Chapter 10: Analog and Digital Video Technologies

Chapter 10 Objectives

At the conclusion of this chapter, the reader will be able to:

- Describe the spectral (frequency-domain) composition of an analog video signal.
- Describe the nature of a digital television signal
- Draw a block diagram of a television transmitter.
- Identify the parts of an NTSC (RS170A) analog video waveform.
- Draw a block diagram of an analog television receiver.
- Describe the characteristics of high-definition television (HDTV)
- Describe the steps in HDTV transmission
- Draw a block diagram of a HDTV receiver

Among the technologies that have shaped our modern society, television ranks high in influence. Rare is the household that doesn't have a TV set; many homes have several. Broadcast TV is a daily source of news, entertainment, and other information for most Americans. The Internet now sports services and applications that are pretty stiff competition for terrestrial broadcasting - - these include YouTube, NetFlix, Hulu, and a wide variety of other platforms. The technologies behind television are the foundation behind these services. This chapter will show you how the foundational technologies of both analog and digital television (DTV) work.

DTV receivers are now common worldwide. In 2005, the US passed the Digital Transition and Public Safety Act, which mandated full-power public broadcasts to transition to digital format in 2009; the actual transition occurred in June 2009, rendering analog receivers useless without the use of a converter box. Cable TV broadcasts are not required to be digital at all, and some cable systems still use analog transmission methods.

The modern DTV receiver is one of the most complex electronic systems devised by humankind. It has everything: VHF and UHF RF circuitry; PM, FM, and AM demodulation; complicated digital signal processing (DSP) and microprocessor circuitry; and in most cases, sophisticated switching power supply technology. Modern TV receivers use specialized DSP chipsets to decode and display information on flat liquid-crystal displays (LCDs). They're really specialized computers meant for reception of digital TV signals.

A DTV receiver is really just a combination of an RF receiver or “tuner,” digital data demodulator, digital signal processor, and a display monitor. The display monitor of a digital receiver often uses the same technology as a computer monitor, though other display technologies (such as plasma, DLP, and organic LED may be used. The digital TV signal is carried as a high-speed computer data stream on an analog RF carrier. Because DTV uses digital error correction techniques, minor defects in the signal quality do not affect the picture or sound reproduction at the receiver.

Due to the ever-falling cost of electronics, TV prices have also fallen - - and in many cases, failed TV sets are simply replaced, not repaired. So why is it important to understand this technology? Primarily because the technologies that enable television are employed in many other systems; in particular, cable TV, radar, security systems, machine vision, Internet-based video services, and some remote presence technologies (such as "first person view" on drone aircraft) are common applications of this knowledge base. Analog television formats (such as National Television Standards Committee, or NTSC) still find extensive application in industry.

How to Use this Chapter

This chapter retains much information that might be considered of historical or reference value. Not many people are going to be working with and repairing analog equipment, but at the same time, many modern digital standards are hard to understand without some background in analog. The reader may want to focus on sections of the chapter relevant to his or her needs, and refer back to the principles covered under analog video as needed.

10-1 Analog Television Principles

The signal from a television station contains information from two primary sources, the *video* information signal (picture), and the *audio* information signal (sound). When early experiments were being conducted with wireless TV transmission, it was decided that this would probably too much information to squeeze on to one carrier signal, so the system shown in Figure 10-1 was developed.

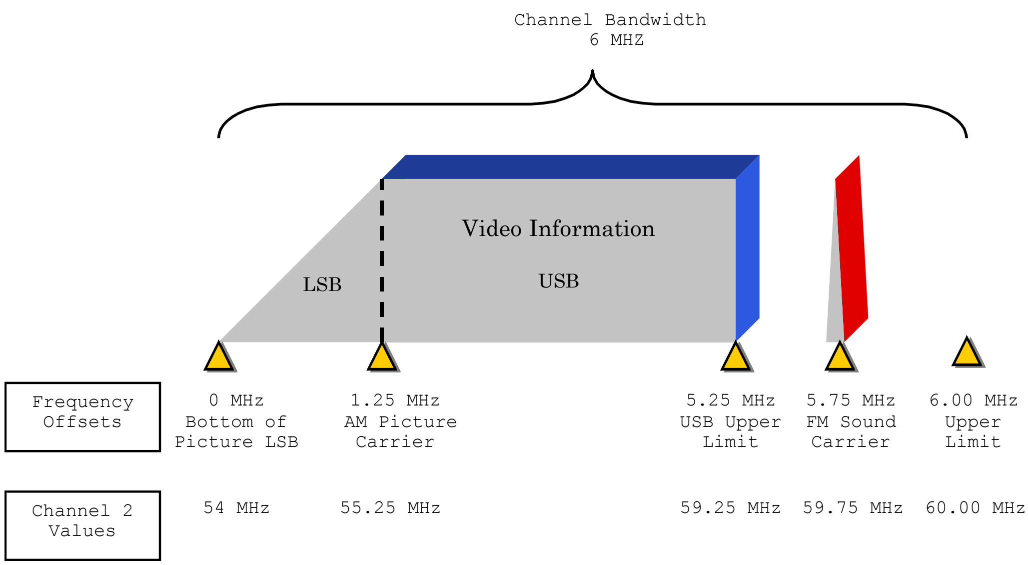

Figure 10-1: The Spectrum of an Analog Television Signal

Analog TV Transmission

The picture is sent using AM and the sound is sent with FM. The reason for this is simple: Using two different types of modulation reduces the chance that picture and sound will interfere with each other. In early television receivers (developed in the 1940s and 1950s), this was a real problem. Circuits had not yet been developed to separate closely spaced signals. Using AM and FM was the best technical solution available at the time.

TV broadcasts are *channelized*, just like AM and FM broadcasting. In Figure 10-1 the frequencies for channel 2 are shown; channel 2 uses the space between 54 and 60 MHz. That's a lot of bandwidth! The picture requires most of that bandwidth, because displaying moving images requires a lot of information to be sent. That translates into a large bandwidth.

The TV picture is sent using a special form of sideband emission called *vestigial sideband*, or *VSB*. You might recall that both the upper and lower sidebands of an AM signal contain identical information. The upper sideband of the picture carrier in Figure 10-1 uses a 4 MHz bandwidth (55.25 MHz to 59.25 MHz) by itself. If we transmitted the entire lower sideband, the picture alone would require 8 MHz of bandwidth! The TV transmitter uses a special filter to remove part of the lower sideband, which reduces the *video* bandwidth requirement.

The sound is transmitted on a second carrier, which is always 5.75 MHz above the bottom of the channel, or 4.5 MHz above the picture carrier. (This latter fact comes in handy when we analyze a TV receiver's operation.) FM is used, and the maximum deviation is limited to 25 kHz (compare with 75 kHz maximum deviation for broadcast FM in the 88-108 MHz band). The reduced deviation means that TV sound doesn't have quite the fidelity of an FM broadcast, but with proper receiver design, good reproduction can be obtained. Furthermore, many stations now transmit a stereo sound signal; the multiplexing technique is almost exactly the same as that used for broadcast FM stereo.

Bandplans

Table 10-1 shows the plan for the VHF and UHF television channels. Notice the wide range of frequencies that must be covered; this requires specialized antennas for receiving, and good circuit design throughout the TV tuner sections.

Channel Number	Base Channel Frequency, MHz
2	54
3	60
4	66
(Skipped)	(72-76 MHz)
5	76
6	82
7	174
8-13	180-216 MHz in 6 MHz steps
14	470 MHz
15	476 MHz
16-69	482-800 MHz in 6 MHz steps
[Old Channels] 70-83	806-884 MHz in 6 MHz steps

Table 10-1: VHF and UHF Television Bandplan for the United States

Notice that there are several skips in the channel plan. The first skip from 72 to 76 MHz is a frequency range allocated to licensed remote control and telemetry devices. The skip between channels 6 and 7 covers 88 to 174 MHz, which contains the FM broadcast band, as well as the VHF public service, military, aviation, commercial, and amateur radio bands. The UHF television channels, which are a later addition to the plan, start at channel 14, and originally went up to channel 83. In the 1980s the frequency range 806-890 MHz was reallocated for mobile radio and cellular telephone services, so on modern sets the highest UHF channel is now 69.

Digital Bandplans

Digital television service uses exactly the same channel plan. Each digital TV channel uses the same 6 MHz slot as was used for analog television. This allowed a smooth transition to the digital system, as inconsistent bandplans would make it difficult to manage the use of channels. DTV provides an interesting advantage - - because of data compression, each 6 MHz frequency slot can actually carry multiple sub-channels, each with different content. This why a DTV receiver can tune channel 9, 9.1, 9.2 and so forth. The ".1" portion designates a sub-channel. The broadcast station chooses the resolution and data rate for each sub-channel so that the aggregate total bit rate remains within the limit of 19.2 million bits per second (19.2 Mb/s).

Example 10-1

What is the percentage of modulation and information frequency for an analog FM sound carrier whose frequency swings between a minimum of 691.74 MHz (f_{min}) and a maximum of 691.76 MHz (f_{max}) 5,000 times a second?

Solution
The deviation must be calculated in order to find percentage of modulation. The carrier frequency is not given, but the min and max frequencies are. The carrier frequency lies exactly in the middle between f_{min} and f_{max}. Therefore, the deviation is:

$$\delta = \frac{f_{\max} - f_{\min}}{2} = \frac{691.76\ MHz - 691.74\ MHz}{2} = \underline{10\ kHz}$$

Now that the deviation is known, percentage of modulation can be calculated:

$$\%Mod = 100\%\left(\frac{\delta}{\delta_{\max}}\right) = 100\%\left(\frac{10KHz}{25KHz}\right) = \underline{\underline{40\%}}$$

The *information frequency* is equal to the *deviation rate* (DR), which is given as 5,000 cycles per second. Therefore:

$f_m = DR = \underline{\underline{5KHz}}$ By inspection.

Transmitted Power Levels

Most VHF television transmitters operated in the 15-25 kW power range, where the FCC had authorized a maximum effective isotropic radiated power (EIRP) of 100 kW. (EIRP is a measure of the effective transmitted power, and is controlled by the transmitter output power, and the design of the antenna. EIRP is covered in detail in the chapter on antennas.) UHF TV uses power levels about 4 times larger (60-100 kW), with a maximum allowed EIRP of 500 kW. The FM sound carrier power must be maintained at a level between 10% and 20% of the peak video (AM) transmitter power.

DTV transmitters operate at a maximum power of 1,000 kW (that's a million watts!) EIRP, though many operate at a level well below that. The broadcasters are required to deliver enough signal strength to cover the geographic area they're designated to serve, and each station ends up operating at an individually-assigned power level.

The power levels developed by television transmitters, both analog and digital, are tremendous. You might wonder why such power is necessary (and whether or not TV station employees glow in the dark when they go home at night). The answer to this question comes from examining the *bandwidth* required by a TV signal. Because a TV signal uses such a wide bandwidth when compared to conventional AM and FM voice transmission, more power must be applied to overcome the various external and internal noise sources in the receiver's signal path. All other things being equal, noise power is always proportional to bandwidth.

Example 10-2

What range of frequencies may be transmitted by a DTV station on channel 41? What would the picture and sound carrier frequencies be for an analog transmitter on the same channel?

Solution
According to Table 10-1, channels 14 to 69 are spaced in 6 MHz steps beginning at 470 MHz.

Therefore, the beginning of channel space for 41 is (41-14)*6 MHz away from 470 MHz, or 632 MHz, and the end of the channel is at (632+6) MHz or 638 MHz. The range of frequencies the DTV transmitter may use is 632 to 638 MHz.

To calculate the analog picture carrier frequency, add 1.25 MHz to the channel base frequency of 632 MHz:

$$f_{c(pict)} = f_{ch} + 1.25MHz = \underline{\underline{633.25MHz}}$$

To get the sound carrier frequency, add 5.75 MHz:

$$f_{c(pict)} = f_{ch} + 5.75MHz = \underline{\underline{637.75MHz}}$$

A scanning receiver with wideband FM receive capability can receive the sound from an analog TV station. If you tune the receiver to 637.75 MHz and set it for WBFM reception, you should clearly hear the channel 41 sound.

It is not possible for a conventional receiver (AM or FM) to decode the sound or picture for a DTV transmission; the DTV signal sounds like "noise" interspersed with a buzzing sound in an analog receiver. The "noise" is actually the encoded digital data signal.

An Analog Television Transmitter

The block diagram of a typical analog TV transmitter is shown in Figure 10-2. Notice how it is really two transmitters in one.

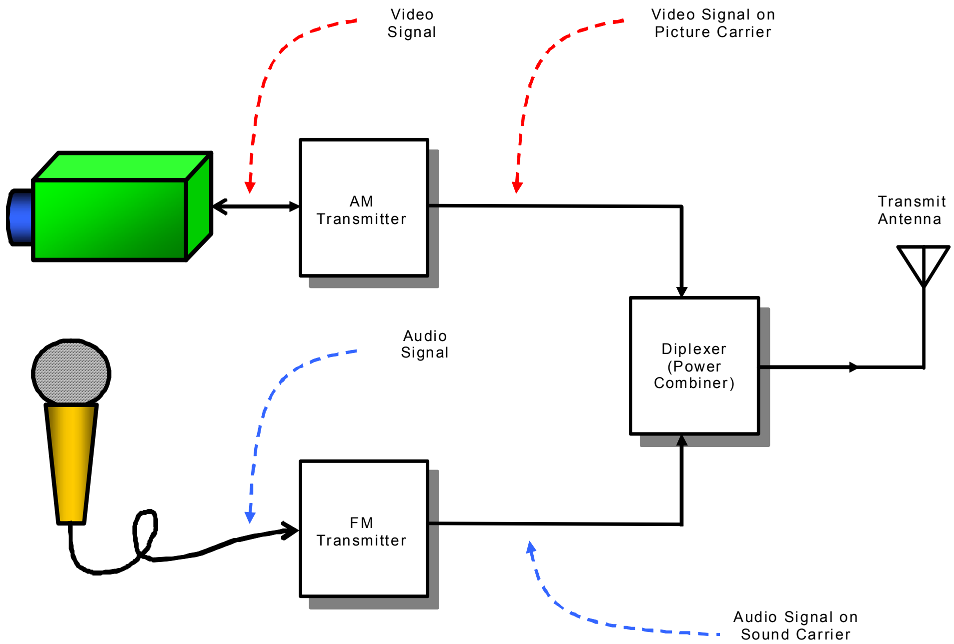

Figure 10-2: An Analog Television Transmitter

The AM transmitter in the figure generates the *VSB* AM modulated picture carrier; the FM transmitter produces and modulates the sound carrier. The picture and sound carrier signals are combined in a special circuit called a *diplexer*. The diplexer allows the AM and FM signal components to flow to the antenna but prevents any signal from flowing between the two transmitters. The two transmitters are essentially isolated from each other. If the diplexer were not used, energy would attempt to flow from one transmitter's output into the other, which not only would waste considerable energy, but would likely result in the release of smoke (think transmitter tug-of-war!). The diplexer is a special filter built from *transmission line* sections. Transmission lines are the subject of a later chapter.

Section Checkpoint

10-1 What circuit technologies are found in TV receivers?
10-2 Why are two different carriers used in analog TV?
10-3 What type of sideband emission carries the picture information?
10-4 Why is VSB used for the television picture in analog TV?
10-5 How much deviation constitutes 100% modulation of the sound carrier in analog TV?
10-6 In the US bandplan, how much frequency space is used for each TV channel?
10-7 Why does the bandplan "skip" between channels 6 and 7?
10-8 Why don't new TV sets receive channels 70 to 83?
10-9 What are typical peak transmit power levels for VHF and UHF TV transmitters?
10-10 What is the purpose of a *diplexer* circuit?
10-11 How are a computer and DTV receiver similar?
10-12 Why do analog and digital TV systems employ the same bandplan in the US?

10-2 The Analog Video Signal

The video signal is perhaps the most complex and misunderstood portion of the analog television system. This complexity is due, in part, to the fact that color was introduced after millions of sets were in use, and therefore, a color TV signal must be compatible with black and white receivers. This is similar to the problem that arose with FM stereo broadcasting.

The color television standard in the United States is called *NTSC*, which was developed in 1953 by the national television system committee. Other countries use different systems; for example, you may run across systems designed for *PAL* (Phase Alternation Line), which is used in the mainly in the United Kingdom and Germany, or *SECAM* (Sequential Couleur Avec Memoire), which is used primarily in France. Once you've learned the details of one system, the others can be rapidly learned.

Although analog video signals are no longer transmitted, we can learn much by studying how they work; in particular, NTSC video signals are still commonly employed to carry low-resolution video in applications such as security systems, industrial automation, and other applications. The NTSC standard is also described by the Electronic Industries Association of America (EIA) standard RS-170A; you may see video described as "RS170A"; this the same thing as the NTSC standard.

Motion Picture Principles

Television uses the same method as motion pictures for transmitting animated images. A movie consists of a rapidly displayed sequence of still images, each taken at a consecutive point in time. If the images are presented rapidly enough, persistence of vision causes the individual frames to fuse together into a moving picture.

The trick in generating convincing motion is to present images rapidly enough to prevent the viewer from perceiving *flicker*. For example, in commercial motion pictures, there are 24 frames for each second of film. The rate of 24 fps (frames per second) is not quite fast enough to prevent the sensation of flickering (especially near the periphery of human vision), so the movie projector rapidly projects each frame of the film *twice* in succession (producing for the eye 48 images per second). This eliminates the sensation of flickering, while conserving the amount of film needed to produce a show.

Analog television uses a process called *scanning* to collect the information from a scene. In the NTSC system, there are 29.97 complete *frames* (analogous to the frames of a movie) transmitted every second. This rate is too slow to prevent the perception of flicker, so each frame is transmitted twice as a set of *fields*. There are two interlaced fields for each transmitted frame, so the eye sees a total of (2)(29.97) fields per second, or 59.94 fields per second, which is high enough to prevent the sensation of flicker.

Scanning the TV Picture

To gather information from a scene, a system of *scanning* is employed, as shown in Figure 10-3. Although vacuum tubes are no longer used in television, it's a little easier to visualize what's happening by looking at how they work.

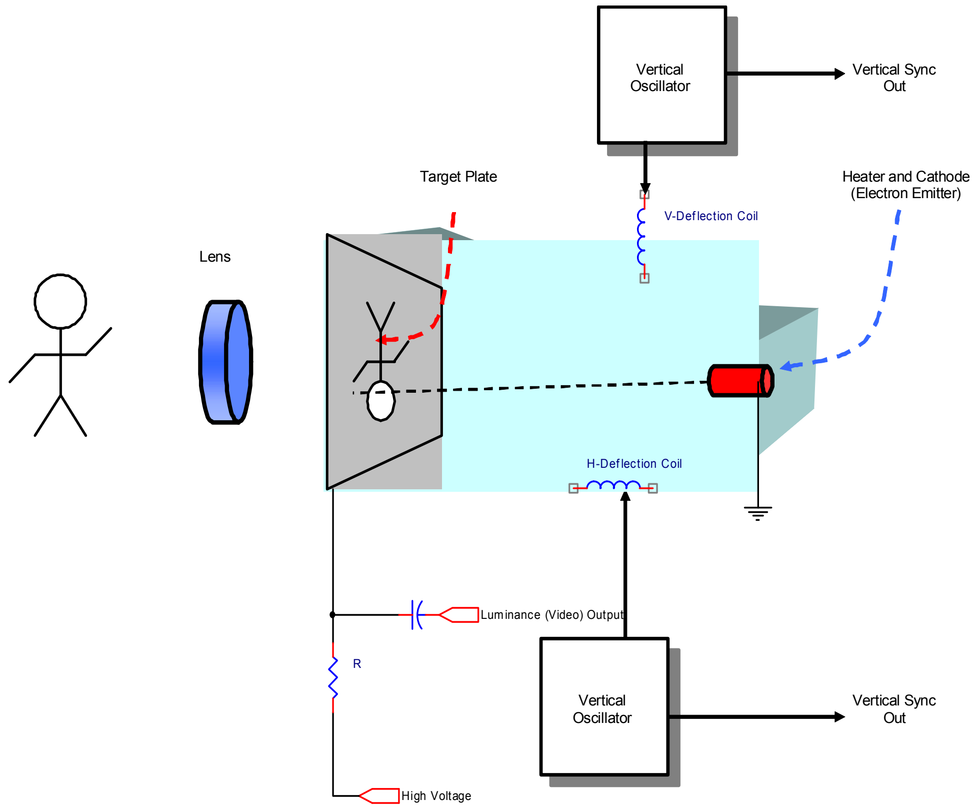

Figure 10-3: Scanning a Scene with an Ancient Tube Camera

The camera tube of Figure 10-3 is really a modified vacuum tube. It has a *heater* that heats the *cathode*, which is coated with a substance that emits electrons when heated. The cathode produces a stream of electrons, which are accelerated toward the *target plate*. The electron beam is made to scan the target by the use of two oscillators (horizontal and vertical) and two deflection coils. The scanning follows the same path your eyes are following as they read this page. It starts in the upper left, scans horizontally to the right, then rapidly returns to the left (the *horizontal retrace*) and scans the next line down. The process is repeated until the entire scene has been scanned, then the electron beam rapidly moves from the bottom up to the top (the *vertical retrace*) to scan the scene again.

The target plate is coated with a mosaic of photoresistive material. *Photoresistive* materials change their electrical resistance when light strikes them. When the electron beam strikes the target, it charges it. If light is striking the material at that point, the resistance to current flow from the electron beam decreases, and the resulting voltage drop across the load resistor *R* increases. If light is not striking the material, its resistance increases, and as a result, the current through the load resistor *R* decreases, resulting in a decrease in voltage. The resulting output voltage variations mirror the dark and light areas of the scene, as shown in Figure 10-4.

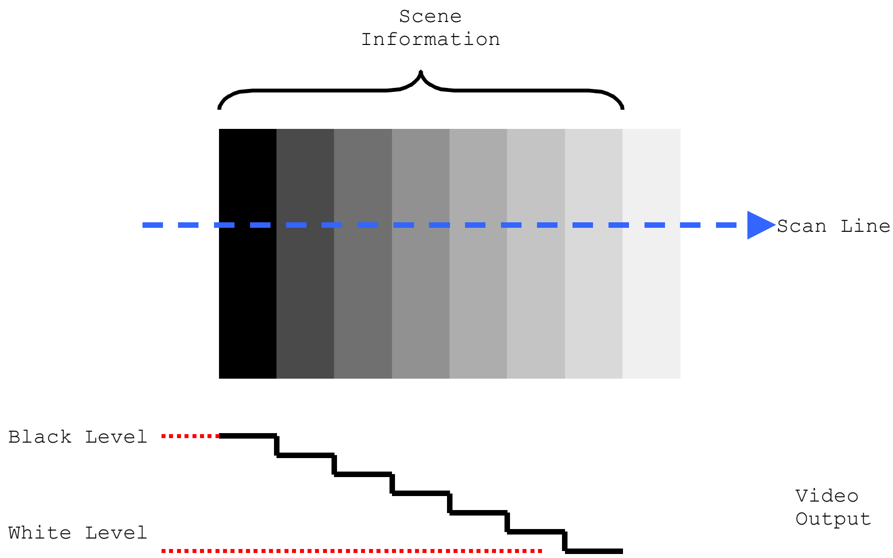

Figure 10-4: Camera Output Voltage versus Scene Brightness

Voltage Represents Brightness

It's important to note that for analog video, black represents a higher voltage and consequently, power level required from the transmitter. This was a deliberate design decision; since most scenes are lighted, it takes less power on average to transmit the analog TV picture this way.

In the NTSC system, a complete TV picture *frame* has 525 lines, and is completely scanned 29.97 times every second. There are therefore (525 lines / frame) (29.97 frames/sec) or 15,734 lines scanned per second. This also means that each frame is scanned in 33.37 ms, and that each horizontal scan line lasts for 63.5 µs. This system uses an *interlaced* scanning method, as shown in Figure 10-5.

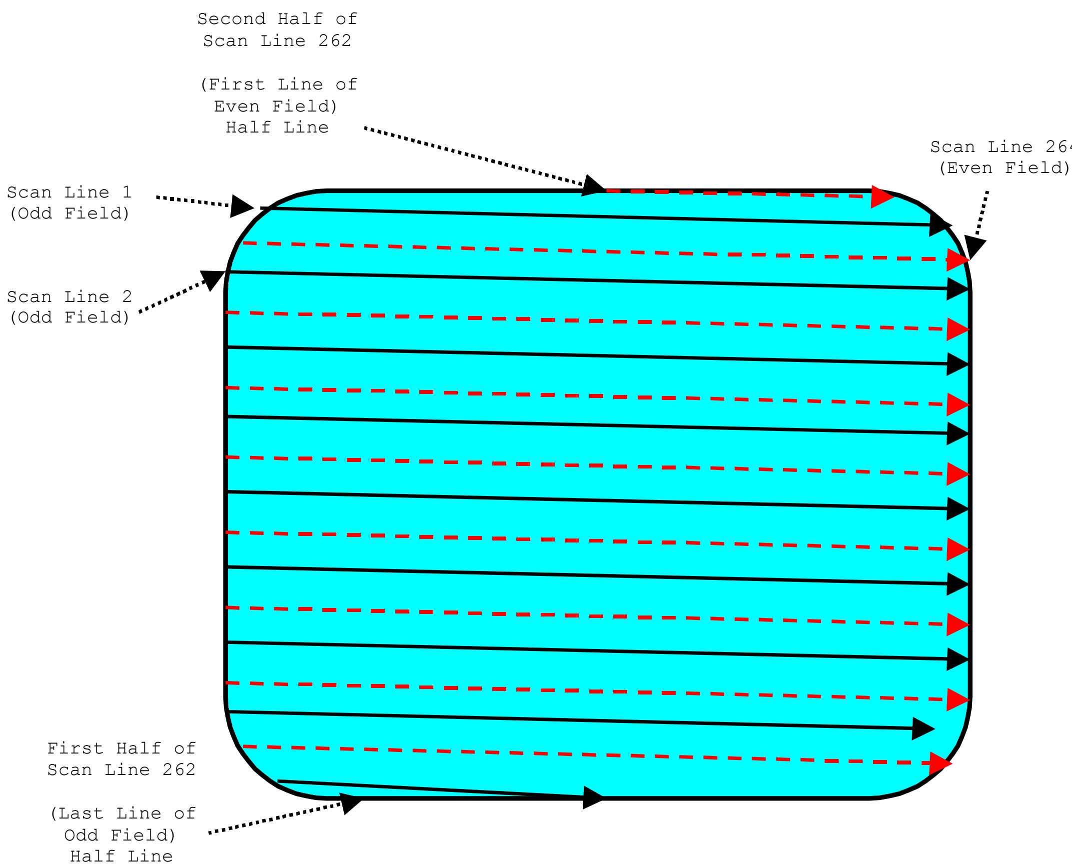

Figure 10-5: Interlaced Scanning in Analog Television (NTSC System)

Interlaced scanning is used to eliminate the perception of flicker. Recall that each frame is scanned and displayed twice as two *fields* for the viewer. Since there are 525 horizontal scan lines in a frame, there are 262 1/2 horizontal lines in each field. Each frame of video consists of an *odd* and an *even* field. The *odd* field scans the first line, the third line, and so on; the *even* field immediately follows, and scans the remaining lines. This can be a little confusing, so it's important to remember that each *frame* is equivalent to one frame of a motion picture, and each frame contains two *fields*. These two fields are very similar in content, and share about 30% of their information.

Notice that the even and odd video fields have one peculiar characteristic that differentiates them. The last (bottom) scan line of the odd field is only a half-line; the first scan line of the even field is only a half-line also, and starts in the middle. A receiver can therefore detect which field is which by looking at this timing information. Typically, a short horizontal sync interval ("half-line") followed by a vertical sync pulse signals the *beginning* of the even field.

Solid State Imaging Devices

A modern video camera uses a CCD (charge coupled device) or MOS (metal oxide semiconductor) imager as shown in Figure 10-6(a). These imagers are practically identical to those in digital cameras. A CCD imager consists of a rectangular matrix or array of photosensitive sites fabricated on a silicon "die" (a section of a silicon wafer). Each of these sites has a diode junction (which is reverse-biased) and a small capacitance. The operation is quite straightforward. The CCD is placed behind a lens so that it receives incoming light from the scene to be photographed. A control circuit located on the CCD chip is commanded to charge up all the capacitors in the first (top) row of the array. All the cells in the row therefore start at the same voltage. Light striking the array causes a current to be drawn through the reverse-biased diodes at each photosite. The brighter the light, the higher the discharge current, and the lower the voltage falls at that particular pixel location. After a small amount of time is allowed to pass, the voltages of the "capacitors" at each of the sites are read out (again by giving the CCD chip a command) as shown in Figure 10-6(b). These voltages represent the dark and light values for one horizontal scan line of the scene. The process is repeated for each row in the CCD imager's array until the entire scene has been scanned. In order to keep the signals compatible with NTSC standards, CCD imagers for television may be scanned at the same frequency (15.75 kHz, or 63.5 μs/line) as vacuum tube imagers, or higher (with computer signal processing.)

CCD imagers have many advantages over vacuum tubes. They're much more rugged, use only a fraction of the power, and take up a lot less space. They also don't need high voltage supplies. All of these are tremendous advantages. Color CCD imagers are also common; color is detected by fabricating a color filter array (consisting of microlenses) on top of the CCD chip. The color filter array usually employs a Bayer pattern as shown in Table 10-2.

R	G	R	G	R	G	R	G
G	B	G	B	G	B	G	B
R	G	R	G	R	G	R	G
G	B	G	B	G	B	G	B

Table 10-2: Bayer Pattern for CCDs

To recover the color information from a Bayer-filtered CCD requires an additional circuit called a *color encoder*. The color encoder chip mathematically converts the color values formed by the adjacent cells surrounding each photosite to approximate the hue and saturation of the pixel. Note that most of the pixels in the Bayer array are green; this is because the human eye sees the best detail under green light, and is also most sensitive to green.

A modern imaging chip does not output an analog voltage like the old tube camera; instead, an analog-to-digital converter on the chip converts the read-out cell voltages to binary numbers, each of which represents the brightness of a point in the scene. A digital signal processor directly works with the sequence of binary numbers to represent the data in the scene. The color encoding function is typically incorporated either into the imaging chip, or the companion chipset, eliminated the need for additional circuitry.

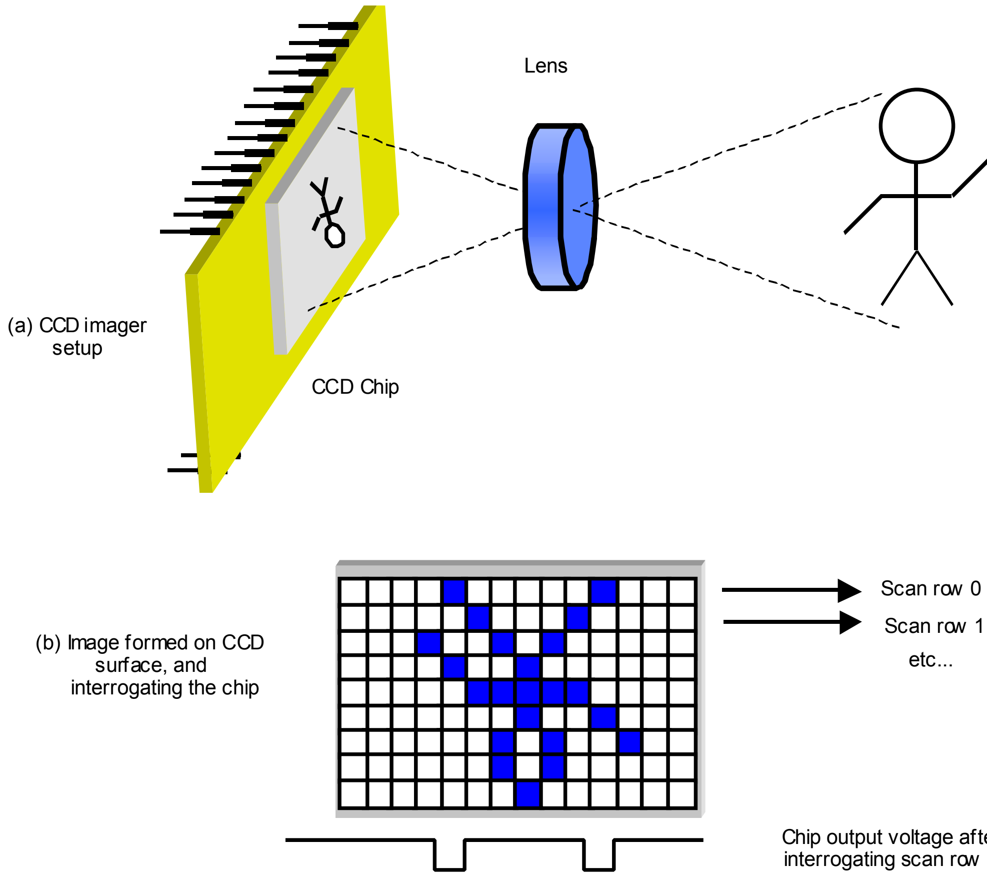

Figure 10-6: CCD Imager Operation

Synchronizing the Receiver

In order for a legible picture to be displayed on a receiver, the horizontal and vertical scanning of the receiver's picture tube must exactly match the scanning pattern from the transmitter. In other words, the scanning in the receiver must be *synchronized* to that of the transmitter. Vertical and horizontal *synchronization pulses* are added to the video signal as it leaves the camera for this purpose. Figure 10-7 shows a portion of video signal with the horizontal synchronization pulses added.

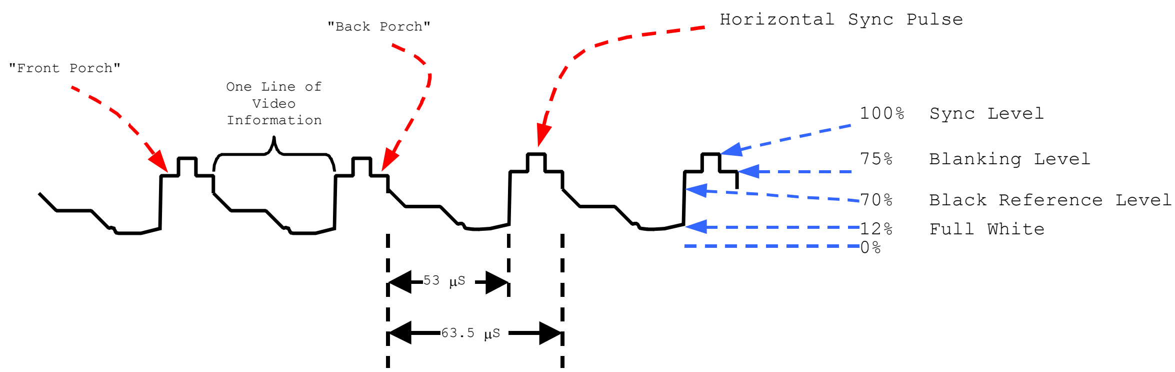

Figure 10-7: Analog Video with Horizontal Synchronization Pulses

In a video signal, different voltage levels are used to represent the lightness or darkness of parts of a scene. In addition, other voltage levels represent the *synchronization* information, as shown in Figure 10-7. The percentage levels in the figure are voltage percentages, with respect to the peak video voltage, which is nominally 1 volt. (A standard video signal has a maximum positive value of 1 volt, and a minimum close to 0 volts; it is therefore close to 1 Vpp. It rides on a DC level.) The *black level*, which is 70%, represents the darkest possible area in a scene, while the *white level*, 12 %, is the brightest possible level. Notice how the white level is a *lower* voltage, which corresponds to less transmitted power. This is used to conserve transmitter energy, since most scenes consist of light picture areas. The carrier is never allowed to reach zero amplitude, for that would result in poor noise rejection at the receiver.

The *blanking level*, 75 %, represents the "blacker than black" condition. In a receiver, it is necessary to turn off or *blank* the electron beam during retrace (when the beam is sweeping back to the left side, or from the bottom back to the top). At the end of each horizontal scan line, the voltage rises up to this level, where the receiver's electron gun is guaranteed to be shut off. The electron gun must be turned off to prevent a *retrace* line from being drawn as the beam is rapidly swept right-to-left in preparation for the next scan line.

The *sync level,* also known as the *peak pulse level*, is the highest positive voltage possible. Two types of synchronization are transmitted: *horizontal* and *vertical*. The horizontal sync pulse occurs at the end of each horizontal scan line, and is used to synchronize the horizontal sweep oscillator in the receiver to the horizontal sweep of the transmitter. Since there are 15,734 horizontal lines scanned per second, the frequency of the horizontal sync pulses is 15.734 kHz.

The *vertical* synchronization pulse is sent at the end of every *field*; therefore, the frequency of the vertical sync is 59.94 Hz. The vertical synchronization is also sent at the 100% (peak) level. To see the vertical sync pulses, more waveform must be examined, as in Figure 10-8.

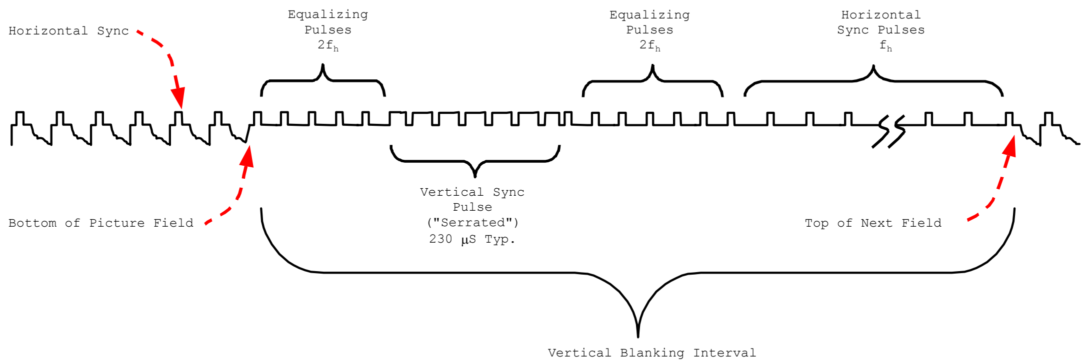

Figure 10-8: Slowing the Timebase Shows the Vertical Sync Pulse

At the end of a frame, the electron beam must be made to move from the bottom of the picture tube to the top. During this time, the electron beam in the receiver must be turned off to prevent a visible upward streak in the picture. This time period is called the *vertical blanking interval*. A vertical synchronization pulse is sent during this time. The vertical synchronization pulse occurs about three horizontal periods after the end of the frame. In order to keep the receiver's horizontal oscillator from dropping out of synchronization during the vertical sync interval, *equalizing pulses* are sent. The equalizing pulses are at *twice* the horizontal frequency. About six equalizing pulses are sent, then the vertical sync pulse is sent (which is "serrated" by six or seven additional horizontal pulses), then finally six more normal horizontal equalizing pulses are sent. For the remainder of the vertical blanking period, normal horizontal sync pulses are sent, to ensure that the horizontal oscillator in the receiver is still locked to the transmitter.

You might wonder how the two sync pulses (vertical and horizontal) can share the same voltage -- how can the receiver separate them? The reason this works is that the sync pulses are at two different and widely-spaced frequencies. A receiver extracts the vertical sync with a low-pass filter (sometimes called an *integrator*), and the horizontal sync is extracted with (you guessed it), a high-pass filter, or *differentiator*. Another way of saying this is that *frequency division multiplexing* is used for the horizontal and vertical synchronization signals.

Resolution and Bandwidth

Resolution is the ability of a television system to display or *resolve* small details in a picture. It is measured as the maximum number of *lines* that can be displayed horizontally or vertically. Compared to even the most inexpensive digital camera or camcorder, the resolution of analog NTSC video is extremely low!

The *vertical resolution* of an NTSC analog television signal is around 340 lines. This is considerably less than the 525 lines available in a frame. How did we lose 185 lines? A TV set is only designed to display about 485 of the 525 available lines. Forty of the lines are used during the interval between fields called the *vertical blanking interval*. (Twenty lines are lost during the vertical blanking interval for each *field*, and there are two fields per frame; see Figure 10-5). During this time, the electron beam is sweeping back to the top of the video display in preparation for painting the next field on the screen. It takes time for the vertical oscillator to move the electron beam back up to the top of the screen. Furthermore, about 30% of the information in the remaining 485 scan lines is redundant or *duplicate* information. This means that the vertical resolution is closer to 70% of 485, or about 340 vertical lines.

The *horizontal resolution* of a NTSC signal can be calculated by examining the details of one horizontal scan line from Figure 10-7. One horizontal scan line takes 63.5 µs to complete, but only 53 µs is actually available for transmitting picture information (the rest is required for transmitting the horizontal sync and blanking pulse).

The "lines" of resolution in television work are counted as consecutive vertical white and black lines, which alternate. One sine wave cycle could therefore represent a white line at its negative tip, and a black line at the positive peak. Each sine wave cycle therefore represents two lines of resolution. If we know the available bandwidth, this will give us the maximum sine wave video frequency; and knowing this, we can figure out how many of the sine wave cycles will "fit" into the 53 μs time slot. Multiplying this number by two (there are two lines per sine wave cycle) will give the video resolution. This can be expressed as:

(10-1) $$HR = BW \times T_{horiz} \times 2$$

Where HR is the horizontal resolution, in lines, BW is the available bandwidth, and T_{horiz} is the amount of horizontal time available.

Example 10-3

Calculate:
a) The theoretical horizontal resolution for an NTSC video signal, given that the FCC limit for bandwidth is 4.2 MHz
b) The resolution that would result if 6 MHz of bandwidth were available

Solution
By using equation 10-1, we get:

$$HR = BW \times T_{horiz} \times 2 = (4.2MHz)(53\mu s)(2) = \underline{\underline{445\ Lines}}$$

Increasing the bandwidth increases the number of lines in a proportional manner:

$$HR = BW \times T_{horiz} \times 2 = (6MHz)(53\mu s)(2) = \underline{\underline{636\ Lines}}$$

Equation 10-1 yields results that are fairly generous; in real life, the horizontal resolution of an NTSC receiver is around 320 lines, instead of 445 lines. There are two reasons for this. First, generating two crisp adjacent lines on video display requires a *non-sinusoidal* signal shape, which has more bandwidth than a pure sine wave; second, the addition of the *color* or *chrominance* signal reduces the available bandwidth.

Section Checkpoint

10-13 How is flicker prevented in motion pictures?
10-14 Explain how a television picture is scanned.
10-15 What is the difference between a *field* and a *frame*?
10-16 How many frames are sent per second in NTSC video?
10-17 How does a video camera tube convert light in a scene into a varying voltage?
10-18 How does interlaced scanning work?
10-19 What is unique about the odd and even fields in a video signal?
10-20 What is added to the video signal to keep the receiver scanning in step with that of the transmitter?
10-21 Why is *blanking* needed during vertical and horizontal retrace?
10-22 What types of circuits can be used to isolate vertical and horizontal sync in a receiver?
10-23 What factors control the *vertical resolution* of a video signal such as NTSC?
10-24 What factors control the *horizontal resolution* of a video signal (see Equation 10-1).

10-3 Analog TV Receiver Operation

A television receiver is a collection of subsystems that in essence, have the task of converting the RF signal from the antenna back into picture and sound. In order to do this, three tasks must be accomplished. First, the appropriate carrier signal must be selected and amplified; second, the picture and sound carriers must be demodulated; and last, the recovered picture and sound information signals must be appropriately processed. The sound is fed to an audio amplifier and loudspeaker, just as in radio; the recovered picture information is a *video* signal, and must be disassembled into its component parts to be useful.

TV receivers use the same superheterodyne approach as AM and FM broadcast receivers, with two major differences. First, the IF frequency of a TV receiver is usually about 45 MHz, due to the large bandwidth (6 MHz) of a broadcast TV signal. Second, because the picture information is on an AM carrier, automatic gain control (AGC) is an absolute necessity - but because a video signal has a wide range of values, an averaging AGC can't be used. TV uses *keyed AGC*, which will be discussed in detail. Figure 10-9 is a simplified block diagram of a monochrome (black and white) receiver.

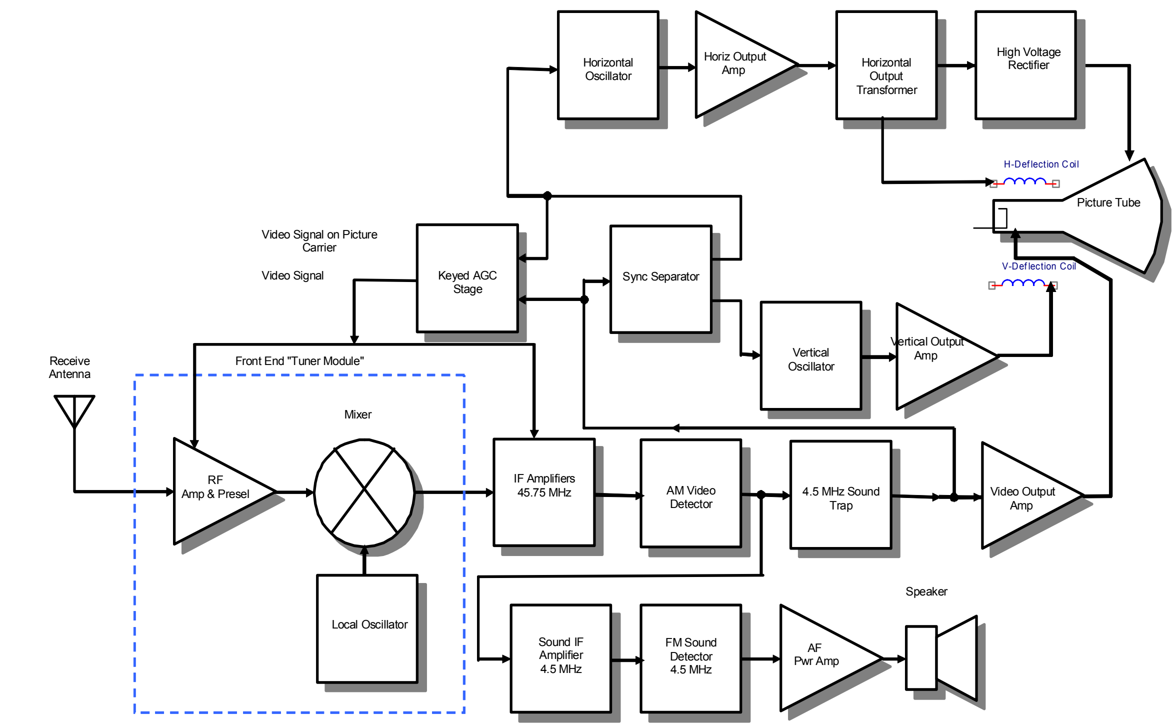

Figure 10-9: A Black and White TV Receiver Using a Picture Tube

RF Stages

The RF section of a television receiver is very similar to that of any other superheterodyne receiver. The incoming carrier signal from the antenna passes into an RF amplifier, then into a frequency converter for translation down to the IF frequency. The RF amplifier and frequency converter stages are usually contained in a complete "tuner module" that is sealed within in a metal box. The tuner module usually accepts a *control voltage* (not shown) to select the channel, and may also provide a buffered *local oscillator output* for use with a frequency synthesizer loop (and microprocessor control). The tuner