NTSC BROADCAST STANDARDS

In 1941 a group of television engineers and government policy makers established the standards for creating and broadcasting black-and-white television; these standards are essentially still in effect today. The National Television Standards Committee (NTSC) addressed various technical specifications for image reproduction and reception, ensuring compatibility between every television camera and TV set across the country and with those of any other nation that shared the NTSC system: Japan, Mexico, Canada, and much of South America. In the early 1950s NTSC changed these standards slightly to accommodate the addition of color to the television signal.

NTSC Analog Video Basics

**NTSC Frame Rate; Interlaced Scanning**

Film and video share the process of recording a scene as a series of still images and then replaying those images in rapid succession to create the illusion of motion. While film runs at a frame rate of 24 fps, the frame rate for NTSC video is slightly less than 30 frames per second (discussed later). The major difference, however, is how those images are created and then played back. As we’ve seen, film does this through a mechanical and photochemical process, but NTSC video uses an electronic process known as interlaced scanning.

As with film, the creation of the image begins with the lens gathering the light from the scene and focusing it on the image plane. In video, the imaging plane, or target, is the face of a CCD chip (for charged coupled device) (Figure 1). The CCD chip is a solid
state sensor (measuring either \(\frac{1}{4}\), \(\frac{1}{3}\), \(\frac{1}{2}\), or \(\frac{3}{4}\) across) composed of hundreds of thousands to millions of light-sensitive photodiodes called **pixels** (short for picture elements), which are linked together (coupled) and aligned in tight horizontal rows.

When these pixels, which are actually tiny capacitors, are struck by the incoming light, they build up an electronic voltage that corresponds to the intensity hitting *that* particular spot.

The CCD chip outputs this pixel specific voltage information in two series of stacked horizontal rows, or **scan lines**. First the CCD outputs the odd-numbered horizontal lines (1, 3, 5, 7, etc.), one at a time, from the top to the bottom, creating a half-resolution image that is called a **field** of video.

There are exactly 262.5 horizontal scan lines in one field of NTSC video. Then, after hitting the bottom halfway through that last scan line, the scanning pattern returns to the top of the chip (called **vertical retrace**) and outputs the even-numbered rows (2, 4, 6, etc.), from the top to the bottom, to fill in the rest of the information with a second field of video. This second field of video is also composed of 262.5 horizontal lines. These two fields of video are interlaced to comprise one full frame.

**Fig. 1:** CCD (Charged Coupled Device) Chip. Individual pixels (1) collect brightness information and feed a corresponding charge to the vertical registers (2), which carry it to the horizontal register (3); it then feeds the raw video signal (4) to an output amplifier (and an analog to digital converter in the digital video system). The pixels are read one row at a time at the horizontal charge transfer area; once the information is collected, the row above gets transferred one row down to be collected. The charges in the rows are therefore “coupled” to one another.
One full frame of NTSC video, therefore, is made up of 525 horizontal scan lines. The NTSC standard process of reading one field of video and then integrating a second field is called interlaced scanning, and the entire process happens at a rate of 30 frames per second, which therefore means that there are 60 fields per second (in fact, slightly slower; see later). This scanning system is often written as 60i (i for interlaced). Interlaced scanning was developed to ensure a “flickerless” image. An additional NTSC standard is the aspect ratio of the video frame—the dimensional relationship between the height and the length of a frame of video. The NTSC standard aspect ratio is 4:3, which is essentially the same dimension as for a frame of 16mm film (1.33:1).

Meanwhile, on the inside of a standard video monitor, the whole process is duplicated in reverse and in perfect synchronization (Figure 2 and Figure 3). An electron gun at the back of the CRT (cathode ray tube) (1) sprays a stream of electrons with fluctuating electrical voltage against the inside face of the tube (also the target), which is lined with hundreds of thousands of voltage-sensitive phosphors (also pixels). This stream of electrons excites the phosphors, which glow with analogous intensity to the amount of
current with which they are being struck—electricity is turning back into light. As you probably already suspect, the electron gun scans the face of the CRT in exactly the same NTSC standard pattern as we saw with the CCD chip: first one field, top to bottom (262.5 lines)(A), then the retraces vertically (2) to begin writing the second field, top to bottom (another 262.5) (B) which is interlaced with field A. This process creates one 4:3 frame, with 525 lines of resolution, in 1/30th of a second. In fact, the stream of electrons coming out of the CRT gun exactly duplicates the electrical current information of the CCD scanning process field by field, scan line by scan line and pixel by pixel.

In a plasma flat screen monitor, the horizontal rows of pixels are made up of hundreds of thousands of tiny colored fluorescent cells that glow when charged by the grid of address electrodes lining the back of the pixel rows. And with LCD (liquid crystal display) flat screens, each pixel is a tiny liquid crystal activated by a transistor. No matter what the display technology, if you are screening an NTSC signal the interlaced lines of information and scanning rate remain exactly the same.
**NTSC Color Video**

In the early 1950s NTSC developed the standards for color television. In an effort to make color television compatible with all preexisting monochrome receivers, NTSC in effect added the color component over the existing black-and-white signal, rather than create a whole new, fully integrated signal. This ensured that even though a program was broadcast in color, viewers who owned black-and-white TV sets could still receive the signal. This decision to ensure compatibility was based as much on economic considerations as on technological concerns. It was certainly not a decision based on the quality of the image, as this “color add-on” policy has numerous shortcomings in terms of image quality.

To achieve a color image the video signal is divided into the three primary colors of light: red, green, and blue (RGB). Achieving a color image involves the additive process of mixing these three primary colors to create an accurate color blend, in addition to the brightness information. In a standard CRT monitor there are three electron guns, one for each color, and each pixel comprises three tiny light-sensitive phosphor strips, one red, one green, and one blue (Figure 4). In flat screen displays each and every pixel is made up of three separate cells for each color (Figure 5).

And correspondingly, in most video cameras there are three CCD chips that are used to record the light intensities of each primary color.
The element of the video image that determines image brightness (shades of black and white) is called the luminance signal (also written as Y). The color component of the video signal is referred to as chrominance (also written as C, or chroma). Chrominance is made up of hue, which determines the tint of a particular color, and saturation, which determines the intensity of the colors. Rather than fully integrating the color component into the signal, the NTSC system simply superimposes the color signal on top of the existing black-and-white signal along a subcarrier frequency (3.58 MHz). While this has ensured compatibility with all monitors, it has also required a few sacrifices, the most important being literally slowing down the frame rate. The original black-and-white NTSC video signal had a true frame rate of 30 fps, but the addition of color slowed that down to 29.97 fps. So, to be perfectly accurate, the frame rate for NTSC video is 29.97 frames per second and the field rate is 59.94i, although you will usually see this number rounded to 60i.

Summary of NTSC Broadcast Video Standards

- Frame rate = 29.97 fps interlaced
- One frame = two interlaced fields (59.94i)
  - Horizontal lines per field = 262.5
  - Horizontal lines per frame = 525
- Aspect ratio = 4:3

Other Broadcast Standards

As mentioned earlier, NTSC video standards ensure system compatibility in any country that uses it. Unfortunately, there is not a single global broadcast standard. Other
television standards that are common around the world are **PAL** (Phase Alternating Line), used by China and most of the countries in the European Union, and **SECAM** (Séquential Couleur Avec Mémoire), used in France, Russia, and many African and Eastern European nations. The primary differences between NTSC and PAL or SECAM are the frame rate and the number of horizontal lines. Both PAL and SECAM contain 625 horizontal lines (producing superior resolution) and they have a frame rate of 25 frames per second (which allows for much easier film-to-tape conversions). If you purchase a video camera in England, it will likely be a PAL system camera. The same model camera in the United States will be NTSC. The various systems are not compatible with each other, so you cannot play video recorded in NTSC on a PAL or SECAM system and vice versa.

**Timecode**

The system in video by which every frame is assigned a specific and unique number is called **timecode** (T.C.). Recorded right along with the video data for each and every frame is an electronic number with four fields based on the 24-hour clock: hours:minutes:seconds:frames. This numbering system is vital to the workflow of every video project. We use timecode to quickly log, reference, or locate specific frames, to calculate the length of shots, scenes, and entire projects, to maintain audio and video synchronization, to ensure frame-accurate edits, to calculate trims and transitions in editing, etc. In short, timecode is the way we keep track of the frame-by-frame timing of every element, in every
stage of a project. All DV cameras have timecode, but some offer a choice of two different flavors: nondrop-frame timecode (Figure 6 [1] using colons) and drop-frame timecode (Figure 6 [2] using semi-colons).

Nondrop-frame timecode is simple to understand, but is seldom used. Nondrop-frame T.C. simply counts frames according to the original B&W video frame rate, assigning a new number to each video frame at a consistent rate of 30 frames per second. But as we discussed above, the true frame rate of color NTSC video is slightly slower: 29.97 fps. So simply allocating frame numbers to frames 1 to 30 to video that is actually running at 29.97 frames per second means that we are calling 1 second (30 frames) what is in real time 1 second and a fraction—because one second should have turned after 29.97. In essence, nondrop-frame timecode isn’t reflecting real time; it is simply counting frames, so we end up accumulating slightly more frame numbers than actual frames per second (30 numbers/second vs. 29.97 actual frames/second) (Figure 7).

Because it takes a fraction of a second longer to count off thirty frames, the difference between nondrop-frame T.C. counting time and true video running time is 1.8 frames per minute. That may not seem like much, but when nondrop-frame T.C. counts off 1 hour of
time in a program—which looks like this: 01:00:00:00—it would ostensibly have “counted” 108,000 frames. However, in true NTSC running time there are only 107,892 frames of video in an hour-long program. The discrepancy between constant 30 fps counting and true 29.97 video time after 1 hour is 108 frames, or 3 seconds and 18 frames. By using nondrop-frame timecode, when the timecode numbers display 1 hour (01:00:00:00) your video will in fact be shorter by 3 seconds and 18 frames (00:59:26:12). That may not seem like such a big deal, but in broadcast television, where programs and commercials must conform to frame-accurate timing, it is crucial to have a precise frame count.

Nondrop-frame timecode is a bit of an artifact from an era when linear tape editing machines needed perfectly sequential timecode to stay in sync. Today, with DV cameras and nonlinear editing, drop-frame timecode is the standard and default method for counting and addressing frames with ID numbers. Drop-frame timecode does not actually drop any video frames, but it does skip over some timecode numbers from time to time in order to adjust the frame count to accurately reflect the true 29.97 fps of NTSC video. To be precise, the drop-frame T.C. system skips over the :00 and :01 frame numbers once every minute, except for the tenth minute. Here is how the T. C. numbers change at each minute of footage (except for every tenth minute): L 00;09;26;28, 00;09;26;29, 00;09;27;02, 00;09;27;03 L This method compensates for the slowed-down video frame rate and, in the end, is completely frame accurate. After an hour of drop-frame timecode counting we will arrive at T.C. 01;00;00;00 for exactly 1 hour of video footage.

1 30 frames/second × 60 seconds × 60 minutes = 108,000 frames, but in reality the counting should reflect 29.97 frames/second × 60 seconds × 60 minutes = 107,892 frames.
DIGITAL VIDEO STANDARDS

NTSC broadcast standards were devised in the analog video era. However, film and video production around the turn of the century was manifestly transformed by the digital revolution, and with the revolution came a reappraisal and overhauling of standards. Analog video (and audio) means that the creation, recording, playback, and distribution of the video/audio signal are accomplished in videotape via electronic waveforms and magnetic particles, which are, respectively, analogous to the original light values of the image and the acoustic waves of the audio. Digital video and audio, on the other hand, create, record, and disseminate video and audio by transforming light values and acoustic energy into binary code, or a series of ones and zeros. There are numerous advantages to digital media: superior resolution, greater flexibility for creative manipulation, the ability to make copies with no generational loss, nonlinear editing, and more stable archiving.

Today, the revolution is complete and we have entered a phase of technological evolution. Although NTSC broadcast standards, and analog media in general, are clearly being phased out, both by government mandate and by popular demand, this system still exists side-by-side with a new set of digital video standards established by yet another consortium of engineers and government policy makers, called ATSC (Advanced Television Systems Committee). Emerging from computer technology, digital video standards have introduced changes in a number of areas; most important for us are changes in the aspect ratio and frame rate of video, the number of horizontal lines that make up a frame, and the scanning process itself. It is important to understand the new standards because every time you pick up a DV camera to shoot your movie, you are faced with a menu of possible formats. Should you shoot in high definition (HD) or in
standard definition (SD)? Some cameras allow you to shoot at either 60i, 60p, 30p, or even 24p. Should you choose the 4:3 aspect ratio or 16:9? According to the most current count the new ATSC digital television standards allow for eighteen digital video formats, with six of those being for High Definition Television (HDTV).\(^2\) With the standards for digital video somewhat in flux, it’s pretty clear that we are still in the middle of this digital evolution. Nonetheless, one thing is for sure: the analog era is over.

In order to fully understand digital video formats it is important to introduce two technical concepts: progressive scanning and vertical lines of resolution.

**Progressive Scanning**

**Progressive scanning** (Figure 8) is used in computer monitors and some digital video systems. Progressive scanning differs from interlaced scanning in that one frame is not made up of two interlaced fields (odds lines first, then even lines); instead, progressive scanning draws a full frame of video (all horizontal lines) from top to bottom at a rate of 30 frames per second, and in some systems 60 frames per second. These are written as 30p and 60p. The resolution of progressive scanning is visibly superior to interlaced scanning, and all modern flat screen technologies (like LCD or plasma screens) are compatible with progressive scanning. Progressive scanning is indicated with the letter “p” after the frame rate and interlaced scanning is indicated with the letter “i.” For example, the NTSC system scans at 60i (60 interlaced half-resolution fields per second) and one of the high definition systems scans at 60p (60 full resolution frames per second), fully twice as many lines of information.

\(^2\)HDV Filmmaking, by Chad Fahs, Thomson Course Technology PTR, Boston, MA, 2006, pg. 7.
Whenever there is an evaluation of video image resolution quality you will hear the term resolution. Resolution generally refers to the ability to reproduce visual detail: sharpness of line, subtlety and degrees of luminance, and accuracy of color. Video resolution is affected by many factors, including lens quality, the scanning system, the number of pixels, data sampling rates, color depth sampling, and data compression (all explained later). All of these variables affect overall resolution, and the general rule of thumb is that the bigger the numbers, the better the resolution. More horizontal scan lines are better than fewer, more pixels are better than fewer, more data sampling is better than less: the more information the compression files retain, the better. Of course, as the resolution statistics for a camera increase, so does another number—the price.

**Vertical lines of resolution and horizontal pixels** are specific terms: they refer to the number of horizontal lines from top to bottom and the number of pixels that comprise each horizontal line for any given format. Because the vertical dimension of the frame is composed of horizontal lines stacked up on top of each other, the more horizontal scan
lines a system has the better the **vertical resolution**. Because it comprises the number of horizontal scan lines, the vertical resolution is fixed by the particular system standard (Figure 9).

![Fig. 9: The higher the number of horizontal scan lines, the better the vertical resolution of the image. 10 scan lines makes it difficult to see the actual shape of an object (left). 25 horizontal scan lines add significantly more visual information (middle). 50 scan lines (right) make it possible to see nuances of shading and volume](image)

One detail you should be aware of is that only the **active lines** are counted when describing a system’s vertical lines of resolution, meaning only the scan lines that are visible to the viewer. All systems hide some of their scan lines behind a display mask, because the top and bottom edges of the raster are used for video system information (like horizontal blanking pulses and timecode) instead of picture information. As we mentioned above, the NTSC system has a total of 525 horizontal scan lines; however, a viewer only sees the 480 lines that make up the image. So, as you will see in the **ATSC Standards Table below**, we say that NTSC video has a vertical resolution of 480 active lines. Compare this with the two HD video systems, which have either 720 or 1080 vertical lines of resolution, and you can see why the HD image is clearly superior.
The ATSC digital television standards supports 18 different digital video formats. (i = interlaced scanning, p = progressive scanning) Source, ATSC

The ATSC standards also clearly articulate the number of maximum horizontal pixels that can make up each scan line. However, the horizontal resolution factor is not fixed. Instead, it is determined by the specific video format you use. Again, the more pixels along the horizontal dimension, the better the resolution of the image. For example, analog VHS tape delivered a resolution of 240 horizontal pixels; consumer DV is capable of around 500 horizontal pixels and professional DV formats, such as DVCPRO, have 720 horizontal pixels (as do commercial DVDs). One can see why VHS vanished so quickly! In fact, the standard analog NTSC broadcast signal can display only 330 horizontal pixels. So the VHS format underutilized the resolution potential of standard broadcast television while the resolution power of DVCPRO is not realized to its fullest. This is precisely why the NTSC analog broadcast system is being replaced with the new digital broadcast standards.