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technical reports written by Tektronix covering CRT design and theory of operation; some were published and now are out-of-date and no longer in print, others were never published.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

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ACCELERATION SCHEMES

In a monoaccelerator tube the electrons are accelerated between the cathode and the first anode. The focus lens decelerates and then accelerates the electrons back to their entrance velocity and its overall effect on acceleration is zero. Once the electrons have passed the second anode of the focus lens in a monoaccelerator, no other force is applied to change their axial velocity.

The light output from a phosphor increases approximately as the voltage through which the beam electrons have been accelerated. In a monoaccelerator CRT this is the voltage difference between the cathode and the first anode, or approximately 3-4 kV. Frequently the light output from the CRT screen in a tube of this type is too low to produce a visible display of a fast risetime or high frequency signal. The specification sheet for a CRT may not state that the tube is a monoaccelerator. The exception would be a CRT using a low helix-voltage.

The light output could be increased by increasing the gun voltages, but this would increase the deflection factor. An increase in plate length would decrease the deflection factor but for a 6 to 1 increase in the acceleration potential, the plates would protrude beyond the screen of the CRT. Other than the bulky size of the plates, the capacitance between the plates would increase enormously and the use at high frequencies would be lost.

In order to overcome the problem of low light output, various schemes are used where the beam's electrons are kept at a relatively low voltage in the deflection region and then accelerated after deflection to a higher energy level. This concept of acceleration is called post deflection acceleration and is abbreviated PDA or just "post". Monoaccelerator tubes are referred to as just "mono". The main advantage of a post vs a mono is higher light output for viewing fast signals.

A monoaccelerator tube usually has a conductive coating or Aquadag on the inside of the tube from the deflection plates to the face plate. In some early PDA CRT's this coating was split into regions by an insulating gap (Figure 6-1). Each band had a different potential and accelerated the electrons in what had been the electron drift region. Because the acceleration occurs after deflection, the tube's deflection factor is not as adversely affected as in a monoaccelerator which has the same overall accelerating potential. The equipotential lines in Figure 6-1 show the lens action of this type tube. This type tube suffered from distortion and compression.

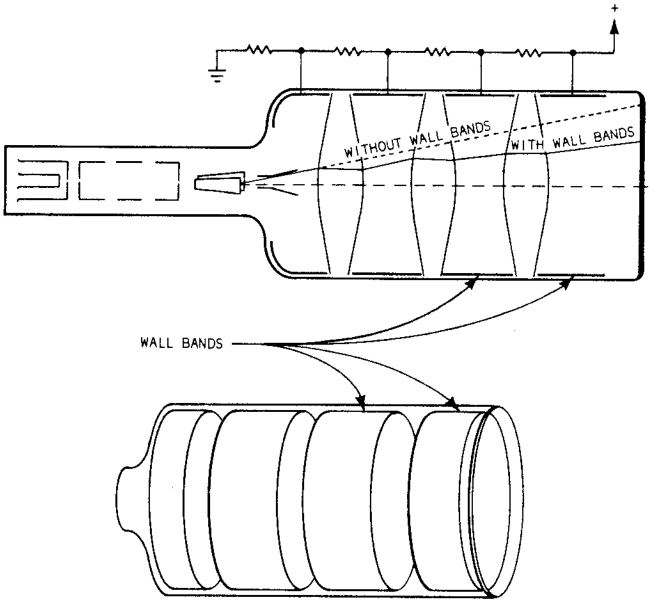

Figure 6-1

An innovation by Tektronix was to make a continuous electron lens over the entire funnel by using a helically wound resistive material in place of the Aquadag coated surface separated by insulated gaps. The type tube shown in Figure 6-2 is called a helix PDA tube. This type of tube has compression but not as severe as the wall-band Aquadag type.

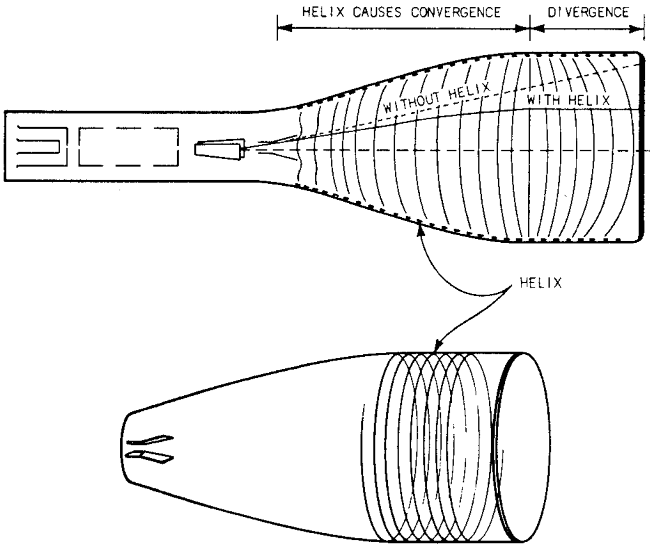

Figure 6-2

The helical post system allows the gun and deflection sections to be operated at lower voltages than a mono tube. The lower operating voltage reduces the velocity of the beam in the deflection region and is an aid to better deflection sensitivity. After the beam has been deflected it is then accelerated between the D1-D2 plates and the screen.

When a helix is used the electrons are accelerated after being deflected but compression reduces the scan and deflection sensitivity (Figure 6-2). Notice the equipotential lines are convex from the D1-D2 plates until over halfway to the screen. The electrons which do not enter perpendicular to the field lines, therefore, are bent toward the axis. Near the screen the electron velocity is such that the weak diverging field has little effect.

The overall acceleration potential using a helix PDA is usually 10 kV or greater. The increase in light output more than offsets the disadvantage of compression. A typical tube might have a scan compression factor of 1.7:1 for the vertical and 2.1:1 for the horizontal deflection.

Compression effects are not all bad. Since the beam passes through a convergent field, not only is scan reduced but also spot size.

A helix PDA tube has compression due to the convergent action of the field (Figure 6-3). This compression can be eliminated by a mesh located just past the D1-D2 deflection plates. This mesh forms a radial accelerating field (Figure 6-4). The combination of the mesh and the voltage distribution formed by the helix produce concentric spherical equipotential surfaces (Figure 6-4).

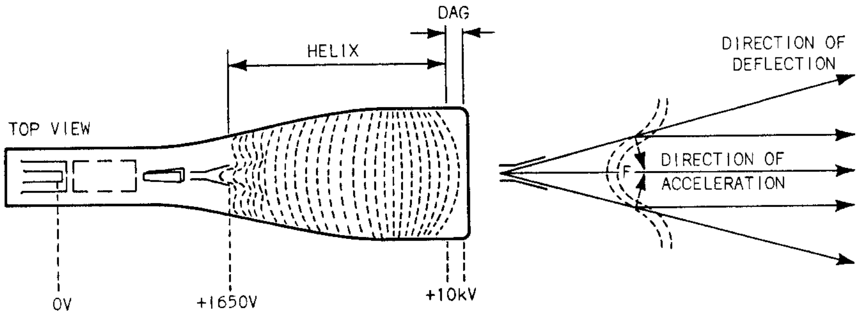

Figure 6-3

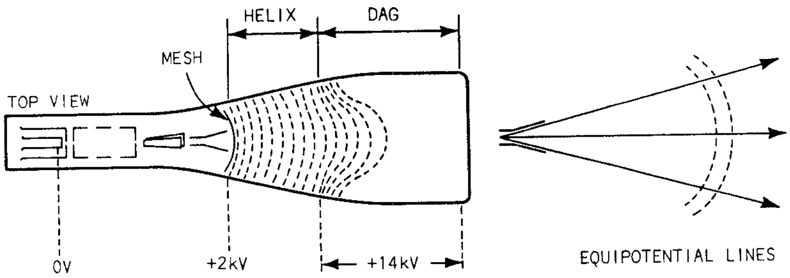

Figure 6-4

The mesh is a field-forming electrode. The electric field is then radial from the center of the deflection plates and little compression takes place. (The electrons pass normal to the equipotential surfaces and therefore increase in velocity. The path of the electrons continue in a straight line.) This system allows electrons to be accelerated without helix compression. Since the electrons travel in a straight line after deflection, the scan and deflection factor are about the same as the monoaccelerator tube.

This system suffers, however, from part of the beam current being intercepted by the mesh. The mesh is at a positive voltage and since it is a conductor it will collect electrons when struck by the beam. This reduction in beam current offsets somewhat the hoped for increase in light output. The mesh may intercept between 30-50% of the available beam current and since compression is no longer present, the spot size increases.

The advantage of lower deflection is traded for an increased spot size and decreased light output for the same accelerating potential. It is usual, though, to increase the accelerating voltage in a mesh tube to regain the light output lost to collection by the mesh,especially since little compression occurs as the voltage is increased.

The need for a shorter CRT with low deflection factor, motivated development of the magnifier or scan expansion tube. Reduced deflection factor (magnification) results from the effects of a mesh, or frame grid, on the force lines of a PDA CRT using a single, continuous, post deflection anode. The mesh distorts the normal force lines into a cone, creating a divergent lens (Figure 6-5). This lens action causes expansion. Controlled expansion produces a CRT with lower deflection factor.

In Figure 6-5A, conductive material surrounds the inner CRT wall, extending from the face plate to a point ahead of the deflection plates. The mesh appears in a plane between the deflection plates and conductive coating termination. Force lines emanate from the rear coating edges because the conductor completely surrounds the CRT bottle with equal voltage. Remove the mesh and this field develops approximately as the force lines nearest the deflection plates in Figure 6-3. In place, the mesh shapes the field into a divergent lens.

Figure 6-5B depicts the deflection magnification effect upon a electron beam. This technique reduces deflection factor to realize as much as 2 X deflection magnification.

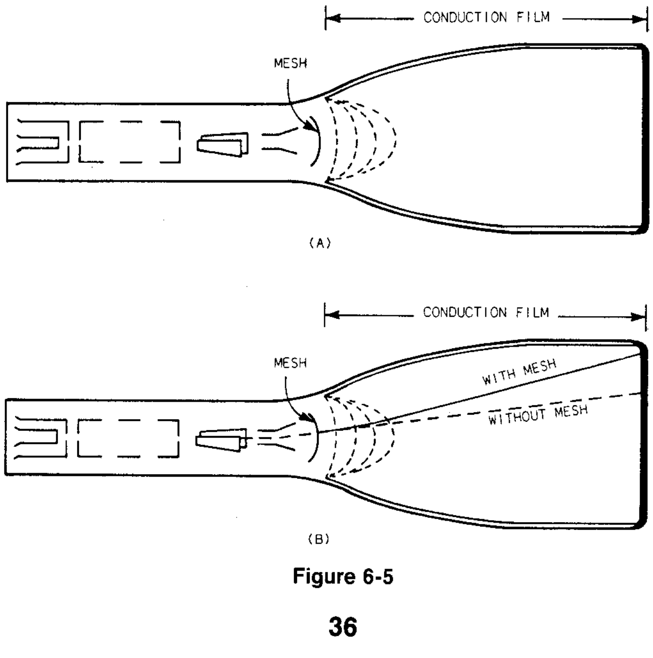

Figure 6-5

In any tube using a mesh, a shadow pattern can be seen on the screen when the spot is defocused. This shadow is not seen when the scope is operated in the normal mode.

The field-forming electrode configuration may be either mesh or frame-grid. The mesh tube has a structure with conductors running in both planes—similar to wire gauze. Its chief advantage is that it may be curved in both planes to obtain the desired field curvature. The major disadvantage is that it intercepts more of the beam current (30-50%) and defocuses the spot in both X and Y axis. The frame-grid has conductors running in only one direction and intercepts substantially less beam current (15-30%).