

TECHNICAL SECTION

AN INTERACTIVE, RECONFIGURABLE DISPLAY SYSTEM FOR AUTOMOTIVE INSTRUMENTATION

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ABSTRACT

The decision to improve consumer interface with on-board vehicle systems in the new Buick Riviera presented many challenges. The major challenges were how to display the information and how to optimize the driver's interface with the display. Challenges were met with the development of an interactive and reconfigurable display system based on CRT (Cathode Ray Tube) and transparent membrane switch technologies. Human factors concerns were resolved, design requirements were met, limitations in existing technologies were overcome, and testing has verified that original design goals were met or exceeded.

IN THIS PAPER WE WILL SUMMARIZE the development of the Graphic Control Center (GCC). The GCC is standard equipment on the 1986 Buick Riviera. It combines many display and control input systems into one reconfigurable system. We will first present an account of the evolution of the overall design concept from a systems viewpoint. We will then show how human factors and testing augmented the development of the display/control system. Then we will discuss the design features of the CRT controller and the CRT monitor assembly. Finally we will present an overview of the test program used to validate this system.

EVOLUTION OF DESIGN CONCEPT AND VEHICLE SYSTEM GOALSNeed for a Versatile Control Unit -

This electrical system started as a list of possible Electrical/Electronic features and functions being considered for the mid and late 1980's. Initial design objectives indicated that the vehicle would be smaller, including the instrument panel area, and that the theme of the vehicle would call for "Cockpit" styling. The intent was to consolidate the controls in the upper portion of the panel for good "eyes on the road" controls position. The image of the vehicle required that the displays and controls be as contemporary, and as advanced as possible. Also, styling and human factors allowed for the controls/displays area to be moved closer to the steering wheel for ease of reach in activating controls.

As the architecture of the electrical/electronics system solidified it defined that the vehicle system would utilize a central processing module that would allow for increased vehicle diagnosis, ease of feature interaction and versatility for future expansion. This fact led to the need for developing a control system that would be as versatile and expandable as the vehicle system itself.

The initial developmental control panels utilized Vacuum Florescent displays in conjunction with conventional control buttons. Each feature, therefore, required instrument panel real estate dedicated to each specific control/display panel. Based on the final decision of content on the

1986 production intent, the dedicated display requirements numbered a minimum of eight (8), and the controls were in excess of 100 individual switches.

In order to achieve the initial program objectives of styling and system architecture, the decision was made to provide a universal display that would be reconfigurable, [thus allowing for the ability to share display/controls amongst many features]. This led to a study of functions in the instrument panel system to determine which items were adaptable to a shared display/control format. The outcome of the study concluded that the controls would be split into two types:

Primary - Required for the normal operation of driving the vehicle, and;
Secondary - Feature or function controls and displays not specifically required to operate the vehicle.

The secondary controls were to be integrated into the reconfigurable control system. They include:

Radio
Heater/Ventilation/Air Conditioning (HVAC)
Trip Monitor
Sidereal (including Clock, Day, etc.)
Gages
Diagnostics (vehicle status, failure codes, service, etc.)

Selection of the Display Technology

- The next program decision required was to decide which technology should be utilized for the display. System architecture for the vehicle was defined to be a central logic processing module that would interface with other "dumb" modules via a Universal Asynchronous Receiver Transmitter (U.A.R.T.) data link. The dumb modules would only include enough intelligence to interpret the link data, perform minimal local tasks (such as displaying information to the vehicle operator) and provide information to the system, (including putting switch or sensor status into the system via the link). Thus, the secondary reconfigurable display/control device would also be a "dumb" module. Since the system was digital in format, and the display should be universal, it was obvious that a "Dot Matrix" type of display was desired.

An analysis was conducted to determine the state of readiness of various "Dot Matrix" type displays. The following technologies were reviewed.

L.E.D. (Light Emitting Diode)
L.C.D. (Liquid Crystal Display)
Miscellaneous Future Twisted

Neumatic Technologies
Plasma Displays
Gas Discharge Displays
C.R.T. (Cathod Ray Tube)

A criteria chart was developed to measure the acceptability of the various technologies to vehicle parameters. The major parameters were brightness, design flexibility, development adaptation, packaging, weight, support electronics, durability, environmental compatibility and cost. After much evaluation the decision was made to use CRT as the display media.

Selection of the Switch Technology

- The other major decision was the form that the controls, or switches, would take. Again, in order to achieve the reconfigurable requirement for the system, not only would the displays have to be reformatable, the controls would also have to be reconfigurable.

As a result of further analysis, it was decided that the controls or switches would be displayed on the CRT monitor, and a transparent switch would be mounted in front of the monitor. This allowed us to define the required controls utilizing software. The controls, including location and function could be changed, or reconfigured, by changing the displayed video. This type of control became known as a soft switch. The two main technologies considered for the transparent switch were an I.R. light matrix and one based on membrane switching. The selected form is a transparent membrane switch which will be discussed later in this paper.

Screen Format Selection - The CRT touch screen uses a free format display as opposed to segmented displays. The most important issues in the development program became the display "Graphics", and the priority of information and control functions. Controls were to be grouped by major features. The motive was to include all of the controls of a particular feature on a single display. This display was to be called one "Page". The Radio, for example, would have one page of controls, as would Climate controls, Trip Monitor, etc.

In order to select the desired page of controls, perimeter switches (located on the periphery of the CRT display) were added. They were identified as "Hard Switches" since their function never changed, and were always exposed to the vehicle operator.

Due to the human factors input only a specific density of controls were to be allowed on any one page. This soon led to prioritizing of controls within individual features, since the control

content of many features exceeded the limit for density. A "Sub-Page" structure was included so that less important controls for any one feature might then be put on a second page, and accessed via a specific soft key on the primary page. This is best understood by reviewing the Paging Structure Chart (Figures 1&2). Further study indicated that only a few controls are regularly used for operating the various features. An example was that for Radio; normal tuning, volume control, band selection and on/off are the most frequently used controls. Therefore, it was determined that by placing a limited number of controls from all the features on one page, 90% of the time the driver needs could be handled from a single page. This page is called the "Summary" page.

Not only was the CRT to be used to control functions, it would also be utilized to display vehicle diagnostics, vehicle status, and act as a window into the vehicle electrical system. With the universal display capability of the CRT, it also would readily adapt to new and future applications of feature, or graphic appearance changes. The CRT display is completely software driven, and therefore easily changed by simply reprogramming the CRT controller software. As the vehicle goes through continuous product improvements, the control system can be changed, features added, etc. without requiring redesigning of the instrument panel to locate a new control panel.

The CRT required adaptation of the vehicle electrical system in order to optimize CRT usage. For the CRT to control various controls, the concept of a "Networked or Central Logic" control system in the vehicle was necessary.

Another adaptation was necessitated by the warm-up time required by the CRT tube itself. This was implemented in the total vehicle design. Activation of the door handle on the car was used to wake-up (or turn on) the display. By the time the driver was in the car, the tube would come up instantly. The vehicle interior environment was also designed to better accept the CRT technology. An example of this is the revisions to the air conditioning duct work in order to allow cold air to flow through the CRT monitor.

Lastly, consolidating the controls into one unit inherently increases the reliability of the total system simply by reducing the number of required system components. The number of logic modules for the vehicle system was also reduced by the central logic controller

concept. This led to better utilization of the microprocessors since individual processors were not required for individual features on the car.

HUMAN FACTORS TESTING AND DEVELOPMENT:

Initial Display Design - The evolution to the final product was an iterative process. This included the human factors engineering that went into the product, based on inputs from human factors experts, and in-vehicle human factors testing. From the beginning of the 1986 CRT system, human factors had considerable design influence. As first conceived, the CRT was used as a display device exclusively, and driver input was done from a switch device remote from the display. Human factors engineering considerations dictated the switch be transparent and on the face of the CRT. This increases driver hand/eye coordination. It was then decided that the program would use a transparent membrane switch instead of an infrared light beam switch. This was primarily due to ease of use. The membrane switch allowed the driver to locate his finger, and then press, avoiding inadvertent function activations while locating his finger. As the display content and page structure was defined initially, consideration was given to function location, monitor placement, appearance and ease of use. The display was divided into two major areas. The first being a fixed location "Hard Switch" area located on the perimeter of the screen containing the six major access controls (Climate, Summary, Radio, Gage, Diagnostics, and Trip Monitor). The other was a reconfigurable "Soft Switch" area located in the center of the display, consisting of 25 different soft switches arranged in a 5 x 5 matrix.

Determining Optimum Control Locations - Initial prototype design focused on control location. This included insuring the CRT location within the instrument panel was as high and close to the driver as practical within the styling theme for the vehicles interior. The first design also addressed how individual pages of the system would be accessed, nested within each other, and the functional density per page. The hard switches located on the perimeter of the screen were defined and initially located. Audible feedback was also added at this design level.

Driver controls and displays for each of the pages were also defined at this stage of development.

Consideration was given to locating primary controls high and close to the driver. Less frequently used controls were located further from the driver and lower in the display. As an example on the radio page, the volume control were located in the upper left of the display, the easiest location for the driver to access. The less frequently used functions were located lower and to the right of the volume controls. Some controls like Balance and Tone were located on nested pages. These nested pages left the primary Radio controls (ie. Volume, on/off, tuning, frequency display and AM/FM located on the top half of the display). Only the lower portion of the display was reconfigured to display balance and tone controls. As a guide when a function appears on more than one page it's location on the screen would be the same on all pages. This allows the driver to expect this control in only one location. For example, the radio volume controls appear on the summary, radio one and all nested radio pages in the same location. At this phase of design, the summary page was also created. This was intended to be the most frequently used page, displaying primary controls and selective information from all access areas.

Display Legibility - Subsequent design iteration emphasized display legibility, clarity, contrast and visibility in direct sunlight. This design also enhanced all graphics including available fonts. All fonts were revised to improve appearance and increase legibility. The vehicle gage page graphics display was also redesigned to improve legibility. It displayed analog and digital readings for RPM, oil pressure, battery voltage, and coolant temperature. Switch target size and location were also revised to improve appearance and increase driver performance. The brightness of the CRT was increased to improve visibility in direct sunlight, and the membrane switch was enhanced to improve system legibility. This included an anti-glare coating to reduce reflections which were washing out the display. Hard switches were also relocated and prioritized based on importance of function.

Accommodating Human Factors
Recommendations - Throughout the development of this system, human factors testing was conducted on all phases of the design, and as a result the operation of several functions were modified or added. For instance, human factors testing at the Virginia Poly-technical Institute indicated that

manual radio tuning was the most difficult function to perform. Consequently, the method of tuning the radio was redesigned. Tune up and down were replaced by seek up and down. This replaced a manual function with an automatic one. A manual tune page was added to allow the driver to tune in weaker stations. This page had separate controls for fast and slow tune up, and fast and slow tune down. The previous design combined all four functions into two target locations. A "Function tests OK" page was also added to the diagnostic system. This eliminated confusion as to whether or not a diagnostic was active at the time of a manual inquiry and message display.

As previously indicated, human factors testing was a significant part of the design development process. Testing began when the concept was first spawned at Delco Electronics in Santa Barbara, California. This occurred before the concept was applied to a production program. Testing included measuring the time it took a driver to perform various CRT control functions, the accuracy in completing tasks, and eye dwell time on the display. Preliminary testing took place in the winter of 1982.

The next phase of testing was conducted at Ohio State University. Suggestions were made on improvements from a human factors standpoint. Suggestions included locating the same control on different pages in the same physical location. The University staff also conducted in-vehicle testing on the original prototype CRT system. This testing included in-vehicle measurement of driver performance in operating the CRT system. As a result of this testing, design modifications were instituted to further improve the useability of the system. This testing was completed in the spring of 1983.

Additionally, Virginia Poly-technical Institute was contracted to complete a series of in-vehicle on-road tests of four different vehicles, including a base and three prototype versions of the CRT system. This testing measured driver performance in adjusting the radio, climate control, trip computer and a no task event. Performance criteria included the ability of the driver to maintain speed control, lane control, brake frequency and duration, number of eye glances to complete a function and eye-dwell time. Information was analyzed, summarized, and used to locate deficiencies within the system. Parameters included system

sensitivity to location within the instrument panel, visibility problems with early designs in direct sunlight and in glare conditions, and the ability of the driver to easily operate his controls. All of which were resolved in previous design changes or caused new modifications to be made. One aspect of this testing indicated the importance of powertrain performance on the ability of the driver to perform other tasks. This required the correlation of ride and handling performance with the performance of a driver control system.

The summary of all testing including both CRT system performance and performance of the powertrain and suspension systems suggests the 1986 Riviera system is equal to or slightly better than a similarly equipped non-CRT Riviera of the previous model year.

CRT SYSTEM

It would be misleading to portray the CRT as a stand alone system. The CRT is fully integrated into the vehicle electrical system and as such, depends on the networked logic referred to earlier. In order for the CRT to operate the radio and HVAC functions, remote radio and HVAC modules were also required. In order to display the diagnostics and vehicle status information, sensors and a central body computer module were also required. A complete description of the vehicle system is beyond the scope of this paper. We will limit our continuing discussion of components to the CRT controller, and the CRT display.

CRT CONTROLLER

The CRT Controller addresses 50K of ROM (Read Only Memory), 2K of keep-alive RAM, and 16K of Dynamic RAM (Random Access Memory) through two microprocessors configured in a Master/Slave communications relationship. The Master processor is a Motorola 6803 addressing 48K of EPROM, 2K of keep-alive RAM and 16K of Dynamic RAM. This processor is the Master of the parallel communications bus, and also handles the communications required of being a slave on the UART data bus. In addition, the Master processor is responsible for controlling the generation of video information, and vertical and horizontal sync pulses.

The Slave processor is a 2K on-board ROM. This processor is the Slave on the parallel communications bus, but it the Master on the serial communications bus with the

radio. The Slave processor also has the responsibilities of scanning the matrix membrane switch and retrieving its data (switch closures), controlling of the CRT relay (monitor on/off), and has input ports for other digital I/O not currently being used.

Graphics generation occurs when the Master processor receives switch information pertaining to a particular switch closure from the slave processor. The Master processor, knowing which switch location was closed and what screen is currently on display, obtains the next screen data from EPROM and builds that screen in Dynamic RAM. The screen is then shifted out from Dynamic RAM to the monitor for display.

Because the CRT system is on the UART link, the vehicle operator or service technician can call up the display of diagnostics for any system module residing on this link. For the operator this provides instant information should a problem exist. More detailed diagnostics for the service technician became an invaluable tool to help facilitate the repair operations.

CRT DISPLAY ASSEMBLY

The CRT display consists of three subassemblies; the monitor, the front face assembly, and the decoding electronics (Figure 3). The monitor has been custom designed for this application. The front face assembly consists of the transparent switch and support components to provide the backlit graphics used on the hard switches. The decoding electronics perform three main functions, which include:

- 0 Interface with the vehicle system, and inform the controller of switch actuations.
- 0 Drive the LED annunciators.
- 0 Provide audio feedback to the user of switch actuations.

CRT MONITOR - The cathode ray tube (CRT) monitor is similar in appearance to any 5 inch (diagonal measurement) commercially available CRT monitor. Appearance, however, is where similarities end. This CRT monitor, which measures approximately 140mm x 140mm x 150mm deep, has been specially designed for the automotive environment. The compact size allows it to be situated within the instrument panel of the car. The electronics design has taken into account the temperature, voltage and vibration extremes anticipated in automobiles.

Power and Brightness - It is fed with conditioned battery voltage nominally 13.5 volts DC. Internal power supplies boost the voltage to 24 VDC for much of the electronics and up to 13000 vdc for the high voltage circuitry needed to drive the Cathode Ray tube.

The electron beam inside this 112° deflection tube activate a custom blue-green phosphor blend developed to match the vacuum fluorescent displays in the digital instrument cluster. This high efficiency monitor is able to produce a luminance level of over 800 ft-lamberts for direct sunlight viewability. The high brightness is needed in order to view the CRT in worst case lighting conditions while providing an almost "dead-front" look when unpowered due to the low transmissivity of the membrane switch. The CRT was designed to operate with a horizontal synchronization frequency of 15.6 KHz and a vertical synchronization frequency of 75 Hz. Two coaxial cable connections between the controller and monitor for video and horizontal sync. are utilized.

Special Features - Several special features have been integrated into the CRT system through the electronics in the monitor or software and electronics in the CRT controller they include: display On Entry (DOE), wake-up, Retained Accessory Power (RAP), sleep mode, and user controlled brightness.

Display on entry is initiated when the driver's door is opened. At that time, the CRT monitor receives a signal from the controller to preheat the CRT filament. When the driver's door is then closed, both the instrument cluster and the monitor become active. A wake-up signal is sent to the CRT monitor from the controller, activating a relay within the monitor, and the words "Riviera by Buick" are displayed.

The "retained accessory power" and "sleep" modes become active when the driver turns off the ignition. For up to ten minutes or until the doors are opened, many of the accessories within the vehicle stay active, including the radio functions controlled by the CRT monitor.

In the retained accessory power mode, the controller switches the monitor to the radio page, allowing the user to access the functions on this page, i.e. volume, tuning, graphic equalizer, etc.

If the user does not make a selection within 30 seconds, the monitor is put into the "sleep" mode by turning off a relay. The user can wake-up the monitor at any time by touching the radio page hard switch. With the

monitor in this stand-by state, battery charge is conserved, since only the CRT filament is kept warm allowing "instant" video.

A feature incorporated after initial in-car evaluation, was adjustable brightness. With the park lights on, the user can shift the intensity of the monitor to be brighter or dimmer than that of the instrument panel.

All the graphics displayed on the CRT monitor are stored in the memory of the CRT controller. The monitor/controller system is connected to the UART communications network. The controller communicates with the radio over a secondary serial, pulse width modulated, data link.

Ventilation and heat dissipation were of major concern in design and placement of the assembly within the instrument panel of the vehicle. Because the more than 250 components housed within this compact monitor are cooled primarily through convection. The panel has been equipped with venting louvers on top, in front, and a large vent hole is directly under the CRT monitor. When the air conditioner is in use, a small hole in the AC duct provides cooling to the back heat sink of the monitor.

FRONT FACE ASSEMBLY (TOUCH SWITCH) - In trying to fulfill the system requirements, many switch technologies were considered, including I.R. (infra-red), capacitance, acoustical and transparent membrane. Each technology had its strong and weak points. It was decided that the membrane switch had the most advantages for in-car use. The major advantages were: the switch's ability to allow the user to locate the desired switch location, and after verifying that it was the correct location, push to actuate, ability to custom design switch size and contact force, its thickness allowed packaging the switch to coordinate with the design styling concept, and cost.

This feature helped eliminate the inadvertent switch actuations that occurred when testing other systems. In our experience prototypes built using the membrane switch have outperformed prototypes built with other touch technologies.

The switch assembly consists of a transparent membrane switch, circuit board assemblies for illuminating the hardswitch graphics, a light pipe for directing the light to the graphics, and circuit board assemblies for LED annunciators to indicate which hardswitch is active (Figure 5).

Sunlight Viewability Concerns. A major problem was the effect that placing the switch in front of the CRT would have on the display appearance. The switch consists of various layers, two of which are very reflective. When placed in front of the CRT, which has a reflective phosphor, it can cause poor viewability in direct sunlight. Contrast ratio and viewability studies were performed analytically for various filter densities, colors and locations within the switch assembly. These studies indicated that a 15-20% filter in front of the switch elements would be optimal. The color of the switch was selected to optimize sunlight viewability and to match the vacuum fluorescent cluster in the vehicle. Vehicle evaluation at GM's Desert Proving Grounds in Phoenix, AZ verified the analytical results.

In performing the viewability studies, it became apparent that the various switch layers would need to be fully laminated together in order to minimize the number of layer/air interfaces. This presented a major obstacle because the development of an optically clear adhesive, which would not delaminate nor degrade in an automotive environment, required a major engineering effort. It was the development of this optically clear adhesive, coupled with the filter which made the switch truly transparent. Comparison between displays using the transparent switch and displays using a simple contrast enhancement filter, show very little difference in image quality.

Switch Design - The membrane switch consists of two major sub-assemblies. A static laminate containing the lower switch element and the support. The support is the backplane against which the user presses. It provides mechanical resistance to the force being exerted. The switch element and support are laminated. The dynamic laminate consists of the top switch element and the applique, which is used not only to provide the hard switch graphics, but also the front hardcoat. This hardcoat is not only resistant to mechanical abrasion, but also to chemical attack. The gloss level on the hard coat matches the gloss level of the instrument cluster. Hard switch colors were developed to match graphics throughout the car. Development was required since any color chosen would be altered by the conductive layer on switch elements. The switch filter was located within the dynamic layers and the dynamic layers are also fully laminated. The switch sub-assemblies are held together using a

perimeter adhesive and separator dots within the switch area. The switch is 2.5mm thick which facilitated meeting the design packaging requirements, as well as reducing the parallax problems encountered with other touch technologies.

Human Factors Improvements

Accommodated - As the product evolved, the transparent membrane switch assembly was able to accommodate most of the human factor recommendations including:

- 0 The ability to have the user locate the switch, verify the location and then press to activate the switch.
- 0 Minimizing the Parallax problem with a low-profile and having the switch pads larger than the switch graphics.
- 0 The development of a custom filter and surface appearance to enhance viewability.
- 0 The incorporation of visual annunciators (LEDs) to indicate which hardswitch was active.
- 0 The hard switches should actuate with a higher force than the soft switches.

We were very pleased with the development of the transparent switch. Not only were we able to achieve a truly user-friendly display, but we were able to establish guidelines for future interactive devices.

VALIDATION TESTING

The testing and validation of the CRT system was accomplished in a six part testing program. These included the 1984-5 pull-ahead vehicle fleet, the 1984-5 lab system level testing, 1986 vehicle testing, 1986 lab system level testing, CRT assembly component validation at AC Spark Plug Division, GMC, and CRT validation testing at Zenith Electronic Corporation in Chicago. Each of these will now be discussed in detail.

First, 1984-5 pull-ahead vehicle testing, during the development, the need to evaluate CRT performance on a larger scale than prototype builds could facilitate was apparent. This need was resolved with the creation of a "pull-ahead" CRT vehicle. This program installed a version of the 1986 system in some 1984 production instrument panels. The vehicles were built on the production assembly line along with non-CRT vehicles. This allowed evaluation of the CRT in an assembly plant and provided early insight to

special processing requirements associated with a CRT. 102 vehicles (2 Pilot and 100 Production) were built in this program. Many were distributed to selected dealers across the country to provide early field feedback. The remainder were distributed between the suppliers of the system, engineering, service, and sales. Engineering placed 6 on durability schedules completing 360,000 miles of hot and cold weather testing. Vehicles were also used to complete EMI and EMC testing. In total, more than 3 million miles of testing and evaluation were realized from this program.

The pull-ahead system also underwent extensive lab performance testing. Eleven systems completed 23,100 hours of power/temperature cycling in the Electrical/Electronic laboratories of engineering. This testing provided early indications of system improvements that were implemented in prototype 1986 version systems.

The third phase of testing was in vehicles with 1986 level CRT systems. Fifteen prototype 1986 models were built with the systems. Of these, five were placed on durability schedules at the GM Proving Ground facilities, and 250,000 miles of durability were completed. In addition to prototype vehicles, instrument panels were also installed in other models. This provided an additional test bed of CRT systems. A total of 25 of these cars were built and added an additional 500,000 miles of experience. Both types of vehicles were used for systems development and all types of testing including EMC and EMI.

The 1986 systems lab testing consisted of power/temp cycling of 55 complete system through 115,500 hours of testing. Testing also included performance at temperature extremes (-40°C and $+85^{\circ}\text{C}$).

For design validation, we placed twenty-four CRT assemblies through power/temp cycling, thermal shock, mechanical vibration and shock, humidity, altitude and EMC testing. Twenty-eight CRT assemblies were tested to verify reliability goals were met. Also an additional 12 monitors were design validated by the vendor. The combined tests resulted in 155,712 total test hours.

Combined testing represents over 3,750,000 miles and 294,000 hours of extensive testing and evaluation.

SUMMARY

The development of this new graphic control Center was accomplished by extending the limits of then current technologies. Throughout the development the goals dictated by human factors and reliability were never overlooked. The system was modified to meet and exceed the initial goals. Future interactive displays will benefit from the accomplishments of this program.

ACKNOWLEDGEMENTS

Many people both within and outside General Motors Corporation, have contributed their innovative and technical skills to this project.

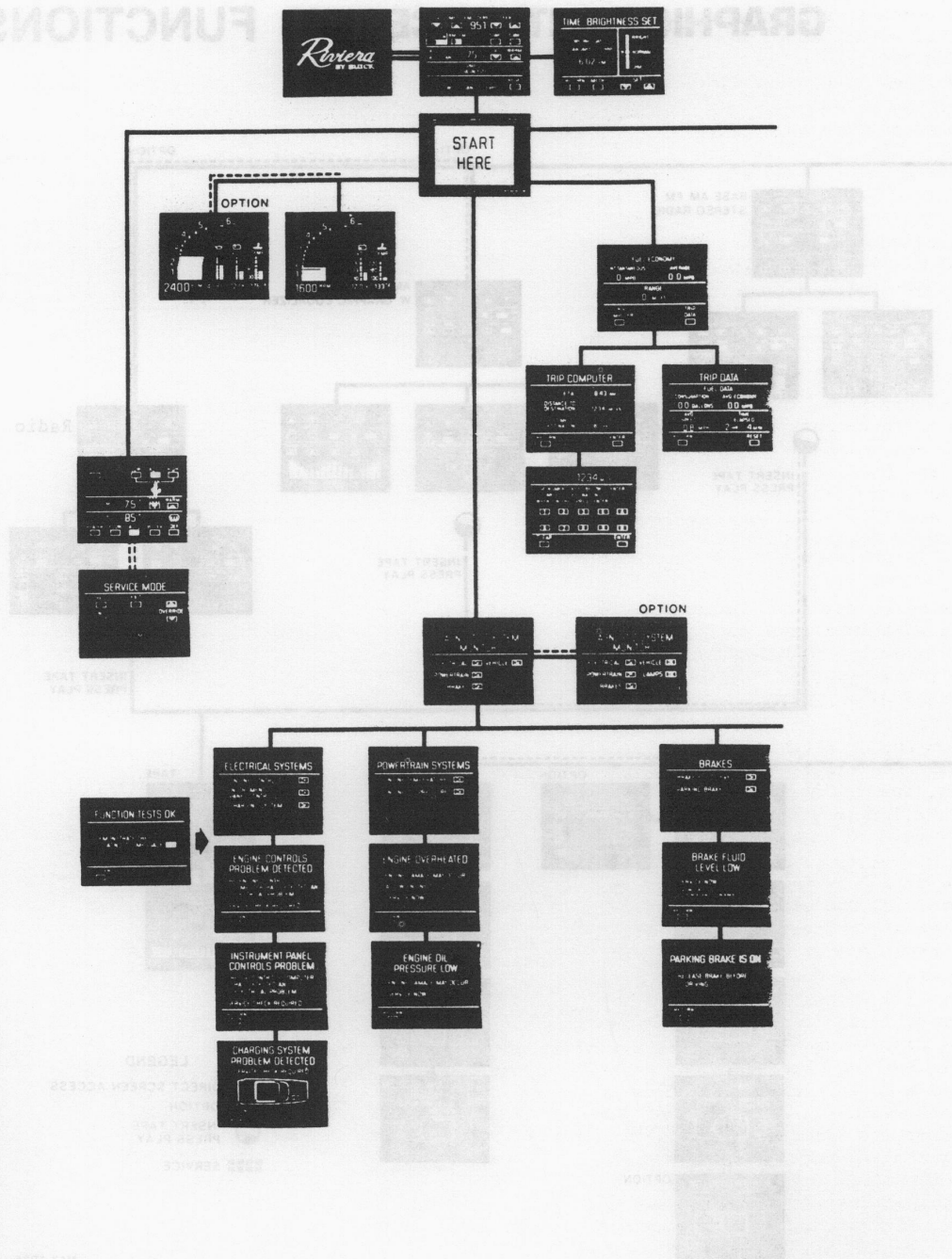


Figure 1

GRAPHIC CONTROL CENTER FUNCTIONS

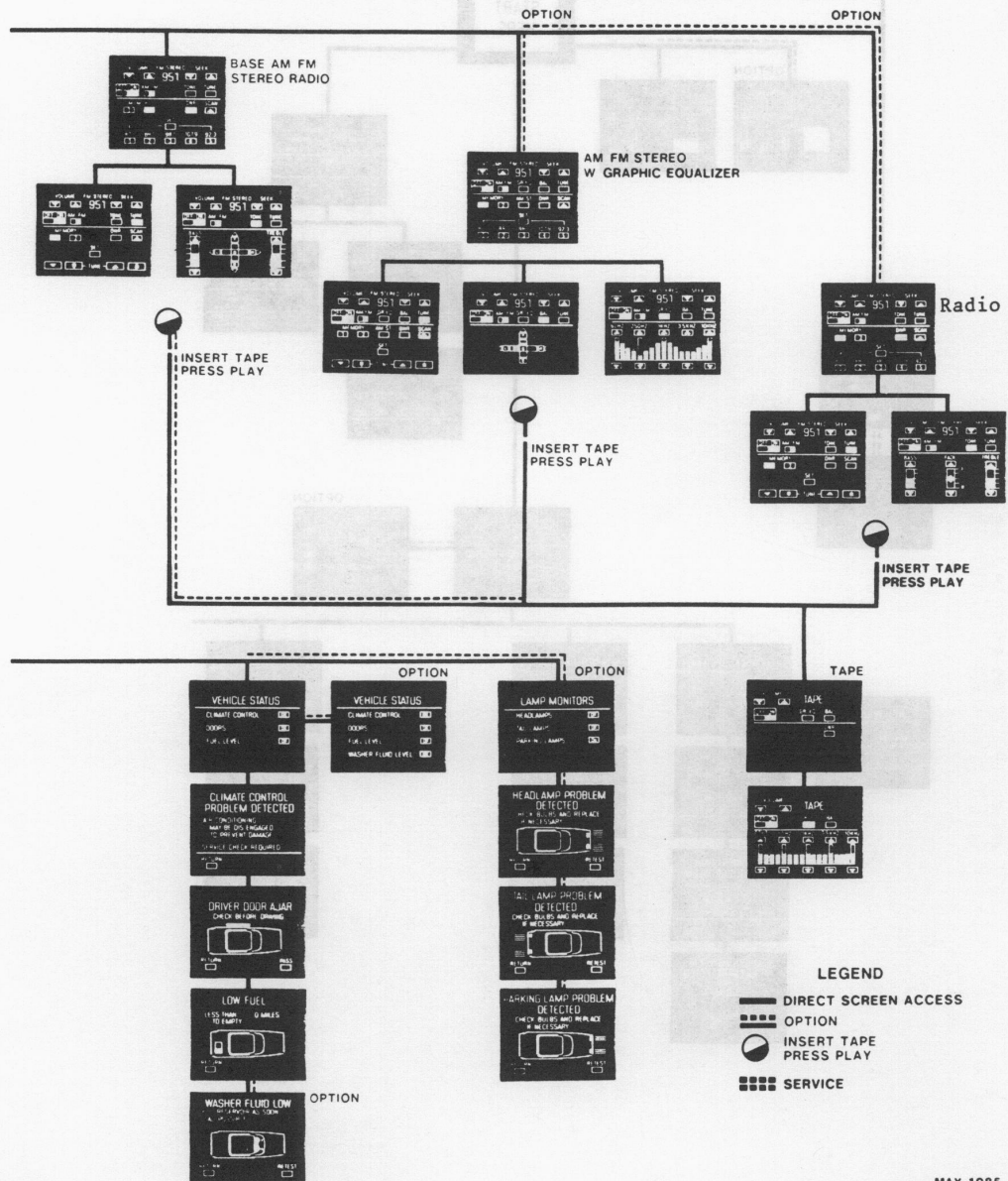


Figure 2

CRT ASSEMBLY

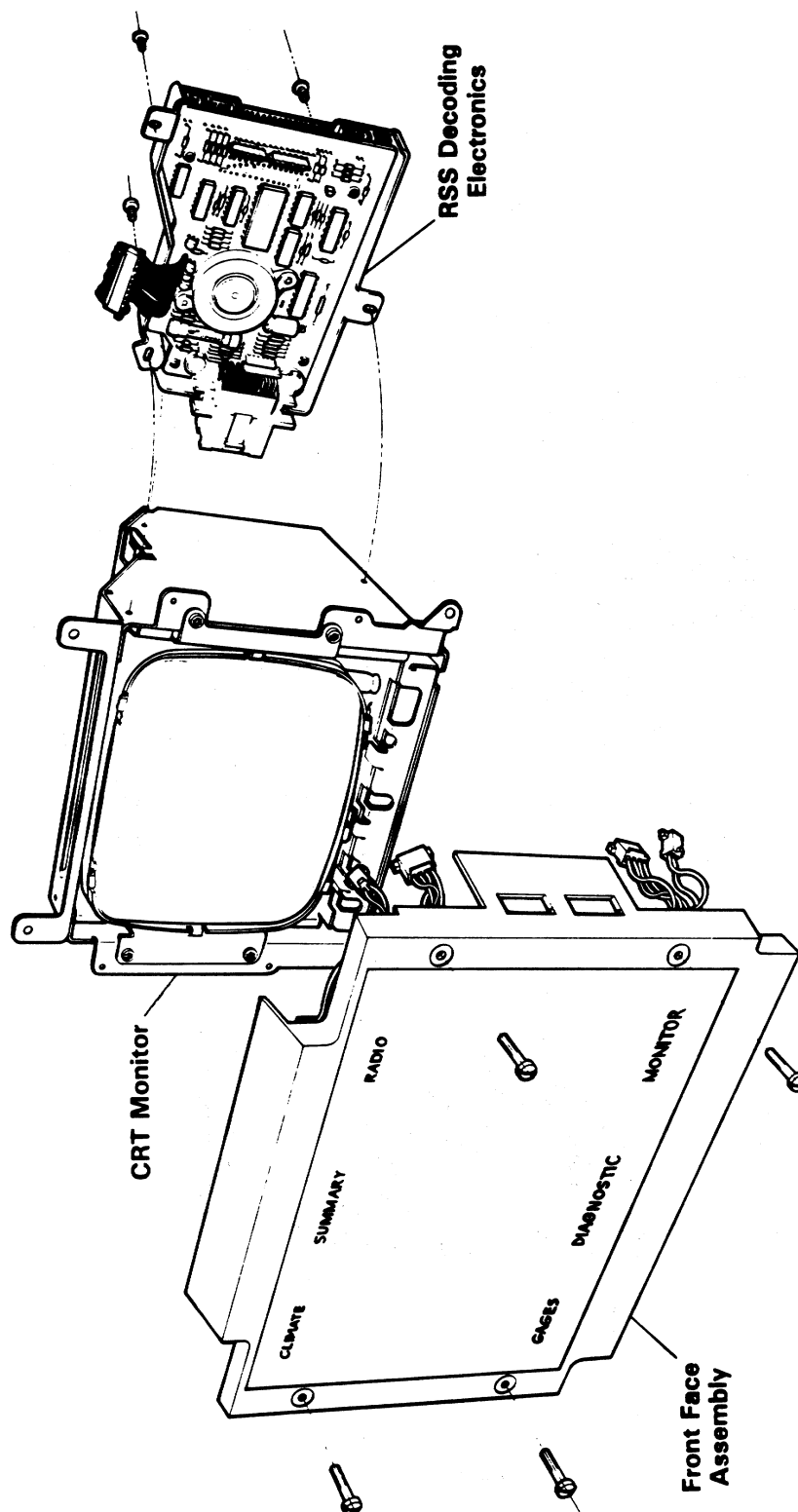


FIGURE 3

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CRT MONITOR

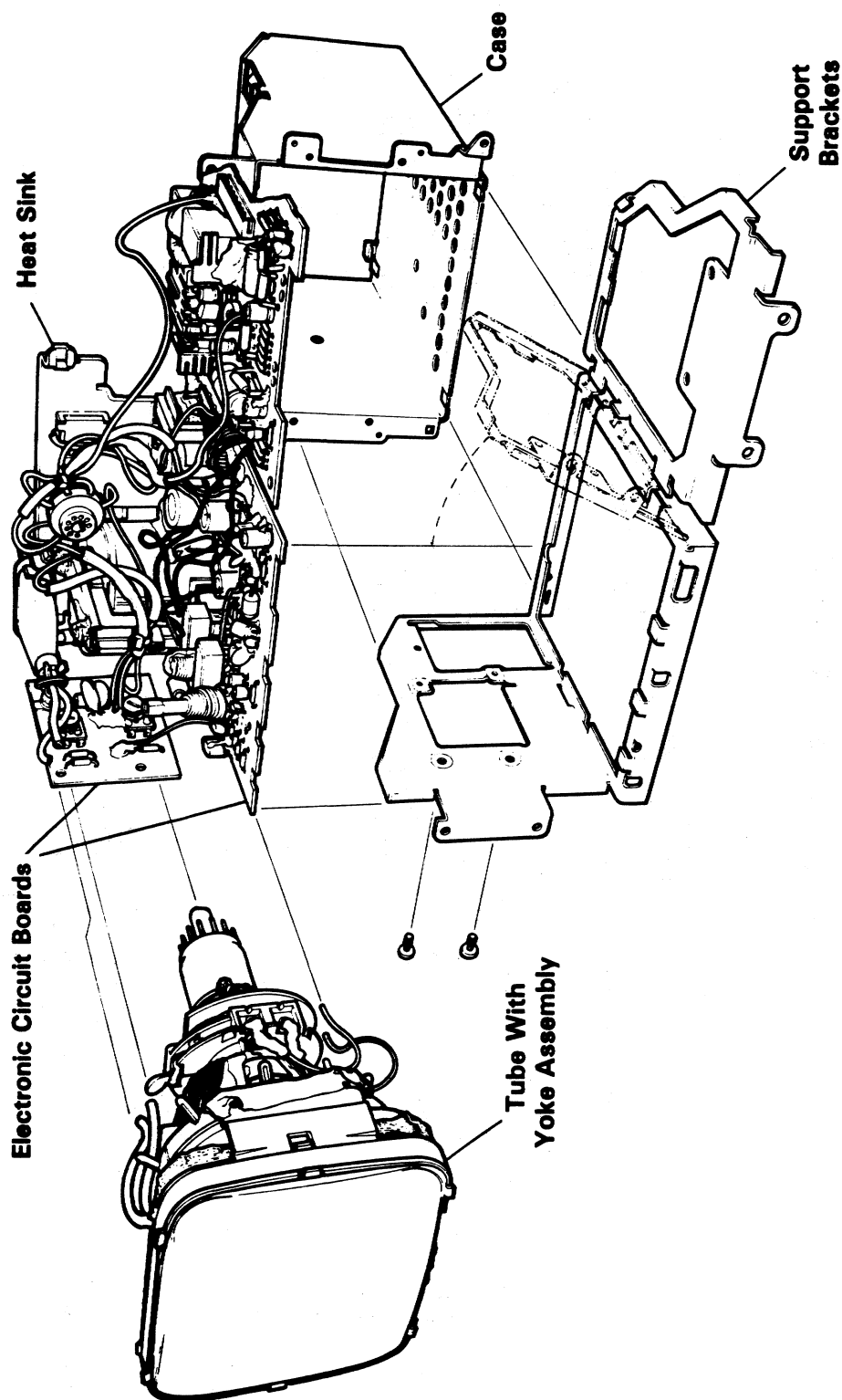


FIGURE 4

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FRONT FACE ASSEMBLY

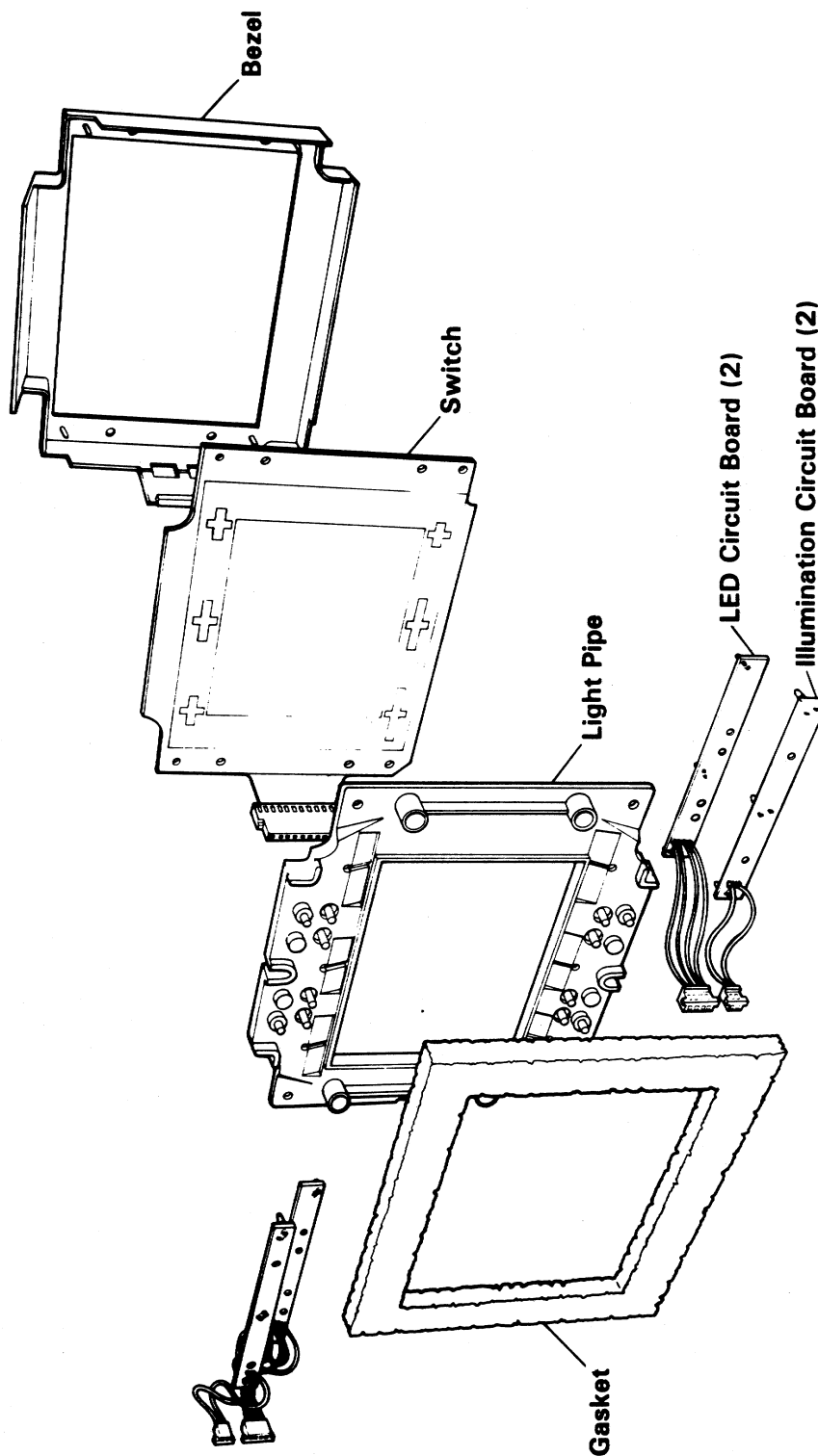


FIGURE 5

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