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tech tips

Understanding How Color Video Cameras Work

Many consumers capture their unforgettable moments with portable, convenient camcorders, and business and industry use video cameras for security, process control, and remote monitoring. Video camera and camcorder servicing is a growing segment of video servicing that offers great opportunity for servicers trained and equipped in camera service. Understanding how video cameras work is the first step in servicing them effectively. This Tech Tip explains the basic operation of color video cameras, using a universal functional block diagram.

Cameras and Camcorders

A video camera is a device that converts visual images into electrical signals that can be viewed, recorded, or broadcast. Video cameras are found in two basic configurations - as a stand-alone unit, or as part of a camcorder.

As a stand-alone unit, a video camera's composite video output signal feeds an external connector where it connects to another stand-alone video device such as a video recorder or monitor. Originally all cameras were stand-alone units, but today almost all consumer cameras are part of the common camera/recorder/viewfinder combination known as a camcorder. Stand-alone cameras are still widely used by industry for monitoring and surveillance applications, and for developing high quality video signals in broadcast and video production studios.

Camcorders are very popular with consumers because of their convenience and small size, but broadcasters and video production facilities also use camcorders

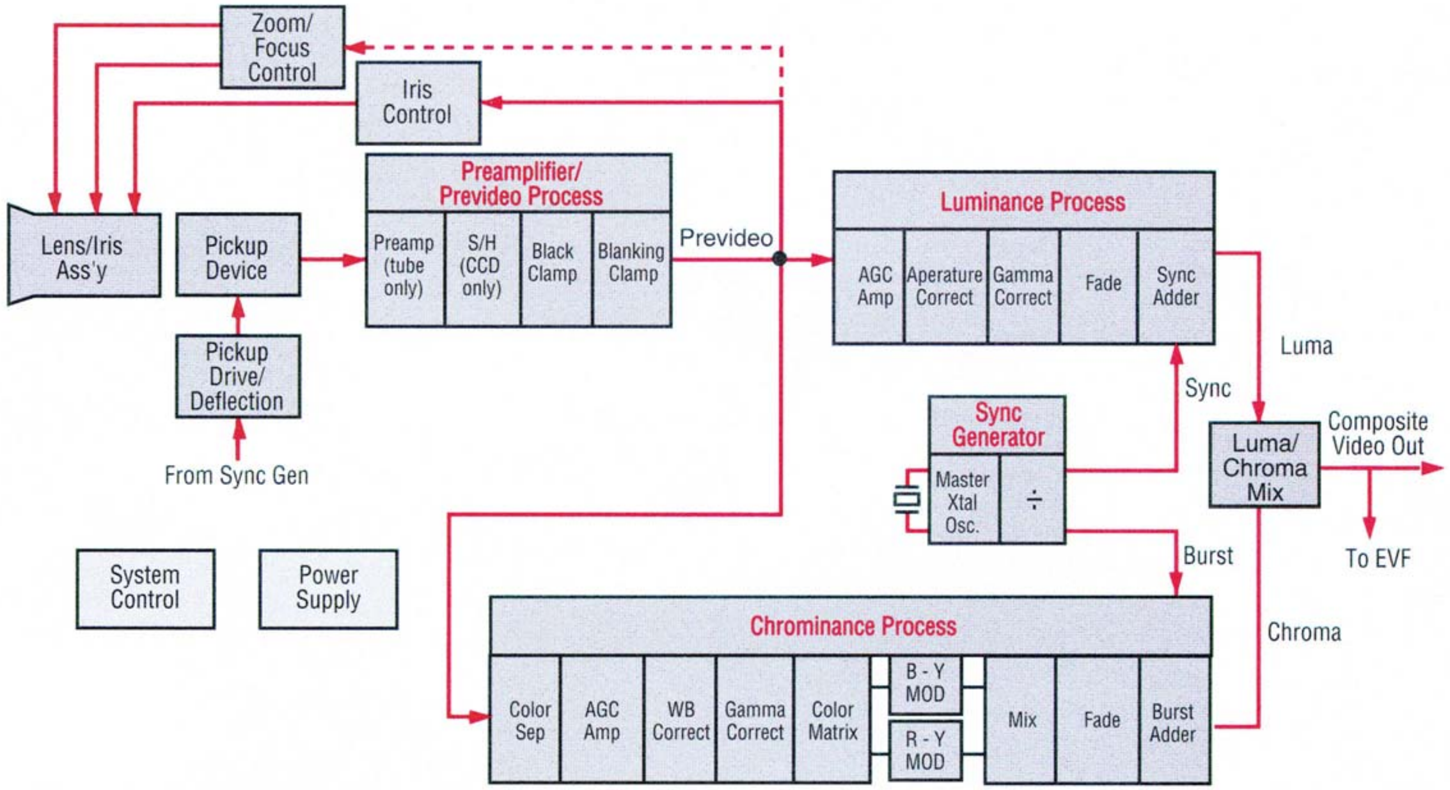


Fig. 1: Color video camera block diagram

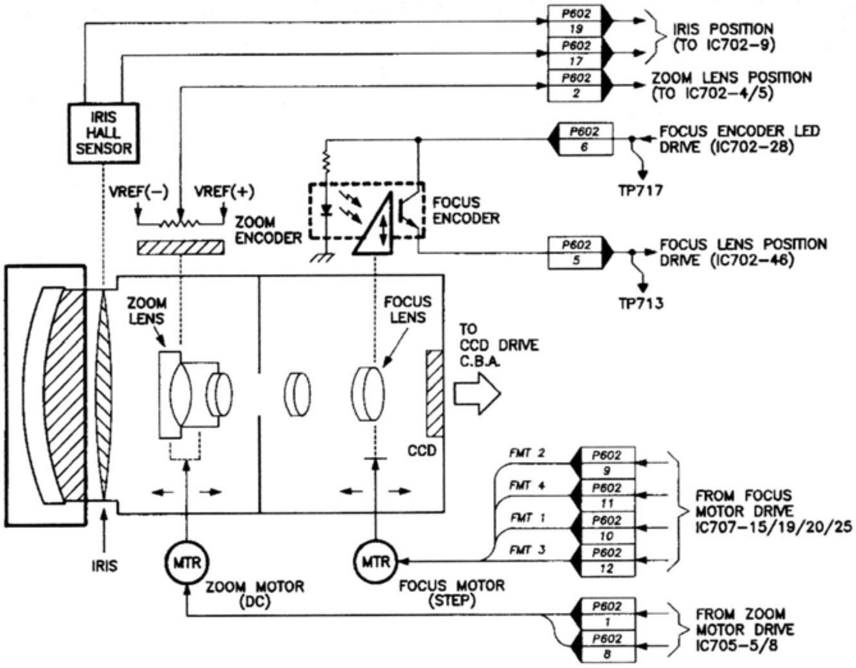


Fig. 2: The iris controls the amount of fight entering the lens assembly. The zoom lens provides a variable focal length for viewing close-up images or magnifying far away images, while focus maintains a well defined image. (Illustration courtesy of GE.)

extensively for field shots. Camcorders combine a camera, a VCR, and a small viewfinder to form a convenient unit for recording and playing back video images. Functionally there is little difference between a stand-alone camera and a camera within a camcorder, except that the camcorder camera shares some of its support and control circuits (power supply, system control, Y/C adder) with the VCR section.

Universal Camera Functional Block Diagram

The basic operation of all video cameras is very similar. The Universal Video Camera Block Diagram in Figure 1 shows the interconnection and signal flow between the major functional blocks. The order of some blocks may vary slightly depending on individual camera design and the type of pickup device used. Following is a brief description of the operation of each functional block.

Lens/Iris Assembly

The lens assembly focuses light from the scene onto the pick-up device's light sensitive surface. The auto-iris circuit controls the amount of light passing through the lens using a small motor to open and close the iris diaphragm. Under bright light conditions the auto-iris circuit reduces the size of the iris opening so less light strikes the pickup device.

Controlling the light striking the pickup device controls the amplitude of the prevideo signal, as explained in the next section. The iris control circuit samples the amplitude of the prevideo signal to obtain feedback on the amount of light that is striking the pick-up device.

The iris diaphragm is spring-loaded so it automatically closes when power is removed, or if the motor or iris control circuit fails. Thus, a failure in the iris control or iris drive circuit prevents light from reaching the pick-up device and results in no video output from the camera.

Auto-focus cameras have a small motor inside the lens assembly to position the internal lenses for proper focus. This focus motor is part of the focus control circuit. Focus control circuits either maximize the high frequency information in the prevideo signal, or respond to an infrared or LED sensor.

Some cameras include an electronic zoom control. The zoom control circuit operates a motor that changes the lenses according to input from the user operated control.

Sync Generator

The camera's composite video output signal contains luminance, sync, 3.58 MHz subcarrier chrominance signals, and chroma burst signals, which all must be synchronized to each other. A master sync oscillator, usually running at two or four times the 3.58 MHz (3.579545 MHz) color frequency, is divided down to produce these synchronizing signals. The sync generator provides horizontal and vertical drive signals to the pick-up device, composite sync and burst for the video output, and 3.58 MHz subcarrier reference signals for the R-Y and B-Y color modulators.

Pick-up Device

The pickup device changes the visual image into electrical signals. Three different types of image pick-up devices are used in video cameras; MOS, CCD, and vacuum tube.

MOS and CCD pick-up devices

MOS (Metal Oxide Semiconductor) and CCD (Charge Coupled Device) image pick-up devices are solid state devices very similar to each other in operation and performance. Both consist of thousands of photodiodes arranged into a matrix of horizontal rows and vertical columns.

Each individual photodiode receives light from a small area of the picture scene. This causes it to produce a small electrical charge proportional to the amount of light striking its surface. Thus, the entire photodiode matrix becomes an electrical "picture" of the scene. The pick-up device is scanned and the voltage levels (which correspond to the brightness levels) at small, individual points across the pick-up surface are sampled. These small areas of the picture sampled by each photodiode are called picture elements or pixels.

By repeatedly scanning the photodiode matrix, the individual electrical charges for the whole picture are collected and assembled. The scanning method used to collect these charges is one major difference between MOS and CCD pick-ups.

MOS devices use a scanning method that results in 4 output signals: white, yellow, cyan, and green (Older three-line MOS devices didn't have a green output signal). One disadvantage of MOS devices is that the output signals are low level (40-50 mV) and require low-noise preamps to amplify the signals to a level usable by standard signal processing circuits.

CCD devices have a single video output line that contains all the luminance and chrominance information needed to generate NTSC composite video. The output signal level is high enough so no preamps are required. CCD devices have proven to be more reliable than MOS devices.

Although the output of a solid state pickup device contains electrical information that corresponds to the visual scene, the output signal is not in analog NTSC format. Instead, it is a digitally sampled signal containing the charges from the individual photodiodes or scene pixels. Signal processing in the Previdеo Process block converts this signal into an analog signal.

Tube pick-up devices

Tube pick-up devices are special CRTs that use magnetic yoke deflection and a high voltage supply to produce and scan an electron beam across a light sensitive surface or target. Each of the common pick-up tubes; Vidicon, Saticon, and Newvicons are similar in operation. The output from a tube pick-up device is an analog signal, similar to the NTSC luminance signal.

Tube pick-ups have several major disadvantages compared to solid state pickups: 1) They are larger, more fragile. and require heater and high voltage. 2) Because they depend on a hot cathode emission, they are subject to wearout. 3) Pickup tubes require many scan correction circuits to produce an acceptable output. 4) Their very low output level (200 uV or less) requires extremely high-gain low-noise preamplifiers. For these reasons, tube pick-ups have been entirely replaced by solid state CCD and MOS devices in consumer cameras, and they are being phased out of most broadcast and industrial camera applications.

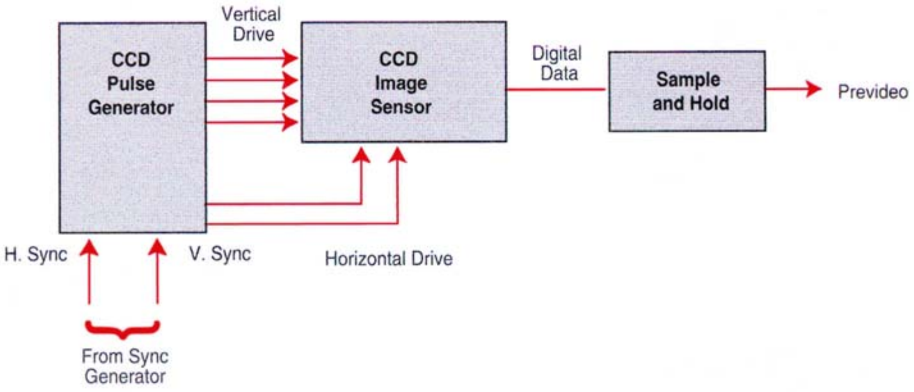


Fig. 3: A CCD pickup is scanned using 4 vertical pulses and 2 horizontal pulses. The output of the CCD is digital data that is converted to an analog signal.

Pick-up Drive/Deflection

Tube and solid state pick-up devices require external signals to control their raster scanning process. Tube pick-up cameras use magnetic yoke deflection (similar to television receivers) to move an electron beam across the target surface. Deflection circuits synchronized to the master sync generator generate the horizontal and vertical yoke currents.

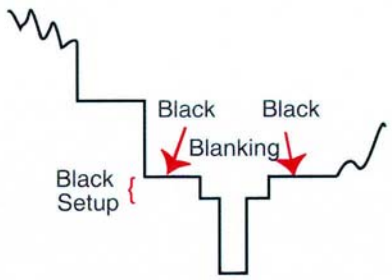


Fig. 4: The black clamp circuit sets the black portion of the camera's composite video output signal and the blanking clamp circuit fixes the level during blanking time.

In solid state pick-ups the horizontal rows and vertical columns of photodiodes are electronically selected to develop an output signal. The drive pulses, provided by the pick-up drive circuit, are synchronized to the master sync generator.

Previdеo Process

The Previdеo Process section performs several functions. First, preamplifiers immediately following tube and MOS pick-up devices increase the output to a level that is useable by the following signal processing circuits. This amplification is important for maintaining an adequate signal-to-noise ratio. CCD devices produce a higher output and do not require a preamplifier.

Solid-state pick-ups require an additional signal processing stage. Unlike tube pick-ups that produce an analog output, the output of a solid-state pick-up is a digitally sampled signal. Scanning the photodiodes to collect the individual charges produces an extra, high frequency carrier signal. A sample and hold circuit, or a low pass filter, removes this unwanted carrier and passes only the low frequency information that corresponds to the light level at each pixel (analog luminance).

Following the sample and hold stage is a black clamp. This stage is responsible for establishing the black level of the composite video output signal, as Figure 4 shows. The pick-up device scans an optically black area of the pick-up surface at the end of each horizontal scan line to produce the black reference level.

The last Previdеo Process stage is the blanking clamp. This circuit clamps the entire blanking period to a fixed level with respect to the previously established black level. The difference between this blanking level and the black reference level is called black setup, as Figure 4 illustrates.

We call the output signal from the Previdеo Process section "previdеo" since it contains luminance picture information and a color carrier signal. Yet the signal still doesn't contain the sync or color burst reference signals that are part of a composite video signal. Also, the color carrier signal is in a form that can't be used by other standard NTSC video devices without further chroma processing.

Luminance Process

The Luminance Process circuits are fairly simple since they process more conventional luminance signals. The AGC amp works with the iris control to maintain a constant signal level. At low light levels (when the iris is fully open) the AGC adds amplification to maintain a constant signal output. This circuit normally amplifies only during low light levels when the iris is already wide open and cannot open any further to increase the signal amplitude.

The aperture correction circuit, sometimes called edge correction, is responsible for reproducing sharp picture detail. Ideally, the pickup device should see very sharp edges in the scene, such as the edge of a door. But, pickup devices have a limit to the small size of picture transitions and objects they can detect. This limitation is due to the relatively large size of the light sensitive area or "aperture" of the individual photodiodes. (In pickup tubes this size limit is due to the size of the electron beam hitting the target). The aperture correction circuit senses the black to white picture transitions (and vice versa) in both the horizontal and vertical directions in the picture scene. It then adds fast spikes to the signal at these times to enhance the signal transitions and sharpen the edges of picture objects.

The gamma correction stage provides additional gain for darker picture portions of the camera's video signal to correct for the normal black compression that occurs in all television and monitor CRTs. Gamma correction allows the light levels of the reproduced picture to match the original picture scene exactly.

Many consumer cameras include a fade to black feature. Pressing the fade button tells the fade circuit to decrease the video signal slowly to black, and to return from black slowly to normal picture as the button is released.

The last stage of the Luminance Process section is the Sync Adder. The Snyc Adder adds horizontal and vertical sync pulses from the sync generator to the video signal. The composite luminance and sync (Y) output of the Luminance Process section is sent to the Luma/Chroma Mixer.

Chrominance Process

The chrominance process section removes the color information from the Prevideo signal and processes it into the standard NTSC format that can be added to the luminance signal.

The Color Separator separates the chrominance from the rest of the prevideo signal with a filter in tube cameras, and with sample and hold circuit or signal delay/summing circuit in MOS and CCD cameras. The Color Separator output signal has R-Y and B-Y signals, or individual red, green, and blue signals, depending on the camera design.

The chroma AGC amplifier operates in step with the luminance AGC. It amplifies the color signal during low light conditions when the iris is wide open and unable to hold the signal level constant.

White balance compensates for differences in the color of indoor and outdoor lighting. The White Balance Correction stage adjusts the level balance between the red and blue color signals to ensure that the camera reproduces white when it is pointed at white objects. The auto white balance circuit analyzes the color composition of light arriving at the camera by examining either the output of the R-Y/B-Y separator circuit, or an external white balance sensor. After averaging the color over a period of time, it applies a correction signal to either the red or blue channel.

The Chrominance Processing section also contains gamma correction circuitry. As with the luminance signal, the gamma correction circuit adjusts the chroma signal to correct for known CRT compression.

The Color Matrix (R-Y/B-Y separation) circuit separates the color signal into R-Y and B-Y signals. These two signals are then modulated onto separate 3.58 MHz subcarrier signals, with the R-Y subcarrier shifted 90 degrees from the B-Y subcarrier. These two modulated subcarriers add to produce the chrominance signal, which varies in amplitude according to color saturation, and varies in phase according to color hue. After passing through a fade circuit similar to the luminance section, a reference burst sample is added to the color signal during each horizontal blanking period.

Luma/Chroma Adder

After processing the luma and chroma signals, they are added in the

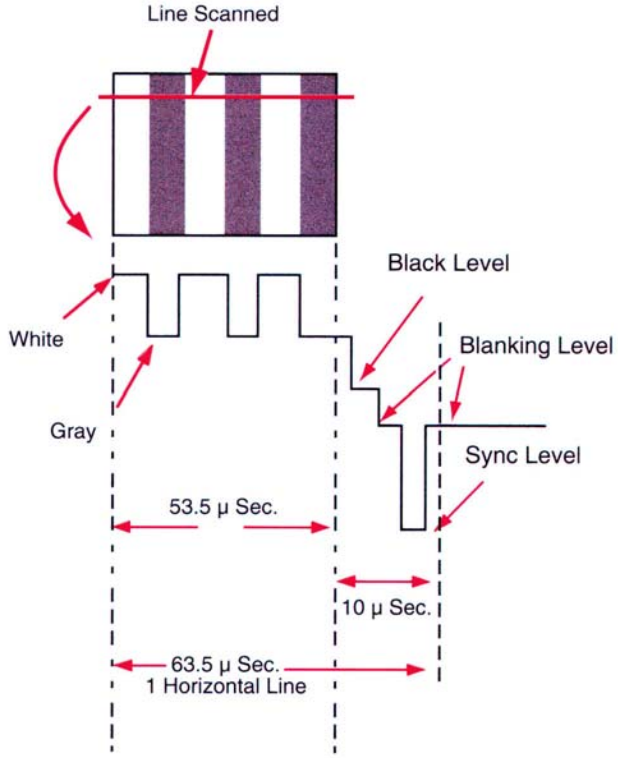


Fig. 5: Scanning the pickup device produces signal levels that vary with the brightness levels of the scene. The camera adds black, blanking and sync pulses.

luma/chroma adder circuit to form the NTSC composite video signal. The NTSC composite video signal contains luminance, vertical and horizontal sync, color burst signals, and a 3.58 MHz subcarrier reference signal. This signal goes to the electronic viewfinder (EVF) and to the camera's video output jack. In a camcorder the luma/chroma adder circuit may be part of the VCR circuits.

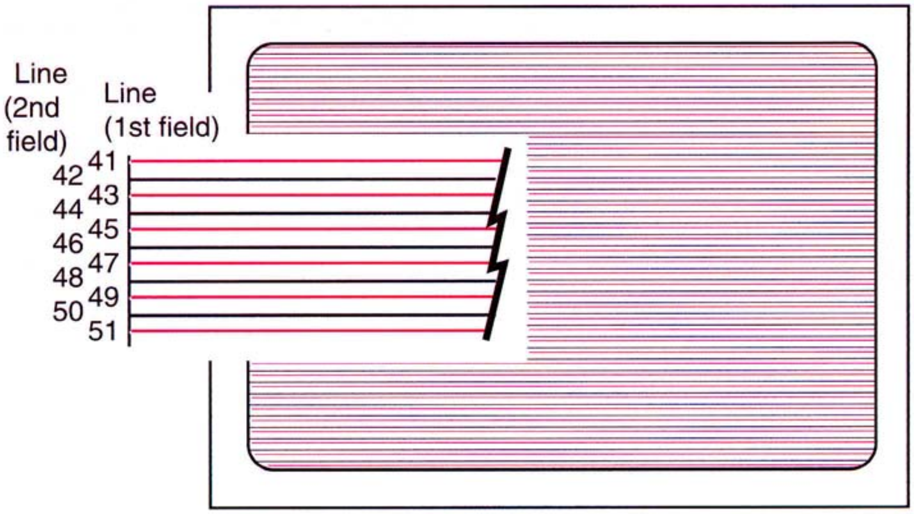


Fig. 7: The picture is scanned in two sets of lines. Each set of scan lines is a field. The entire picture (two fields) scan is a frame.

The Composite Video Output Signal

Now that we've covered the basic operation of a video camera's major functional blocks, let's take a closer look at how everything comes together to produce the composite video signal.

Signal Sampling

The pickup device converts the incoming picture into many individual voltage levels, with each voltage level corresponding to the brightness level of the picture at each photodiode. As the pickup device is scanned, a continuous sample of these Individual voltage levels forms an electrical representation of the picture.

Horizontal Scan

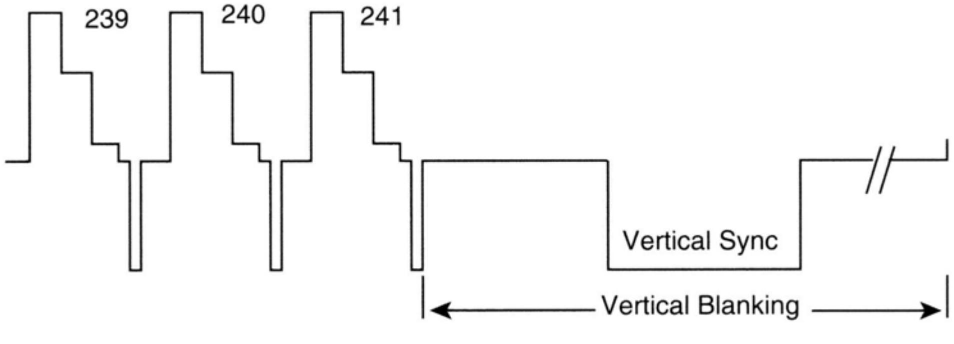
The scanning of the pickup device starts at the upper left corner of the scene, and moves horizontally across the scene along a thin line. The voltage samples along this scan line are assembled into a continuous video signal. The voltage changes in this video signal correspond to the brightness level changes in the scene along the scan line.

As the scanning process reaches the right edge of the pickup device, the camera scans a black reference stripe and produces a blanked output. Scanning from the left to the right side of the scene takes about 53.5 microseconds. While the output of the pickup device is blanked, the camera adds a horizontal sync pulse and readies itself to begin scanning from the left side of the scene again.

After 1 horizontal line, which takes 63.5 microseconds (scan time + blanking time + sync time as Figure 5 shows), the scan process starts all over. This time, however, the horizontal line is shifted a bit lower in the scene. Again, the scanning process produces voltage samples corresponding to the picture brightness levels, plus blanking and sync pulses are added to the signal after the scanning process reaches the right edge of the scene.

Vertical Scan

The scanning process continues down the scene, with each horizontal scan line occurring slightly lower than the previous line. The 241st horizontal scan line occurs at the bottom of the scene. Upon its completion, the camera generates a blanking pulse and sync pulse that are much longer than the pulses after the preceeding horizontal lines. In fact, this blanking pulse at the bottom of the scene lasts for a period equal to 21 horizontal scan lines, as illustrated in Figure 6. We call these vertical blanking and vertical sync pulses because they occur after the entire scene is scanned vertically from top to bottom. We also call them inactive because they contain no picture information.



Fig, 6: The camera generates a vertical blanking pulse after line 241 that lasts for 21 lines.

After vertical blanking, the camera resets its scanning process to the upper left corner of the scene. Here the process repeats with another 241 active horizontal scan lines, plus vertical blanking and sync. This complete set of 241 active horizontal scan lines, plus vertical blanking and sync pulses equal to another 21 lines (262 lines total) is known as one vertical field. Each field, created by one full scan from the top to the bottom of the scene, occurs in approximately 1/60th of a second.

Interlaced Scan

Although each field scans the entire scene from top to bottom, two fields are used to represent the complete scene. We call the two fields "even" and "odd," and together they make up a "frame." A frame includes all the scan lines in one full picture. The adjacent scan lines in each field are spaced far enough apart so that another

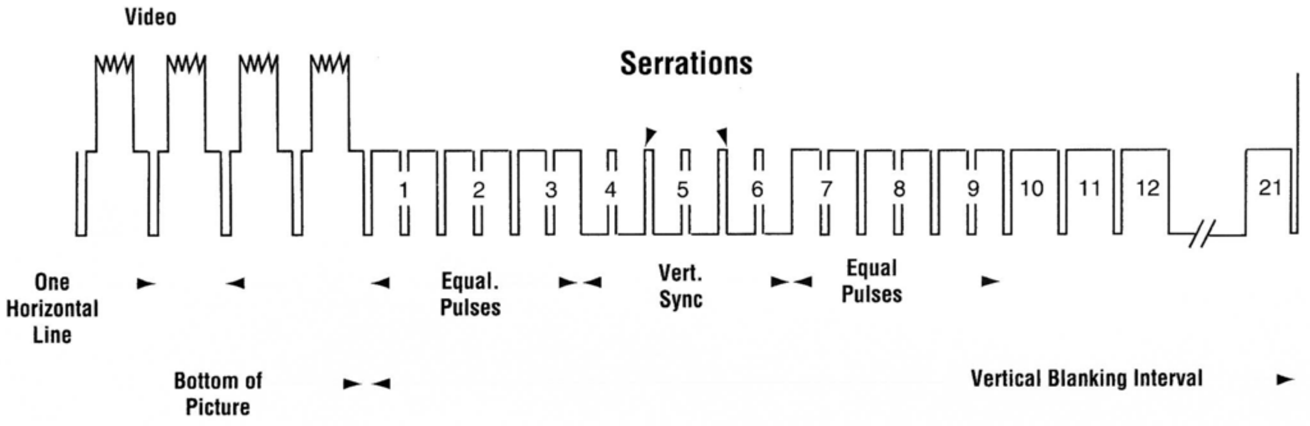


Fig. 8 Equalizing pulses and serrations during the vertical interval insure proper interlace scanning and maintain horizontal sync .

scan line will fit between them. In fact, each line in the second field scans the open spaces between the scan lines of the first field, as illustrated in Figure 7. We call this interlaced scan. Since one frame requires two fields to complete, each frame takes place in 2/60ths (1/30th) of a second.

Why not just scan out the entire set of 482 scan lines in one pass, instead of scanning it in two fields? If all the lines were scanned sequentially, you would see flicker in the television picture. The picture would flicker because the bottom part of the picture would be scanned 1/30th of a second after the top part. After 1/30 of a second the brightness of the CRT phosphors at the top of the screen would have dimmed enough that your eyes would detect the drop in brightness. Another solution would be to increase the scanning speed so that all 482 lines would be scanned in one pass within 1/60th of a second. This won't work however, because the produced video bandwidth would exceed the maximum allowed by the NTSC system.

Instead, the camera scans the first field (odd field) consisting of lines 1, 3, 5, etc. in 1/60th of a second and the second field (even field) scans lines 2, 4, 6, etc. in another 1/60th of a second (Figure 7). With this scan method the brightness in every area of the recreated picture is refreshed every 1/60th of a second. Since the human eye cannot detect brightness variations that occur this fast, the picture appears continuous and flicker-free. Additionally, the video bandwidth stays within the NTSC limit of 4.2 MHz.

Due to the timing requirements of interlaced scan, each field includes an extra half horizontal scan line. The first (even) field adds this extra half-line at the end of the field, while the second (odd) field adds the extra half-line at the beginning of the field. That means that each field contains 241.5 active scan lines, plus vertical blanking and sync time equal to another 21 scan lines, for a total of 262.5 scan lines per field. Each frame thus includes 525 total horizontal scan lines.

Because vertical blanking and sync last for 21 horizontal scan cycles after each vertical field, a potential problem exits with the scan oscillators in a television or monitor. If the horizontal oscillator in a TV or monitor was allowed to run for this long without sync, the oscillator could drift off frequency before it receives another horizontal sync pulse. During interlaced scan, some extra signals are added to the vertical blanking and sync pulse interval to prevent this problem (Figure 8).

These extra signals, which are substitute horizontal sync pulses, are inserted during the vertical blanking and sync periods. The substitute horizontal sync pulses during the vertical blanking interval are called "equalizing pulses" and the pulses during vertical sync time are called "serrations."

Since the odd field ends with a half line of video before vertical blanking and the even field ends with a full line of video before vertical blanking, the spacing of the equalizing pulses and serrations is at half horizontal line intervals, as Figure 8 shows.

Scan Frequencies

Each horizontal scan line, including blanking and sync, takes approximately 63.56 microseconds. At this rate, 15,734 horizontal scan lines are completed every second (one second divided by 63.56 microseconds). This makes the horizontal scan frequency 15,734 Hz (or more exactly 15,734.26 Hz).

Each vertical scan of the scene from top to bottom, plus vertical blanking and sync, takes about 1/60th of a second. Thus, 60 vertical scan cycles are completed every second for a vertical scan frequency of 60 Hz (actually 59.94 Hz). This is also called the vertical field rate. Since two fields make up one complete one frame, 30 new frames are completed every second, meaning the vertical frame rate is 30 Hz (actually 29.97 Hz).

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