, and a desktop computer has been reported to avoid some of these problems.) (Ref. 18)

Television Test-Pattern Method

Television resolution is usually determined by televising a test pattern having wedge-shaped alternate black and white bars with a calibrated scale, as shown in Figure 9. The bars may be either vertical or horizontal, and the calibration is usually in the number of TV lines. The vertical lines are sometimes calibrated in megahertz of video bandwidth for determining system performance for NTSC systems. The resolution is visually determined by the point at which the individual lines are just discernible on the monitor or receiver under test. A variation of this method uses the radial resolution test chart shown in Figure 10, which allows resolution to be evaluated at all angles rather than just vertical and horizontal.

As with other visual techniques, there is a certain amount of subjectivity with the test-pattern method. Furthermore, unless the associated electronics performance is significantly superior to that of the CRT, the result will be a measure of system performance rather than the CRT alone. (Ref. 1, 3, 5, 9, 19-21)

Aperture/Slit Scan Methods

Aperture/slit scan methods have greater potential for accuracy since the methods are photometric rather than visual. However, these methods are more complex and require greater operator knowledge to avoid errors. Most of these methods either electrically scan the beam past a stationary detector having a finite area, as shown in Figure 11, or mechanically scan the detector across a stationary trace, as shown in Figure 12. The resultant beam profile is displayed on a CRT or plotter as a curve of light intensity versus position.

Both slits and round apertures are commonly used. Each has distinct advantages. A slit is best where the profile of a scanned line is necessary. The slit is oriented 90° to the direction of the scan. An aperture has the advantage of allowing a beam to be scanned past it in any direction to produce a profile of the beam in that plane.

The double-slit method is similar except that a second slit is spaced a known distance from the first. This distance is used to calibrate the horizontal scale of the display; the display then shows a pair of profiles separated by the effective slit spacing, as shown in Figure 13, and may be scaled accordingly.

Ideally the slit(s) should have the narrowest possible width, or the aperture should have the smallest possible diameter, because the measured spot or line size may be increased by as much as the slit width or aperture diameter, as shown in Figure 14. In practice, the minimum slit or aperture size is usually determined by signal-to-noise considerations. Usually a slit or aperture of about 10% of the beam diameter is adequate to avoid significant errors, although it has been reported that up to 40% is acceptable for truly Gaussian beams.

The slit method allows more light to reach the detector since the slit samples more area of the spot than an aperture would. The slit is also easier to position since the trace may traverse anywhere along the length of the slit. Usually the trace is imaged at the plane of the slit or aperture using a lens or microscope. The light passing through the slit or aperture is detected with a photomultiplier tube.

As an alternative, a fiber-optic probe may be placed at the image plane of a microscope and the output coupled to a photomultiplier tube via a fiber-optic cable, as shown in Figure 15. The advantage of this method is that the fiber position may be viewed through an eyepiece to aid correct positioning. The photomultiplier tube is separate from the microscope, reducing the mass and increasing the mechanical stability of the microscope. Mechanical stability is of key importance when spot sizes of 5 mils or less are to be measured. The microscope must be rigidly supported so that no motion relative to the CRT faceplate occurs. Local magnetic fields and electrical noise on the deflection system must also be minimized. These considerations apply to other resolution measurement methods as well.

Several scan methods are currently in use. Mechanical scanning of the microscope assembly across a stationary spot or trace is widely used in aperture/slit scanning methods. Although this method is slow due to mechanical constraints, in many cases it allows a display to be measured using its own circuits without applying external electrical scanning signals. It is also relatively free of phosphor decay effects – an important consideration for long-decay phosphors such as type GR (previously P39). (The phosphor designation GR uses the Worldwide Type Designation System (WTDS), recently adopted jointly by EIA, Pro-Electron of Europe, and EIA of Japan. All new phosphor registrations will be two-letter designations, with the first letter identifying the phosphor color.)

Even “faster” phosphors such as WW (previously P4) will show some decay problems when using 60-Hz electrical scanning. The presence of decay effects may be verified by using triangular scanning waveforms instead of a ramp. Any non-symmetry between the superimposed beam profiles is usually caused by decay effects, as shown in Figure 16.

Electrical scanning of the CRT spot past a fixed microscope is the only practical way to profile shadow-mask color CRTs without the screen structure affecting the profile. Such scanning also eliminates the effects of phosphor “noise” or graininess on spot profile smoothness for conventional settled screens.

Either line scan in a single axis or a fast line scan in one axis with a slower mechanical or electrical scan on the other axis (perpendicular to the slit) may be used. The two-axis electrical scanning avoids phosphor burning by reducing current density. Z-axis duty cycling may be used to hold the average beam-current density to a safe level while measuring the beam profile at high peak-current densities with either scan method. (Ref. 3-6, 9, 11, 13, 14, 32-23)

Variable Slit-Width Method

The variable slit-width method uses a calibrated, adjustable-width slit aligned parallel to a scanned line. The line is imaged and centered on the slit by a lens with known magnification, and the light passing through the wide-open slit is measured with a photomultiplier tube. The slit width is then reduced until a reading of one-half is obtained. The width of the reduced slit divided by the magnification is a measure of the width of the line. Note that the width of a Gaussian spot at which a reading of 1/2 light output is obtained is not equal to the 50% amplitude of the line, but instead is closer to 80%. A related approach uses a spot photometer with two apertures of known size instead. (Ref. 4)

Image Dissector and CCD Methods

These two methods are distantly related to the aperture scanning technique. The first images the trace with a lens on the photocathode of an image-dissector tube. The image dissector may be thought of as a photomultiplier tube having a very small effective area (aperture) on its photocathode. This small aperture may be electrostatically or magnetically scanned across the photocathode (and thus across the image of the CRT spot or line) using conventional CRT scanning techniques. The output of the image dissector is then displayed on a CRT or x-y plotter. Figure 17 shows a block diagram of the system. (Ref. 34)

The other technique, shown in Figure 18, has recently been introduced as a commercial trace-width measurement product. In it, a line scan on the CRT being tested is imaged with a lens onto a linear CCD array positioned perpendicular to the direction of CRT scan. The instrument then measures the trace width at any selected percentage of peak amplitude by internally comparing that level to the peak amplitude and measuring the time required to scan between the selected level of the rising and falling portions of the spot profile. The trace width, in mils, is displayed directly on a digital LED display. The entire profile may also be displayed on an oscilloscope if desired. The oscilloscope is particularly useful to aid focusing and triggering and to evaluate the effects of phosphor graininess or "noise." As this instrument requires little skill or judgment, it is particularly well suited for manufacturing applications. (Ref. 35)

Since both of these methods use a stationary CRT spot or line while in effect moving the detector, structured screens such as color shadow-mask CRTs are not easily measured with them.

Spot Contour Plotting Methods

Two recently developed methods of electrical scanning offer further significant measurement advantages, but increase system complexity by requiring a desktop computer for control and data manipulation. Both methods produce a two-dimensional iso-intensity plot of the spot. The plot shows spot intensity contours, making beam aberrations such as coma and astigmatism easily visible. These are not readily apparent in conventional x or y plane profiles.

The first method uses a series of radial scans in 30° increments through the spot center. The light from the screen is sampled by an x-y microscope with a small fiber-optic pickup and fed to a photomultiplier tube (PMT). The PMT output signal is converted to digital form and processed by a desktop computer system to normalize, interpolate, compute percentages, and plot the intensity contours at preselected percentage levels on an x-y plotter. Figure 19 shows a block diagram of the system, and Figure 20 shows a copy of a typical printout of profiles, contour plots, and spot diameters at various percentages of peak intensity. The advantage of contour plotting is that it provides the CRT design engineer with more quantitative and qualitative data than conventional single-axis or two-axis beam profiles. Changes in spot shape and size with operating voltages and currents are readily demonstrated. (Ref. 32)

The second method, shown in Figure 21, is similar except that a dot-matrix scan format is used. Dot-matrix scanning offers the advantages of uniform spacing of data points over the measurement area, faster operation, and handling of the data in array form. The data stored in the array may be easily accessed to plot conventional spot profiles, compute MTF or convolve with system scan rates and video bandwidth to derive system performance. Figures 22 through 26 are examples of typical CRTs measured with the dot-matrix spot contour plotting system. (Ref. 36)