CRT SYSTEM SPECIFICATION AND SELECTION

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INTRODUCTION

Requirements for CRT systems are appearing in nearly all of today's flight simulator specifications. The CRT system, together with an interactive keyboard, is used at instructor and operator stations to perform functions previously accomplished with dedicated devices such as switches, potentiometers, lights, repeater instruments, and plotters. Specification and selection of such CRT system hardware requires a firm definition of the CRT's use and an understanding of what impact each specification requirement has on the configuration and cost of the resulting system. If careful analysis of each desired display system characteristic is not performed, the resulting specification will impose impossible or costly constraints on prospective suppliers.

The molecular array illustrated in Figure 1 depicts relationships between pairs of system specification components. No one component stands on its own, but it will distort the whole system if given too much weight. By systematically weighing each component when establishing requirements, costly or unnecessary characteristics will be avoided.

The following issues of discussion are designed to clarify the complexities of dictating characteristics and to suggest options or features desirable in simulator applications. The order of discussion is typical of a logical approach to developing an end product specification.

DISPLAY CONTENT

After deciding that a CRT system is desirable for a particular application, the number and types of displayable elements must be established. For instance, if only alphanumeric data is to be shown, the worst-case page character content must be established. This count will influence the issues of display update frequency, CRT size, page refresh rate, and character generation technique. A human factors review is suggested at this point to adopt ground rules on the appearance of the CRT pages. Page format, importance of data recognition, and total alphanumeric character count will dictate the number of CRT's required for easy viewing. If a menu or check list is to be exhibited, line spacing is important for orderly review of page content and efficient use of the CRT viewing area. However, if emergency procedures are the prime exhibit, perhaps a large, blinking, or even a multi-color character display will be necessary, and frugal use of display area loses importance.

For graphic applications, a worst-case count of page contents must also be made and tabulated (see Table 1). The number of visible vectors, blanked vectors, arc segments, circles, and special symbols are included in this tabulation. Length will be an important segregating parameter in systems which have different drawing rates. Orientation of vectors is another needed sorting criterion.

TABLE 1
WORST-CASE PAGE CONTENT

Quantity*	Data Type
4000	Alphanumeric/small character mode, 62 different visible characters, with an even distribution of each character
2000	Alphanumeric/large character mode, 62 different visible characters, with an even distribution of each character
600	Straight lines (short, 0 to 0.25 inches, any orientation)
105	Straight lines (long, 0.25 to 21 inches, any orientation)
5	Circles (small, 0 to 4 inches diameter)
5	Circles (large, 4 to 12 inches diameter)

*Displayable data distributed simultaneously over 4 CRT displays.

RASTER VERSUS CALLIGRAPHIC

Now the first branch in the specification process appears. If alphanumeric, bargraphic, or color alphanumerics are desired, the display writing and refresh technique of raster scan (TV) systems will be chosen and all future decisions will be biased in that direction. Down the other branch lie calligraphic writing and refresh techniques, with their own set of biases.

Raster scan display generation techniques suffer from one major presentation limit — segmentation. Since a display page

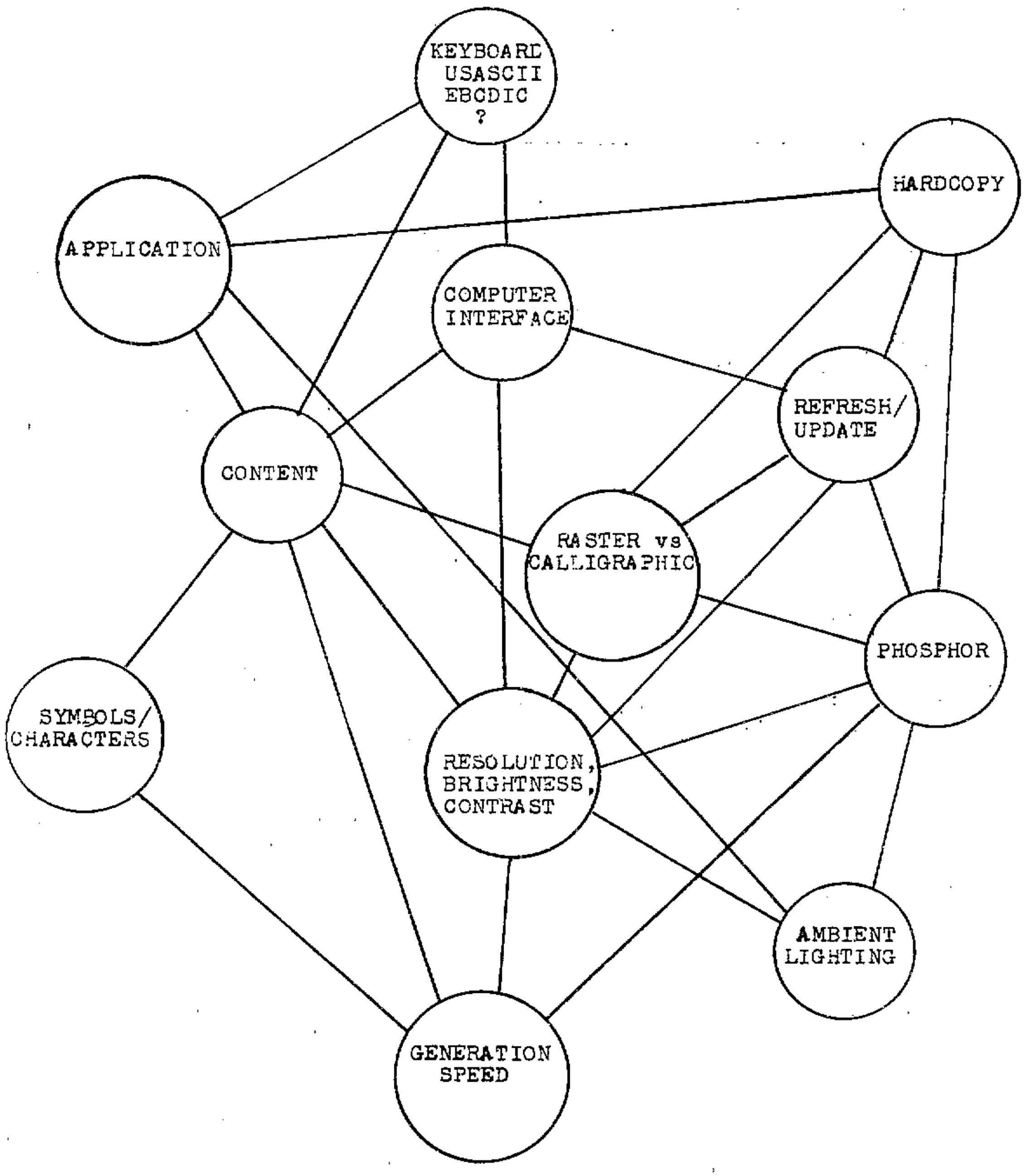

Figure 1 SPECIFICATION COMPONENTS, LINES BETWEEN PAIRS ILLUSTRATE RELATIONSHIPS AND/OR NEED FOR TRADEOFF

is composed of a discrete number of raster lines across or down a CRT, some squaring off and segmentation of picture elements occurs. For alphanumeric data, experience in the industry has shown that this characteristic is not objectionable. The number of readable rows of data and characters per row should be compared at this point with the worst-case count established when analyzing display content.

Bar-graph presentations are natural applications for raster scan displays because all lines run horizontally or vertically where segmentation has no adverse impact. Bar-graph or thermometer-type presentations have been found quite adequate on recent simulators for presenting such cockpit instrument "repeaters" as fuel flow, tachometer, nozzle position, oil pressure, and fuel quantity.

Color raster scan and raster scan in general are economical relative to calligraphic techniques because of the tremendous commercial market for television CRT's. Color tubes suffer more from segmentation than monochromatic displays because of the number of color triads across a screen, but they make up for this loss by the additional information color cues provided. Some displays now use European TV standards to get additional raster lines and hence improve resolution. This improvement is in the magnitude of 580 versus 480 usable raster lines. European systems use a 50-hertz refresh rate, which may result in some flicker, caused by an optic beat, if illuminated, with the 60-hertz ambient lighting typical to the United States.

The argument in favor of raster scan display generation for alphanumeric and bar-graph presentations does not say that graphics may not be presented on a raster system. It must be realized, however, that line segmentation or stair-stepping will occur on lines that are not horizontal or vertical. By stipulating a 1000-line raster, rather than 480 or 580 lines, a marked improvement in display presentation can be realized. With the increase in raster lines, either the refresh memory buffer must increase in size or the display generation process must increase in speed accordingly. Since major advances have been made in both reducing the memory cost and increasing the speed of display generation, raster scan techniques can be expected to start replacing some calligraphic systems if purchase specifications are not written with disqualifying constraints.

Raster scan displays offer several advantages over a calligraphic presentation:

- TV camera video may be mixed with digitally generated graphics and alphanumerics, or the display system monitor can double as a visual system monitor.
- Scan conversion video of actual cross-country maps or system diagrams may be mixed with digital video. This type of system was supplied with the AJ37 flight simulator, where photographs of actual maps were used in place of time-consuming digital data generation to produce detailed background displays.
- Display content or data load does not affect CRT refresh rate; therefore the phenomenon of flicker is eliminated or, at worst, subject only to ambient lighting optic beat if a 50-hertz refresh rate is applied.
- TV cathode ray tubes are shorter in length owing to recent advancements in deflection techniques.

A disadvantage peculiar to raster scan graphic display techniques appears when it becomes necessary to change a previously generated display page. As part of each update, either the whole page must be erased and rewritten, or each element deleted must be overwritten with nulls (or erase elements identical to those previously displayed) in addition to writing the update data. Display systems that refresh from an accessible instruction list do not present this problem, since by merely deleting an instruction from the refresh list the element is deleted and the remainder of the display is unaffected.

Calligraphic displays seem to be the most popular in the military user's world today because of their smooth and definitive line structures. These systems allow presentations which represent the real world without imposing a noticeable strain on the viewer's imagination. Calligraphic displays can be viewed from relatively short distances even on large CRT screens where raster scan segmentation would be objectionable at the same distance, particularly if in color.

When applying a calligraphic display generation technique, care must be taken not to exceed the electron beam total deflection time relative to a minimum refresh rate of the CRT phosphor. The numbers of graphic elements listed in Table 1 are considered here for the first time. During the process of specifying CRT phosphor, display brightness, and refresh rate, this tabulation will be consulted several times and the table's contents will be reevaluated to determine whether elements can be added or deleted. If specific vendor display systems are being considered, their average draw times for characters, vectors, moves, and circles should be multiplied by the tabulated worst case and a sum of the time calculated for comparison with the refresh frame rate. If the specification is being written for quote requests, the tabulated worst case can be passed on to the vendors. Table 1 was used in a recent simulator display system specification (UPT-IFS).

Widely available phosphor beam penetration calligraphic systems are limited to four usable colors and the display content must be reduced relative to a monochromatic CRT. By reducing the display data load, time is allowed for switching the high-voltage supplies necessary to produce color changes. Another reason for limiting the data load is to allow refresh of the phosphor often enough to prevent flicker and to obtain phosphor brightness. The red phosphor available today is a less efficient light producer than phosphors used on monochromatic CRT's. In some cases, therefore, it may be necessary to draw red images twice as often as any other color.

On calligraphic CRT's, the time required to generate a display page becomes the problem of greatest concern. For this reason, continual evaluation of absolutely necessary display content must be performed while specifying phosphor, resolution, brightness, refresh rate, and update rate in order to keep the total draw time down to an allowable value.

UPDATE AND REFRESH RATES

Update rate refers to the frequency of change of a CRT page. Refresh rate is the frequency of rewriting the page on the CRT.

Update rates of specific CRT page elements, such as stylized meters, may be necessary five times a second, while malfunction lists require updates only once per aircraft instrument change. When updates are required only infrequently, care must be taken not to specify an entire page change rate faster than the user needs, since both CRT phosphor and computer interface specifications are affected. If update is seldom, a storage tube phosphor CRT may be selected, with great advantages realized in display content capacity, elimination of refresh timing constraints, and refresh memory cost. Calligraphic techniques are generally used with storage tubes and in some cases, hybrid calligraphic/raster systems are produced. The hybrid technique provides advantages of both raster and calligraphic displays. One specific hybrid case uses a scan converter on which calligraphic images are painted and the image is then scanned off in any desirable raster format (horizontal or vertical, 525 line or 1000 line). Raster scan advantages realized by this method include the capability of mixing video and its compatibility with TV monitors.

Where fast update rates are required on selected parameters of a static page, the storage tube technique may still apply. In these cases, tubes with selective erase or "write through" capabilities may be used, or, in the scan converter application, both selective erase and tube multiplexing can be used. The scan converter multiplexing technique switches between converters, thus allowing major updates of one converter to occur while the stable converter is being viewed. Development of alignment techniques between multiplexed scan converters has led recently to paralleling three tubes and generating a red, green, and blue calligraphic TV picture.

Refresh and update rates dictate both the storage medium location for the CRT page and the transfer capacity of the CRT system/computer interface. Refresh of a CRT picture at 30 frames per second requires that the entire picture memory representation be accessed 30 times per second. If the host computer has an I/O structure that will support this transfer rate, display refresh may be done directly from the computer's memory. When the host computer structure is inadequate or there is insufficient memory access time to support refresh from the computer directly, a dedicated refresh memory medium is incorporated into the display system hardware. When the CRT must be connected to a serial or modem I/O channel, dedicated refresh memory becomes a must for both update and refresh.

Because of the interdependence of system components, refresh speed, display content, picture generation technique, computer interface type, and update rate are all contributors to the analysis of the next issue: phosphor selection.

PHOSPHOR SELECTION

Since no single criterion directs selection of a CRT's phosphor, the discussion analysis must run between the issues discussed previously and those yet to be presented. Phosphors make the CRT presentation possible by turning computer-controlled signals into a display for the user. When the screen phosphor is impacted by an electron beam, a change in energy level is generated and luminescence is produced. There are two phases of luminescence. One occurs during the excitation by the electron beam and is called fluorescence. The second phase persists after the excitation and is called phosphorescence, afterglow, or persistence.

Since phosphors are available with persistence ranging from microseconds to seconds (see Table 2), flicker may usually be eliminated by judicious selection of a CRT phosphor in combination with control of other factors such as:

- Ambient light
- Brightness
- Persistence of phosphor

TABLE 2
STANDARD PHOSPHOR CHARACTERISTICS

Phosphor Number	Fluorescent Color	Phosphorescent Color	Persistence: Class	Persistence: Decay to 10% Brightness	Application
P4	White	White	Medium Short	60 Microseconds	60-hertz television
P7	White	Yellowish Green	Medium Short Long	50 Microseconds 0.35 Seconds	Radar and Oscillography
P22	Green Red Blue	Green Red Blue	Medium Medium Medium Short	24 Milliseconds 27 Milliseconds 23 Microseconds	Color Television
P28	Yellow-green	Yellow-green	Long	70 Milliseconds	Surveillance Radar
P39	Yellowish-green	Yellowish-green	Long	150 Milliseconds	Medium-Frame-Rate Displays and Radar
P38	Orange	Orange	Very Long	1.05 Seconds	Low-Repetition-Rate Displays and Radar

- Refresh rate
- Angle of vision (foveal and peripheral)
- Color
- Display area illuminated

In situations where refresh occurs at 50 to 60 hertz, the short-persistence phosphor P4 ([1]) can be used and over 90 percent of the observers will find the flicker frequency acceptable. Longer-persistence phosphors must be selected from the yellow-green class (e.g., P39) when low refresh rates must be used. It might appear that as refresh rate is decreased, longer-persistence phosphors such as P28 or P39 could be specified and flicker could be avoided to the satisfaction of any user. But this is not so since the fluorescent light output contrasts so greatly with the phosphorescent output. This phenomenon may manifest itself in another form with a phosphor such as P7, which is a mixture of blue and yellow-green. In the case of P7, flicker appears when the short-persistence phosphor decays away and the long-persistence phosphor remains phosphorescent.

During the selection process, a life cycle cost consideration appropriate at this time is the burning characteristic or the phosphors. Unless sufficient time is allowed between electron impacts to dissipate the heat generated from the impact, the phosphor will reach a burning temperature. In general, the orange phosphors tend to burn or age readily. CRT monitor specifications typically include requirements for circuitry that turns off the tube if deflection is lost.

If a light pen is to be used, it may be necessary to have the CRT phosphor doped to match the pen's sensors.

DISPLAY RESOLUTION

Resolution can be defined in two ways: 1) as the minimum distance between illuminated points and 2) as the number of display locations a display generator can address. A person with normal (20/20) vision can resolve detail to approximately 1 minute of arc under good viewing conditions of illumination and contrast. With the resolving detail of the eye thus defined, a display's resolution capability can be considered once the distance between a viewer and the CRT is established. For applications where the viewer is approximately 30 inches from a CRT, a 0.020-inch spot size (2'17") and address resolution of 0.016 inches (1'50") are not uncommon in calligraphic applications. Raster scan images have a direct correlation between picture element addressing capability and picture element size. Displaying 525 raster lines along a 12-inch viewing area results in a 0.022-inch spot/address resolution (2'31"). A calligraphic display uses its resolution characteristics to present smooth line drawings over its entire CRT face, while a raster scan display is limited by the inflexibility of its picture element array.

([1]) This combination of 60-hertz field rate and P4 phosphor is the standard for home black and white television.

Contrast ratio and brightness are two closely related contributors to a CRT's resolution rating, with contrast ratio being the more important. Contrast ratio is defined in terms of the brightness of excited phosphor at a given spot relative to brightness at an adjacent spot that has no excited phosphor but reflects ambient light. The equation used most frequently in simulator specifications to express contrast ratio is:

$$C = \frac{B + B_b}{B_b}$$

where:

B_b = screen brightness from reflected ambient light

B = screen brightness from excited phosphor when ambient light is excluded.

By specifying a contrast ratio of 2:1, a satisfactory resolvable/viewable picture will result for a typical room ambient light level.

Important to contrast evaluation is the determination and specification of ambient light level. A vendor is put in an impossible bidding position if he cannot control the ambient lighting or the lighting level is left undefined in the request for quote. Most simulator specifications either identify a working environment light level or provide that the level be adjustable by the CRT user to the point where the display is usable. A complete definition of working environment necessarily includes the type of room lighting and how much light will be present at the CRT working area.

If high ambient lighting or spot source lights surround a CRT display, some form of glare-resistant coating or optical treatment might be considered for the CRT face plate. Etching the implosion shield disperses point light sources such as the lamps and indicators found in a cockpit. An adverse effect on etched surfaces which is not present on optically coated CRT's is the diffusion of the phosphor illumination spot, thus making it appear greater in size and reducing the apparent resolution. Conversely, an antireflective optic coating improves resolution by increasing the contrast ratio, but the light it does reflect is not dispersed and point light sources are reflected as interference with the CRT image.

TURNING POINT

Thus far in the analysis of CRT system specification and selection issues, the emphasis has been on getting a usable system from a viewer's standpoint. Now the analysis turns to a discussion of features and options important to the user, the programmer, and maintenance personnel. Each issue discussed henceforth is a "nice to have" item that can become an absolute necessity as economic aspects of its system application are realized.

SPECIAL AND STANDARD CHARACTER GENERATION

Selection of display character set and display generation technique can affect the processing time required. The character set must include all symbols and alphanumeric figures that are required in the display content page formats. This is an absolute requirement in nongraphic systems unless the character generator is specified as being of the programmable type. Some vendors now offer character generation equipment with a random-access memory (RAM) that the user can program at his convenience. Some authorities endorse RAM's in this type of application for reasons of future flexibility and anticipated beneficial effects on life cycle costs.

On graphic systems, character set definition is of equal importance, but seldom used symbols or those subject to rotation are normally left out of any character set specification. In cases where the special symbols occur frequently, there is a tradeoff possible between a character generator's generation time and random graphic draw time and memory usage. As refresh memory or computer memory capacity is taxed, the character generator disadvantages dim by comparison with the amount of memory required to draw a special symbol. RAM memories have therefore not been common in calligraphic character generators, but as the trend towards greater hardware flexibility continues, this will soon be an option offered by major system suppliers. If the flexibility improvement trend does not bring this about, life cycle cost demands will.

One frequent requirement placed in specifications is the stipulation that USASCII, FIPS-15, or MIL-STD-806 compatible alphanumeric character codes must be used. However common these codes may appear, they eliminate a great deal of equipment that has been designed to operate with EBCDIC codes. This requirement may even force an EBCDIC computer to perform special processing to support the display system and its keyboard. If specifications stipulated instead that display system hardware be compatible with the computer's coding format, a broader field of suppliers could be considered.

HARDCOPY

Permanent copies of CRT presentations are often desirable for history or debriefing purposes. Photographic processes have traditionally been used to copy both calligraphic and raster scan displays. These methods take approximately 12 to 30 seconds to produce one picture, during which all CRT update must be stopped. Storage tube and raster display copying is relatively inexpensive, but for refreshed calligraphic CRT's a second dedicated CRT with special phosphor must be allocated to the copier.

In some situations (e.g., police bulletins), CRT update may be halted during copying and the time may be taken away from further use of the CRT page; however, simulator instructor/operator stations using CRT's cannot allow this much time to elapse without student monitoring capability. To prevent loss of CRT usage, snapshots of display page instruction memory can be made by reading its content into a mass memory and later reading it out to a hardcopy device. If the host computer is equipped with a printer, alphanumeric pages can be produced without special photographic copying devices. If the computer is equipped with a combination printer/plotter, both alphanumeric and graphic display pages may be copied. The latter approach has the advantage of making hardcopy available without interfering with instructor/operator actions and at the same time making effective use of an inexpensive computer peripheral option. The only disadvantage of a printer/plotter copier is that CRT display intensity variations cannot be duplicated.

INSTRUCTION SET

Selection of instruction sets is affected mainly by the expected efficiency of programming. Raster scan hardware should accept cursor positioning commands to allow page update without updating the whole page. Erase operations that blank out portions of adjacent or overlapping images are to be avoided. Operations with foreground (operator-modifiable) and background (computer-modifiable only) instructions are desirable. If color displays are being generated, the option of having color selection bits (op-code) imbedded in each character code must be weighed against a color changing command. The op-code saves instructor/operator transfer data words, but makes it difficult to change color since each op-code must be changed. As stressed before, the desirability of having a programmable character set weighs heavily in any system analysis.

Designers of calligraphic hardware have been developing sophisticated instruction sets that should start appearing in raster scan systems that use microprocessors in their display generators. Some of the more desirable capabilities of calligraphic systems are:

- Relative position operations supplementing the absolute drawing operations
- Op-codes imbedded in the data word to eliminate the redundant mode switching commands from data transfer or refresh files.
- Two-way communication with its refresh memory to facilitate diagnosis of coded programs
- Matched arithmetic formats with the host and peripherals (e.g., if the host computer uses magnitude and sign, the display system should conform).
- Instructions for jumping or branching forward and backward in the refresh file.
- Control registers readable by the host computer to facilitate diagnostic operations.

An ideal way to evaluate the power of a display system's instruction set is to establish a benchmark CRT page (or pages) and have prospective vendors supply the page coding and estimate its total draw time. A supplemental step worth including is that of having a benchmark display element to another page location after first generating the basic benchmark. This latter step will reveal hidden update peculiarities and will demonstrate the use of the jump or branch instruction. Figure 2 illustrates a benchmark CRT page that could be used on a calligraphic display; the dotted squares indicate relocation of a page element.

Besides the instruction set interface between the computer and display generation equipment, some consideration of data word format is needed. When specifying a system interface, it would be wise to have at least the I/O registers match in bit length. Another seldom considered but necessary characteristic to be specified at the time of purchase is the bit weighing orientation. If the least significant bit (LSB) is bit 0 of the computer, the display system must orient its interface LSB accordingly.

BUILT-IN TEST

Built-in test capability, as discussed herein, is taken to mean built-in test pattern (BITP) capability that uses the display generator's full display-oriented instruction set, as opposed to built-in test equipment (BITE) where diagnostics are performed by the hardware.

BITP is a system option that saves both hardware troubleshooting and program debug time. Troubleshooting is aided by BITP since it repeatedly cycles through a private program and gives the technician a signal with which to trigger his oscilloscope. By supplying a BITP independent of computer resources, standalone tests can be made of the display system at such times as receiving inspection and

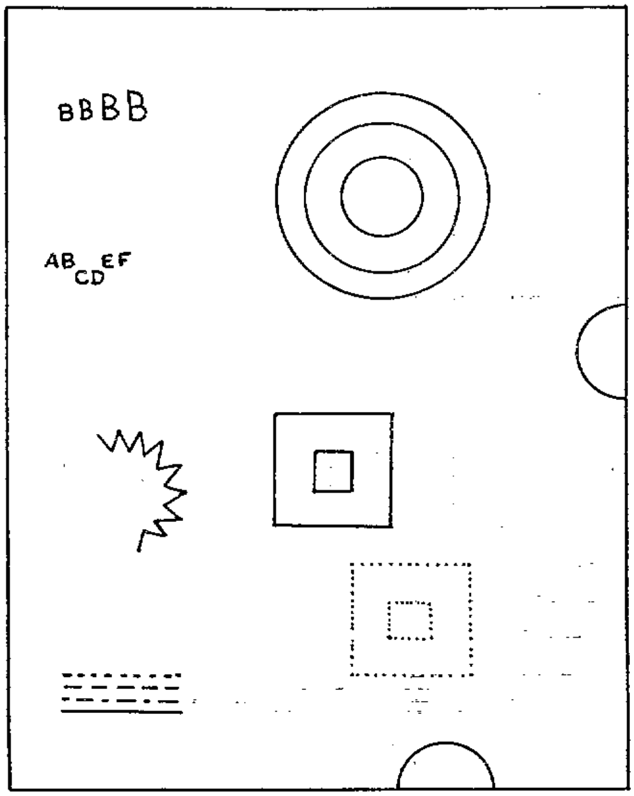

Figure 2 CALLIGRAPHIC BENCHMARK PAGE

during batch operations on the host computer when the CRT's are not in use.

Program debug time, during program testing of new CRT page formats, is saved by allowing the programmer to quickly test the instruction set operation of the display processing or generation equipment. If an instruction has a processing malfunction, the test pattern will not match the normal operating pattern.

Savings in either programming or hardware fault isolation time will reduce life cycle cost and make this option well worth the increase in initial hardware cost.

PACKAGING CONSIDERATIONS

Seemingly minor details involving packaging of CRT's and their driving equipment are often ignored when specifying a system design, but they come back later to haunt the designer. Some of these are:

CRT Tilt - Chassis modifications can be eliminated if tilt angle is called out before design starts. A CRT is sometimes tilted to reduce glare or to direct the CRT face toward the user.

Implosion Shield - Although most CRT's now have a bonded glass shield on their face, some applications require additional protection to be added in the form of a separate shield. Safety reviews establish this requirement, depending upon the application.

Shock and Vibration - When CRT's are located on simulator motion platforms, the CRT mount, chassis, and enclosure must be designed accordingly.

Weight - Mechanical designers of the console need to know how heavy each unit is to ensure that the console won't tip with a shifted load, such as the load produced by someone sitting on the work surface. Location of mounting holes along the chassis edges becomes important once the actual detailed console structure design begins.

Standard Sizes - If mechanical designs are required to conform to RETMA rack standards, associated system hardware may be purchased from distributor inventories.

Separability - The desired separation between the host computer, the display generation equipment, and the CRT monitors should be specified. This dictates the type of cable and cable drivers to be designed into the system. This is also the place to specify which cables will be provided by the seller and which by the buyer, and for power cabling and grounding constraints from the seller to ensure reliable operation of the equipment.

High Voltage - Safety standards of appropriate controlling agencies must be stipulated to protect maintenance personnel. The composite effects of X-ray radiation must be calculated relative to the total number of CRT's near the user and his observation distance from any X-ray sources.

Controls - Panel controls necessary for day-to-day operation deserve a front panel location to allow the user easy access. Maintenance controls, alignment procedures, and special test equipment identification require definition in advance of delivery. This allows training of personnel and purchase time for unusual test equipment. Sometimes the complexity will suggest the need for a service contract.

CONCLUSION

By careful analysis of a CRT application and systematic consideration of each issue discussed in this paper, a descriptive specification of a functional and economical CRT system can be generated. Selection of a final vendor depends upon his systems capabilities in satisfying the specification. As with any other procurement, the interactions illustrated in Figure 1 can be cut or weakened by budget constraints and they can be repaired or strengthened by budget relaxations. The most economical system is the one that entails the minimum maintenance cost, computer time, and memory, while meeting the total needs of the CRT system application.

ABOUT THE AUTHOR

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