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Digital TV - Truth & Myths

By Doug Smith W9WI

Cable, satellite, VCRs, DVDs, big-screen – television has certainly changed over the last fifty years. However, it might (or might not) surprise you to learn that the underlying standards that define how a TV picture is "painted" on your screen really haven't changed since 1953. As we enter the 21st Century, however, the way television signals are transmitted is changing, and in a big way. Like it or not, digital television is coming to a TV set near you.

Television is, of course, a scheme for transmitting moving pictures from one place to another. A lens is used to focus the desired scene on a light-sensitive target; the amount of light striking each point on that target is measured and converted to an electrical current. Information about the amount of that current is transmitted to the other end, where it causes another current to flow. When that current strikes an *electrically*-sensitive target, it causes bursts of light, which you see as a TV picture.

In analog TV, signals directly proportional ("analogous") to the amount of light are transmitted. Leave the lens cap on the camera (resulting in a completely black picture) and the transmitter operates at 75% of full power. Open the lens and point it at the sun (resulting in a completely white picture, until the pickup chip burns out!) and the transmitter operates at 5% of full power[1]. Any power value between 5% and 75% is possible – 10%, 40%, 61.547213%.

Digital TV transmits numbers – "digits" – representing the amount of light. An analog TV transmitter would transmit a grey screen by operating at 40% of full power. A digital transmitter would transmit the same grey screen by sending the number 32768 over and over again.

❖ Why digital?

That sounds complicated. Digital TV requires two extra steps: convert the current generated by the camera to a number; then, at the receiver, convert the number back to a current. Why not just stick with analog and dump the conversion? There are several good reasons.

First, noise and interference. Again, in analog, any power value between 5% and 75% is possible. A power level of 61.547213% is perfectly permissible. In over-the-air digital TV, only eight specific power levels are allowed.

Let's say that your analog station is transmitting a grey screen, at 40% power. Due to a burst of noise, your receiver sees 63% power. 63% is a perfectly valid value. Your TV can't tell whether it received 63% because the station wanted it to, or because of the noise burst. You'll get a dark spot in the grey screen.

Now, let's say your digital station is transmitting a grey screen. Let's say "grey" is represented by the power level 43.75% – one of the eight specific levels permitted by the digital standard. Due to a burst of noise, your receiver sees 63% power. 63% is not a valid power level. Your TV knows something went wrong, and it can act accordingly. (More on this later.)

Digital television also allows "data compression." Imagine you want to transmit a picture of the American flag: "blue," "blue," "blue," "blue," "blue," {214 more times}; "red," "red," "red," {416 more times}, "red"{new row} "blue," "blue," "blue," etc... You have to transmit 640 current levels, for each of the three primary colors, for each of the 480 visible lines.

There's a lot of redundancy in that transmission. Why not just transmit "display 220 blue dots, then 420 red ones, then repeat on the next 10 rows"? In analog TV that's not possible, but in digital it's very possible.

By throwing away the redundancy, less data needs to be sent to transmit a picture. Analog TV requires 6 MHz of radio spectrum to transmit a 480-line[2] picture. Digital TV requires less. This allows several options:

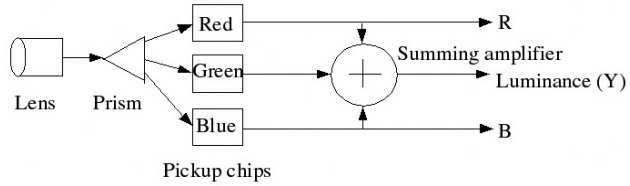
- Transmit more than 480 lines. Divide the picture into smaller "slices," resulting in a sharper image.
- Transmit more than one 480-line picture at the same time, on the same channel.
- Give back some of the 6MHz for reuse by other services. (politically unlikely!)

Digital TV transmits numbers representing a TV picture, rather than the picture itself. There's nothing technical that *requires* those numbers represent a TV picture. A station could, instead, send numbers representing the music on a CD. Or a computer program. Or meteorological data. After the 9/11 attacks, the digital capabilities of WNYE-TV were used to broadcast data used in the recovery efforts.

❖ Data compression: more details

Digital television takes advantage of redundancy in the picture. It also takes advantage of the characteristics of human vision. We see black-and-white outlines far more sharply than we see colors. TV takes advantage of this by transmitting a sharp black-and-white image, and less-well-defined color information.

A color TV camera splits the image into red, green, and blue light. Digital TV measures the amount of light of each of these three colors at each point on the screen. The three color signals are then averaged back together to yield a black-and-white, or *luminance*, signal. The red and blue signals are also taken, with every other measurement tossed out. Green isn't transmitted at all. (Since luminance is red+green+blue, if you take luminance-red-blue, then green is what's left. The TV receiver can take care of that subtraction.)

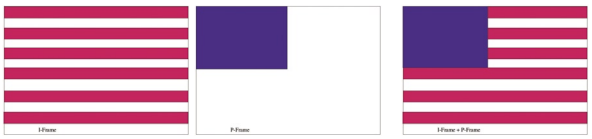


Red, blue, and a black-and-white "luminance" signal are transmitted in color television – both analog and digital.

We now have a collection of luminance, red, and blue measurements, or *pixels* ("picture elements"). These measurements are arranged in *macroblocks*. Macroblocks are useful since they can be predicted to move as a group. It's likely that Brian Williams' face will move across the screen. It's far less likely that Willian's face will morph into a Ferrari! Telling your TV to move macroblock 2389 from one place to another is far easier than completely redescribing the macroblock at a different location.

Macroblocks are then assembled into *frames*. Each frame represents one still picture. As you may know from analog TV, or the movies, showing a sequence of still pictures in rapid succession creates the illusion of a moving picture. Digital TV uses three types of frame:

- **I frame**: Each I-frame is a complete still picture in itself.
- **P frame**: A P-frame is the difference between the current still and the previous I-frame. If you were transmitting a video of someone adding the blue field to the American flag, an I-frame might show the flag with its red and white stripes; the succeeding P-frame might show the blue field and the person's hand.
- **B frame**: A B-frame is bidirectionally-predicted by preceding and subsequent frames. Obviously, it cannot be displayed until the following I-frame is received!

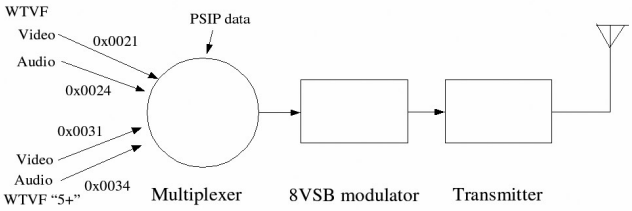


An I-frame might show the white background of the American flag, with its red stripes; a subsequent P-frame might contain only the blue field. Each further P-frame might contain one of the fifty stars.

All of the frames making up a TV picture are assembled in order into a series of numbers. This stream of data is then broken up into chunks of 188 numbers ("bytes"), creating a "packetized elementary stream," or *PES*. This data stream is *multiplexed* with audio and other data, and sent to the transmitter.

❖ A few words on audio

As with the video, digital TV audio is sent as a stream of numbers. One or more audio streams, coded in the Dolby AC-3 standard, may be transmitted. AC-3 audio offers eight different audio *services*. It is possible to split the dialog from the music and sound effects, and transmit dialog separately in several different languages. Additional channels containing a description of the action for the visually-impaired, or emergency messages meant to override all programs, etc., are possible.



Audio and video streams for two separate programs are multiplexed, along with "PSIP" data, before being transmitted.

The most popular use for the additional audio capabilities is surround sound. Analog TV allows for simple two-channel stereo sound. Many digital stations transmit "5.1 surround." There's a second pair of stereo speakers behind the viewer, a center speaker directly in front of the viewer, and a "subwoofer" which plays very low-frequency sounds at a very high level. You can almost feel the program.

And again, as with the video, the stream of numbers representing the audio is assembled into a PES of 188-byte "packets." And again, this stream is multiplexed with video and other data, and sent to the transmitter.

❖ Protocol, PSIP

Remember that we've said it's possible to transmit more than one picture on the same channel, and more than one stream of audio. How does your digital TV know what to display? That's where the *Program and System Information Protocol*, or *PSIP*, comes in.

Each audio/video stream contains a *protocol ID* – a number that uniquely identifies that stream. WKRN-DT in Nashville carries two programs. The video for the simulcast of their analog signal uses protocol ID 21, while the audio uses ID 24. Their "Nashville WX Channel" uses protocol IDs 31 (video) and 34 (audio). If you want to watch the analog simulcast, you tell your TV to decode the streams with protocol IDs 21 and 24; the rest are ignored.

The PSIP contains a number of *tables*. The one that's relevant here is the Virtual Channel Table, or "VCT." Information in the VCT includes:

- *Major channel number* – the channel number displayed to the viewer. This number comes from the datastream – not from the tuner – so the channel displayed may not be the same channel on which the station is actually broadcasting![3]
- *Minor channel number* – distinguishes between multiple program streams on the same station. WKRN's analog simulcast is minor channel 1; Nashville WX Channel is minor channel 2.
- *Short name* – a brief description of the program stream. "WKRN-HD" for minor channel 1; "WKRN-SD" for minor channel 2. This is usually shown to the viewer when they change channels.
- Transport stream identification – a list of the protocol IDs for the streams that make up this program. For WKRN's minor channel 1, this list would include 21 for the video and 24 for the audio.

As with audio and video, the PSIP information is assembled into 188-byte data packets, which are multiplexed with audio and video and then transmitted.

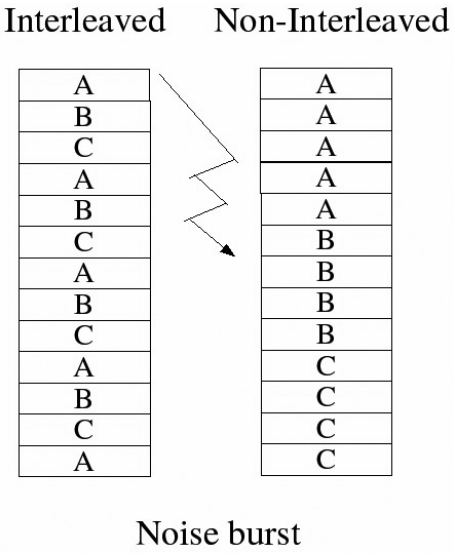
❖ The RF side of things

OK, we now have a pile of 188-byte data packets. You could just send them to the receiver over the Internet, but I suppose that's not what the television broadcasters had in mind!

The radio spectrum is an unfriendly place for data. Noise, interference, "ghosts," lightning, any number of things can cause the data received to be different from what was transmitted. We've already mentioned that, by using digital transmission instead of analog, we can detect that something was received incorrectly. What do we do about it?

First, a 20-byte "Forward Error Correction," or *FEC*, code is attached to each data packet. This is a calculated number, based on the contents of the packet. The receiver makes the same calculation. If the results match, the receiver knows the packet was received correctly. If the results don't match, in some cases the receiver can use the FEC to fix the error! When the errors are severe, they can't be repaired, but at least the receiver knows to discard the invalid data.

Next, the data packets are *interleaved* with other packets. The idea is to ensure a burst of noise and interference clobbers a small part of several packets, rather than completely destroying one packet. If a noise burst destroys seven bytes of each of ten packets, the FEC can repair the errors. If the same burst destroys 70 bytes of one packet, the packet cannot be fixed – it must be discarded.



The noise burst wipes out two each A, B, and C packets in the interleaved data signal. Error correction can fix the damage. However, the burst wipes out all five A packets in the non-interleaved signal; error correction cannot restore the lost data.

Finally, the stream of data is sent to the transmitter. The DTV transmitter has a carrier at 310 kHz above the bottom of the channel. The strength of this carrier is controlled by the data stream. The stream is split into groups of three bits; each group can encode eight different amplitudes. The group 000 corresponds to 6.25% transmitter power; the group 111 corresponds to 93.75%; there are six other values in between.

At the receiver, as you might guess, we pull it all apart again. The receiver measures the strength of the received signal at the appropriate times, determines which of the eight permissible amplitudes the transmitter meant to send, decodes it to three bits, stuffs the stream of bits back together to create the data packets, and applies the FEC to fix or discard damaged packets. It presents the PSIP information, allowing the viewer to select which program they wish to watch, then checks the protocol IDs and processes only the packets corresponding to the program selected.

Video packets are decompressed; red and blue data subtracted from luminance to make green; and the data is sent to a digital-to-analog converter and then to the picture tube. Audio packets are split among the channels, sent to a digital-to-analog converter, and on to the speaker(s). And voilá! We have TV.

❖ Channel allocation issues

There's been a bunch of confusion over just where in the spectrum digital TV operates. The

Chicago DTV Channels

Station	Analog	Digital, interim	Digital, permanent
WBBM	2	3	11
WMAQ	5	29	29
WLS	7	52	7
WGN	9	16	19
WTTW	11	47	47
WYCC	20	21	21
WCIU	26	27	27
WFLD	32	31	31
WWTO	35	10	10
WCPX	38	43	43
WSNS	44	45	45
WPWR	50	51	51
WYIN	56	17	17
WXFT	60	59	50
WJYS	62	36	36
WGBO	66	53	38

FCC hasn't helped, by changing their mind at least twice! A secondary goal of the digital transition has been to free up spectrum for land-mobile use. The original plan was for all digital TV to be UHF in channels 14-59; channels 60-69 and 2-13 would be reassigned to land-mobile. The plan was later amended to use channels 7-51; and finally amended again to the current plan, channels 2-51[4].

Each TV station holding a construction permit on April 3, 1997, was assigned a second channel for digital operation. All such stations were expected to begin broadcasting a digital signal by May 1st of 2003. Many stations have obtained many extensions! Originally, analog television was be shut down at the end of 2006. Most observers never believed this deadline would be met.

Late in 2005, Congress stepped back in. An analog drop-dead date was set for February 17, 2009. On this date, all analog TV transmitters must be turned off; all over-the-air TV becomes digital. [5] Congress' action also provides up to $1.5billion to subsidize digital-to-analog converters. Households will be able to apply for vouchers for up to two converters per home.

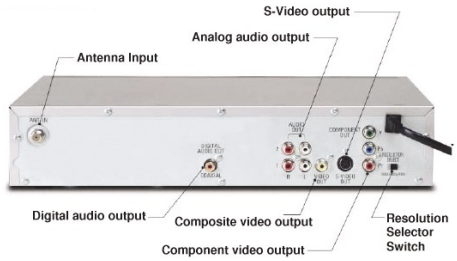
When analog TV *is* shut down, channels 52-69 will be reassigned for land-mobile use. Stations whose temporary digital channel is in this range will be required to move their digital operation to their current analog channel[6]. Most other stations will be allowed to choose whether to leave their digital operations on their second channels, or move them to their current analog channel. (Stations whose *analog* channel is above 51 will be required to remain on their second channel.)

A number of applications for new TV stations were on file in April 1997. Many of these have since been granted. However, these stations aren't automatically receiving a second channel for digital. Some of these stations have signed on as analog stations, and will "flash-cut" to digital operation on the same channel at some future date. Others have signed on as digital, and provided cable systems with digital-to-analog converters so they can be carried in analog form on cable. A few have petitioned the FCC to assign them a second channel for digital.

A number of stations have already "jumped the gun," closing down their analog operations early and becoming digital-only. Stations have lost leases on their analog sites; have suffered major analog transmitter failures; or have simply proven that literally *nobody* is watching their analog over-the-air signal (and thus, their transmitter is serving only to deliver their signal to cable systems, which could be served just as well by downconverting their digital signal). The company that has the post-transition rights to channel 55 has arranged for three stations whose analog signals are on that channel to move early. One station (KLEP in Newark, Arkansas) has announced it can't afford to convert to digital; KLEP has already surrendered its license to the FCC and gone off the air.

❖ Watching over-the-air DTV

On July 1st, 2003, the FCC began requiring new TVs of 36" or larger to contain a digital tuner capable of receiving over-the-air digital TV. Older TVs, even those marked "HDTV Ready," usually don't contain this tuner. A separate "set-top box" is necessary. These boxes connect to your high-definition TV with a VGA computer monitor connector, Y-Pb-Pr coaxial cables, or a DVI digital interface. Many can also be connected to a standard-definition TV, either through one of these interfaces, or through the standard single coaxial cable used with analog TV. I've seen set-top boxes on sale for roughly $400 at Circuit City, and I'm sure competing stores like Best Buy also carry these devices.



A rear view of the Sylvania 6900DTD digital TV set-top box shows the various connections available for viewing digital signals on your existing TV – or a new high-definition display.

A Samsung 43" high-definition display. A set-top box (like the Sylvania 6900DTD) is necessary to receive digital broadcast signals on this display. Note the high-definition display is much wider than a traditional TV.

(Be sure the set-top box you buy has an interface in common with your TV! And don't forget the audio; some kind of audio cables will also be necessary.)

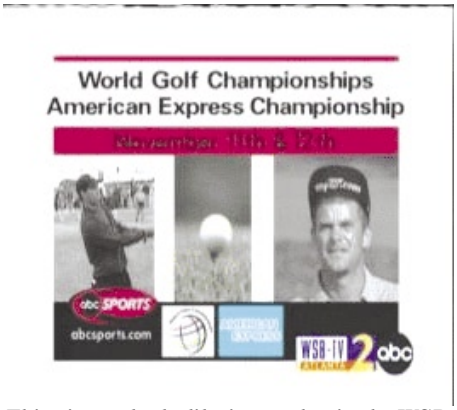
Chances are your existing analog TV antenna will work fine for digital reception. Severe ghosts will kill digital TV, but a slightly noisy signal is no problem. If your analog reception suffers from computer noise or interference from other TV stations, going digital may well clean up your picture.

❖ DX and other tricks

Yes, digital TV *can* be DXed. The current distance record stands at about 800 miles, for reception of eastern North Carolina stations in Louisiana, via tropospheric propagation.

The most exciting analog TV-DX is via Sporadic-E. Unfortunately, this type of propagation usually only affects channels 2-6, and so far there are very few digital stations operating on these channels. Still, digital E-skip *is* possible. The first DTV sporadic-E logging goes to Gerard Westerburg of Lexington, Kentucky, who received a PSIP packet from KOTA-DT channel 2, Rapid City, South Dakota via E-skip in 2003. Since then, a number of DXers have received digital audio and video via the skip mode.

Remember that the DTV signal has a carrier 310 kHz above the bottom of the channel. This can be monitored on a wideband scanner. For example, the signal of WKGB-DT, channel 48, Bowling Green, Kentucky, is too weak to decode on my DTV receiver. However, their carrier on 674.31 MHz is plainly audible on my Kenwood TH-F6 handheld. While you can't tell *which* DTV station you're hearing, you can tell that a station is present.



This picture looks like it was shot in the WSB-TV control room in Atlanta! - but it was actually shot by Jeff Kadet in Macomb, Illinois, 575 miles from WSB. Yes, you <u>can</u> DX digital TV.

❖ More resources

One could fill an entire issue of *MT* and still not fully explain the technology and regulatory activity behind digital TV. Here are a few websites where you can read more about this technology:

FCC's digital TV FAQs:
www.fcc.gov/cgb/consumerfacts/digitaltv.html
Digital TV standards:
www.atsc.org/standards.html
Program System and Information Protocol (PSIP) standards:
www.psip.org/
8VSB modulation standard:
www.8vsb.com/
WNYE-DT and 9/11:
www.skystream.com/corp/cussuccess_eas.asp
DTV receivers and tuner cards: (just a few examples)
www.tvantenna.com/products/dtv/stb/SIR-T351.html
www.tvauthority.com/HDTV-Tuners/HDTV-Tuners.asp
Digital TV DX photos: (these pages have a lot of graphics and will be SLOW to load!)
www.dxfm.com/tv_images_digital.htm

Footnotes:

1. "Synchronizing pulses," which tell your TV where on the screen to display the next burst of light, are transmitted at 100% power. Black is limited to 75% to ensure the TV can tell the difference.
2. American analog TV is usually quoted as having 525 lines, however roughly 45 of these lines are used for synchronizing signals that aren't visible to the viewer.
3. Indeed, it usually isn't. The major channel number is usually the same as the station's analog channel. In WKRN's case, it's 2, even though WKRN's digital signal is actually broadcast on channel 27.
4. Broadcasters prefer VHF channels, where less power is necessary to achieve the same coverage. At the same time, land-mobile interests prefer UHF where antennas are smaller, and there's less noise and interference.
5. The House of Representatives proposed Dec. 31, 2008 as the deadline; the Senate proposed April 7, 2009. The latter date was rumored chosen because it's the day after the NCAA basketball championships!
6. For example, WTVF-DT whose digital channel is 56; they'll be required to move to channel 5 when their analog transmitter on that channel is shut down.