How Plasma Displays Work

by Tom Harris

For the past 75 years, the vast majority of televisions have been built around the same technology: the **cathode ray tube** (CRT). In a CRT television, a gun fires a beam of **electrons** (negatively-charged particles) inside a large glass tube. The electrons excite **phosphor atoms** along the wide end of the tube (the screen), which causes the phosphor atoms to light up. The television image is produced by lighting up different areas of the phosphor coating with different colors at different intensities (see How Televisions Work for a detailed explanation).

Cathode ray tubes produce crisp, vibrant images, but they do have a serious drawback: They are **bulky**. In order to increase the **screen width** in a CRT set, you also have to increase the **length** of the tube (to give the scanning electron gun room to reach all parts of the screen). Consequently, any big-screen CRT television is going to weigh a ton and take up a sizable chunk of a room.

Photo courtesy Sony

A plasma display from Sony

Recently, a new alternative has popped up on store shelves: the **plasma flat panel display**. These televisions have wide screens, comparable to the largest CRT sets, but they are only about 6 inches thick. In this edition of **HowStuffWorks**, we'll see how these sets do so much in such a small space.

What is Plasma?

If you've read How Televisions Work, then you understand the basic idea of a standard television or monitor. Based on the information in a video signal, the television lights up thousands of tiny dots (called pixels) with a high-energy beam of electrons. In most systems, there are three pixel colors -- red, green and blue -- which are evenly distributed on the screen. By combining these colors in different proportions, the television can produce the entire color spectrum.

The basic idea of a plasma display is to illuminate tiny colored fluorescent lights to form an image. Each pixel is made up of three fluorescent lights -- a red light, a green light and a blue light. Just like a CRT television, the plasma display varies the intensities of the different lights to produce a full range of colors.

The central element in a fluorescent light is a **plasma**, a gas made up of free-flowing **ions** (electrically charged atoms) and **electrons** (negatively charged particles). Under normal conditions, a gas is mainly made up of uncharged particles. That is, the individual gas atoms include equal numbers of protons (positively charged particles in the atom's nucleus) and electrons. The negatively charged electrons perfectly balance the positively charged protons, so the atom has a net charge of zero.

If you introduce many free electrons into the gas by establishing an electrical voltage across it, the situation changes very quickly. The free electrons collide with the atoms, knocking loose other electrons. With a missing electron, an atom loses its balance. It has a net positive charge, making it an ion.

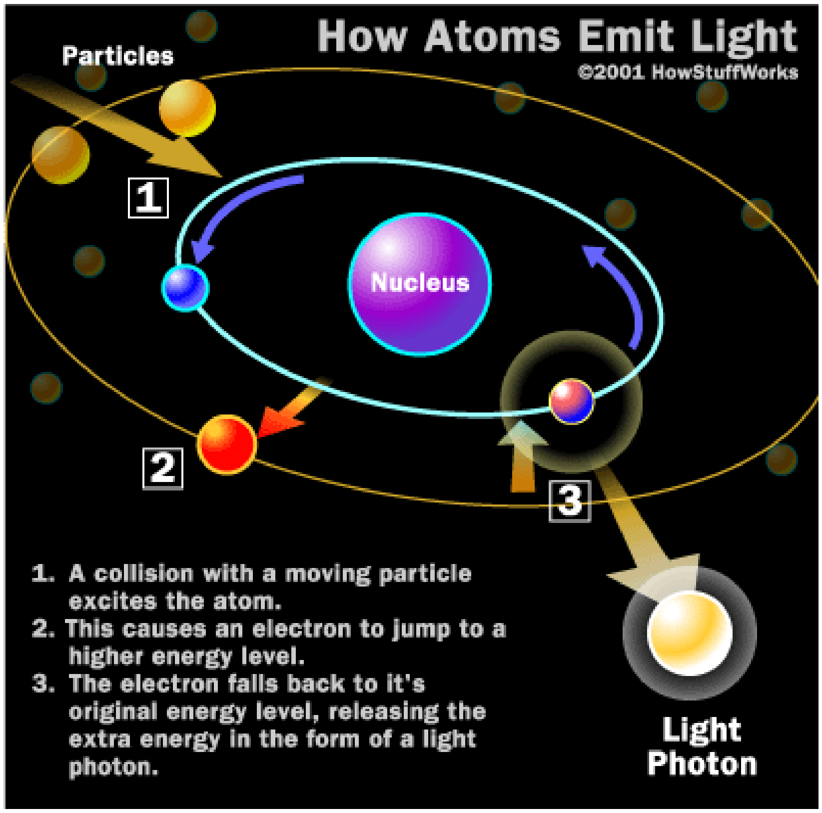
In a plasma with an electrical current running through it, negatively charged particles are rushing toward the positively charged area of the plasma, and positively charged particles

Tuning In

Most plasma displays aren't technically televisions, because they don't have a television tuner. The television tuner is the device that takes a television signal (the one coming from a cable wire, for example) and interprets it to create a video image.

Like LCD monitors, plasma displays are just monitors that display a standard video signal. To watch television on a plasma display, you have to hook it up to a are rushing toward the negatively charged area.

separate unit that has its own television tuner, such as a VCR.

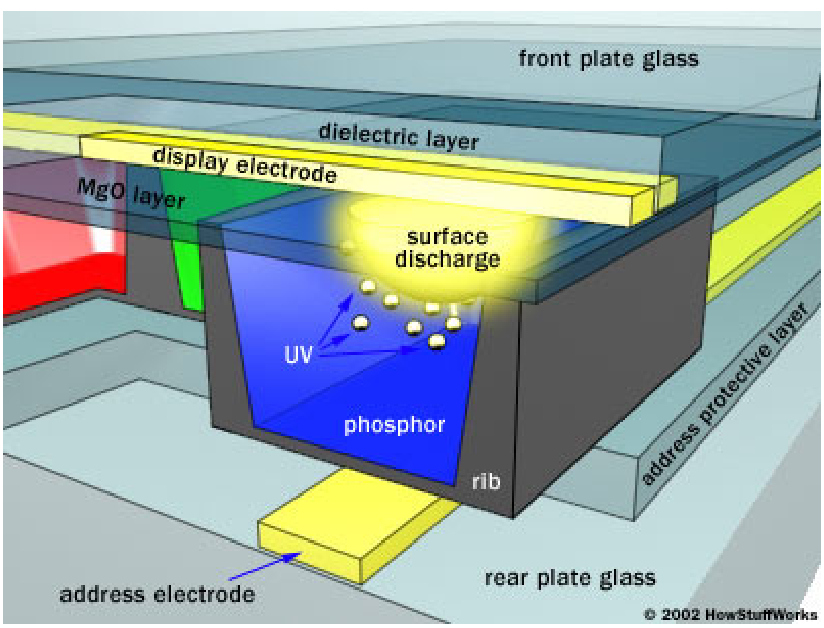


In this mad rush, particles are constantly bumping into each other. These collisions excite the gas atoms in the plasma, causing them to release **photons** of energy. (For details on this process, see How Fluorescent Lamps Work.)

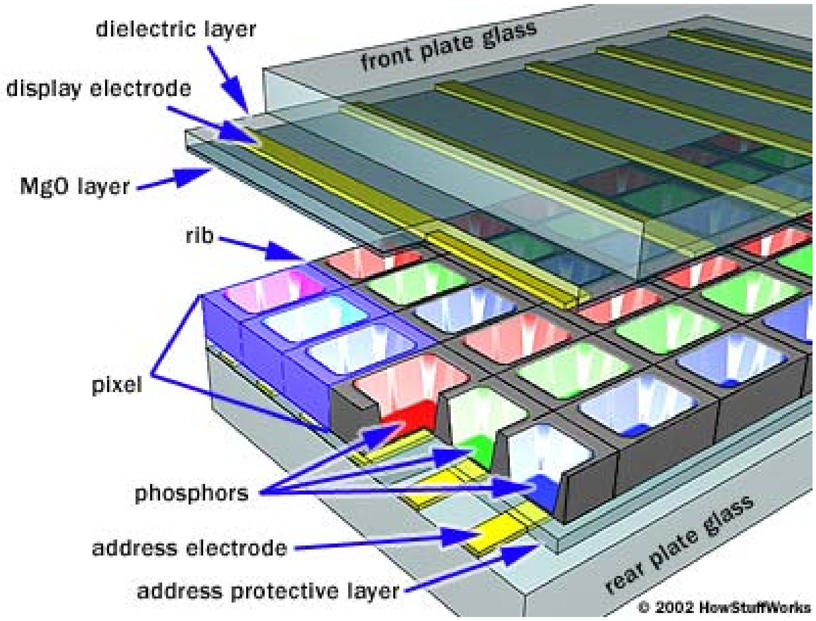
Xenon and neon atoms, the atoms used in plasma screens, release **light photons** when they are excited. Mostly, these atoms release **ultraviolet** light photons, which are invisible to the human eye. But ultraviolet photons can be used to excite visible light photons, as we'll see in the next section.

Inside the Display

The xenon and neon gas in a plasma television is contained in hundreds of thousands of tiny **cells** positioned between two plates of glass. Long electrodes are also sandwiched between the glass plates, on both sides of the cells. The **address electrodes** sit behind the cells, along the rear glass plate. The transparent **display electrodes**, which are surrounded by an insulating **dielectric material** and covered by a **magnesium oxide protective layer**, are mounted above the cell, along the front glass plate.



Both sets of electrodes extend across the entire screen. The display electrodes are arranged in horizontal rows along the screen and the address electrodes are arranged in vertical columns. As you can see in the diagram below, the vertical and horizontal electrodes form a basic **grid**.



To ionize the gas in a particular cell, the plasma display's computer charges the electrodes that intersect at that cell. It does this thousands of times in a small fraction of a second, charging each cell in turn.

When the intersecting electrodes are charged (with a voltage difference between them), an electric current flows through the gas in the cell. As we saw in the last section, the current creates a rapid flow of charged particles, which stimulates the gas atoms to release ultraviolet photons.

The released ultraviolet photons interact with **phosphor material** coated on the inside wall of the cell. Phosphors are substances that give off light when they are exposed to other light. When an ultraviolet photon hits a phosphor atom in the cell, one of the phosphor's electrons jumps to a higher energy level and the atom heats up. When the electron falls back to its normal level, it releases energy in the form of a **visible light photon**.

The phosphors in a plasma display give off colored light when they are excited. Every **pixel** is made up of three separate **subpixel** cells, each with different colored phosphors. One subpixel has a red light phosphor, one subpixel has a green light phosphor and one subpixel has a blue light phosphor. These colors blend together to create the overall color of the pixel.

By varying the pulses of current flowing through the different cells, the control system can increase or decrease the intensity of each subpixel color to create hundreds of different combinations of red, green and blue. In this way, the control system can produce colors across the entire spectrum.

The main advantage of plasma display technology is that you can produce a very wide screen using extremely thin materials. And because each pixel is lit individually, the image is very bright and looks good from almost every angle. The image quality isn't quite up to the standards of the best cathode ray tube sets, but it certainly meets most people's expectations.

The biggest drawback of this technology has to be the **price**. With prices starting at $4,000 and going all the way up past $20,000, these sets aren't exactly flying off the shelves. But as prices fall and technology advances, they may start to edge out the old CRT sets. In the near future, setting up a new TV might be as easy as hanging a picture!

To learn more about plasma displays, as well as other television technologies, check out the links on the next page.

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How Television Works

by Marshall Brain

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Television is certainly one of the most influential forces of our time. Through the device called a **television set** or **TV**, you are able to receive news, sports, entertainment, information and commercials. The average American spends between two and five hours a day glued to "the tube"!

Have you ever wondered about the technology that makes television possible? How is it that dozens or hundreds of channels of full-motion video arrive at your house, in many cases for free? How does your television decode the signals to produce the picture? How will the new digital television signals change things? If you have ever wondered about your television (or, for that matter, about your computer monitor), then read on! In this edition of **HowStuffWorks**, we'll answer all of these questions and more!

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How Television Works

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Two Amazing Things About the Brain

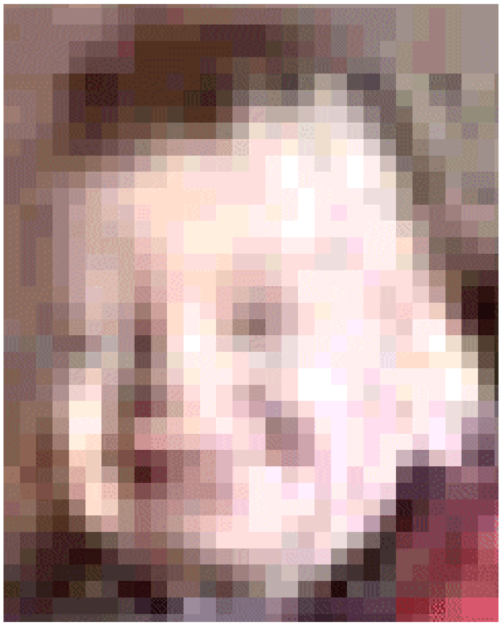
Let's start at the beginning with a quick note about your brain. There are two amazing things about your brain that make television possible. By understanding these two facts, you gain a good bit of insight into why televisions are designed the way they are.

Start by watching the following video clip. Simply click on the picture and at the dialog that appears select the "Open" option:

Click here to download the 15-second, full-motion version of this file (350KB).

This is a standard piece of home video showing a happy baby playing with a toy. It is encoded as an MPEG file so that you can view it on your computer, and it embodies the two principles that make TV possible.

The first principle is this: **If you divide a still image into a collection of small colored dots, your brain will reassemble the dots into a meaningful image.** This is no small feat, as any researcher who has tried to program a computer to understand images will tell you. The only way we can see that this is actually happening is to blow the dots up so big that our brains can no longer assemble them, like this:



Most people, sitting right up close to their computer screens, cannot tell what this is a picture of -- the dots are too big for your brain to handle. If you stand 10 to 15 feet away from your monitor, however, your brain will be able to assemble the dots in the image and you will clearly see that it is the baby's face. By standing at a distance, the dots become small enough for your brain to integrate them into a recognizable image.

Both televisions and computer screens (as well as newspaper and magazine photos) rely on this fusion-of-small-colored-dots capability in the human brain to chop pictures up into thousands of individual elements. On a TV or computer screen, the dots are called **pixels**. The resolution of your computer's screen might be 800x600 pixels, or maybe 1024x768 pixels.

The human brain's second amazing feature relating to television is this: **If you divide a moving scene into a sequence of still pictures and show the still images in rapid succession, the brain will reassemble the still images into a single moving scene**. Take, for example, these four frames from the example video:

1

2

3

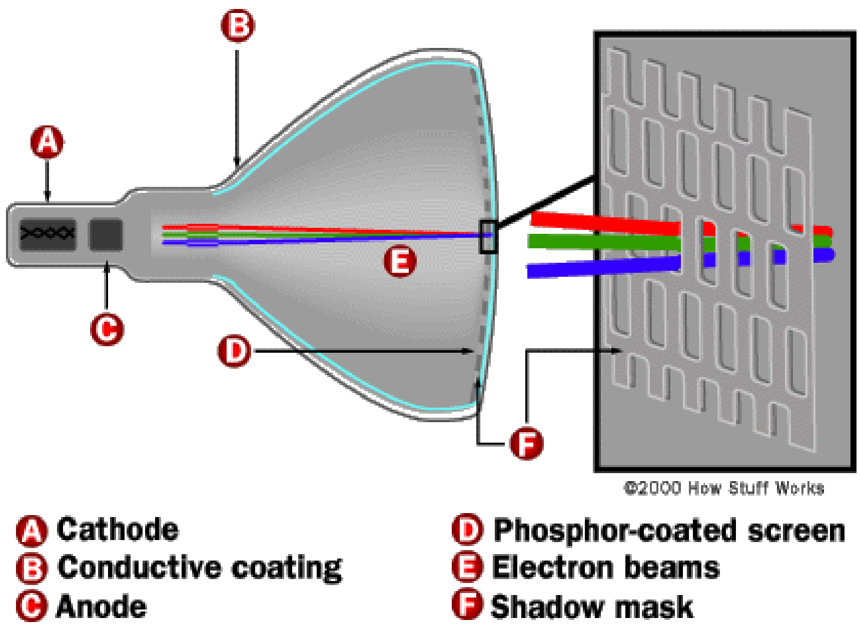
4

Each one of these images is slightly different from the next. If you look carefully at the baby's left foot (the foot that is visible), you will see that it is rising in these four frames. The toy also moves forward very slightly. By putting together 15 or more subtly different frames per second, the brain integrates them into a moving scene. Fifteen per second is about the minimum possible -- any fewer than that and it looks jerky.

When you download and watch the MPEG file offered at the beginning of this section, you see both of these processes at work simultaneously. Your brain is fusing the dots of each image together to form still images and then fusing the separate still images together into a moving scene. Without these two capabilities, TV as we know it would not be possible.

The Cathode Ray Tube

Almost all TVs in use today rely on a device known as the **cathode ray tube**, or **CRT**, to display their images. LCDs and plasma displays are sometimes seen, but they are still rare when compared to CRTs. It is even possible to make a television screen out of thousands of ordinary 60-watt light bulbs! You may have seen something like this at an outdoor event like a football game. Let's start with the CRT, however, because CRTs are the most common way of displaying images today.



The terms **anode** and **cathode** are used in electronics as synonyms for positive and negative terminals. For example, you could refer to the positive terminal of a battery as the anode and the negative terminal as the cathode.

In a cathode ray tube, the "cathode" is a heated filament (not unlike the filament in a normal light bulb). The heated filament is in a vacuum created inside a glass "tube." The "ray" is a stream of electrons that naturally pour off a heated cathode into the vacuum.

Electrons are negative. The anode is positive, so it attracts the electrons pouring off the cathode. In a TV's cathode ray tube, the stream of electrons is focused by a focusing anode into a tight beam and then accelerated by an accelerating anode. This tight, high-speed beam of electrons flies through the vacuum in the tube and hits the flat screen at the other end of the tube. This screen is coated with phosphor, which glows when struck by the beam.

As you can see in this drawing, there's not a whole lot to a basic cathode ray tube. There is a cathode and a pair (or more) of anodes. There is the phosphor-coated screen. There is a conductive coating inside the tube to soak up the electrons that pile up at the screen-end of the tube. However, in this diagram you can see no way to "steer" the beam -- the beam will always land in a tiny dot right in the center of the screen.

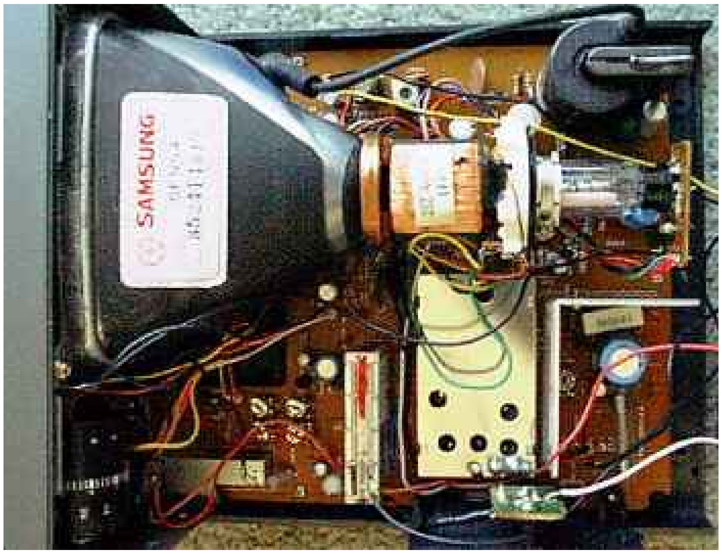
That's why, if you look inside any TV set, you will find that the tube is wrapped in coils of wires. The following pictures give you three different views of a typical set of **steering coils**:

Phosphor

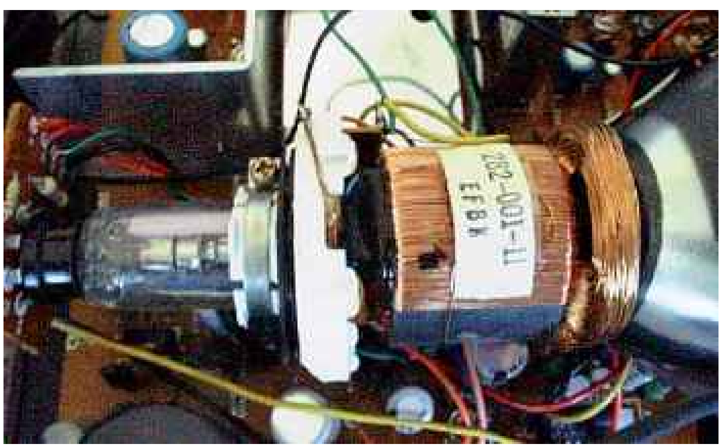
A **phosphor** is any material that, when exposed to radiation, emits visible light. The radiation might be ultraviolet light or a beam of electrons. Any fluorescent color is really a phosphor -- fluorescent colors absorb invisible ultraviolet light and emit visible light at a characteristic color.

In a CRT, phosphor coats the inside of the screen. When the electron beam strikes the phosphor, it makes the screen glow. In a black-and-white screen, there is one phosphor that glows white when struck. In a color screen, there are three phosphors arranged as dots or stripes that emit red, green and blue light. There are also three electron beams to illuminate the three different colors together.

There are thousands of different phosphors that have been formulated. They are characterized by their emission color and the length of time emission lasts after they are excited.



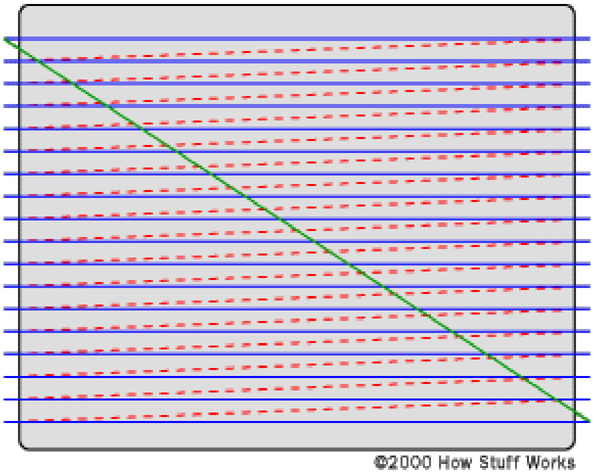
(Note the large black electrode hooked to the tube near the screen -- it is connected internally to the conductive coating.)



The steering coils are simply copper windings (see How Electromagnets Work for details on coils). These coils are able to create **magnetic fields** inside the tube, and the electron beam responds to the fields. One set of coils creates a magnetic field that moves the electron beam vertically, while another set moves the beam horizontally. By controlling the voltages in the coils, you can position the electron beam at any point on the screen.

The Black-and-White TV Signal

In a black-and-white TV, the screen is coated with white phosphor and the electron beam "paints" an image onto the screen by moving the electron beam across the phosphor a line at a time. To "paint" the entire screen, electronic circuits inside the TV use the magnetic coils to move the electron beam in a "**raster scan**" pattern across and down the screen. The beam paints one line across the screen from left to right. It then quickly flies back to the left side, moves down slightly and paints another horizontal line, and so on down the screen, like this:



In this figure, the blue lines represent lines that the electron beam is "painting" on the screen from left to right, while the red dashed lines represent the beam flying back to the left. When the beam reaches the right side of the bottom line, it has to move back to the upper left corner of the screen, as represented by the green line in the figure. When the beam is "painting," it is on, and when it is flying back, it is off so that it does not leave a trail on the screen. The term **horizontal retrace** is used to refer to the beam moving back to the left at the end of each line, while the term **vertical retrace** refers to its movement from bottom to top.

As the beam paints each line from left to right, the intensity of the beam is changed to create different shades of black, gray and white across the screen. Because the lines are spaced very closely together, your brain integrates them into a single image. A TV screen normally has about 480 lines visible from top to bottom.

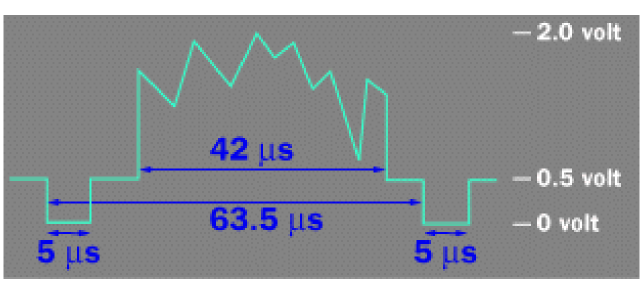
All TVs use an **interlacing** technique when painting the screen. In this technique, the screen is painted 60 times per second but only half of the lines are painted per frame. The beam paints every other line as it moves down the screen -- for example, every odd-numbered line. Then, the next time it moves down the screen it paints the even-numbered lines, alternating back and forth between even-numbered and odd-numbered lines on each pass. The entire screen, in two passes, is painted 30 times every second. The alternative to interlacing is called **progressive scanning**, which paints every line on the screen 60 times per second. Most computer monitors use progressive scanning because it significantly reduces flicker.

Because the electron beam is painting all 525 lines 30 times per second, it paints a total of 15,750 lines per second. (Some people can actually hear this frequency as a very high-pitched sound emitted when the television is on.)

When a television station wants to broadcast a signal to your TV, or when your VCR wants to display the movie on a video tape on your TV, the signal needs to mesh with the electronics controlling the beam so that the TV can accurately paint the picture that the TV station or VCR sends. The TV station or VCR therefore sends a well-known signal to the TV that contains three different parts:

- **Intensity information** for the beam as it paints each line
- **Horizontal-retrace signals** to tell the TV when to move the beam back at the end of each line
- **Vertical-retrace signals** 60 times per second to move the beam from bottom-right to top-left

A signal that contains all three of these components is called a **composite video signal**. A composite-video input on a VCR is normally a yellow RCA jack. One line of a typical composite video signal looks something like this:



The horizontal-retrace signals are 5-microsecond (abbreviated as "us" in the figure) **pulses** at zero volts. Electronics inside the TV can detect these pulses and use them to trigger the beam's horizontal retrace. The actual signal for the line is a varying wave between 0.5 volts and 2.0 volts, with 0.5 volts representing black and 2 volts representing white. This signal drives the intensity circuit for the electron beam. In a black-and-white TV, this signal can consume about 3.5 megahertz (MHz) of bandwidth, while in a color set the limit is about 3.0 MHz.

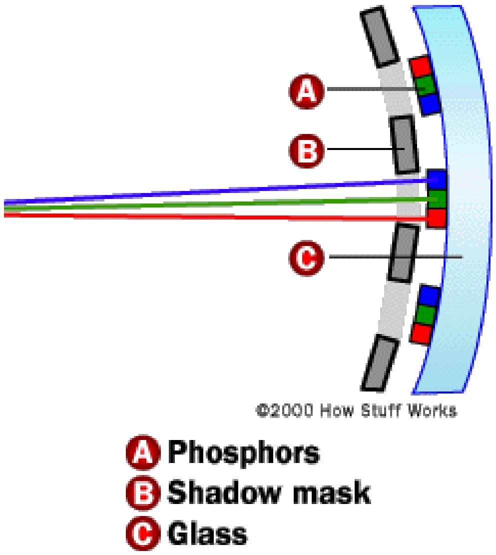
A vertical-retrace pulse is similar to a horizontal-retrace pulse but is 400 to 500 microseconds long. The vertical-retrace pulse is **serrated** with horizontal-retrace pulses in order to keep the horizontal-retrace circuit in the TV synchronized.

Adding Color

A color TV screen differs from a black-and-white screen in three ways:

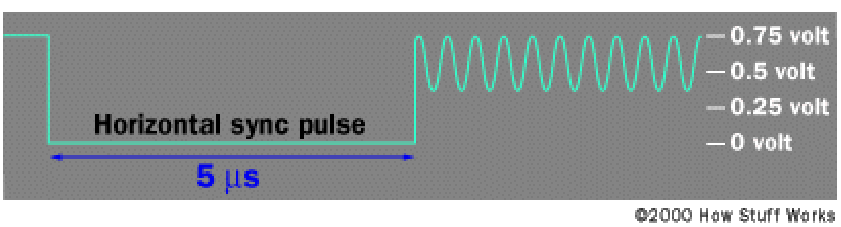
- There are three electron beams that move simultaneously across the screen. They are named the red, green and blue beams.
- The screen is not coated with a single sheet of phosphor as in a black-and-white TV. Instead, the screen is coated with red, green and blue phosphors arranged in dots or stripes. If you turn on your TV or computer monitor and look closely at the screen with a magnifying glass, you will be able to see the dots or stripes.
- On the inside of the tube, very close to the phosphor coating, there is a thin metal screen called a **shadow mask**. This mask is perforated with very small holes that are aligned with the phosphor dots (or stripes) on the screen.

The following figure shows how the shadow mask works:



When a color TV needs to create a red dot, it fires the red beam at the red phosphor. Similarly for green and blue dots. To create a white dot, red, green and blue beams are fired simultaneously -- the three colors mix together to create white. To create a black dot, all three beams are turned off as they scan past the dot. All other colors on a TV screen are combinations of red, green and blue.

A color TV signal starts off looking just like a black-and-white signal. An extra **chrominance** signal is added by superimposing a 3.579545 MHz sine wave onto the standard black-and-white signal. Right after the horizontal sync pulse, eight cycles of a 3.579545 MHz sine wave are added as a **color burst**.



Following these eight cycles, a **phase shift** in the chrominance signal indicates the color to display. The amplitude of the signal determines the saturation. The following table shows you the relationship between color and phase:

Color	Phase
Burst	0 degrees
Yellow	15 degrees
Red	75 degrees

Magenta	135 degrees
Blue	195 degrees
Cyan	255 degrees
Green	315 degrees

A black-and-white TV filters out and ignores the chrominance signal. A color TV picks it out of the signal and decodes it, along with the normal intensity signal, to determine how to modulate the three color beams.

Getting the Signal to You

Now you are familiar with a standard composite video signal. Note that we have not mentioned sound. If your VCR has a yellow composite-video jack, you've probably noticed that there are separate sound jacks right next to it. Sound and video are completely separate in an analog TV.

You are probably familiar with five different ways to get a signal into your TV set:

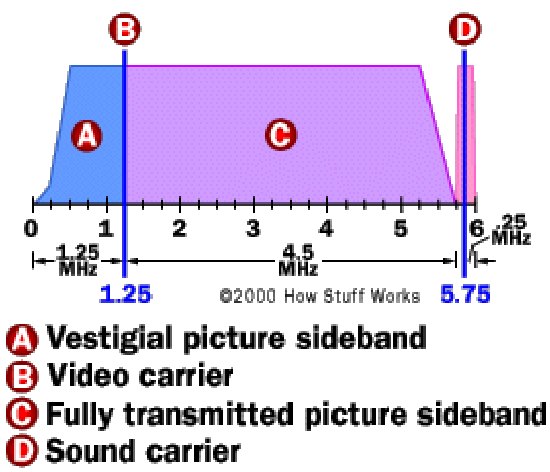
- Broadcast programming received through an antenna
- VCR or DVD player that connects to the antenna terminals
- Cable TV arriving in a set-top box that connects to the antenna terminals
- Large (6 to 12 feet) satellite-dish antenna arriving in a set-top box that connects to the antenna terminals
- Small (1 to 2 feet) satellite-dish antenna arriving in a set-top box that connects to the antenna terminals

The first four signals use standard NTSC analog waveforms as described in the previous sections. As a starting point, let's look at how normal broadcast signals arrive at your house.

A typical TV signal as described above requires 4 MHz of bandwidth. By the time you add in sound, something called a **vestigial sideband** and a little buffer space, a TV signal requires 6 MHz of bandwidth. Therefore, the FCC allocated three bands of frequencies in the radio spectrum, chopped into 6-MHz slices, to accommodate TV channels:

- 54 to 88 MHz for channels 2 to 6
- 174 to 216 MHz for channels 7 through 13
- 470 to 890 MHz for UHF channels 14 through 83

The composite TV signal described in the previous sections can be broadcast to your house on any available channel. The composite video signal is amplitude-modulated into the appropriate frequency, and then the sound is frequency-modulated (+/- 25 KHz) as a separate signal, like this:



To the left of the video carrier is the vestigial lower sideband (0.75 MHz), and to the right is the full upper sideband (4 MHz). The sound signal is centered on 5.75 MHz. As an example, a program transmitted on channel 2 has its video carrier at 55.25 MHz and its sound carrier at 59.75 MHz. The tuner in your TV, when tuned to channel 2, extracts the composite video signal and the sound signal from the radio waves that transmitted them to the antenna.

VCRs are essentially their own little TV stations. Almost all VCRs have a switch on the back that allows you to select channel 3 or 4. The video tape contains a composite video signal and a separate sound signal. The VCR has a circuit inside that takes the video and sound signals off the tape and turns them into a signal that, to the TV, looks just like the broadcast signal for channel 3 or 4.

The cable in **cable TV** contains a large number of channels that are transmitted on the cable. Your cable provider could simply modulate the different cable-TV programs onto all of the normal frequencies and transmit that to your house via the cable; then, the tuner in your TV would accept the signal and you would not need a cable box. Unfortunately, that approach would make theft of cable services very easy, so the signals are **encoded** in funny ways. The set-top box is a decoder. You select the channel on it, it decodes the right signal and then does the same thing a VCR does to transmit the signal to the TV on channel 3 or 4.

Large-dish satellite antennas pick off unencoded or encoded signals being beamed to Earth by satellites. First, you point the dish to a particular satellite, and then you select a particular channel it is transmitting. The set-top box receives the signal, decodes it if necessary and then sends it to channel 3 or 4.

Small-dish satellite systems are digital. The TV programs are encoded in MPEG-2 format and transmitted to Earth. The set-top box does a lot of work to decode MPEG-2, then converts it to a standard analog TV signal and sends it to your TV on channel 3 or 4.

Digital TV

The latest buzz is **digital TV**, also known as DTV or HDTV (high-definition TV). DTV uses MPEG-2 encoding just like the satellite systems do, but digital TV allows a variety of new, larger screen formats. The formats include:

- **480p** - 640x480 pixels progressive
- **720p** - 1280x720 pixels progressive
- **1080i** - 1920x1080 pixels interlaced

A digital TV decodes the MPEG-2 signal and displays it just like a computer monitor does, giving it incredible resolution and stability. There is also a wide range of set-top boxes that can decode the digital signal and convert it to analog to display it on a normal TV. For more information, check out How Digital Television Works.

Monitors vs. TVs

Your computer probably has a "**VGA monitor**" that looks a lot like a TV but is smaller, has a lot more pixels and has a much crisper display. The CRT and electronics in a monitor are much more precise than is required in a TV; a computer monitor needs higher resolutions. In addition, the plug on a VGA monitor is not accepting a composite signal -- a VGA plug separates out all of the signals so they can be interpreted by the monitor more precisely. Here's a typical VGA pinout:

- pin 1 - Red video
- pin 2 - Green video
- pin 3 - Blue video
- pin 4 - Ground
- pin 5 - Self test
- pin 6 - Red ground
- pin 7 - Green ground
- pin 8 - Blue ground
- pin 9 - No pin
- pin 10 - Digital ground
- pin 11 - Reserved
- pin 12 - Reserved
- pin 13 - Horizontal sync
- pin 14 - Vertical sync
- pin 15 - Reserved

This table makes the point that the signals for the three beams as well as both horizontal and vertical sync signals are all transmitted separately. See How Computer Monitors Work for details.

For more information on television, display types and related topics, check out the links on the next page!

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