Basics of Video: From Simple Analog to HDTV

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Video signals can be divided into two categories; analog and digital. Both use a variety of standards, formats, and available interfaces. Analog video had been the broadcast standard in the United States since it's inception, however, in 2009 it was fully replaced by digital video broadcasting. Nonetheless, analog video is still used in many systems today. One good example is closed circuit security systems. On the other hand, the market's transition to flat panel televisions has enjoyed the rapid growth, availability and superior image quality of digital video.

It is the goal of this application note to explain the simplest form of a video signal, the analog signal, and then expand to the majority of key video formats, standards, and interfaces used in analog and digital systems.

Video Formats

A color space is a defined representation of a set of colors (often red, green, and blue, or RGB) and all colors that can be produced through combinations of the originals. Broadcasting pure analog RGB video requires large bandwidth because each color is transmitted independently and simultaneously. Broadcast standards were developed to limit the bandwidth required for transmission. The most notable composite video standards are NTSC, PAL, and SECAM.

The National Television System Committee created the NTSC video transmission standard for color television in 1954 and it has remained the standard in the United States. The NTSC standard was designed to be legacy compatible with the existing 525-line interlaced monochrome (commonly known as "black and white") video equipment already in use. It was adopted throughout most of North America, Western South America and Japan.

In Europe, the NTSC standard was modified to work more efficiently with the existing 625-line interlaced monochrome video standard. This alteration of NTSC was named the Phase Alternating Line (PAL) system. The PAL standard requires that the phase of the color information reverse on each line of video. This phase reversal reduces cumulative error giving more accurate hue (color) compared to NTSC. The PAL standard was developed throughout the late 1950s and 1960s and was first implemented as a broadcast standard in 1967. It has been adopted throughout Europe (with the notable exception of France), Africa, Southern Asia, Australia, and Eastern South America.

In 1967 France adopted a different color video transmission standard, SECAM (Sequential Color with Memory). SECAM utilizes two separate color components; one for each field (even and odd lines) of interlaced video. It uses frequency modulation in conjunction with the typical amplitude-variation scheme. The SECAM standard was adopted in France, Western Africa, Eastern Europe and Northern Asia.

Like the various composite analog video standards, there are many Digital Television (DTV) standards in use worldwide. In the United States, the Advanced Television Systems Committee developed the ATSC standard for digital video transmission. Most countries have adopted the Digital Video Broadcast Standard (DVB) and Japan uses Integrated Services Digital Broadcasting (ISDB). All of the current DTV standards are designed to work within the existing 6MHz channel bandwidths established for composite video transmission.

The original, uncompressed digital video requires much more bandwidth than its analog composite counterpart. To allow digital transmission within traditional bandwidth requirements, video compression is a necessity. MPEG-2 compression was widely used in early generation digital video standards, but the popularity and growth of digital video is demanding higher quality images with lower bit rates than MPEG-2 can provide. More recently the MPEG-4 AVC compression standard, offering improved image quality and substantial reduction in bit rate, is now being widely used.

Digital computer graphics utilize many different formats with seemingly countless variations. The numerous formats result from a slew of available resolutions and aspect ratios in computer monitors. In recent decades, the Video Graphics Array (VGA) and the Extended Graphics Array (XGA) have been widely used. However, the VGA resolution format is becoming less common in the computing market as resolutions increase. Table 1 shows a brief comparison of the various computer graphics resolutions.

TABLE 1. COMMON COMPUTER GRAPHICS RESOLUTION FORMATS

RESOLUTION FORMAT	ACTIVE PIXELS PER LINE	ACTIVE LINES PER FRAME	COLOR DEPTH (NUMBER OF COLORS THAT CAN BE REPRESENTED)	WIDESCREEN VERSION
VGA	640	480	16 colors for 640x480 resolution 256 colors for 320x200 resolution	WVGA (854x480)
SVGA	800	600	True Color: 24-bit (16,777,216 colors)	WSVGA (1024x600)
XGA	1024	768	High Color: 16-bit (65,536 colors)	WXGA (1280x800)
SXGA	1280	1024	32-bit Color: -24 bits Color (16,777,216 colors) -8 bits non-color data	WSXGA (1440x900)
UXGA	1600	1200	32-bit Color: -24bits Color (16,777,216 colors) -8 bits non-color data	WUXGA (1920x1200)

Resolution and Aspect Ratio

Resolution in video systems is characterized by the total number of horizontal samples per line (or pixels) and the number of lines per frame. A standard television's quality is proportional to its resolution. Similarly, a digital display's (e.g. computer monitor, flat panel plasma/LCD monitor/TV) “display resolution” is measured by the total number of pixels that can be displayed in the rows and columns of the display. However, the “effective resolution” in a digital display is related to the size and number of pixels present in a given area (e.g. pixels per inch - ppi).

The aspect ratio (e.g. 4:3, 16:9) for a cathode ray tube (CRT) television is determined by the ratio of horizontal pixels to vertical ones. Likewise, for a digital display the aspect ratio is determined by the ratio of active pixel rows to the number of active pixel columns. Table 2 compares various display standards.

TABLE 2. COMPARISION OF TELEVISION DEFINITIONS

	NUMBER OF LINES PER FRAME	RESOLUTIONS
Standard Definition (SD)	480 interlaced scan lines	720 x 480i (NTSC)
	576 interlaced scan lines	768 x 576i (PAL)
Enhanced Definition (ED)	480 progressive scan lines	720 x 480p (NTSC)
	576 progressive scan lines	768 x 576p (PAL)
High Definition (HD)	720 progressive scan lines	1280 x 720p (ATSC)
	1080 interlaced scan lines	1920 x 1080i (ATSC)
	1080 progressive scan lines (“Full-HD”)	1920 x 1080p (Blu-ray Disc™)

Components and Terminology

Reading about video can be confusing. There are many terms and phrases, and often they are used or defined incorrectly. The following section gives a concise overview of key terminologies relating to general video signals and systems.

LUMA & CHROMA

A standard composite video signal can be separated into two components; luma (brightness, Y) and chroma (color, C). The luma controls the brightness or gray level of the signal, and the chroma contains the color information. Luma is varied by increasing/decreasing the signal's amplitude in proportion to the brightness of the image (black = minimum voltage, white = maximum voltage). Chroma information is encoded in the phase difference between the signal and the reference, called a color burst.

SUB-CARRIER, COLOR BURST & NTSC COLOR ENCODING

An NTSC signal contains a "sub-carrier" and "color burst." The sub-carrier is 3.579545MHz and is used to modulate color information. The color burst is a block of about 8-10 cycles at the sub-carrier frequency located before the start of active video (see Figures 1 and 3). The color burst is used as an amplitude and phase reference for the chroma components. The color produced by a video system is defined by the chroma's amplitude (the saturation) and the phase difference (the hue) referred to the initial color burst. An NTSC signal has two chroma components; one in-phase and one out-of-phase with the sub-carrier. The two phase shifted chroma components are transmitted using a scheme called Quadrature Amplitude Modulation (QAM).

SATURATION & VIDEO BANDWIDTH

Color saturation, or intensity, is determined by the amplitude of the color sub-carrier. Larger amplitude results in more color saturation as seen on the screen. The human eye is much more sensitive to changes in brightness than color. Therefore that brightness information, the luma, requires the largest portion of the available bandwidth. Conversely, the chroma requires a smaller amount of bandwidth. For NTSC video, the total baseband bandwidth is 4.2MHz, while 6MHz is used for a composite audio and video signal.

TIMING

NTSC video signals can be broken into specific time periods. Common terminology includes: front porch, horizontal sync, breezeway, color burst, back porch, active video, and horizontal blanking (see Figure 3).

The front porch is the time between the end of active video and the beginning of the subsequent sync pulse. The breezeway is the time between the end of the sync pulse and the beginning of the color burst. The back porch is the time between the end of the color burst and the start of active video. Combining the front porch, horizontal sync, breezeway, color burst and back porch gives the horizontal blanking interval. The horizontal blanking interval or retrace time (the time when no video is displayed on screen) allows the system to reset for the next line of active video. Similarly, the vertical blanking interval occurs after each field of video and is required for the system to reset from the bottom of the screen back to the top. See Figure 3 for key timing and amplitude levels of a basic NTSC video waveform.

HORIZONTAL AND VERTICAL SYNCHRONIZATION

Every video signal, analog or digital, must define not only the video information but also the locations and boundaries of the pixels. This is known as synchronization and there are two components: horizontal synchronization (HSYNC) and vertical synchronization (VSYNC). HSYNC defines the start and timing of each line of video. VSYNC defines the start and timing of each frame of video. The HSYNC and VSYNC signals can be contained with the color information in a composite format or component format with separate sync signals for each color.

The majority of analog video interfaces, such as composite, component, and S-video, use an edge triggered bi-level sync. The term bi-level indicates the transition from one level to another. Figure 1 depicts a high to low bi-level sync pulse and color burst from an NTSC composite video waveform.

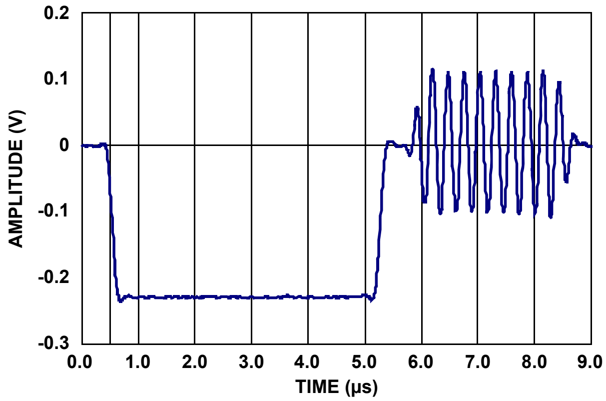


FIGURE 1. NTSC BI-LEVEL SYNC PULSE WITH COLOR BURST

Another type of synchronization pulse is the tri-level sync. Analog HD video uses tri-level sync. Tri-level sync uses a negative going pulse and a subsequent positive going pulse, which is centered at the blanking level. The system uses the midpoint of the low to high transition (or zero crossing) to trigger the start of a video line. Unlike the bi-level sync that introduces a DC offset due to a negative going pulse, tri-level sync has a net DC offset value of zero. This effectively reduces some issues during signal processing and helps to more accurately synchronize the components of an HD video signal. Figure 2 depicts a tri-level sync pulse from a 1080i/30 HD video waveform.

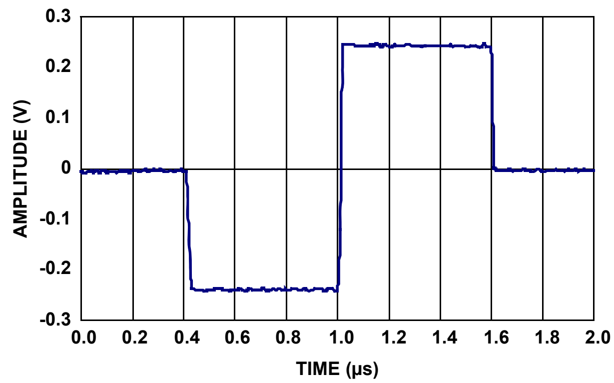


FIGURE 2. 1080I/30 (HD) TRI-LEVEL SYNC PULSE

Sync separators are available, like the ISL59885, that can extract either a bi-level or tri-level sync from the incoming video. It is also capable of handling non-standard video inputs, such as Macrovision, where there are extra pulses inserted within the horizontal blanking period.

LEVELS

Video signal amplitude levels are typically expressed in IRE (Institute of Radio Engineers) units. Standard video signal amplitude ranges from the lowest value of -40 IRE at the negative sync tip to the highest value of 100 IRE at the reference white level. The value 140 IRE is equivalent to $1V_{P-P}$, so 1 IRE is equivalent to 7.5mV. The typical video blanking/black levels occur at 0 IRE (for NTSC the blanking level is 0 IRE and the black level is 7.5 IRE), a negative bi-level sync pulse extends to -40 IRE from the blanking level, and a tri-level sync pulse extends down to -40 IRE and up to 40 IRE referenced from the blanking level.

Displaying Video

Once the segments of the video signal are understood, it is important to look at the next step; displaying the video content. The goal of this section is to define some basic terminology and prevalent issues in video display systems.

REFRESH RATE & FRAME RATE

The refresh rate (or vertical refresh rate) relates to how many times a complete image is displayed in one second. For a CRT, if the refresh rate is too slow then the viewer will experience what is known as "flicker." In this case, the eye can perceive the loss in brightness of the CRT phosphors between complete images. With 60Hz AC power sources, most CRTs and monitors use a minimum refresh rate of 60Hz. A faster refresh rate helps reduce straining on the eye and reduce visible flicker so a growing number of monitors and flat panel HD TVs use refresh rates of 75, 85, 120 or even 240Hz.

Video images are displayed in frames. A single frame of interlaced video consists of two fields, and a frame of progressive (non-interlaced) video consists of one field. For NTSC video content, 30 frames (60 interlaced fields) are generated each second (30fps or 1/30 Hz). This simply means that new frames are shown 30 times every second and each of those frames is redrawn (refreshed) once before a new frame is drawn.

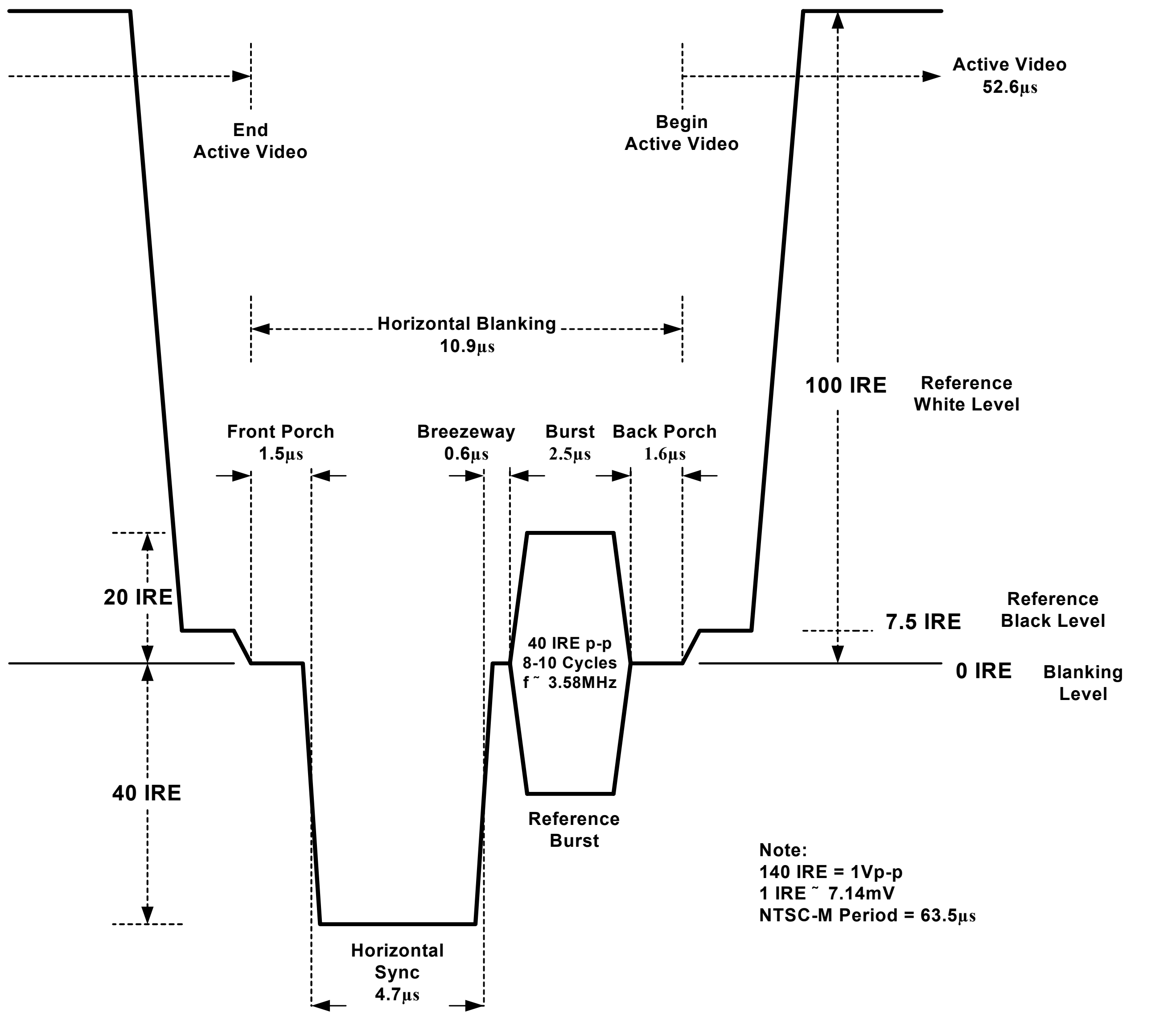


FIGURE 3. NTSC-M COMPOSITE VIDEO WAVEFORM

INTERLACED/PROGRESSIVE (NON-INTERLACED)

NTSC, PAL, and SECAM all use an interlaced field. The first field displays odd lines only and the next field fills in the frame by displaying the even lines. Progressive scan (non-interlaced) displays the image line-by-line sequentially. Progressive scan is the display method for pixel based displays, such as LCD computer monitors and televisions. Interlacing requires only half the bandwidth of progressive scanning. However, progressive scanning gives higher vertical resolution, no spectral artifacts, and no blurry edges from interlacing. In practice, interlaced video is notated with an "i" after the vertical resolution number (e.g. 1080i) and progressive video is notated with a "p" (e.g. 1080p). See Figure 4 for a simple depiction of interlaced and progressive scan display methods.

SCAN LINES

The term "raster scan" is used to indicate the presence of video scan lines in the horizontal direction. In cathode ray tube (CRT) televisions, each line of video is displayed by the electron beam scanning across the screen horizontally (row) activating phosphors. After each row is activated, the beam returns to the original side and advances to the next active line (interlaced or progressive formats) repeating the same procedure; thus generating an image on the screen. The time that the beam is blanked while returning from a scan is called the retrace or flyback time.

Similarly, digital video displays use an active scan line (row) method to activate rows of pixels one-by-one. When a row is activated the pixels in the row are set to display the desired intensity required to create the image.

HIGH DEFINITION VIDEO

High definition video is broadcast using 30 or 60fps for 720p video or at 30fps for 1080i video. The film industry uses a frame rate of 24fps (1/24 Hz). High definition sources, like Blu-ray Disc™ (BD), are capable of sourcing 1080p content at a frame rate of 24fps (notated as: 1080p/24). For a monitor to properly display a 24fps signal, it must be converted to 30fps (or 60fps if the monitor is compatible). This conversion is called a 2:3 pull-down and can be done by the source (e.g. the Blu-ray Disc™ player), or internally by the display monitor. Newer digital TVs are capable of 120Hz refresh rates, which (as a multiple of 24) allows for a better relationship to 24fps content than systems with 60Hz refresh rates. This relationship yields an integer number of refreshes (5 refreshes/second) for 24fps material, which helps image quality and minimizes pixel blur during fast moving video images (e.g. action movies or sports).

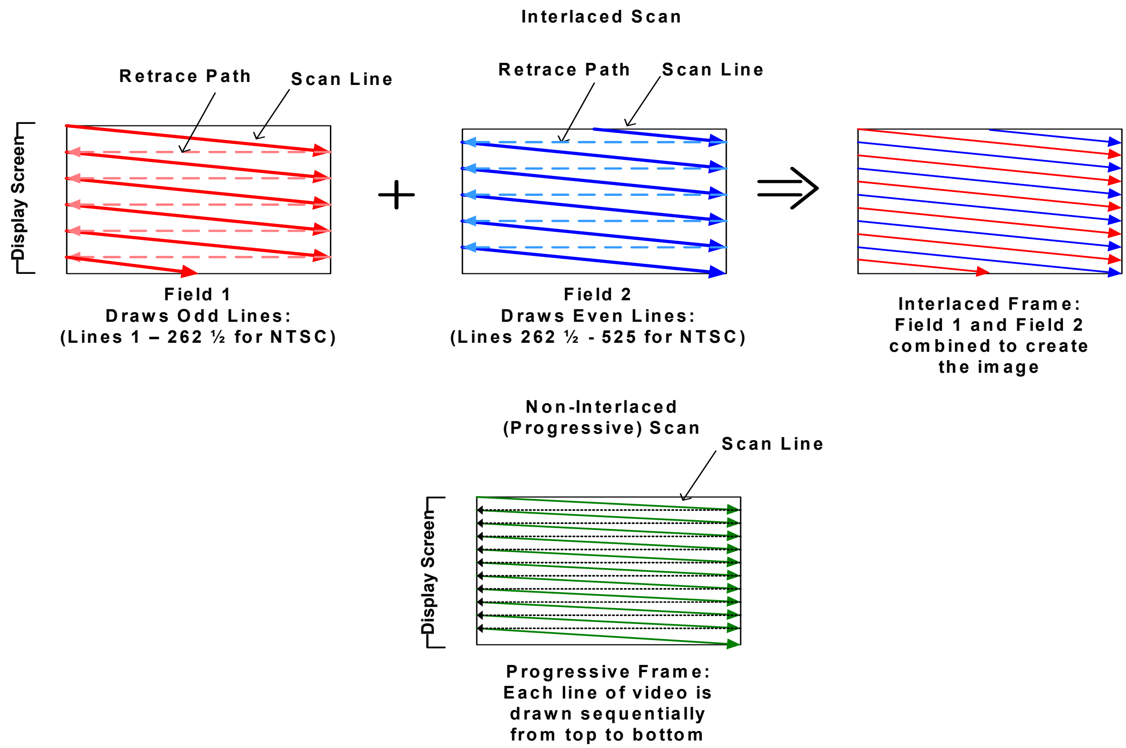


FIGURE 4. INTERLACED SCAN AND NON-INTERLACED (PROGRESSIVE) SCAN

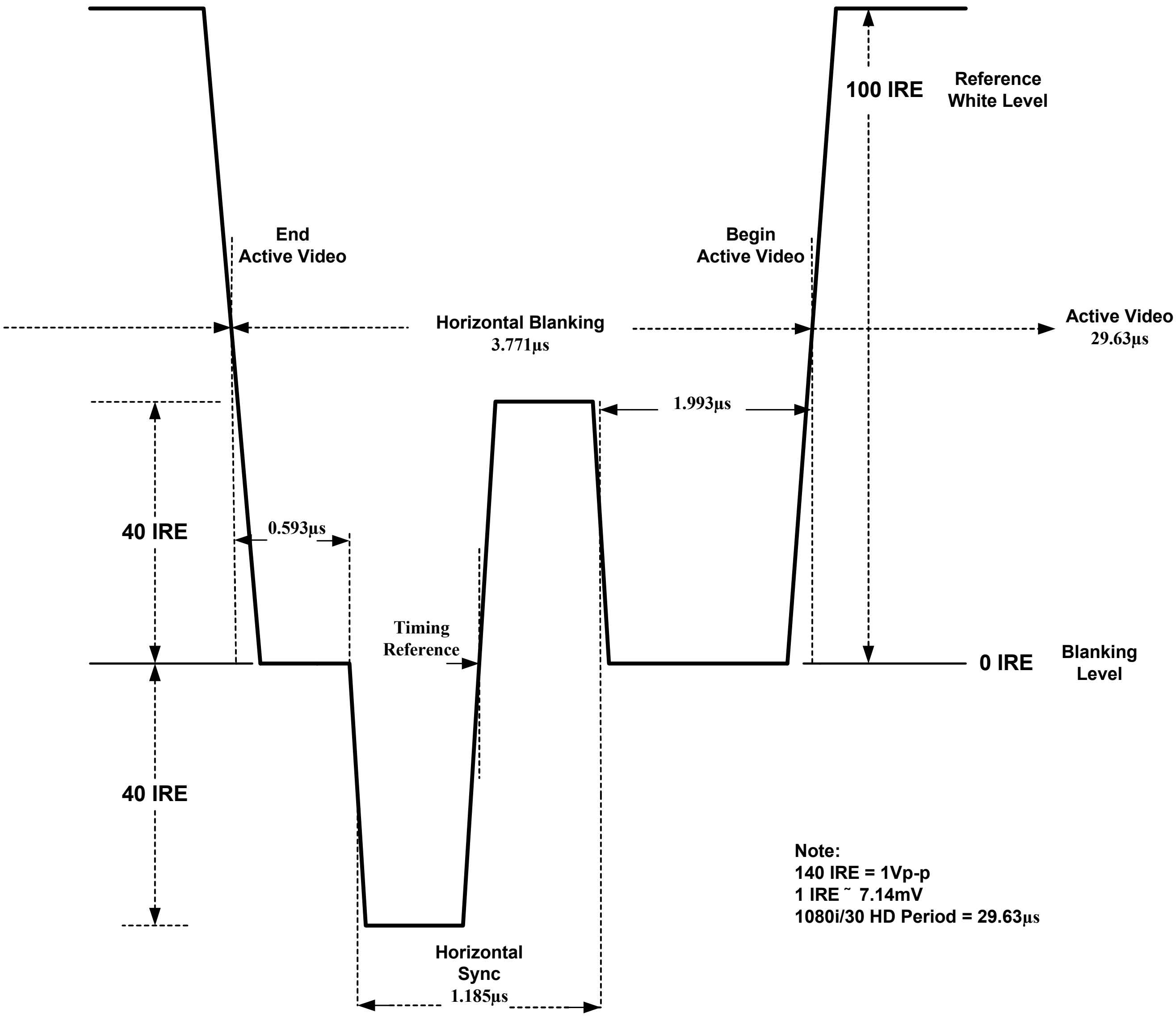


FIGURE 5. 1080I/30 HD VIDEO WAVEFORM

NTSC ANALOG VS. ATSC DIGITAL

Figure 3, Figure 5 and Table 3 allow for a quick comparison between NTSC analog and ATSC digital video signals. The figures are scaled to appropriate amplitudes and timing specifications.

Table 3 is a comparison table of NTSC and ATSC standards. Key video specifications are included and comparisons are made where directly applicable. Note that currently in ATSC broadcasting, there are two HD resolutions available; 1080i and 720p.

TABLE 3. TABLE OF NTSC VS. ATSC SPECIFICATIONS

	NTSC-M	ATSC: 1080i /720p
Video Bandwidth (MHz)	4.2 (analog)	5.38 (digitized)* 25MHz (analog)
RF (Channel) BW needed for broadcast (MHz)	6	6
Vertical Resolution (visible lines)	525 (480i)	1125/750 (1080i /720p)
Frame Rate (Hz)	29.97	30/30,60
Line Rate (kHz)	15.734	33.75/45
Refresh Rate (Hz)	59.94	59.94
Blanking Level (IRE)	0	0
Black Level (IRE)	7.5	0
White Level (IRE)	100	100
Sync Tip Level (IRE)	-40	±40
Sync type	Bi-level	Tri-Level

COMPOSITE VIDEO STANDARDS

There are three widely adopted and implemented composite video standards worldwide: NTSC, PAL, and SECAM. Table 4 compares the standards (including variations of each).

Analog and Digital Video Interfaces

There are many types of video interfaces in use today. Some are analog only and some are digital only, while some can do both. Likewise, some interfaces can transmit HD content and some cannot. The following section will help clear up confusion by comparing and giving an overview of commonly found interfaces.

Composite

The composite video interface is the most common interface that can be found in home video equipment. Typical composite connections use a yellow colored RCA style jack or an "F" connector (for coax cable connection). Composite video requires only one cable to carry the video information. The luma and chroma are combined together and transmitted between desired equipment via the cable. Likewise, in television broadcasting (via air or cable line), the composite video signal is transmitted by modulating the signal on a specific carrier frequency that relates to a broadcast channel (e.g. Channel 3). Figure A in Table 6 depicts a typical composite video connector.

S-video

The S-video (or Y/C) interface can most commonly be found on modern TV, DVD, laptop, and video projection equipment. In S-video, the luma (Y) and the chroma (C) are transmitted along separate wires but within the same cable. The benefit of S-video is the reduction of the filtering effects that are inherent with composite video systems. These effects include undesirable attenuation and spectral images.

The video system receiver must separate the Y and C to perform the required analysis. In order to separate the Y and C, a low pass filter is required and the nature of the filtering process results in an attenuation of the upper band luminance information.

Therefore, S-video is more advantageous because the Y and C are transmitted separately; luminance bandwidth is preserved, and artifacts from the filtering process are minimized. Figure B in Table 6 depicts a typical S-Video (mini-DIN) connector.

TABLE 4. TABLE OF VIDEO STANDARDS AND SPECIFICATIONS

	VIDEO FORMAT VARIANTS		
Specifications	NTSC M/ J/ 4.43	PAL I / (B/G) / M	SECAM (D/K/L) /(B/G)
Video Bandwidth (MHz)	4.2	5.5 / (5.0) / 4.2	(6.0) / (5.0)
Audio Carrier Freq. (MHz)	4.5	5.9996/(5.5)/4.5	(6.5) / (5.5)
RF (Channel) BW need for broadcast (MHz)	6	8 / (7 / 8) / 6	(8) / (7 / 8)
Sub Carrier Freq. (MHz)	3.579545 / 3.579545 / 4.43361875	4.43361875 / (4.43361875) / 3.57561149	Odd Lines: (282xLine Rate) Even Lines: (272xLine Rate)
Vertical Resolution (visible lines)	525 (480i)	625 (576i)	625 (576i)
Interlaced/ Progressive	Interlaced	Interlaced	Interlaced
Frame Rate (Hz)	29.97	25 / (25) / 29.97	25
Line Rate (kHz)	15.734	15.625 / (15.625) / 15.734	15.625
Refresh Rate (Hz)	59.94	50 / (50) / 59.94	50
Blanking Level (IRE)	0	0	0
Black Level (IRE)	7.5 / 0 / 7.5	0 / (0) / 7.5	0
White Level (IRE)	100	100	100
Sync Tip Level (IRE)	-40	-40	-43
Sync type	Bi-level	Bi-Level	Bi-Level

TABLE 5. COMPARISON OF VARIOUS ANALOG AND DIGITAL INTERFACES

	COMPOSITE	S-VIDEO	COMPONENT	DVI	HDMI	VGA
Analog	yes	yes	yes	yes	no	yes
Digital	no	no	no	yes	yes	no
Supports HD Video	no	no	yes	yes	yes	yes

Component

Component video is the purest form of analog video utilized on common consumer electronics. Component video requires that there be a minimum of three separate cables to transmit the three signal components simultaneously. More lines may be utilized for different synchronization methods. Figure C in Table 6 depicts a typical component video connector. Typically in television interfaces, the three parts of a component signal are luminance, and two color difference signals (Y, R-Y, B-Y). In computer graphic interfaces, the three signal components are red, green, and blue (RGB format). Either format allows the gamut to be generated from mathematical combinations of the three signals.

The analog YPrPb signal set is created by the use of a scaled (percentage) version of R-Y (Pr) and B-Y (Pb) color difference signals. RGB transmits a luminance signal on each of the three lines, but YPrPb differs in that it has the luminance on one signal line only. Therefore, YPrPb only requires about one third the bandwidth.

There is a digital version of YPrPb known as YCrCb. It is a scaled and digitized version of the RGB format. Often the chroma signal will be broadcast with full allowable bandwidth and the two color components will be sampled, digitized, and compressed to allow for reduced bandwidth transmission. This method improves the overall efficiency of a system.

DVI

The Digital Video Interface (DVI) was developed to maximize the quality of digital video transmitted from a digital video source to pixel displays like plasma/LCD televisions, LCD monitors, or projectors. DVI was largely developed due to a lack of a standard in the quickly developing digital market. The intention was for the DVI interface to be a universal plug that could be used for both analog (VGA compatible) or digital video transfer. Figure D in Table 6 depicts a typical DVI dual link connector.

The ability to use a digital-to-digital link is far superior to any other method requiring D/A or A/D conversion. This is especially noticeable at higher display resolution levels. Some versions of the DVI connector allow for a second digital link. This allows the second link to act independently or as an overflow to support higher resolution video bit streams. Data rates for the dual connection DVI vary by implementation. The single connection DVI data rate is 3.7Gb/s.

HDMI

The High-Definition Multimedia Interface (HDMI) is the newest and most utilized digital media interface. HDMI uses a small connector slightly smaller than the ubiquitous USB-A connector. Figure E in Table 6 depicts the most common HDMI Type A connector - there are a handful of different HDMI connectors for different applications. The most recent HDMI standard is capable of 10.2Gb/s maximum data rates, and is able to support up to Quad-HD/4k resolution, 3D video, and various audio channels. Specifically, HDMI is able to support up to eight channels of uncompressed digital audio, as well as various compressed audio formats. This makes an ideal connection for systems requiring high bit-rate transfers, like Blu-ray Disc™ players, high definition TV and stereo systems.

With the use of an adaptor, HDMI can be legacy-compatible with DVI. However, the audio-carrying capability of the HDMI component will be lost because DVI supports video only. For example, a source driving through a DVI connection can be connected, via an adaptor, to an LCD monitor that is HDMI ready.

Both HDMI and DVI use TMDS (Transition-Minimized Differential Signal) signaling. The ISL54105 is a high-performance TMDS timing regenerator containing a programmable equalizer and a clock data recovery function for each of the 3 TMDS pairs in an HDMI or DVI signal. The TMDS data outputs of the ISL54105 are regenerated and perfectly aligned to the regenerated TMDS clock signal, creating an extremely clean, low-jitter DVI/HDMI signal that can be easily decoded by any TMDS receiver. The ISL54105 can be used as a cable extender, to clean up a noisy/jittery TMDS source, or to provide a very stable TMDS signal to a finicky DVI or HDMI receiver.

VGA

Computer graphics exist in many variants. However, the most basic and widespread computer video resolution in use is the Variable Graphics Array (VGA). The resolution, number of allowable colors, and number of pixels of the original VGA standard are improved with enhancements such as SVGA, and more so with the development of the Extended Graphics Array (XGA) and its numerous enhancements. Although VGA resolution is fairly outdated in the computer monitor industry, it is still used in other consumer electronics, such as cell phones, digital frames, and hand held video players with smaller screen size and resolutions. Still, the “VGA” style connector is still widely used in the computer industry. The VGA connector has 15 pins and is a D-type connector. Figure F in Table 6 depicts a typical three row, 15-pin VGA connector. It is used to interface computer video cards to projectors and external monitors/TVs.

TABLE 6. IMAGES OF VARIOUS VIDEO INTERFACE CONNECTORS

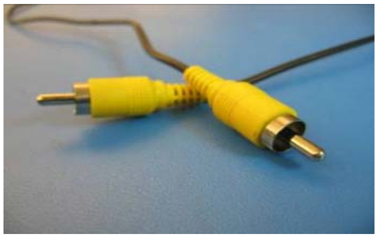
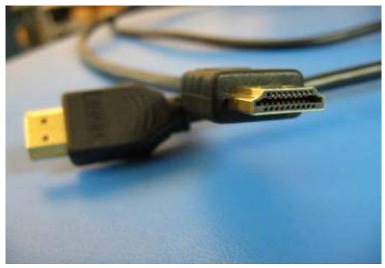


Figure A: Composite	Figure B: S-Video (mini-DIN)	Figure C: Component
		
Figure D: DVI (Dual link)	Figure E: HDMI	Figure F: VGA

DTV Transition

On February 17, 2009 (in the U.S.) the NTSC analog video broadcast standard was officially replaced by the ATSC digital broadcast standard. All televisions containing only an NTSC analog tuner now require the use of an external converter to allow for the reception and viewing of over-the-air broadcast ATSC digital signals. As of March 1, 2007 all equipment sold in the U.S that could receive a television signal was required to have a digital tuner built in.

References for Further Information

- Video Demystified (Keith Jack)
- Analog Communications for Technology (Laverghetta)
- Tektronix: NTSC Video Measurement
- Tektronix: NTSC Measurements
- http://www.dtv.gov/
- Fundamentals of Communication Systems (Proakis)

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