

## Chapter 2 Video

Pictures can be sent through communications systems in various ways, but the most common means today are fax machines and television. So let's talk about those.

### Fax Machines

Thirty years ago, fax machines were very rare — although not entirely unknown. Today, almost every office has at least one fax machine.

Today's fax machine can send letters, pictures, cartoons, photos, and almost anything that you can feed through its slot. Shown in Fig. 2-1, the typical machine consists of five parts: (1) a scanner which can scan a printed page and convert it into an electrical signal, (2) a printer which can take such an electrical signal and print it on paper, (3) a telephone and dial which is used to call other machines, (4) a modem which couples the digital circuitry to the telephone line, and (5) a microprocessor which ties it all together and makes it work.

Since the fax machine contains both a scanner and a printer, it can usually be used as a copier — it can scan one piece of paper, and at the same time print a copy of it in the printer. But that's a secondary function — its main purpose is to transmit that page through the phone to another machine.

To begin the process, you insert the page you want to send into a slot on the fax machine (the slot is on top of the machine shown in the figure), pick up the handset and dial the number of the machine you want to reach, and wait for the call to go through.

When the called machine answers, it sends back some tones whose purpose is to let your machine know that the connection has been made. When you hear these, you generally press a START button, hang up the handset, and wait for the call to finish.

Let's skip ahead to this point, and look at how your fax machine scans the page you want to send. Fig. 2-2

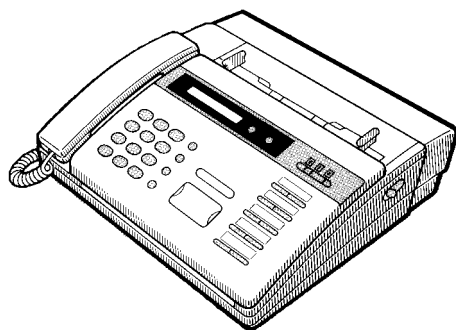


Fig. 2-1. A typical fax machine

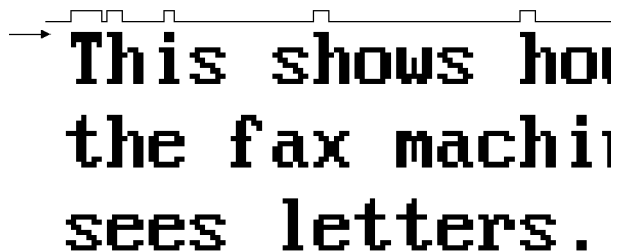


Fig. 2-2. Enlarged view of some text being sent

shows an enlarged view of some typewritten text that we want to send.

When you push the START button, a photosensitive scanner head starts to sweep across your page, from left to right, starting at the upper left corner. The small arrow at the top left of Fig. 2-2 shows where it starts and the direction it moves in. It never sees your entire text; it only sees the narrow area of white and black that it passes over. It only sees the tops of the letters **Th** and the top of the dot over the **i** (as well as the tops of the two **n**'s further on the right), since all the other letters are shorter. As it scans from left to right, it sees the dark areas shown in Fig. 2-3.



Fig. 2-3. What the fax scanner sees

This is an important concept to understand — the fax machine doesn't actually try to read the letters themselves. It only looks at the patterns of white and black. In other words, your page could contain English, Chinese, or Russian letters, drawings, or chicken scratchings. Only the patterns of light and dark are sent.

As the scanner goes across the page, it outputs a waveform like that shown at the top of Fig. 2-2. This is a digital signal which shows a low value of voltage when the scanner is passing over white paper, and a higher voltage when it passes over black ink. Although more expensive fax machines can handle grays, the typical inexpensive fax machine doesn't sense differences in grays — if a gray is light it is treated as if it is white, and if it is dark then it is assumed to be black.

As the scanner head is moving right, its output is sent to the microprocessor as a digital signal. When the head reaches the right margin, the microprocessor goes to work; meanwhile the head returns back to the left and the paper moves up about 0.01 inch. Eventually (after the microprocessor has finished processing this signal,) the head will start another sweep across the page, but this time about 0.01 inch lower down on the paper. It

will then scan another strip of text, and so on, until it eventually reaches the bottom of the page. In this way, the 11-inch height of the paper is divided into slightly under 1100 strips, each about  $\frac{1}{98}$  of an inch high (that's about 0.01 inch), and each strip is scanned for light and dark areas across the width of the paper. (Let's be exact here: in so-called standard mode, there are 98 strips per inch; in fine mode, used for more detailed documents, there are 196 strips per inch.)

But let's return to the microprocessor, which gets the signal shown at the top of Fig. 2-2. This signal has only two voltage levels (assuming we're dealing with an inexpensive black-and-white fax machine.) A digital signal like this can't be directly sent through the telephone line; besides, it would be inefficient to do so. And so the microprocessor analyzes the signal and sends a *description* of the signal, rather than the signal itself.

The microprocessor measures distance on the paper in *pixels* rather than inches; each pixel is  $\frac{1}{203}$  or about 0.005 inch. The word pixel is an abbreviation for *picture element*; it is the smallest spot that the fax machine can see or print. If you look at the printout in Fig. 2-2, you will see that the letters look as though they are made out of square blocks; these are the pixels. The 8.5-inch width of the paper is therefore a bit over 1700 pixels wide.

As the microprocessor receives the signal from the scanner head, it counts off the number of pixels of white and black, and generates a description of the signal in terms of pixels. For example, if it sees an entirely blank sheet of paper, it simply sends a message to the other machine that there are 1700 white pixels. On the other hand, if there is a lot of printing on that line, the description might read

10 white pixels,  
black pixel, black pixel, black pixel  
17 white pixels,  
black pixel, black pixel, black pixel, black pixel,  
12 white pixels,  
etc.

You can see that the description of a blank page is a lot shorter than the description of a page with a lot of print. Information about white pixels gets very compressed, whereas each black pixel is described individually. Hence the time it takes to send a page depends on how much writing is on it. A white page might feed through in 10 or 15 seconds; an average letter might take 30 seconds; a page with a lot of black might take two or more minutes. You can notice the difference as you watch the machine send or receive a page. Blank or nearly blank pages feed through at a speedy clip; complex pages feed through in tiny spurts.

The advantage of sending descriptions rather than the actual waveform is that *for an average page* this takes less time than sending the actual waveform would.

At this point, it doesn't pay to delve much deeper into the fax machine, since our primary purpose in discussing fax machines is to lead into a discussion of TV; let's just say that the description coming out of the microprocessor is itself a digital message. Since the telephone line is not able to carry digital data directly, a *modem* converts the digital data into tones which are then transmitted through the line. The word modem stands for *modulator/demodulator*, the device which converts (modulates) data to tones on one end, and then changes (demodulates) the tones back to digital data at the other end.

Before moving on to TV, let's summarize: the fax machine divides the printed page into horizontal strips about 0.01 inch high (and therefore about 1100 strips per 11-inch page), and scans each strip from left to right. The black/white info from each strip is sent from the sending machine to the receiving machine, but as a description rather than as the data itself. It takes anywhere from 10 seconds to perhaps 2 minutes to send a page, depending on its complexity, which means that the time to send the information for one strip takes anywhere from  $\frac{10}{1100}$  second (about 0.01 second) for a near-blank page in standard mode, up to about  $\frac{120}{2200}$  second (about 0.06 second) for a fairly complicated page in fine mode. In terms of what we learned about bandwidth in Part 1, it takes a fairly long time to send the picture and therefore not much bandwidth is needed.

## Television

Let's summarize normal TV in terms similar to what we just did for fax machines. The TV camera divides a picture into 525 nearly-horizontal strips (the height of the strip depends on the size of your TV screen), and scans each from left to right. The information, which includes not just black and white but also greys and colors, is sent as the actual waveform, not as a description. Regardless of how complex, light, or dark the picture is, it takes the same  $\frac{1}{30}$ -th of a second to send that waveform. Furthermore, in order to provide the feeling of motion, the TV camera sends 30 complete pictures per second. As you can guess, the bandwidth for a TV signal must be much higher than that of the fax signal.

Let's look first at what the TV camera does. Fig. 2-3 shows how a lens focuses an image of a person onto a photosensitive plate inside the camera. In studio cameras, that photosensitive plate is inside a vacuum tube called an *iconoscope*; older home cameras used *vidicons*; the latest home cameras use charge-coupled-de-

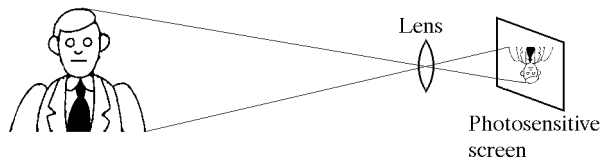


Fig. 2-4. A simplified black-and-white TV camera

vices (CCDs). Either way, the photosensitive screen gets an upside-down image of whatever the camera is pointed at. This image is then split into strips and scanned.

In an iconoscope or vidicon, that scanning is done by a thin electron beam, which is aimed at the screen; in the CCD, the screen is itself divided into tiny spots, each of which can measure the amount of light hitting it, and electronic circuitry then interrogates each spot to see how much light it got. Since the studio cameras use iconoscopes, I will talk about the beam as doing the scanning.

As in the fax machine, scanning is done from left to right, and top to bottom of the picture. But since the picture in the TV camera is upside down, in the camera it starts at the bottom right, and goes from right to left, and bottom to top, as shown in Fig. 2-5.

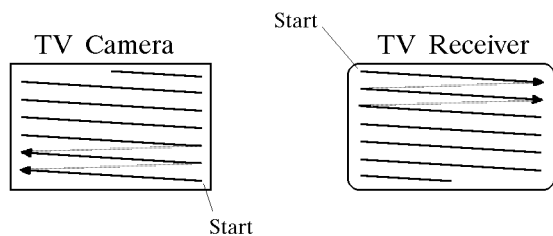


Fig. 2-5. Scanning in the camera and receiver

You'll note that, unlike in the fax machine, the strips in the TV camera are not exactly horizontal. There is a very slight tilt to them, because as the scanning goes from side to side, it is also moving upward, although much slower. You can also see a thin line, called a *retrace* line, which shows how the beam jumps from the end of one line to the beginning of the next.

Fig. 2-5 also shows the beam as it moves in the picture tube in your home TV receiver. Here again, you will note that there is a slight tilt to the lines, but here the scanning starts at the top left, and so the beam moves slightly down as it moves right. What is impressive about the whole setup is that the beam in the camera is exactly synchronized with the beam in not just your TV set, but also the beam in every single other set that is tuned to the same station. At the exact instant that the beam is at the bottom right corner of the camera screen,

it is at the top left corner of possibly millions of TV sets around the country. This must be so to make sure that an item in any particular spot of the picture shows up in the corresponding spot on every TV set's screen!

Let's return to Fig. 2-5. The correct name for what we have been calling strips is actually *scan lines* or *sweep lines*. We mentioned earlier that there are 525 strips in the picture, while Fig. 2-5 shows only 6½ lines. What actually happens is that the 525-line picture (also called a frame, like a frame of movie film) is divided into two 262½-line fields. The first field of each frame ends on a half-line at the bottom, while the second field of that frame begins with a half-line at the top. This is shown in Fig. 2-6, though we obviously don't have the space to show all the lines.

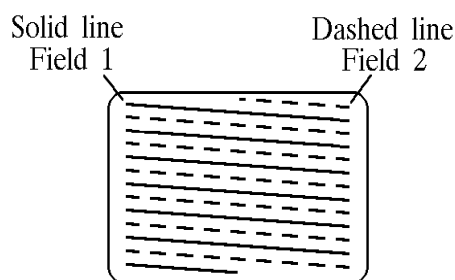


Fig. 2-6. Two fields make a frame

You will note how neatly the lines of field 2 fit between those of field 1. This process is called *interlacing*, so that a normal TV picture is said to be *interlaced*.

To understand why interlacing is needed, let's consider movie film. In order to show motion on the screen, the movie projector projects a series of slightly-different frames on the screen, at the rate of 24 frames per second. But if the projector lit up the screen just 24 times each second, most of us would be badly annoyed by the flicker. So the projector actually puts each frame on the screen twice, for a total of 48 "flashes" per second.

TV has a similar problem. It transmits 30 complete frames per second, but to avoid flicker has to light up the screen more often than that. It is not really practical to flash each frame on the screen twice, because then either the TV transmitter would have to send each frame twice (which would require more bandwidth) or else the TV set would have to store each frame in an internal memory so it could display it a second time (which wasn't practical decades ago when TV was designed.) So television was designed to transmit each frame in two halves — the two fields, with 60 fields per second.

Note that storage of frames was not practical years ago, but the prices of memory circuits have dropped to the point where it now is. Most computer monitors

(which work on the same principles as a TV set) therefore do not use interlacing.

So let's put some of the numbers back together:

- There are 30 frames per second. (In a color picture, there are 29.97 frames per second, or 0.1% less.)
- There are 60 fields per second (or 59.94 fields per second in color.) This means that the electron beam moves up and down 60 times per second in the picture tube. Although the entire vertical swing takes about 16.7 milliseconds ( $\frac{1}{60}$  second), the beam takes only about 15.3 ms to move from the top to the bottom, and then another 1.3 ms or so to rapidly swing back to the top. This upward movement is called the *vertical retrace*, and the beam is turned off during that time to make the vertical retrace invisible.
- Each frame contains 525 interlaced lines, or  $262\frac{1}{2}$  lines per field.
- The 525 lines of a frame repeat 30 times per second, so there is a total of  $525 \times 30$ , or 15,750 lines per second. Thus the electron beam moves left-right a total of 15,750 times per second (which drops slightly to 15734.25 with color.) The side-to-side swing thus takes about 63.5 microseconds ( $\frac{1}{15750}$  of a second), but about 11  $\mu$ s of that is needed to rapidly return the beam to the left during the *horizontal retrace*. As before, the beam is turned off during that time to make the retrace invisible.
- During the 1.3 ms vertical retrace, the beam is still moving left-right approximately 21 times, although it is invisible. Some of these invisible lines are therefore used to carry digital information rather than a picture. For example, the "closed captioning" text is sent during that time.

Remember that the beam motion must be completely synchronized between the camera and all TV receivers watching that channel to make sure that all objects appear in the right place on every screen. Making all of these beams move together requires that the beam motion circuitry in every TV set be synchronized with the camera. Let's look at Fig. 2-7, which is a very simplified block diagram of a typical black-and-white TV set.

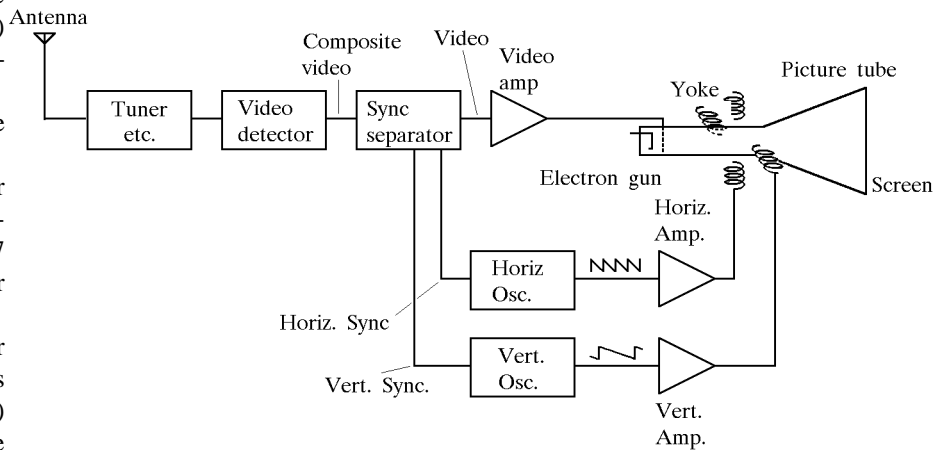


Fig. 2-7. Black-and-white TV block diagram

The signal coming in from the antenna goes through a box labelled "Tuner etc." There is actually a lot of circuitry in this box, but we're not nearly ready to discuss it, so let's just say that this is where the signal is amplified, and the particular channel is selected. The signal then goes into the video detector, whose output is a signal called *composite video*. This signal is in turn sent to the sync separator, which separates the composite signal into three parts: video, horizontal sync, and vertical sync.

The video signal contains the actual picture information, including whether a particular pixel should be light or dark. (It also tells what color that pixel should be, but more on that later.) This signal is amplified by a video amplifier and sent to the picture tube.

Meanwhile, a beam of electrons travels from the electron gun to a layer of phosphor material on the screen. Whenever the electron beam hits the screen, the phosphor material lights up to produce a visible spot. The brightness of that spot can be varied by changing the strength of the beam; that in turn is controlled by the video signal from the video amplifier.

## DETOUR

We've been avoiding discussing color for a while, but we have to cover it eventually, so here goes.

In a color set, there are three video amplifiers and three electron beams in the tube, one for each of the three colors (red, green, and blue.) There are also three color phosphors on the screen, with a "shadow mask" behind the screen which masks the screen so the red beam can only reach the red phosphor, and so on.

If you look at a color set's screen with a magnifying glass, you can see the tiny color dots (or sometimes stripes, as in Fig. 2-8) which make up the picture. But if

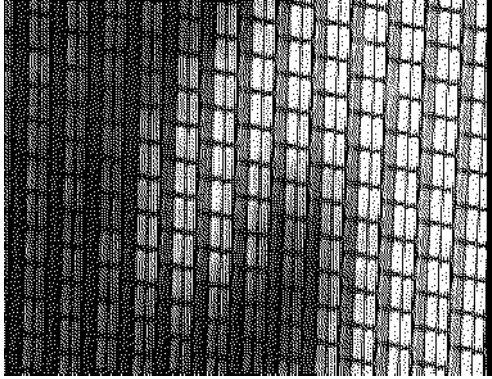


Fig. 2-8. Phosphor stripes on a color TV picture tube

you lean back, the tiny color dots blend together into other colors. For example, when a red dot, a green dot, and a blue dot are all lit up next to each other, from a distance their colors add to produce a white dot. A red dot and a green dot together, without blue, produce yellow. The various colors on the screen are thus put together out of various combinations of tiny red, green, and blue dots (or stripes).

Normally, all three electron beams move across the screen together, but their intensity varies depending on what the color is supposed to be at that point.



Returning back to Fig. 2-7, motion of the electron beam (or beams in color) is controlled by the horizontal and vertical *deflection circuits*, which consist of two oscillators, two amplifiers, and the *yoke*.

The horizontal oscillator produces a sawtooth wave at a frequency of 15,750 Hz. This signal is amplified by the horizontal amplifier, and sent to a pair of coils in the yoke. The yoke looks like a doughnut-shaped ring which is slipped over the neck of the picture tube. It contains four coils which produce a magnetic field as current flows through them. Two coils, positioned above and below the neck, move the beam left and right, while the other two move it up and down.

The sawtooth horizontal sweep signal is sent to the two horizontal deflection coils in the yoke. The sawtooth voltage sweeps the beam from left to right, and then suddenly swings it back to the left (the horizontal retrace) in preparation for the next sweep line. Since the beam is normally turned off during that retrace sweep, it can't be seen during that return trip.

Meanwhile, the vertical oscillator produces another sawtooth wave, but this one at 60 Hz. It too is amplified, and then sent to the vertical deflection coils in the yoke. It sweeps the beam slowly down (in about  $\frac{1}{60}$  of a second), and then rapidly returns it to the top. Again, the

beam is turned off during this vertical retrace, but if you turn up the brightness on your set, you may be able to see the beam as it returns to the top. (Actually, it doesn't return to the top fast enough, so you can see it swing back and forth a few times as it returns to the top.)

The two oscillators run even if you don't tune to a working channel. This makes sure that the beam continues sweeping across the screen, rather than settling in the middle of the screen and burning the phosphor at that spot because of too many electrons. But the two oscillators may not run at exactly the right frequencies, since the components in the oscillators are not precise enough to maintain the correct frequencies themselves.

The job of maintaining the exact frequencies and phases is handled by the horizontal and vertical synchronization (sync) signals, which come from the sync separator. These sync signals originate at the TV studio (typically, a single sync generator in the studio would feed all the cameras to make sure they all sweep at the same time; this is required to allow smooth switching and fades from one camera to another,) and are transmitted as part of the TV signal. The sync separator strips them from the composite video signal and sends them to the appropriate oscillator.



In the absence of the sync signals — when you're not tuned to a working channel, for instance — the vertical and horizontal oscillators “free-run”, meaning that they oscillate without being synchronized to a station. If the free-running frequency is not close enough to the frequencies required by the station, however, the sync pulses may not be able to synchronize them. Hence most TV sets have a pair of controls, called VERTICAL HOLD and HORIZONTAL HOLD, which bring the free-running frequency into range. You may have noticed what happens when you misadjust these controls.

When you turn the VERTICAL HOLD control off its normal setting, the vertical oscillator's normal frequency will vary out of range of synchronization, and the oscillator will suddenly oscillate at the wrong frequency. When this happens, the vertical position of the picture will be wrong, and it may roll up or down, depending on which way the control is set.

When you turn the HORIZONTAL HOLD control away from its normal setting, the horizontal oscillator will change to a different frequency, and parts of the picture will move left or right. This normally slides the picture sideways and then suddenly tears the picture into diagonal bars.

In addition to the VERTICAL SIZE and HORIZONTAL SIZE controls (which vary the gain of the vertical and horizontal amplifiers to make the picture larger or

smaller), many older TV sets also have a VERTICAL LINEARITY control. This control changes the shape of the sawtooth vertical sweep control, and results in the top of the picture stretching or shrinking a bit. This control is normally set to make people's heads appear the right size.



Let's return now to the composite video signal, the signal that comes out of the video detector in Fig. 2-7 to the sync separator.

If you look at the composite video signal with an oscilloscope, you will see a signal that looks something like Fig. 2-9.

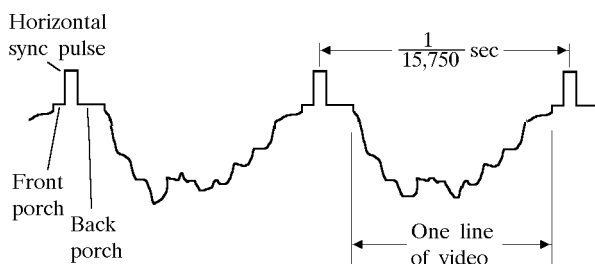


Fig. 2-9. Composite video signal

Fig. 2-9 shows three horizontal sync pulses, each separated by  $1/15,750$  second, the time for one horizontal line. Each of the pulses sits on top of a *pedestal*, which consists of a *front porch* and a *back porch*. The jagged line between any two horizontal sync pulses represents the video signal for one sweep line. As this figure shows, two consecutive sweep lines are generally somewhat similar to each other, though not identical, because they are essentially almost-adjacent strips of the same picture. (I say "almost adjacent", because they are separated by one strip of the interlaced second field.)

The voltage of the video information represents the brightness (also called the luminance) of the picture. In Fig. 2-9, black is up, near the sync pulses, while white is down, and there are various shades of gray between. This polarity makes the most sense when we talk about a pedestal; keep in mind, though, that most transistor amplifiers invert their signal, so depending on where you connect the oscilloscope, the signal may be either as shown in Fig. 2-9, or upside down (with the sync pulses pointed down, and white being up.) For example, the standard output of a VCR's or camcorder's VIDEO OUT jack is an upside down signal, with the tips of the sync pulses being down at 0 volts, and the white peaks of the video signal at approximately +1 volt.

Every  $262\frac{1}{2}$  horizontal sync pulses comes a vertical sync pulse. The shape of this sync pulse depends on the

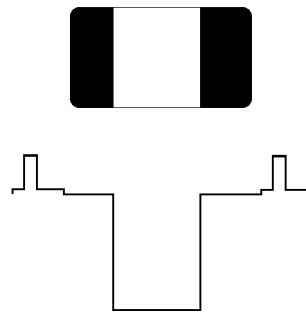


Fig. 2-10. A TV picture with one white bar

circuit that generates it. In commercial TV, it looks like a half-dozen horizontal sync pulses strung together, with some extra short pulses before and after them; this is often called a *serrated* sync pulse (like the serrations in a steak knife.) In computer monitors (which are usually not interlaced and timing is not as crucial) the vertical sync pulse is often just a single, but very long pulse.

The pedestal looks somewhat different in a color signal, because the back porch contains nine cycles of a 3.579545 MHz signal called the *color burst*. The color information is carried on a 3.579545 MHz "subcarrier" (we will define that word later) and the color burst is used to synchronize a color oscillator in the TV set.

## Bandwidth

Let's return to the question of bandwidth of a TV signal. Suppose we aim a TV camera at a black sheet of paper containing a thick vertical white bar, and look at the resulting composite video signal; we will see something like Fig. 2-10.

The top of Fig. 2-10 shows the screen, while the bottom shows one line of the composite video signal. Since the picture is identical from top to bottom, all the visible scan lines will look the same.

What we now want to ask is this: What is the spectrum of the composite video signal?

With some fancy mathematical analysis, we could come up with an exact answer. But we needn't go that far if we're willing to accept an approximate answer instead of the exact numbers. Looking at the video signal, we see a signal which, except for the horizontal sync pulse, would look like some sort of a square wave. Its frequency is 15,750 Hz, the same as the frequency of the sync pulses. Since the sync pulse is relatively small compared with the rest of the wave, ignoring it will produce an error in our answer, but not a tremendously large one.

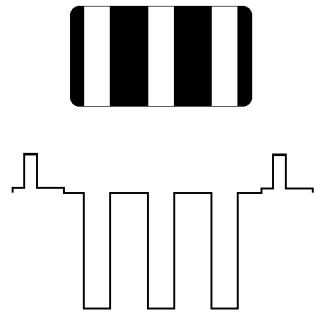


Fig. 2-11. A TV picture with three white bars

But we already know what makes up a square wave — a fundamental plus odd harmonics. Hence this signal consists of a 15,750 Hz fundamental, plus harmonics at multiples of 15,750 Hz (but, since the signal is not exactly a square wave, there will also be some even harmonics.) There will (at least theoretically) be an infinite number of harmonics, but after the first few dozen harmonics their amplitudes will be so small compared with everything else that we might as well forget about them.

Let's now increase the number of bars from one to three, as in Fig. 2-11.

As before, we can again approximate this signal with a square wave (still ignoring the sync pulses), but this time the frequency is three times higher than before. A square wave with a frequency of  $3 \times 15,750 = 47,250$  Hz now consists of a fundamental frequency of 47,250 Hz, and odd harmonics starting at  $3 \times 47,250$  Hz.

In the same way, we could extend our process to as many bars as we want. For example, if there were 300 vertical bars on the screen, then the fundamental frequency of the square wave would be  $300 \times 15,750$  Hz or 4.725 MHz, and the harmonics would start at approximately 14 MHz.

There is only one problem with this idea — if you look at Fig. 2-7, you see that the received TV signal has to go through the box labelled “Tuner etc.” And this part of the TV set generally has a maximum bandwidth of about 4 MHz (depending on the set.) In other words, our TV picture with 300 black vertical bars will not pass through that part of the set because even the fundamental frequency, the lowest frequency in the video signal, lies above 4 MHz!

Even a picture with just 100 bars would have some difficulty. Its fundamental frequency of 1.575 MHz would make it, but even the lowest harmonic, at 4.725 MHz, would not. In other words, the square wave video signal would be reduced to a sine wave. As a result, the signal would gradually change from white to black, or

from black to white; on the screen, the edges of the bars would appear blurred.

The bandpass of the “Tuner etc.” part of the TV set therefore puts a basic limit on the number of vertical bars we can display, sharp or not. This limit varies with the set, but is about 250 lines. We call this the horizontal *resolution* of the TV picture. There is a bit of confusion here — some people (especially advertising types) call this 500-line resolution, on the premise that there are 250 black bars and 250 white bars. Actually, the resolution is even a bit lower than 250 lines, because part of each line (about 11 out of the  $63 \mu\text{s}$  of the horizontal sweep) is used for horizontal retrace, and also because on many sets part of the picture is beyond the edges of the screen.

In the same way, the vertical resolution of a TV set is also somewhat less than 250 lines. Of the 525 sweep lines on the screen, only about 450–480 typically appear on the screen (the others are either above or below the edges of the screen, or else occur during the vertical retrace.) If these sweep lines alternated between one white, the next black, and so on, then the maximum we could get would be about 225–240 white lines separated by an equal number of black lines.

It is possible to get somewhat better than 250 lines of horizontal resolution on a TV screen, but only by bypassing the “Tuner etc.” portion of the TV set. Many TV sets permit that by having a composite video input jack, or even better, separate connectors for video and sync signals. Many camcorders, VCRs, and laser disks offer better than 4 MHz bandpass, and can therefore provide a sharper image, but only when they are connected directly to these special video input jacks.

Bandwidth thus affects not just the sharpness or resolution of the TV picture, but also the speed at which TV pictures can be sent. The number of lines could be increased by either increasing the bandwidth, or by slowing down the transmission so that the entire horizontal line would take longer. For example, the fax machine achieves much greater horizontal resolution at a lower bandwidth by taking more than 1000 times as long to send one line of video.

Or consider TV pictures sent back from a spaceship to Jupiter. A wide-bandwidth signal picks up much more noise than a low-bandwidth one, so TV signals from space are sent at a very low bandwidth to minimize this noise. As a result, they must be sent very slowly to maintain any reasonable resolution. It often takes several minutes to get one picture.

## Color TV

When color TV first started, there were very few color receivers, and very few stations transmitting color. So the color TV system was designed to be completely compatible to make sure that customers with black-and-white sets could receive the color stations, and vice versa.

In color TV, everything happens exactly 0.1% slower than in black-and-white TV — there are 29.97 frames per second instead of 30, and the horizontal frequency is 15,734.25 Hz instead of 15,750 Hz. So the composite video signal consists of 15,734.25 Hz and its harmonics.

We've already mentioned the color burst signal, which is a short burst of nine cycles of 3.579545 MHz which sits on the back porch, just after the horizontal sync signal. This color burst signal is transmitted by every TV station as part of its color signal; it is also output by your camcorder or VCR.

Every color TV set has a very precise internal 3.579545 MHz oscillator, which runs all the time. The incoming color burst synchronizes this oscillator so it constantly stays in exact phase with a master color oscillator located in the TV studio.

In addition to all this, mixed in with the composite video signal, the TV station adds a small signal called the *color subcarrier*. This is a weak signal whose frequency is also 3.579545 MHz, just like the color burst signal. But its phase wobbles back and forth a bit; at any instant of time, its phase tells the TV set what color to make the screen at that moment.

To decide on the exact color to put on the screen, the TV set compares the phase of this local oscillator with the color subcarrier (which has already been synchronized with the master oscillator in the TV studio). The phase difference between the two selects the color.

To make sure that the color subcarrier does not interfere with the picture itself, its frequency is very carefully chosen. Remember that the horizontal sweep frequency in the color signal is 15,734.25 Hz, and that the composite video signal contains mostly harmonics of that frequency. Let's take a look at two specific harmonics: the 227th harmonic (at  $227 \times 15,734.25$  or 3,571,674.75 MHz) and the 228th (at  $228 \times 15,734.25$ , or 3,587,409 MHz). Neatly sandwiched between those, at 3,579,545 MHz, safely out of the way so it won't interfere with either harmonic, is the color subcarrier!

We can explain the process with the help of two waveforms. Fig. 2-12 shows a test signal often used with black-and-white TV signals. This is a "staircase" signal which produces a series of vertical bars starting with a white bar on the left and going through a series of darker and darker grey bars to a black bar at the right. The waveform between the sync pulses represents the

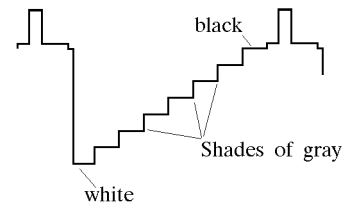


Fig. 2-12. Black-and-white staircase test signal

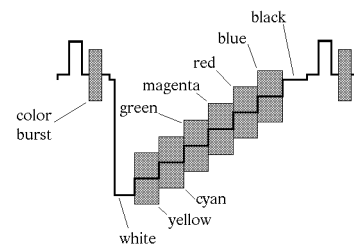


Fig. 2-13. Color staircase test signal

brightness or *luminance* information — up is black, down is white.

Fig. 2-13 then shows the same signal when color is added. On the back porch, just after the horizontal sync pulse, is the colorburst signal, which synchronizes the color oscillator in the TV set. The nine individual cycles of the 3.579545 MHz signal are too small to be seen.

Between the sync pulses is the video signal. The average height of the signal again represents the luminance or brightness information — down is white or bright color, up is black or dark color. Superimposed over this is the color 3.579545 MHz signal, again too small to see the individual cycles. The phase of the signal represents the color or *tint*, while the amplitude of the signal controls the amount or *saturation* of the color. From the wave, we can see that yellow, which is close to white, will be quite bright, whereas blue, which is close to black, will be dark.

## Digital TV

The method we've described up until now is called the NTSC method, named after the National Television System Committee, which defined the method back in the 1950's. It is purely analog; that is, no digital computer circuitry is involved. Keep in mind that computers were in their infancy in the 1950's, and very, very expensive at that.

In the mid 1980's, the Federal Communications Commission (FCC) began considering establishing a new TV service called HDTV, or High Definition TV, which would provide sharper images and a different

screen size from the current system. The original plans were for an analog system, somewhat like the one used in Japan, but then, in 1990, a proposal was made for an entirely digital system. Several companies jumped on the bandwagon, and a number of incompatible systems were proposed. Finally, in 1995, a number of manufacturers — AT&T, General Instrument, MIT, Philips, Sarnoff (the old RCA Laboratories), Thomson, and Zenith — combined into a “Grand Alliance” and proposed a single digital system.

Rather than give anything up when they merged, they incorporated everything into the final HDTV proposal. The system was to provide six picture formats:

| frames/sec | scan lines | resolution<br>(lines) | Interlaced |
|------------|------------|-----------------------|------------|
| 60         | 720        | 640                   | no         |
| 24         | 720        | 640                   | no         |
| 30         | 720        | 640                   | no         |
| 30         | 1080       | 960                   | yes        |
| 24         | 1080       | 960                   | no         |
| 60         | 1080       | 960                   | no         |

The rationale for including all six formats was that different formats could be used for different types of programs — for example, movies (which run at 24 frames per second) would not have to be converted to 30 frames per second, as happens now. The Grand Alliance HDTV system also included five channels of sound for stereo and surround sound, and even provisions for extra data channels for sending computer data.

In order to satisfy the FCC that the system was feasible, extensive laboratory and on-the-air tests were performed, and by the middle of 1996, it looked as though the FCC would give its final approval after almost ten years of discussion, study, and testing.

Suddenly, a group of computer manufacturers, led by Bill Gates, the CEO of Microsoft, stepped into the picture and declared their opposition to the entire industry plan. They then convinced the FCC not to approve the Grand Alliance plan.

In November 1996, the broadcasters and the manufacturers who made up the Grand Alliance suddenly gave in to the demands of Microsoft and the rest of the computer industry, and accepted the computer industry’s plan, even though they stated that doing so would be a tremendous expense for them because it would obsolete much of their current equipment. It appears that the computer industry blackmailed the broadcasters into submission by implying that, if the broadcasters did not agree to the new plan, the computer companies would encourage Congress to charge the broadcasters a fee for using the air waves.

In any case, as of now, HDTV sets are available, though still expensive. The FCC has given the broadcasters until the year 2006 to convert to the new standard, and the current word is that NTSC television, the present analog standard, will cease to exist as of 2006.

If all of this were done with analog methods, the bandwidth would be much larger than current NTSC television, which would mean a reduction in the number of TV stations allowed. But sending the pictures digitally allows digital compression methods to be used. For example, since two consecutive picture frames tend to be very similar, TV stations can transmit just the differences between them. The digital circuitry in the receiver will then insert the changes into the preceding frame, stored in digital memory, to make the new frame.

As a result, four or five complete HDTV pictures could fit into the same channel as just one picture with current TV. Although you will need a new (and much more expensive) TV set or adapter to receive HDTV, there will probably be a period of transition, even after 2006, when both NTSC and HDTV stations will transmit at the same time. The hope is to be able to sandwich HDTV signals into the unused channels between current NTSC stations, without causing interference in either direction.

## Summary

Although this part has just been a limited introduction to television, it has covered several important concepts. Aside from an idea of how TV works in general, we have once again seen the impact of bandwidth on the transmission of information, and also once again seen the interaction between bandwidth and time. Although we haven’t provided any definite proof (that would require some advanced math concepts), we still see that bandwidth is a necessary part of communications — if a signal has no bandwidth, then it cannot transmit any information at all.