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An Introduction to the Cathode-Ray Tube

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Abstract

The cathode-ray tube (CRT) has been around for over 100 years and is still used in various applications. Because the CRT is a well-established technology, CRT's are relatively inexpensive and reliable. While the CRT has many advantages, it is slowly being taken over by other display technologies. This report focuses on the components of the CRT and how they work. The basic physics and chemistry principles behind each part are explained to give a solid understanding of how the CRT works. In addition, a brief future view of the technology is given.

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Introduction

Since the early 1900s, the Cathode-Ray Tube or CRT (sometimes called the Braun Tube) has played an important part in displaying images, movies, and information. A patent was filed in 1938 for the CRT; however, this was a very simple implementation. Over time, CRTs have advanced employing many different techniques to increase image precision and quality. While the technology has been around for several decades and is quite mature, it still has much room for improvement.

While today's CRT displays are much more advanced than those of a decade ago, they are much simpler than other display technologies. This gives the CRT several important advantages: cheap to manufacture and the ability to display high quality images. Due to the low cost, CRTs have a very high resolution to price ratio compared to other displays [Sherman, 2000]. Another important trait is the ability to display colors with high fidelity. For example, on a CRT, to display black, no color is displayed at a certain point giving the area a physically black color; in LCD displays, the closest is a washed out dark gray color.

The purpose of this report is to explain the underlying mechanisms behind CRT displays used in computer monitors and television displays. More specifically, how CRTs are used and the technologies that work together to make the CRT function. Construction, materials (for example phosphors used), and safe disposal methods will not be covered. While there are many new technologies coming out and maturing, the CRT is forcing them to compete on price and image quality. This results in a wide variety of high quality display technologies for the consumer to choose from.

The first section contains the main components of the CRT: the electron gun, the electron beam deflector, and the screen. The second section explains how the components work together to make the CRT work. The third section contains a future view of the technology. In conclusion, the strengths and weaknesses of the CRT will be discussed.

Main Components of the CRT

The cathode ray tube (CRT) is a display device that uses electrons fired at phosphors to create images. The CRT takes input from an external source and displays it, making other devices, such as computers useful.

The CRT consists of three main components: the electron gun, the electron beam deflector, and the screen and phosphors (Figure 1).

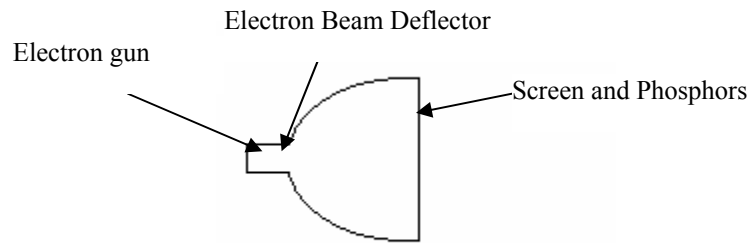


Figure 1. A basic diagram of a CRT. Shows the relative position of each of the components.

The Electron Gun

The electron gun fires electrons, which eventually strike the phosphors; this causes them to display colors. The electron gun consists of two main components, the cathode and the electron beam focuser. These two parts work together to fire an electron and help determine where it will go (Figure 2).

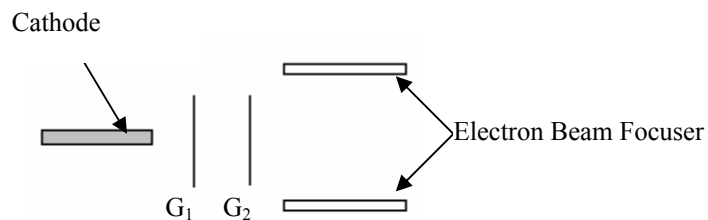


Figure 2. The electron gun.

The Cathode. The cathode is made of a metal conductor, usually nickel. Different voltages at G_1 and G_2 (Figure 2). The difference in voltage between G_2 and the cathode causes a voltage potential, usually between 100 and 1000 Volts, that is large enough to pull electrons off of the cathode [Sherman, 2000]. As the electrons are pulled off the metal, the voltage potential accelerates them, until they reach a final velocity. They then travel at a constant velocity until they reach the screen. The larger the velocity is, the more often electrons are hitting the screen. This is seen as an increase in the brightness. In order to increase brightness, the voltage potential is increased, which in turn increases the final velocity.

As electrons are being pulled off of the cathode, the metal causes electrons to give up. Without any additional mechanisms, the metal would eventually have no more electrons to be pulled off. The electrons are constantly being replenished so that the metal has more electrons to be pulled off.

The Electron Beam Focuser. After an electron has been removed from the cathode and accelerated, it travels through the electron beam focuser (Figure 2). In most monitors and televisions, an electrostatic mechanism is used to focus the electron [Sherman, 2000]. An electromagnetic mechanism can also be used, but will not be discussed here. Electrostatic means that a force is exerted by a constant (static) electric field.

The force exerted can be calculated by Coulomb's Law,

$$F = k |q_1q_2| / r^2. \quad (1)$$

This equation states that the force, F , is equal to k , the electrostatic constant times the charge on one object, q_1 , times the charge on another, q_2 , divided by the distance, r , squared. What this tells us is that the larger the charges are, the greater the force is. It also tells us that as the distance between the objects increases, the force goes down proportional to one over the distance squared. Using this principle, the electron beam can be accurately focused.

The purpose of the focuser is to decide exactly where the electron goes. While we are only looking at the path of a single electron, in practice, the focuser is constantly directing a beam of electrons. The electron beam focuser is one of the main factors in determining resolution [Sherman 2000].

The Electron Beam Deflector

The electron deflector is positioned at the base of the vacuum tube and controls what part of the screen the electron strikes (Figure 3).

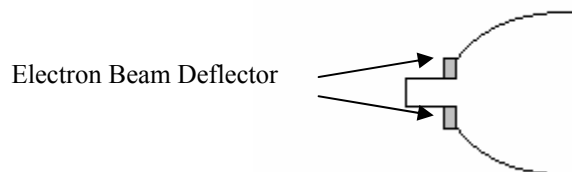


Figure 3. Position of the electron beam deflector.

The electron beam deflector, like the focuser, can rely on either an electromagnetic or electrostatic mechanism. An electrostatic mechanism operates in the same way as described earlier, except in this situation it would change the path of the electron rather than focus it. Most television and computer displays use an electromagnetic coil to control the path of the electron [Sherman, 2000].

The deflector determines the path of the electron. There are really two deflectors, one that controls the position in the x , or horizontal direction and one in the y , or vertical direction

[Martin, 2000]. A current is run through the coil to control where the electron goes. The electromagnetic force causes the electron to move towards either the left or the right in the case of the horizontal deflector. The deflector uses the force to change the path of the electron to determine what part of the screen the electron hits, but not which phosphor.

While the electron travels through the deflector, it accelerates due to the force applied on the electron. Acceleration means a change in the velocity over time. In this case, the direction of the velocity is changing. This new direction determines the path of the electron until it hits the screen (Figure 4).

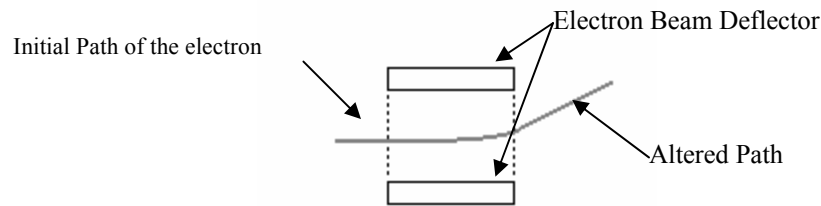


Figure 4. The electron beam deflector. This shows how the deflector diverts the path of the electron, which is initially traveling towards the center of the screen. Based on a diagram in [Morris, 2002].

The Screen

The screen, which is at the front of the CRT, is what actually displays the images. In color CRTs, the screen contains inorganic light-emitting phosphors with three different colors. When they are struck, they give off energy in the form of photons [Earle, 1984].

When the electron fired from the gun strikes the screen and hits an atom in the phosphor, it transfers its energy to an electron in the phosphor. The excited electron then rises to a higher energy level. As the electron falls, it emits energy as heat and visible light [Light, 2005]. When the electron rises, it can only rise to certain positions called an orbital (Figure 5). When it falls, it will always emit the same frequency of light.

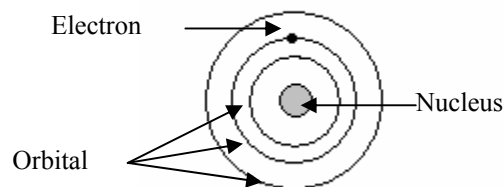


Figure 5. A Bohr representation of an atom. While it is not accurate, it shows what an orbital is. Each of the rings represents an orbital, which the electron can travel in. Consult quantum mechanics for a more accurate representation.

The energy of an electron is given by

$$E = -2.17 \times 10^{-18} * (z^2/n^2) \quad (2)$$

where Z is the atomic number of the atom and n is the orbital. To find the energy given off by going from one orbital down to another, we lower state's energy from the higher state. From Einstein we know that

$$E_{\text{phontone}} = hc/\lambda \quad (3)$$

In this equation, h is Planck's constant, c is the speed of light and λ is the wavelength emitted. Using these two formulas, we can find the wavelength of light emitted by an electron in an atom falling from a certain orbital. When combining the two equations, we find that the wavelength, or color of light, emitted is always the same. Because electrons can only rise to certain orbitals and give off specific wavelengths of radiation, a certain phosphor will always give off the same color light.

Directly behind the screen is a device, such as a shadow mask or aperture grille. The purpose of these devices is to stop stray electrons from hitting the screen, so only the electron beam hits the intended phosphors [Gowan, 2000].

Theory of Operation

The CRT operates by firing an electron beam at phosphors, which give off light. The electron beam is generated at the cathode in the electron gun. A potential (voltage) is applied, which strips off and accelerates the electrons [Moris, Maritn, Weber, 2000]. The electrons then travel to the to the electron beam focuser. An electrostatic mechanism is used to focus the beam

After the beam exits from the electron gun, it travels to the electron beam deflector. The deflector has two mechanisms, one to change the vertical direction and one to change the horizontal direction of the beam. This allows the electron beam to sweep over the entire screen.

When an electron in the beam strikes a phosphor, it excites an electron in the phosphor. After being excited, the electron then releases the energy it got in a form of visible light, which is always the same for that phosphor. Phosphors emitting red, blue, and green light form a color image.

Figure 6 shows the overall path of the electron bean. The electron beam is constantly being created and focused. The refresh rate describes how many times the screen is being redrawn per second and is usually 65 Hertz.

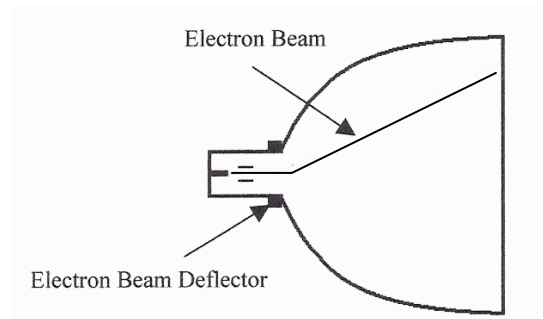


Figure 6. Overall path of the electron beam.

The Future of the CRT

While the CRT is a very mature technology, there is still a lot of room for improvement. For example, in 1984, a resolution of 640 by 400 pixels was considered high resolution [Earle, 1984]. Today, a high-resolution display can have over 2000 pixels in each direction, with millions of colors instead of a few hundred. The trend of increasing resolution and image quality, though perhaps at a slower rate, will continue in the foreseeable future.

One major disadvantage of the CRT is the amount of space it takes up. The CRT electrons need a large amount of space to travel in the vacuum in order for the screen to be large.

In the foreseeable future, CRT displays will continue improving in resolution. This means that higher quality displays will continue to be developed, even though the CRT is a rather mature technology. Some companies are working on making the CRT smaller by moving the electron gun closer to the screen

Conclusion

CRTs are gradually being replaced by other display technologies, such as Liquid Crystal Displays (LCDs). However, the CRT still has many uses. CRTs are easy and cheap to produce because they use a simple design. The CRT has a cost of less than \$0.00005 per color resolution element, much less than other display technologies [Sherman, 2000]. With the ability to compete on price and quality, the CRT will not likely disappear any time soon.

The CRT has many benefits when compared to other display technologies. The two most important ones are price and quality. They can also be used in a wide variety of applications such as radars in addition to televisions. Furthermore, they are fairly bright and can be viewed from a wide range of angles. Finally, they can last a long time and are fairly reliable because the technology is so mature.

One major weakness is that they are large and weigh a lot. This can make them difficult to store and to move. CRTs also use a lot of power compared to other display technologies such as LCDs and Organic Light Emitting Diodes (OLEDs). Another weakness is that they must constantly be refreshed [Sherman, 2000]. This is because when the colors are displayed, they quickly fade out, so the screen must be refreshed to keep it bright. Over an extended period of usage, this can irritate some people's eyes. Table 1 summarizes the benefits and disadvantages of the CRT.

Table 1. Strengths and Weaknesses of the CRT [Sherman, 2000].

Strengths	Weaknesses
Highest resolution technology	High power consumption
Excellent color fidelity	Weight
Excellent contrast/gray scale	Size of footprint
Bright display	Emits electromagnetic radiation
Broad application range	Must be refreshed
Long life and reliability	
Inexpensive	

References

- Earle, A. S. (1984, April 3). Taking a closer look at the RGB monitor. *PC Magazine*, 3, 145-150.
- Goldwasser, S. M. (2005). TV and monitor CRT (picture tube) information. Retrieved January 24, 2005, from <http://repairfaq.ece.drexel.edu/sam/crtfaq.htm>
- Gowan, M. (2002, March 20) How it works: CRT monitors. Retrieved February 19, 2005, from <http://www.pcworld.com/howto/article/0,aid,15765,00.asp>
- Light (2005). In *Microsoft Encarta Online Encyclopedia*.
- Morris, J. E., Martin, A., Weber, L.F. (2000). *The electrical engineering handbook*. Boca Raton: CRC Press LLC.
- Pittelkau, J. (1996, April 29) Behind every monitor is more than a tube and lots of wires. *Mac WEEK*, 10, 27-28.
- Sherman, C. J. (2000). *Cathode Ray Tube Displays*. Boca Raton: CRC Press LLC.