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and technical reports written by Tektronix covering CRT design and theory of operation; some were published and now are out-of-date and no longer in print, others were never published.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
7912 SCAN CONVERTER CRT

The 7912 tube is a double-ended scan converter, with the read gun facing the diode array and the write gun on the opposite side of the target, pointing at the back of the array (Figure 20-1). The input signal is applied to the vertical deflection plate of the writing gun as its beam sweeps across the target. The charge pattern this makes on the diode array is scanned by a low-velocity reading beam, modulating the read current to create the output signal.

The target is an array of pn junctions formed on an n-type silicon wafer by means of standard intergrated-circuit techniques (Figure 20-2). During fabrication the wafer is overlaid by a thermal oxide, in which an array of holes is etched by photolithography. Boron diffused through the holes forms the diodes. A density of 2,000 diodes per inch yields sufficient resolution for the 1/2 by 3/8 in. scan employed. A central area, 0.75 in. diameter is thinned to about 10 micrometer.

Reverse-biased silicon diodes do, however, have a small leakage current that results in a target dark current of about 15 nanoamperes at 30° C and doubles for every 10° C increase in target temperature. While some dark current is desirable to help bias the p region of the diode positive for reduced lag, (induced conductivity) high dark currents will reduce the dynamic range of the target, limiting the maximum obtainable signal current. For the diode-array scan converter, the read beam's current saturation is 300 nA, so that dark currents much in excess of 100 nA cannot be tolerated. This limits the target's maximum temperature to about 60° C.

Increasing the applied target voltage does not increase the silicon array's gain-unlike in a photoconductive vidicon target-but it will reduce lag. On the other hand, dark current increases about 10% per volt in the range of 8 to 16 v, so a compromise must be obtained between dark current and lag. This translates into a compromise between maximum digitizable writing speed and maximum signal dynamic range, usually attained by setting the target voltage to obtain the required dark current (15 nA at 30° C).

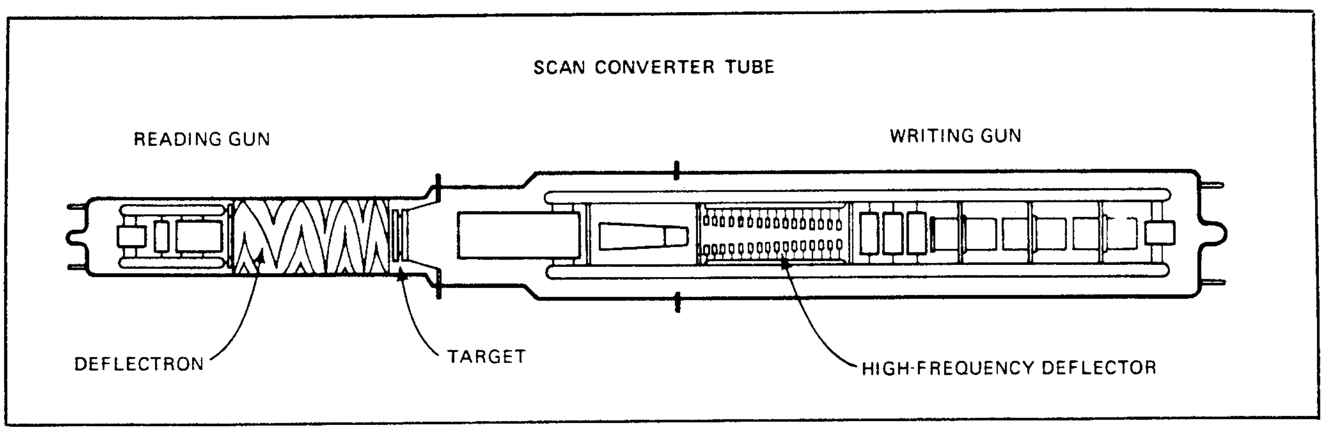

Figure 20-1

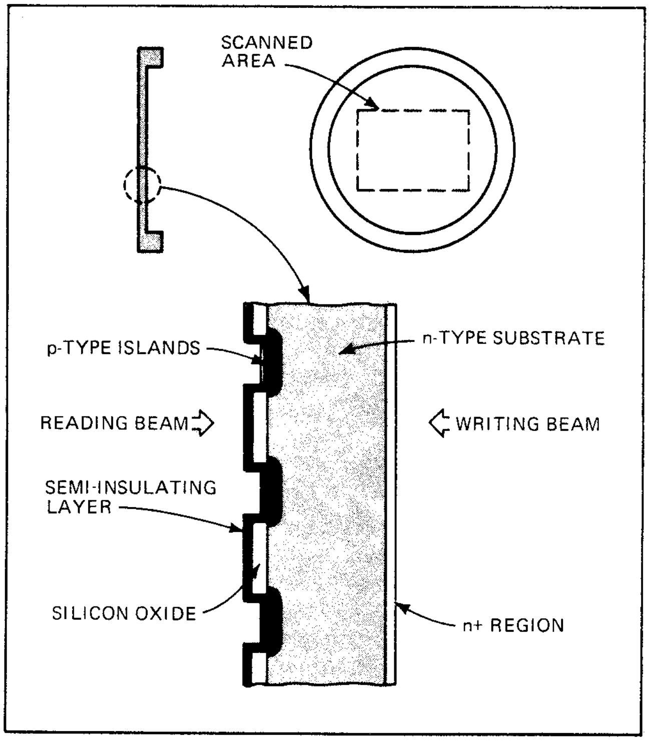

Figure 20-2

In operation, the reading section functions like a vidicon camera's tube. The target substrate potential is held a few volts positive with respect to the reading gun's cathode. On being scanned by the reading beam, the target is charged negatively to the cathode potential, in which condition the diodes are reverse-biased.

During writing, 10-Kilovolt electrons bombard the side of the target opposite the diodes and create many electron-hole pairs near the surface. The holes diffuse through the target and drift across the depletion region formed by the reverse-biased diodes, causing the diodes to conduct and discharge in the written area. When the reading beam next scans this area, the diodes are recharged and a signal current is obtained in the target lead. This provides the output signal, which can be amplified for further processing.

Since the average energy required for the creation of an electron-hole pair in silicon is 3.6 electronvolts, roughly 2,780 electron-hole pairs are created by each incident 10-KV electron. Certain losses occur from the recombination of charge carriers and from the back scattering of some incident electrons, so that the effective charge gain of the target is about 2,000. This gain mechanism is responsible for the sensitivity of the target and the high-speed performance of the scan converter.

Because the penetration of the 10-KV writing-beam electron is small, about 1 μm, and the carriers they generate must diffuse through the wafer, causing losses in collection efficiency and deterioration in resolution, target thickness should be kept to a minimum. This is the reason the target is thinned in the center working region to about 10 μm, a practical thickness.

To further assist collection efficiency, a thin n layer is diffused in this thinned region, to create an internal field and repel carriers away from the surface, where they would recombine.

In the targets used for the scan converter, a semiconducting layer is formed over the diode side of the target in order to prevent charging of the oxide web surrounding the diodes and consequent interference with the operation of the reading beam.

To achieve a large target gain, a high-energy writing beam is required, but for good deflection sensitivity the beam voltage at the deflector should be low. A post-deflection acceleration scheme would do, except that it would require a high voltage at either the beam deflectors or the reading section. Since the vertical deflector has a bandwidth of more than 2 GHz, it is important to keep the average potential near ground to facilitate connection to the vertical amplifier or signal source. The reading section handles signals as low as a few nanoamperes, and maintaining good signal-to-noise characteristics at an elevated voltage presents formidable practical problems. These considerations led to the adoption of a monoacceleration writing gun, with both deflectors and reading section near ground potential.

The writing gun was designed to achieve the best compromise between deflection sensitivity, resolution, accelerator voltage, and beam current. It was important to design for high deflection sensitivity so that the tube could be used with available wideband amplifiers, which have only limited output voltage swing at frequencies above a few hundred megahertz. (Alternatively, such a tube could be used with direct access of the signal to the deflection plates). But only a modest beam current is necessary when a high-gain target provides writing speed; the advantage is that the triode section of the gun can then be designed to maintain a small beam spot size at all grid drives, and tube resolution will not deteriorate at fast writing speeds.

Tradeoffs between the four parameters were optimized by means of a computer program. The best design consisted of a 10-KV mono-accelerator writing gun having a vertical deflection sensitivity of 24v per scan, a beam spot size of 0.001 in., and a scan at the target of 3/8 by 1/2 in. The maximum beam current is in the range of 3 to 10 microamperes.

At high frequencies, the transit time of the electron beam through the deflection plates becomes comparable to the period of the deflecting signal, and the deflection efficiency is decreased. To avoid this, the deflectors of high-frequency scan converters and cathode-ray tubes are usually made in the form of a delay line. For optimum performance, the delay line should have minimum dispersion and the phase velocity of signals on the line should match the electron velocity in the beam.

The vertical deflector used in the scan converter's writing gun consists of two helical delay lines assembled into a balanced deflection system. The deflecting field appears in the gap between the helices, which are contoured to provide the required sensitivity and scan. The final design has a deflection sensitivity of 24 v per scan and a bandwidth of 2.5 GHz as determined from risetime measurements. The delay line's impedance was set to 864 ohms line to line, to match the wideband deflection amplifier available.

The reading section requires a low-velocity beam with minimum shading and good resolution. To accommodate variable scan rates, electrostatic deflection was preferred to the electromagnetic deflection common in vidicons. Generally, however, electron guns which use electrostatic fields for focusing of the beam have poor shading characteristics.

Shading is caused by off-normal landing of the beam on the target and results in a variation in the level of the readout signal's base line. It is particularly objectionable in a measuring instrument, especially when the readout signal is to be digitized by a Schmitt trigger circuit. With appreciable shading, the Schmitt trigger level must be set high to avoid triggering off the uneven base line, which means that small signals cannot be detected and high-speed performance suffers.

Figure 20-4 illustrates the effect observed as the limiting writing speed is approached. The photographs were taken from single-shot sweeps at various signal frequencies. With a 100-MHz signal, both devices have sufficient brightness for adequate film recording. At 500 MHz, the center portion of the sine wave is too fast to record on the CRT, and only the peaks of the waveform can be seen. The scan converter, however, gives a clear signal at 2.4 GHz, a figure that is at five times better than the writing speed of the 7904 CRT.

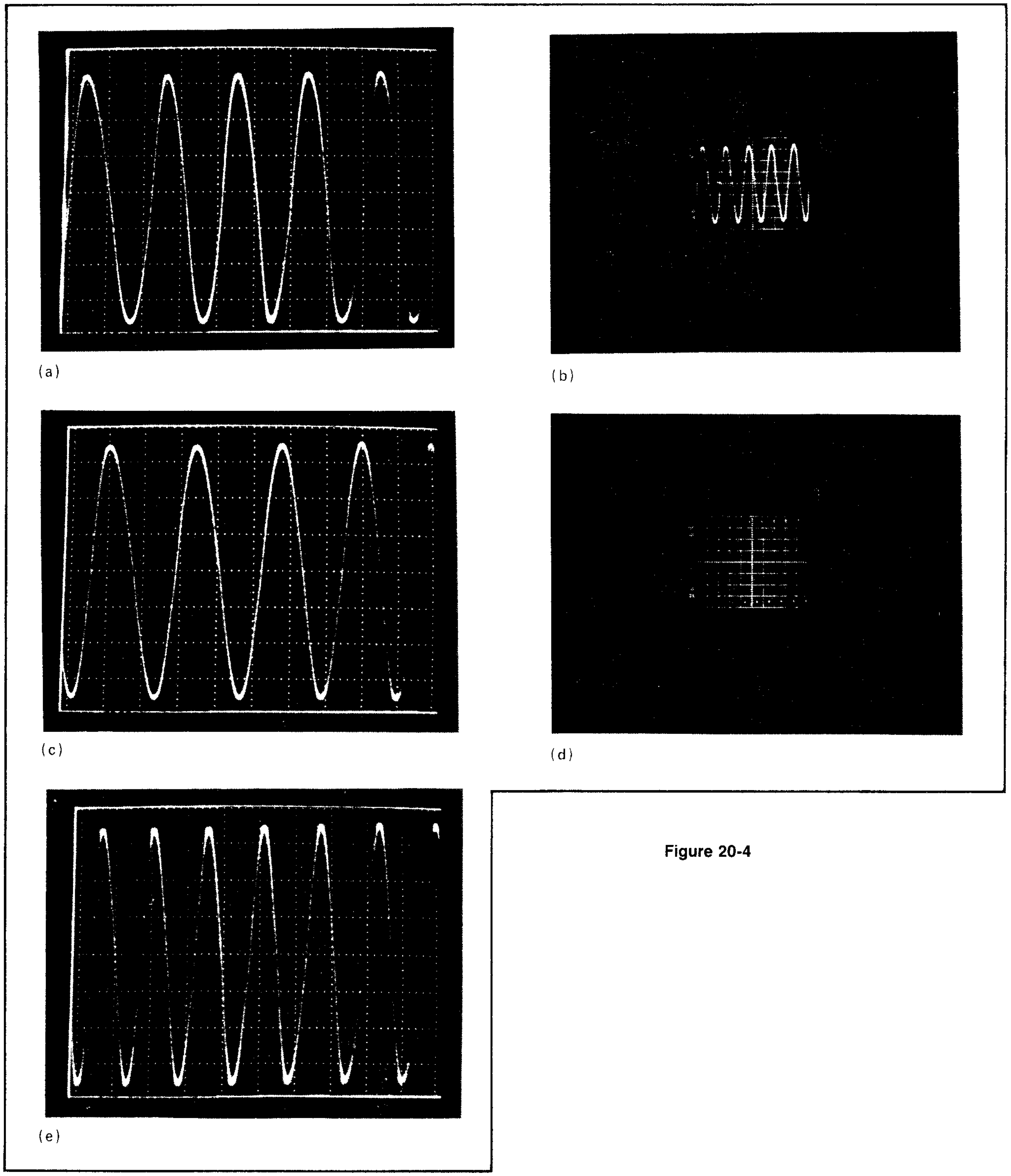

Figure 20-4