March 8, 2005

A Technical Research Report:
The Cathode Ray Tube

Prepared for
Professor Ann Holms
University of California Santa Barbara
College of Engineering

Prepared by
Charles A. De Cuir
University of California Santa Barbara
College of Engineering

Table of Contents

List of Figures

Abstract

The cathode ray tube, which is the driving force behind monitor display technology, functions based on a set of basic components and principles. This report discusses the three main cathode ray tube components: electron beam formation systems, electron beam deflection systems, and screen components. In addition, the report covers the principles behind electron beam display functionality.

Introduction

The cathode ray tube (CRT) is the crux of monitor display technology. It is the device that displays images upon a screen using electron beams. The entire CRT is inside a vacuum sealed tube to avoid air resistance. The electrons are first created at the back of the CRT by an electron gun. The electrons are shot off the gun at a high velocity and travel through a magnetic field, which steers them in a certain direction. The electrons then pass through a filter (shadow mask) and collide with a phosphor screen, to which they transfer their energy and cause the screen to glow. Through specific direction of these electron beams, images are created and displayed on the screen.

The purpose of this report is to explain the basic functionality of cathode ray tube and its primary systems. The functions of the three main systems of the CRT will be discussed in detail. These parts are: electron beam creators, electron beam directors, and screen components. The specific construction of each of these devices will not be explained. Also, the manner in which the electron beam displays imagery will be covered.

The CRT has been in use for a long time, and has inspired devices that have revolutionized society. It has continued to evolve and provide new benefits in new ways. This has been possible through knowledge of its basic functionality. Following this knowledge as a guideline, the CRT has continued to advance to new heights; yet it still operating on the same principles that it always has been.

The first section of this report is dedicated to explaining the functionality of the main CRT components. This section includes a discussion of electron beam forming systems, electron beam deflection systems, and phosphor screens/shadow masks. The second section of this report describes how the electron beam displays imagery. This section includes descriptions of how the beam is organized on the phosphor screen (and by the shadow mask), and how the beam scans the screen to create specific images. In addition, the conclusion provides some information on the evolution of the CRT and its contemporary use.

Primary CRT Systems

The entire cathode ray tube is inside a vacuum sealed tube to avoid air resistance. The CRT functions based on three primary systems: electron beam forming systems, electron beam deflecting systems, and screen components. The electrons are first created at the back of the CRT by an electron gun. The electrons are shot off the gun at a high velocity and travel through a magnetic field deflection region, which steers them in a certain direction. The electron beam then passes through a filter (shadow mask) and collides with a phosphor screen, to which it transfers its energy and causes the screen to glow [Figure 1]. Through specific direction of these electron beams, images are created and displayed on the screen.

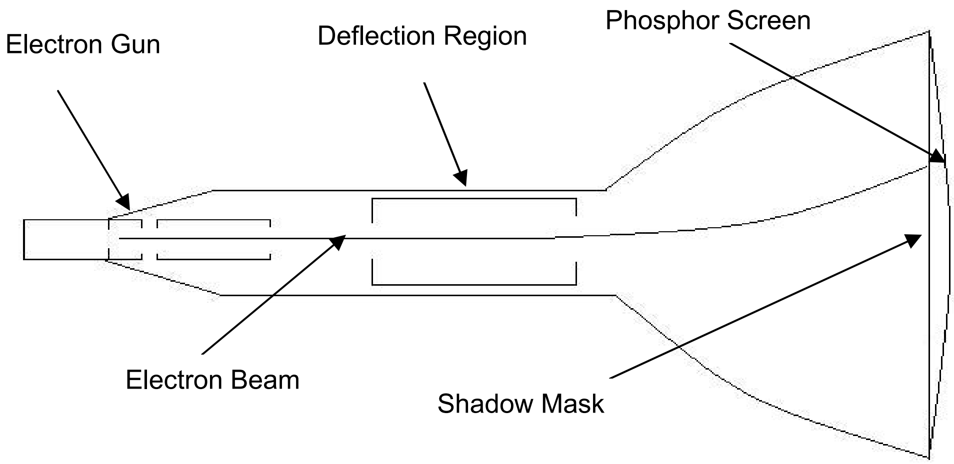

Figure 1: A General Cathode Ray Tube

The electron beam forming systems, electron beam deflecting systems, and screen components, function together respectively.

Electron Beam Forming Systems

The electron beam forming system consists of one device called an electron gun. The electron gun serves to create the electron beam that travels through the CRT. This device can be constructed in many ways, yet it always serves the same purpose.

The Electron Gun

Located at the beginning of the CRT vacuum chamber is the electron gun. This device generates electron flow, and creates the electron beam (cathode ray) that is manipulated throughout the rest of the CRT. The electron gun consists of: a cathode, a heater, an accelerating anode, a focusing anode, and several grids (also called control grid cylinders) [Whitaker, 2001].

The cathode is a small, capped, cylindrical piece of nickel metal. The heater is a conic insulated coil of tungsten located inside the cathode; a current is applied to this coil to heat it. There are three grids positioned in line, in front of the cathode, to make up a pathway for the electron beam [Figure 2]. A grid is a metal cup made of stainless steel (or of another metal with low-permeability) [Whitaker, 2001]. A small aperture is punched or drilled in the cap for the electron beam to flow through

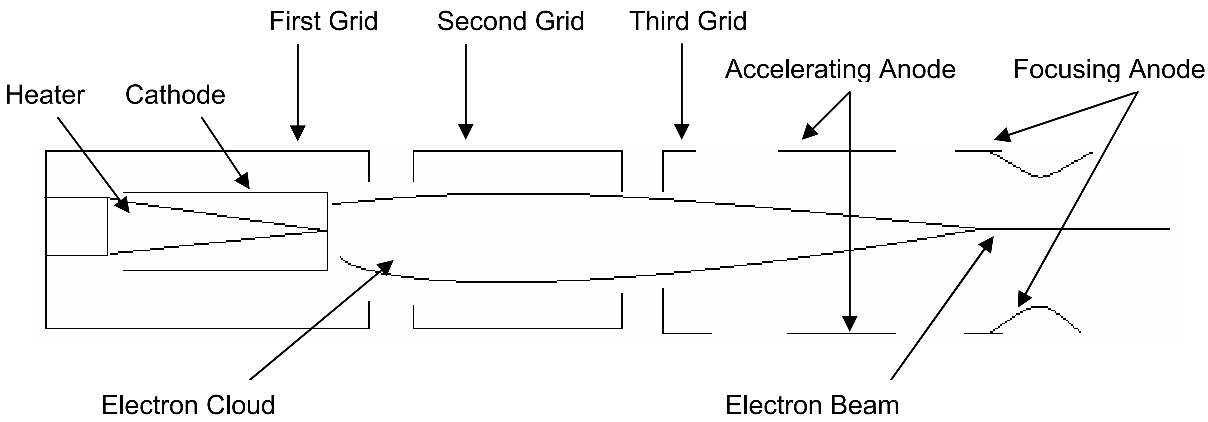

Figure 2: Generalized Structure of An Electron Gun

When the cathode is heated, enough energy is provided to the electrons on the cathode to be released. However, the electrons are released in a cloud, and must be manipulated into a beam before proceeding. The accelerating and focusing anodes serve this purpose. The accelerating anode is located in the third grid [Figure 2]; it emits a large positive electromagnetic field which draws and accelerates the electrons through the grids and towards the screen. The focusing anode also emits a large positive electromagnetic field, however this field compresses the electrons into a very fine beam [Figure 2], instead of accelerating them forward [Marshall, Electron Gun]. These anodes may be constructed in many different ways, however they usually are composed of several electrodes in a row with progressively higher (positive) voltages [Whitaker, 2001]

At the point at which the electrons leave the anodes (and the electron gun as a whole), they are traveling at a reasonable fraction of the speed of light [Marshall, Electron Gun]. In color CRTs, there are three separate electron guns, each of which has its own separate heater, cathode, and anode devices. Each electron gun produces the same type of electron beam. Each beam is dedicated to producing a certain color (red, green, or blue) on the screen.

Electron Beam Deflecting Systems

Once the electron beam has been formed and has left the electron gun, it must then be specifically directed onto the screen. There are two ways in which electron beams are directed: electrostatic deflection and electromagnetic deflection.

The Electrostatic Deflection System

An electrostatic deflection system generally consists of (conductive) metallic deflection plates used in pairs within the neck of the CRT, in front of the electron gun [Whitaker, 2001]. There are two pairs of deflection plates: one pair to control horizontal deflection of the beam, and the other to control vertical deflection [Figure 3]. The plates face each other and create an electrostatic field between themselves (using electric current) that the electron beam travels directly through. By strengthening and reversing the current between the two plates, the magnitude of deflection of the electron beam can be changed. Because the plates are inside the CRT vacuum tube, the magnitude and angle of deflection is limited. The second pair of deflection plates must have a sufficiently wide entrance window to accept the maximum deflection of the beam produce by the first pair of plates. [Whitaker, 2001]. Yet due to the fact that the plates are within the CRT neck, their size, and therefore deflection capability is limited. Also, the electron beam current is limited as well.

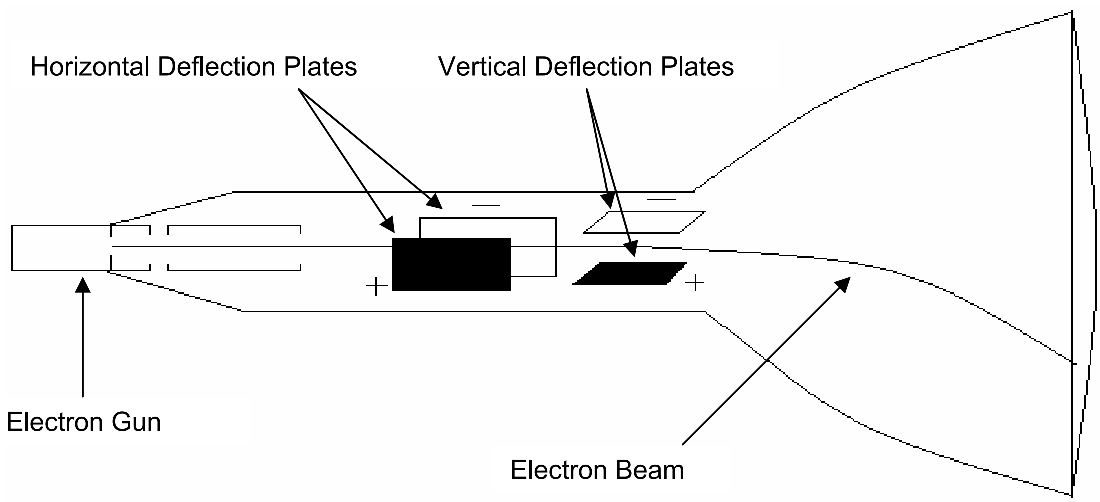

Figure 3: A General Electrostatic Deflection System.

In color CRTs, all three electron beams are deflected simultaneously by the plates.

The Electromagnetic Deflection System

In contrast with electrostatic deflection systems, the components in an electromagnetic deflection system are located outside the CRT vacuum tube. A conductive coil of magnet wire is spun around the outside of the CRT neck. This coil is separated into four parts each of which can have a current applied to it independently [Lee, 1957]. The parts on the top and bottom of the CRT neck control the vertical deflection of the electron beam, while the parts on the sides of the CRT neck control the horizontal deflection of the beam [Figure 4]. When a current is applied to a section of the coil, an electromagnetic field is created that draws the electron beam in its direction. By manipulating the current that travels through the coil sections, the electron beam can be specifically directed [Figure 4]. Because of the location of the electromagnetic deflection system, outside the CRT vacuum tube, the magnitude of deflection is much less restricted than in the electrostatic deflection system, and an electron beam with a greater current can be used. This results in a brighter picture [Whitaker, 2001].

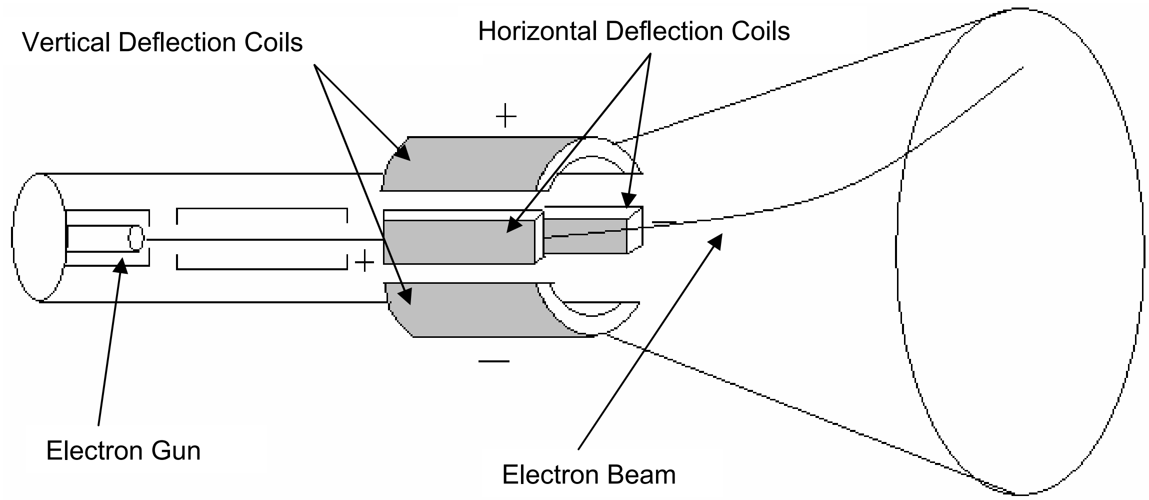

Figure 4: A General Electromagnetic Deflection System.

In color CRTs, all three electron beams are deflected simultaneously by the coil.

Screen Components

The CRT screen consists of two main parts: the phosphor screen and the shadow mask. The phosphor screen turns the electron beam into light, and the shadow mask organizes the beam on the screen.

The Phosphor Screen

The screen is composed of a thin layer of luminescent crystals called phosphors that emit light when bombarded with electrons [Whitaker, 2001]. The electrons in the beam are at an excited energy state, and when they come in contact with the phosphor, they fall back to their normal state and loose energy in the form of light (phosphorescence). Phosphor tends to emit this light/energy slowly, so it appears to glow even after the electron has struck it (luminescence). This allows a single phosphor continuously to emit light for the period of time it takes the electron beam to hit every other phosphor on the screen (there are typically 1,320,000).

Different phosphors allow different amounts of energy loss, and thus, different colors of light. A color screen is made up of triads of three different phosphors: one that emits red, one that emits green, and one that emits blue. When these three colors are added together in different measures (of light) the entire visible color spectrum can be achieved.

The Shadow Mask

When the three electron beams come towards the screen, they must be adequately aimed so that one beam hits red phosphor, one hits the blue phosphor, and one hits the red phosphor. The shadow mask serves this purpose. The shadow mask is a thin sheet of low-carbon steel with the same dimensions as the phosphor screen. It is etched to a desired pattern of apertures that match the phosphor triads on the screen in a one-to-one ratio [Figures 5] [Whitaker, 2001].

The shadow mask is tapered such that if the electron beams are aimed directly at one of its apertures, each beam will strike its corresponding phosphor [Figure 5]. It acts as a calibration device.

Display Functionality of The Electron Beam

In order for an electron beam to successfully display an image, it must first be organized, and then scanned across the screen. The beam is organized using one of two layouts: the triangle layout or the grill layout. The beam is scanned across the screen by what is called a raster scan.

Electron Beam Layouts

The triangle layout and the grill layout are the most common types of layouts used for organization of the electron beam.

The Triangle Layout

The organization of the electron beams is based upon the layout of the electron guns, phosphor triads, and shadow mask. The most common beam organization methods are the triangle layout, and the grill layout (or a variation of it). In the triangle layout, the red, green, and blue (RGB) phosphors are arranged as three dots in a triangle formation [Figure 8]. In this case the electron guns were aligned in a triangle, and the shadow mask is arranged with large circular anodes; one for each phosphor triad [Figure 5] [Jones, 2003].

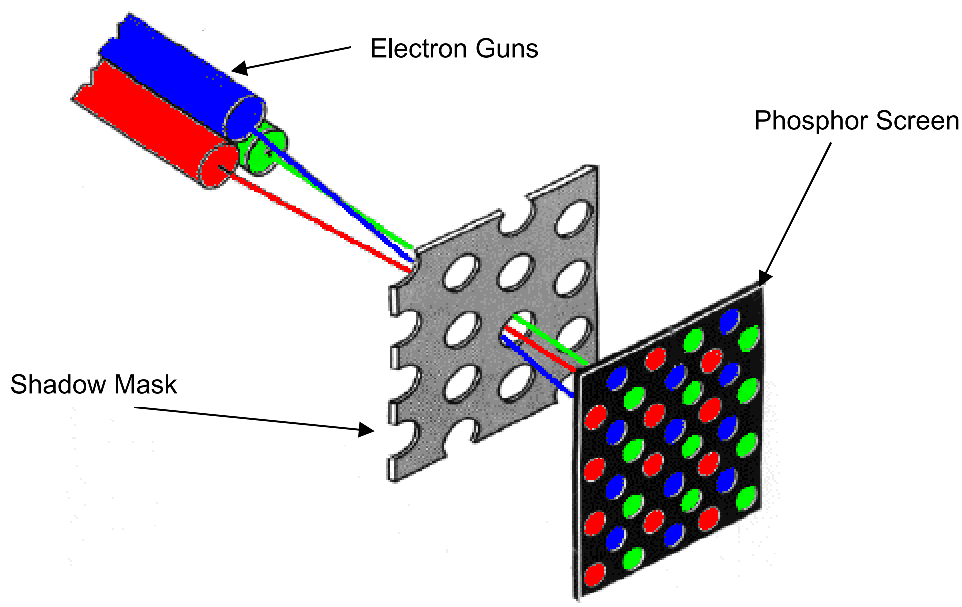

Figure 5: A Typical Triangle Layout [Analog Video, n.d.]

The Grill Layout

In the grill layout, the RGB phosphors are not dots, but lines arranged side by side in a certain pattern [Figure 6]. In this case the electron guns are arranged in a linear fashion as well [Figure 7]. The shadow mask contains one linear aperture for each linear triad of RGB phosphors [Sproson, 1983]. The grill layout is favored because it allows much more phosphor per square area of the screen, than the triangle method does [Jones, 2003]. The grill layout has many different variations, but all are based on a linear arrangement.

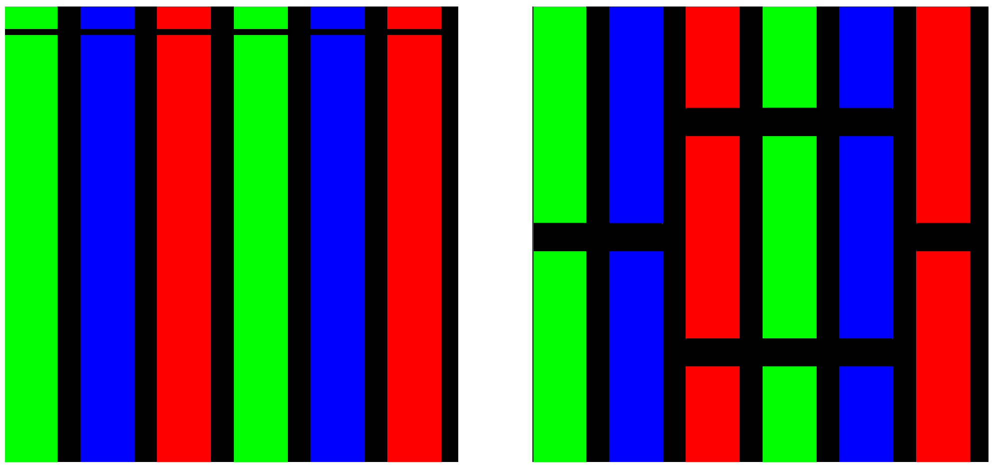

Figure 6: Phosphor Grill Layouts [Jones, 2003].

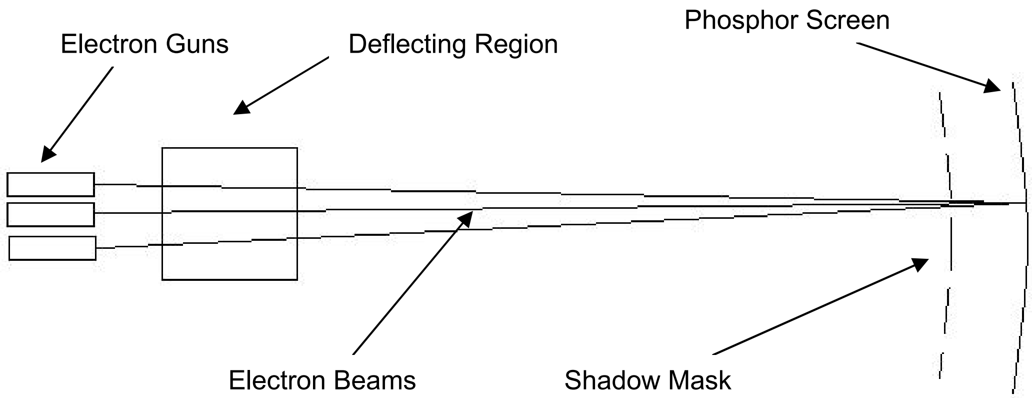

Figure 7: A Typical Grill Layout.

Electron Beam Scanning

In order for an electron beam to completely scan the screen and successfully produce an image, five pieces of information are required from an outside source at any given instant: the strength of the color red (amount of electrons from the 'red' electron gun), the strength of the color green (amount of electrons from the 'green' electron gun), the strength of the color blue (amount of electrons from the 'blue' electron gun), the horizontal position (current applied to the horizontal deflection system), and the vertical position (current applied to the vertical deflection system). A constant stream of information from each of these signals allows the electron beam to scan the screen in a manner called the raster scan.

In a raster scan, the electron beam scans the screen one line at a time from left to right starting in the upper-left corner of the screen [Figure 8]. When the beam arrives at the end of a line (on the far right of the screen), the electron flow is stopped and the deflecting systems are reset to position the beam at the start of the next line (horizontal retrace). When the beam reaches the end of the screen (lower right corner), electron flow is stopped and the deflecting systems are reset to position the beam at its original position (vertical retrace). The five necessary streams of information change with every pixel. A pixel (picture element) is the digital term for an RGB phosphor triad; it is the smallest image-forming unit of a video display [Jones, 2003]. A pixel can only display one color at a time (a combination of RGB values), but a large series of pixels creates a digital display of an image.

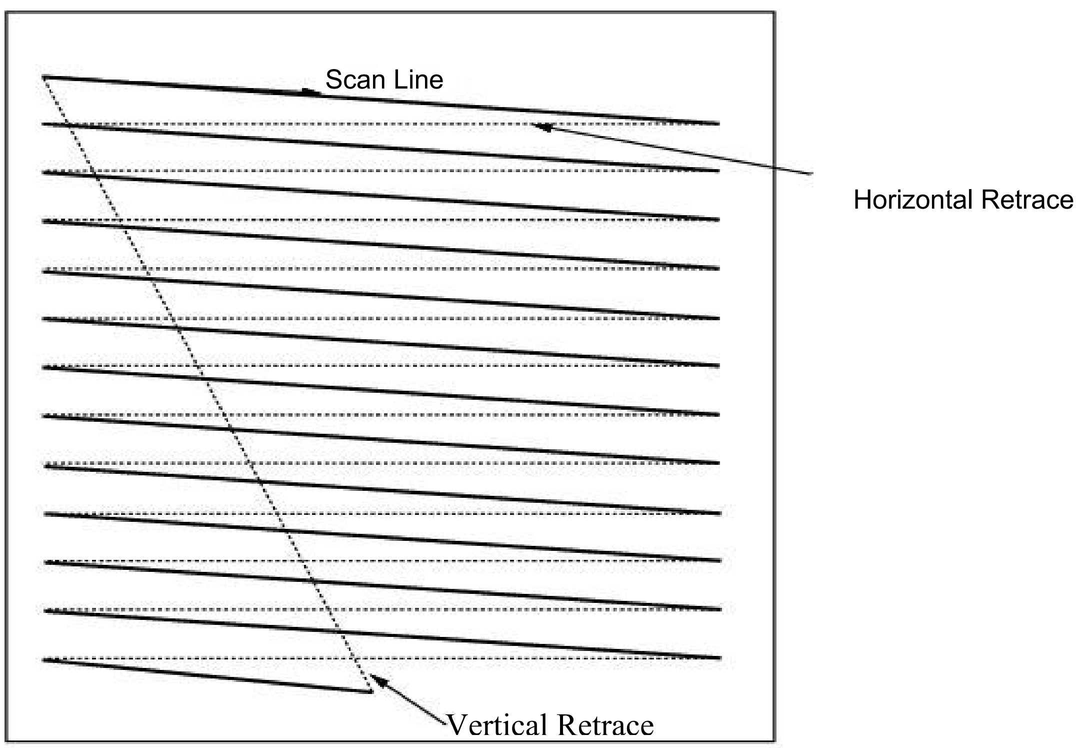

Figure 8: Diagram of A Raster Scan [CRT, n.d.]

Conclusion

There are thousands of different types of CRTs in existence today, some that vary in number of components, some that vary in display style, etc. Yet all CRTs function on the same basic principles discussed in this report. The malleability of these principles allows them to be applied with incredible diversity, and thus they remain a valuable asset. The latest application of CRT technology is shown within the development of the flat panel CRT monitor. Using basic CRT concepts and new micro technology, the size of the CRT has been greatly decreased and has therefore become more convenient. Only the future will tell what wonderful creations will come of the fusion between new technology and the persistent principles that drive the cathode ray tube.

References

Analog Video. (n.d.). Retrieved February 21, 2005, from http://www.danalee.ca/ttt/analog_video.htm

Brian, Marshall. (n.d.). *How does the electron gun inside a TV work, and why is it called an electron gun?* Retrieved February 16, 2005, from http://electronics.howstuffworks.com/question694.htm

Brian, Marshall. (n.d.). *How Television Works: The Cathode Ray Tube*. Retrieved February 16, 2005, from http://electronics.howstuffworks.com/tv3.htm

CRT. (n.d.) Retrieved February 21, 2005, from www.lsi.usp.br/~mkzuffo/PSI5787/opengl/

Heilborn, John. (1992, March). Understanding video displays: from CRTs to shadow masks. *Computer Shopper*, *12*(3), 656. Retrieved January 31, 2005, from InfoTrac Web: Expanded Academic ASAP.

Hoff, Philip. (1998). *Consumer Electronics For Engineers*. New York, NY: CambridgeUniversity Press.

Jones, Des. (2003). *Easy MAMECab Arcade Monitor*. Retrieved January 25, 2005, from http://easymamecab.mameworld.net/html/monitor1.htm

Lee, Kaiman. (1975). *Evaluation of Computer Graphic Terminals*. Boston, MA: Environmental Design & Research Center.

Sproson, N., W. (1983). *Colour Science in Television and Display Systems*. Adam Hilger Ltd, Bristol.

Whitaker, Jerry. (2001). *Video Display Engineering*. McGraw-Hill.