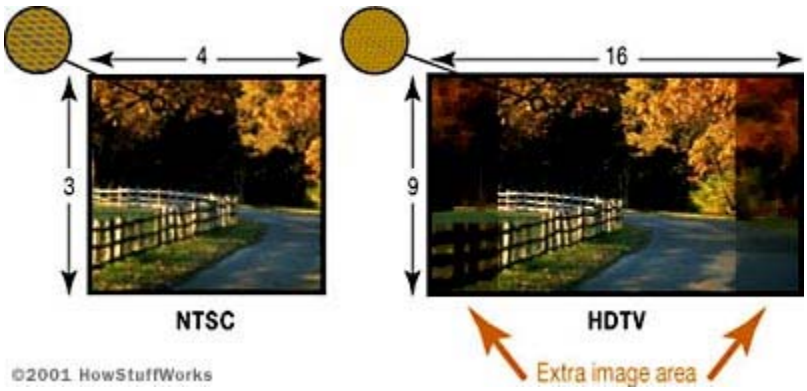
How Digital Television Works

by Marshall Brain

If you have looked at television sets at any of the big electronics retailers lately, you know that **digital TV**, or **DTV**, is a BIG deal right now in the United States. Most stores have whole areas devoted to digital TV sets. You are also hearing a lot about four other topics:

- HDTV and HDTV broadcasts
- Digital satellite services
- Digital cable
- DVDs and DVD players

Unless you are in the small group of people in the United States who have purchased a DTV set, what you have in your living room is a normal **analog** TV that seems to be working just fine despite all the hype.



Most people, faced with this level of product proliferation, can only ask, "What the heck is going on here?!"

In this article, we will explore the world of digital television so that you can understand exactly what is going on in this medium!

Understanding Analog TV

To understand digital TV, it is helpful to understand analog TV so that you can see the differences. (If you have read How Television Works, then you know how analog TV works, and you may want to skip this section.) This section gives you a quick summary of how analog TV works.

The Basics

The analog TV standard has been in use in the United States for about 50 years. To review quickly, here are the basics of analog television transmission:

- A video camera takes a picture of a scene. It does this at a frame rate of 30 frames per second.
- The camera **rasterizes** the scene. That is, the camera turns the picture into rows of individual dots called pixels. Each pixel is assigned a color and intensity.
- The rows of pixels are combined with synchronization signals, called **horizontal sync** and **vertical sync** signals, so that the electronics inside a TV set will know how to display the rows of pixels.

This final signal, containing the color and intensity of each pixel in a set of rows, along with horizontal and vertical sync signals, is called a **composite video signal**. Sound is completely separate. When you look on the back of your VCR and you see the yellow plug, that is the plug for composite video. Sound is either a white plug (on VCRs that do not handle stereo sound) or a red plug and a white plug (on VCRs that do handle stereo).

Using the Signal

There are lots of different things you can do with a composite video signal and a sound signal. Here are just a few:

- You can broadcast them as radio waves. When you stick rabbit ears on your TV set and pick up local stations for free, you are receiving broadcast television from local TV stations.

- You can record them with a VCR.
- You can transmit them through a cable TV system along with hundreds of other composite signals.

Many different kinds of equipment understand composite video signals.

Broadcasting a TV Signal

When a composite video signal is broadcast over the airwaves by a TV station, it happens on a specific **frequency**. In the United States, we know these frequencies as VHF channels 2 through 13 and UHF channels 14 through 83.

The composite video signal is transmitted as an AM signal and the sound as an FM signal on these channels. See How TV Works for details on transmission, and How Radio Works for details on AM and FM. The FCC allocated three bands of frequencies in the radio spectrum, chopped into 6-MHz slices, to accommodate these 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

See How Radio Works for details.

When your VCR wants to display its signal on a normal analog TV, it takes the composite video signal and the sound signal off the tape and then modulates those signals onto a 60-MHz (channel 3) or 66-MHz (channel 4) carrier, just like a TV station would. Instead of broadcasting it, however, the VCR sends it straight to the TV. A cable box or satellite box does the same thing.

Right now you hear a lot about "digital satellite systems" and "digital cable systems," but they are not DTV. The set-top box does receive a digital signal from the satellite or cable; but once received, the signal is converted to an analog signal and sent to your analog TV on channel 3 or 4. This is not "digital television" -- it is a normal composite video signal for analog television converted to a digital format for transmission and then converted back to analog for display.

True digital TV, on the other hand, is completely digital and involves:

- **Digital cameras** working at a much higher resolution than analog cameras
- **Digital transmission**
- **Digital display** at a much higher resolution

You can see the difference in resolution in the next section...

What's Wrong with Analog TV?

If you currently have an analog TV, and it works fine with broadcast TV, cable TV, VCRs, satellite TV, camcorders and so on, an obvious question would be, "What's wrong with analog TV?"

The main problem is **resolution**.

- The resolution of the TV controls the crispness and detail in the picture you see.
- The resolution is determined by the number of **pixels** on the screen.
- An analog TV set can display 525 horizontal lines of resolution every thirtieth of a second. In reality, however, an analog TV displays half of those lines in a sixtieth of a second, and then

displays the other half in the next sixtieth, so the whole frame is updated every thirtieth of a second. This process is called **interlacing**.

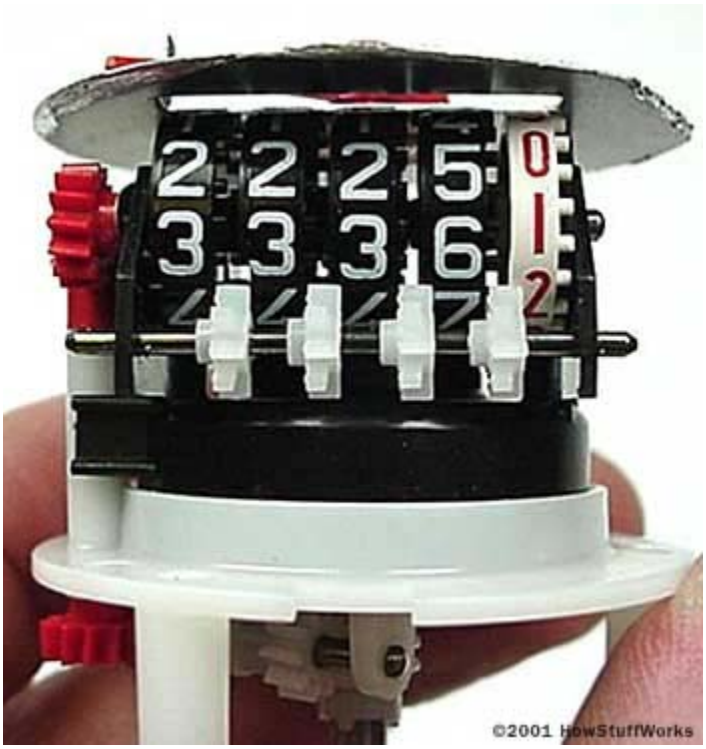
That has been fine for years. But now we have all become conditioned by computer monitors to be comfortable with much better resolution. The lowest-resolution computer monitor displays 640x480 pixels. Because of the interlacing, the effective resolution of a TV screen is perhaps 512x400 pixels -- for example, when an MSN TV (formerly WebTV) box tries to display Web pages on an analog TV display, it can display about 512x400 pixels.

So the worst computer monitors you can buy have more resolution than the best analog TV set; and the best computer monitors are able to display up to 10 times more pixels than that TV set. There is simply no comparison between a computer monitor and an analog TV in terms of detail, crispness, image stability and color. If you look at a computer monitor all day at work, and then go home and look at a TV set, the TV set can look very fuzzy.

The drive toward digital TV is fueled by the desire to give TV the same crispness and detail as a computer screen. If you have ever looked at a true digital TV signal displayed on a good digital TV set, you can certainly understand why -- the digital version of TV looks fantastic! There is no comparison. With 10 times more pixels on the screen, all displayed with digital precision, the picture is incredibly detailed and stable.

Seeing the Difference

It is hard to convey the difference between a DTV signal and an analog signal without an actual demonstration, but here is a static comparison that can help you understand the idea. Below is a picture of an odometer:



This is a nice, crisp picture. Let's assume that this picture is being displayed on a good digital TV so that this is what you actually see. The following photo shows you what you would see on an analog TV:

You can see that the analog TV picture is much fuzzier than the digital TV image. Look, for example, at the teeth on the gears. There is a significant difference in picture quality that is even more obvious when the image is moving. It is that quantitative difference that drives the interest in digital TV. And as if the incredible picture weren't enough, digital TV also offers much better sound.

TV Goes Digital

The term "digital TV" is used in many different ways right now, depending on who you are talking to. There is also the term "HDTV," which is the most advanced form of digital TV in use in the United States. The reason it gets confusing is because digital TV in the U.S. combines three different ideas. This section examines those three ideas.

Digital Signal

The first idea that is new to digital TV is the **digital signal**.

Analog TV started as a broadcast medium. TV stations set up antennas and broadcast radio signals to individual communities. You can put a pair of rabbit ears on your TV and pick up channels 2 through 83 for free. What you receive, as described earlier, is a single, analog composite video signal and a separate sound signal.

Digital TV has started as a free broadcast medium as well. For example, in San Jose, CA, you can tune in to about a dozen different commercial digital TV stations if you have a digital TV receiver and an antenna. The FCC gave television broadcasters a new frequency to use for their digital broadcasts, so right now each broadcaster has an analog TV channel and a digital TV channel. The digital channel carries a 19.39-megabit-per-second stream of digital data that your digital TV receives and decodes.

Each broadcaster has one digital TV channel, but one channel can carry multiple **sub-channels** if the broadcaster chooses that option. Here's how it works:

On its digital channel, each broadcaster sends a 19.39-megabit-per-second (Mbps) stream of digital data. Broadcasters have the ability to use this stream in several different ways. For example:

- A broadcaster can send a single program at 19.39 Mbps.
- A broadcaster can divide the channel into several different streams (perhaps four streams of 4.85 Mbps each). These streams are called **sub-channels**. For example, if the digital TV channel is channel 53, then 53.1, 53.2 and 53.3 could be three sub-channels on that channel. Each sub-channel can carry a different program.

Formats

The reason that broadcasters can create sub-channels is because digital TV standards allow several different **formats**. Broadcasters can choose between three formats:

- **480i** - The picture is 704x480 pixels, sent at 60 interlaced frames per second (30 complete frames per second).
- **480p** - The picture is 704x480 pixels, sent at 60 complete frames per second.
- **720p** - The picture is 1280x720 pixels, sent at 60 complete frames per second.
- **1080i** - The picture is 1920x1080 pixels, sent at 60 interlaced frames per second (30 complete frames per second).
- **1080p** - The picture is 1920x1080 pixels, sent at 60 complete frames per second.

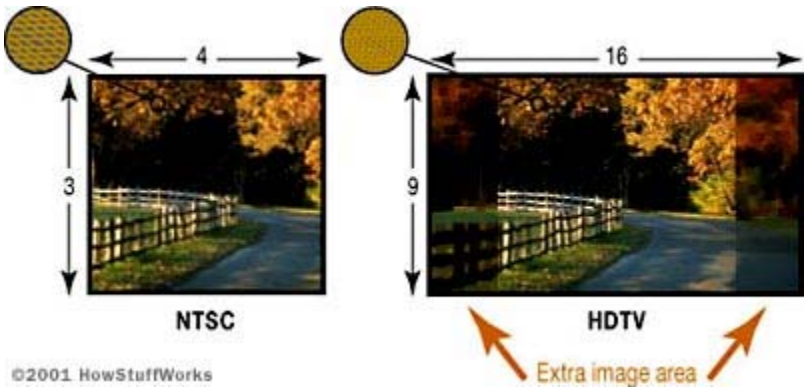
(The "p" and "i" designations stand for "progressive" and "interlaced." In a progressive format, the full picture updates every sixtieth of a second. In an interlaced format, half of the picture updates every sixtieth of a second.)

The 480p and 480i formats are called the **SD** (standard definition) formats, and 480i is roughly equivalent to a normal analog TV picture. When analog TV shows are upconverted and broadcast on digital TV stations, they are broadcast in 480p or 480i.

The 720p, 1080i and 1080p formats are **HD** (high definition) formats. When you hear about "HDTV," this is what is being discussed -- a digital signal in the 720p, 1080i or 1080p format.

Aspect Ratio

Finally, the HD formats of digital TV have a different **aspect ratio** than analog TVs. An analog TV has a 4:3 aspect ratio, meaning that the screen is 4 units wide and 3 units high. For example, a "25-inch diagonal" analog TV is 15 inches high and 20 inches wide. The HD format for digital TV has a 16:9 aspect ratio, as shown below:



The type of signal, format and aspect ratio have all changed in the process of converting from analog

TV to digital TV in the United States.

Digital Compression

The idea of sending multiple programs within the 19.39-Mbps stream is unique to digital TV and is made possible by the digital compression system being used. To compress the image for transmission, broadcasters use **MPEG-2** compression, and MPEG-2 allows you to pick both the screen size and bit rate when encoding the show. A broadcaster can choose a variety of **bit rates** within any of the three resolutions.

You see MPEG-2 all the time on the Web, on Web sites that offer streaming video. For example, if you go to iFilm.com, you will find that you can view streaming video at 56 kilobits-per-second (Kbps), 200 Kbps or 500 Kbps. MPEG-2 allows a technician to pick *any* bit rate and resolution when encoding a file.

There are many variables that determine how the picture will look at a given bit rate. For example:

- If a station wants to broadcast a sporting event (where there is lots of movement in the scene) at 1080i, the entire 19.39 megabits per second is needed to get a high-quality image.
- On the other hand, a newscast showing a newscaster's head can use a much lower bit rate. A broadcaster might transmit the newscast at 480p resolution and a 3-Mbps bit rate, leaving 16.39 Mbps of space for other sub-channels.

It is very likely that broadcasters will send three or four sub-channels during the day and then switch to a single high-quality show that consumes the entire 19.39 Mbps at night. Some broadcasters are also experimenting with 1- or 2-Mbps data channels that send information and Web pages along with a show to provide additional information.

Buying a Digital TV Set

If you go to an electronics store today to buy a new TV set, there are four types of sets that you will see on the shelf:

- **Analog TV sets**
- **Digital-ready sets** - They should be called SDTV sets. These TVs are normally 480p displays with an analog tuner (for the normal channels 2 through 83) built in. The problem with these sets is that their maximum resolution is the low 480p SD resolution, which eliminates the HD resolutions and makes the TV essentially useless in the future if you plan to watch HDTV programs.
- **HDTV-ready sets** - These sets are essentially computer monitors able to display 1080i/p resolution in the 16:9 aspect ratio. They may or may not have analog tuners built in.
- **Integrated HDTV sets** - These sets have a digital tuner for broadcast DTV signals integrated into an HDTV display. With the standards changing so much, you may end up paying for an integrated tuner that becomes obsolete.

The preferred way to handle HDTV is to purchase the components separately:

- A 16:9 HDTV display capable of 720p and 1080i/p resolution
- A digital receiver
- An antenna

Since the HDTV display will be the most expensive piece and will likely last 10 years or more, buying the components in this way allows you to change the receiver if you need to. There are currently three types of receivers:

1. You can purchase a set-top box and a Yagi antenna to receive broadcast HDTV signals.
2. You can purchase a set-top box and a small satellite dish to receive HDTV signals from a satellite. See the DirectTV HDTV FAQ for an example.
3. You can purchase a board for your computer, like the accessDTV board, along with a Yagi antenna, and use it to receive signals on both your computer monitor and your HDTV display.

The accessDTV board allows you to use your hard disk as a storage medium for digital TV broadcasts that it receives. It saves an entire 19.39-Mbps stream (including all sub-channels) to your hard disk.

For more information on digital television and related topics, check out the links on the next page.

Lots More Information

Related HowStuffWorks Articles

- TV Buying Guide
- How accessDTV Works - inexpensive way to get into DTV
- How HDTV Works
- How Cable Television Works
- How Satellite TV Works
- How Television Works
- How Projection Television Works
- How Plasma Displays Work
- How Analog and Digital Recording Works
- How DVDs and DVD Players Work
- How Home Theater Works
- How Radio Works
- How DVRs Work
- How Hard Disks Work

More Great Links

- PBS: Digital Broadcast Timeline
- PBS: Digital vs. Analog
- Current Online Briefing: Digital television and public television
- DTV Professional
- FCC: TV Translators and the DTV Transition
- Berkeley Multimedia: MPEG-2 FAQ