Cathode Ray Tubes:

Getting Down to Basics

FORWARD

This book was written to serve three major purposes:

1. To understand the interaction and interdependence between the CRT and electronic circuitry in measurement devices having CRTs. The cathode-ray tube (CRT), as the output or display section of oscilloscopes, graphics terminals and other measurement devices, requires understanding in isolating a malfunctioning electronic circuit, the design of circuitry that interfaces with the CRT is dependent upon the requirements of the CRT and before these circuits can be fully analyzed the requirements of the CRT must be known. The proper operation of the various controls and adjustments directly associated with the display requires an understanding of the probable effect upon the CRT.

2. To understand the basic theory or principles of CRT design and operation. In today's world of solid-state devices the principles of operation of vacuum devices is relatively unknown. This book is an attempt to give the engineer, technician or other reader a basic understanding of CRT operation.

3. To consolidate previous CRT-technical documents under one cover. Over the past 30 years there have been a number of CRT theory booklets and technical reports written by Tektronix covering CRT design and theory of operation; some were published and now are out-of-date and no longer in print, others were never published.

I wish to acknowledge those whose publications have been used in this book and whose efforts continue to advance the performance of cathode-ray tubes.

Vernon L. Isaac
CRT Product Assurance Manager
Tektronix, Inc.

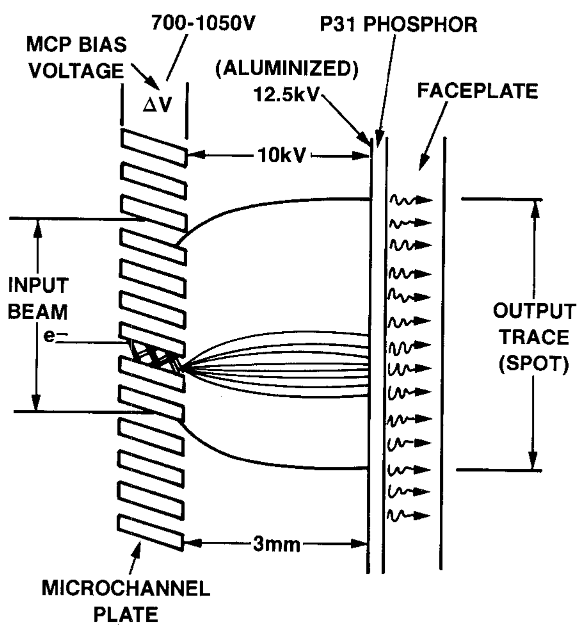
SPECIAL CRTS
7104 MICRO CHANNEL PLATE

The CRT continues to be the dominant display for high frequency, realtime waveforms. Tektronix' contribution to this field is the 7104 general purpose oscilloscope employing a high resolution, high frequency, microchannel plate (MCP) based CRT, the T7100. While the MCP, which multiplies a single electron entering a channel tens of thousands of times, is the heart of these CRTs, they also employ many novel electron features.

MICROCHANNEL PLATE (MCP)

The microchannel plate is an assembled structure of microscopic conductive glass channels. The channels are parallel to one another with the entrance to each channel on one side of the plate and the exits on the other side. See Figure 21-1.

An electron entering a channel will produce secondary electrons as it strikes the channel wall. When a voltage potential is applied across the two main plate surfaces, that is, across the length of the channels, the secondary electrons will accelerate and themselves collide with the channel walls. This dislodges additional secondary electrons. The process cascades down each channel struck by the CRT electron beam and results in a multiplication of electrons.



2. A microchannel-plate.

Figure 21-1

MCPs have had short lifetimes as one of their drawbacks in use as oscilloscope display. The MCPs in Tektronix T7100 CRTs are made using a proprietary process that reduces this drawback. Rather than decreasing rapidly with useage, the gain of the MCP in these tubes remains relatively constant. These same manufacturing processes also result in a fifty percent gain increase. The T7100 CRT employs the MCP in the proximity focus mode. The MCP is located about 0.3cm from an aluminized screen, and with 10 KV applied across this gap, the spreading of the beam from the MCP is minimized. On the 7104' scope, the INTENSITY control adjusts the MCP gain and beam current simultaneously in order to keep a solid trace at all settings. Without this precaution, the trace could take on a granular appearance when beam current was reduced or pushed toward its writing speed limit (3-5 Ghz) in direct access mode.The graininess results from individual input electron and individual channel gain statistics. That is, at any instant, electrons are not deposited into every channel covered by the beam, and a channel previously excited by an electron will have a considerable gain variation from event to event. In designing a CRT, writing speed is but one of the parameters that must be considered. The very large gain in writing speed provided by the MCP is useful in that part of it can be traded off in return for increases in resolution, bandwidth, and deflection sensitivity, and a reduction in unblanking requirements. The writing speed that remains after these tradeoffs is still good for use at several Gigahertz.

SCAN EXPANSION LENS (SEL)

The first CRT element behind the MCP is a variation on a classic quadripole design. The new design offers advantages in terms of both performance and manufacturing costs. The constraint of high bandwidth implies very low sensitivity deflection structures. However, the higher the bandpass of a CRT, the more sensitive the deflectors have to be. To achieve this, the CRT is generally made quite long and the scan relatively small. For the desired scan size and sensitivity of the T7100, the CRT, if made this way, would be over seven feet long. Of course this is not acceptable in a benchtop scope. Some novel techniques were used to shorten the actual CRT. One was the use of a scan expansion lens. Classic quadripole lenses have been used for scan expansion in several CRTs, including the Tektronix T7830. They are particularly advantageous when placed between the deflectors. The chief appeal of this lens can easily be analyzed mathematically. Its liabilities are the need for exacting alignment and dimensional tolerances and the small aberration free aperture to focal length (A/f) ratio off the axes of focus. In the T7100 the scan expansion lens is functionally a quadripole lens. Yet by deviating from the classic quadripole architecture, considerable improvements were made. This lens is far less critical with respect to dimensional and alignment tolerances. It has about triple the off-axis aberration A/f ratio, and allows one to correct a number of gain related geometry defects and to tailor the display linearity to very close specifications (typically one percent for most other CRTs). The deflection sensitivity in the negative axis of the lens can be adjusted over a range of about 20 percent. Another benefit of the scan expansion lens CRT compared to a long CRT is that the lens minimizes certain high frequency deflection artifacts stemming from the vertical deflector acting as a linear accelerator at very high frequencies.

The price of this improved capability and versatility is complexity. Whereas in its simplest form the classic quadripole requires only two potentials, this lens requires up to seven. In operation the SEL is a strong positive lens in the vertical axis and causes the beam to cross over or invert the vertical deflection. The vertical scan is expanded four and a half times. In the horizontal axis, the SEL is a negative lens, which merely enhances the deflection of the beam. The horizontal scan is expanded four times.

DEFLECTORS

The T7100 CRT employs traveling wave (slow wave or delay line) deflectors in both axes. These are helical transmission line deflectors where the velocity of the input signals along the helical conductors is equal to the speed of light, but the phase velocity along the length of the helix is nearly matched to the electron beam velocity as it propagates along the helix. The reason for a slight mismatch of velocities is a slight dispersion of the signal in the helix. That is, not all frequencies propagate down the helix at the same speed. To obtain the best compromise in both the time and frequency domain, the beam velocity must be slightly mismatched to the theoretical helix phase velocity (the velocity at which the power frequencies propagate). The dispersion of these deflectors is small, resulting in only a two percent mismatch of velocities. The phase velocity and thus the beam velocity is about 0.1c for these deflectors. The helix crosses the beam, not at right angles, but at an angle with a tangent of 1/10. Thus, in the vertical deflector, each side of the beam is deflected by the same potential. As the signal propagates across the beam and in the horizontal deflector, all portions of the vertical scan are deflected equally. If the horizontal helix were not so inclined, there would be a twelve picosecond timing error between the bottom and top of the display, yielding a sweep speed dependent orthogonality error. The inclination of the helix in the vertical deflector eliminates beam defocus which otherwise occurs under high dv/dt conditions. Some high dv/dt defocus remains which is dependent upon the displacement of the beam from the horizontal center screen. This is the result of linear accelerator action upon portions of the beam by the deflectors. The effect is scarely evident up to the 1 Ghz bandpass of the 7104 oscilloscope, but due to the outstanding triggering of the scope, one can observe the effect above 1.5 Ghz.

The horizontal deflector employs much the same construction and impedance compensating techniques as the vertical deflectors of the T7100 CRT. It also has the same impendance, 365 ohms. The horizontal deflection sensitivity is less than 2V/div (compared to 3V/div vertically and 7V/div horizontally in the 7904), and the bandpass is greater than 1.5 Ghz, allowing 350 Mhz response in the X-Y mode of the 7104. The vertical deflector is a novel modification of the internal groundplane structure. This is an extremely rugged, low mass high-percussion design that requires no impedance compensation. The structure can be mounted into an otherwise finished electron gun and is easily salvaged from rejected CRTs. The impendance is 200 ohms, line to line. deflection factor is less than 1V/div, and bandpass is about 3 Ghz. The vertical deflector and its groundplane are silver-plated to minimize skin losses. Connections to the vertical and horizontal deflectors are made through carefully spaced neckpins. The vertical deflector also employs stripline leads between the deflector and the in/out neckpins. Both deflectors use external terminations.

ELECTRON GUN

While the gun design may appear complex, it is composed of simple parts. First, and immediately upstream from the vertical deflector is the beam limiting aperture. This contains the cross-sectional profile of the beam in a field free region, to provide maximum current while minimizing the acceleration effect of the vertical deflector on the beam. Ahead of the aperture, there is a dedicated astigmatism lens. Usually, the astigmatism lens is created by a potential difference between the focus exit (second anode) element and the adjacent deflection plates. But because of the exacting requirements of the intermediate spot images, and because the vertical deflector with its internal groundplanes is not the last of the astigmatic lenses, a special low aberration astigmatism lens was developed. This lens is designed to act as a positive lens in the vertical axis with no effect in the horizontal axis. This condition of vertical overconvergence results from the requirements of the scan expansion lens. As noted earlier, the SEL is a strong positive lens in the vertical axis and a negative lens in the horizontal. If the beam is to be focused upon the MCP in the vertical axis a real line image of the cross-over must be formed before the SEL. In the horizontal axis, a vertical line image of the cross-over is required after the SEL. Thus the beam is always more convergent in the vertical axis and requires only vertical astigmatism control. In spite of considerably different optics the vertical and horizontal axis, the design maintains the same magnification of the cross-over in each axis to maintain a round spot on the screen.

The primary focus lens is of the classic Einzel configuration, but considerable effort was made to minimize aberrations of the lens in this application. Preceding the focus lens is a stigmator lens, which is an extremely weak lens used to make slight adjustments to the axis of astigmatism. Rotational alignment errors between the deflection axes and the scan expansion lens produces a slight orthogonality error, which is easily corrected by the rotator coil (wound on a form on the CRT neck) at the exit of the vertical deflector. Rotator coil correction disturbs the alignment of the axes of spot focus to the SEL, so the stigmator makes correctional rotational adjustments of the axes of focus.

Another device used to shorten the CRT is a crossover demagnification lens. This lens produces a real image of the crossover about halfway between the diode and the primary focus lens. The demagnification factor for the T7100 is 5 times, and the focus element for each operates at cathode potential. Since this lens operates in a demagnification mode, its aberrations are insignificant but it has the effect of increasing the magnification of the primary focus lens with the result of roughly doubling the aberration of that lens.

ION TRAP/VACUUM PUMP

The final innovative feature of this CRT is an ion trap/vacuum pump. This pump is incorporated into the structure of the first anode barrel. Gas ions which might normally damage the cathode are drawn out of the anode and deposited upon a gathering or gas adsorbing surface on the grid wafer. Since no change of operating voltages is required, this technique can easily be incorporated into other CRT types.

CATHODE

The cathode is a conventional oxide structure with a somewhat smaller than normal grid aperture. This is a proven design which provides more than adequate writing speed with 50 volts of unblanking. For further writing speed enhancement, the grid may be unblanked to over 70 volts. For easy reclaim of the gun or rebuilding of the entire CRT, the grid, cathode, and heater assembly can easily be removed or replaced intact.

Finally, in addition to the orthogonality coil wound on the neck of the CRT, a graticule alignment coil is wound on the envelope at the glass-ceramic interface. This permits the beam of the CRT to be aligned exactly with the horizontal graticule lines.