

Video Designs Using High-Speed Amplifiers

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ABSTRACT

Video and audio design differ, because video design requires that many different, and sometimes contradictory, op-amp specifications be taken into account. This report discusses some of the challenges a first-time video designer faces, and how they can be met with proper design techniques.

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1 Introduction

Video design has been the domain of discrete circuitry from the days of vacuum tubes. Newer generations of high-speed voltage and current feedback op-amps make it possible to implement video circuitry with op-amps. Using op-amps for video circuit design involves consideration of a different set of parameters, and interpreting data sheet parameters in new ways. An op-amp that advertises a unity-gain bandwidth of 500 MHz, for example, may be barely adequate for video at 6 MHz and a gain of two. The designer must learn to ignore marketing hype and really look at the parameters as they relate to the characteristics of the video waveform.

A first-time designer of video circuitry will encounter many new terms. Appendix A is included to provide definitions of the terms used in this document.

2 The Challenges of Video Design

Because of the complex nature of a video signal, designers must be able to balance simultaneously several op-amp parameters and system requirements. Video signals not only contain wideband ac picture information, but dc components, too. Gradual degradation of the amplitude and phase of the signal, which is acceptable at high frequencies for audio, is unacceptable for video signals. The gain and phase of the video signal at its maximum bandwidth must be as good as that at dc. In fact, degradation of performance at the highest frequencies often has the most, rather than the least, dramatic impact on the video signal.

2.1 NTSC: A Familiar Example

NTSC is used extensively in this report to illustrate video design techniques. Video design, of course, encompasses more than just the NTSC standard. Other countries use PAL and SECAM, and there are high definition television standards. From the standpoint of video design, it does not matter whether the waveform is NTSC, PAL, or SECAM. All these waveforms are methods of combining picture intensity (luminance), color information, synchronization, and sound information into a single RF signal that can be broadcast or transmitted over a cable. Any distortion in analog transmission has the potential to degrade the video, the audio, or both. Even HDTV still is transmitted in an analog fashion. During the broadcast of a digital data stream, if too many bits get dropped, error correction bits cannot compensate; the picture will break up with large, annoying rectangular pixels of unpredictable size and color, or video frames will be completely missed.

Figure 1 shows the complexity of the NTSC waveform. The figure shows a representation of one horizontal line from the screen, displaying a color-bar pattern. In addition to the picture information which is composed of luminance and chrominance, there are portions with critical rise and fall times, similar to digital circuitry. The digital-like portions of the waveform are the horizontal sync and blanking interval, which help the display device to paint the picture, one line at a time, on the screen. While the luminance and chrominance tell the display device what to display, the sync pulses tell the display device where to display it. Vertical sync portions of the NTSC waveform are not discussed here. The sharp rise and fall times of sync pulses are somewhat rounded to accommodate a bandwidth of 6 MHz, but are primarily digital in nature. Appendix B gives NTSC timing.

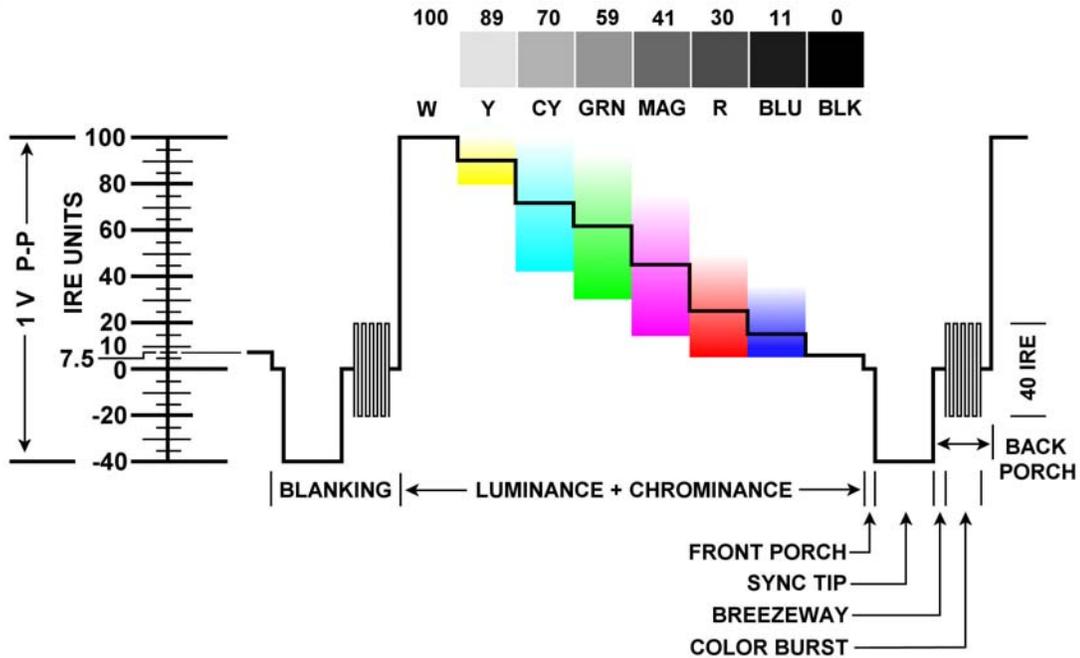


Figure 1. NTSC Horizontal Scan Line

2.2 Video Op-Amp Bandwidth

The designer accustomed to audio frequencies, the degradation of which can be tolerated at high frequencies because of the natural insensitivity of the ear, may be very disappointed by the performance of a marginally-designed video circuit. A video circuit using an op-amp that has inadequate gain over the video bandwidth will produce poor resolution. At high video frequencies, the eye is a much more sensitive error-detector than the ear is at high audio frequencies. Practically no one spends money on aids to enhance hearing at high audio frequencies. On the other hand, there is almost a national obsession with visual acuity, exemplified by the exchange of glasses and contact lenses for laser eye surgery. Visual acuity is about seeing fine detail—detail that corresponds to high frequencies in the video waveform. A fuzzy picture lacks fine detail and is extremely irritating to most viewers.

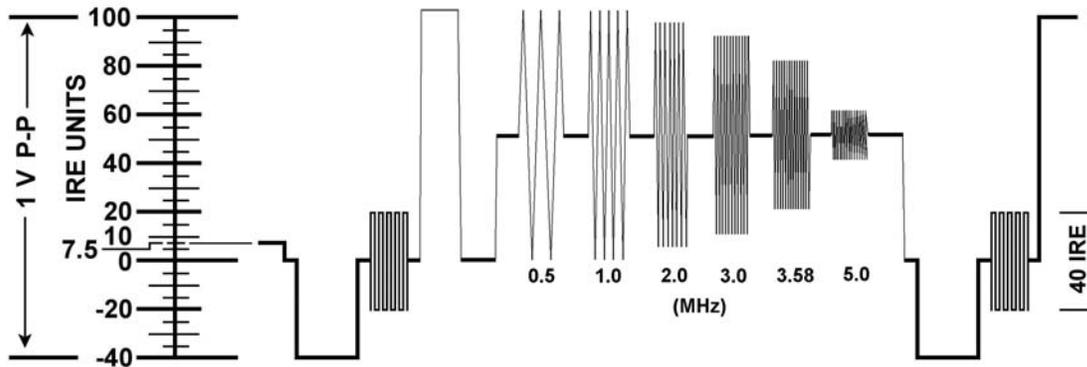


Figure 2. Effect of Inadequate Op-Amp Bandwidth

Figure 2 shows video frequencies from dc to 5 MHz and illustrates what happens when the op-amp bandwidth is inadequate. At dc and frequencies up to 1 MHz, excursions of the luminance go from white (100 IRE) to blacker-than-black (0 IRE; see Appendix A for definitions of terms). When the frequency is increased by 2 to 5 MHz, the amplitude is reduced and the excursions become progressively grayer. Fine detail is lost.

Inadequate op amp bandwidth also affects the chrominance, but in an unexpected way. It affects color saturation, which is related to luminance. Figure 1 shows the luminance pedestal in IRE units for differing levels of gray. The term pedestal (see Appendix A) usually refers to a dc offset that differentiates the black level from the blanking level. It can also be used to designate a luminance level that corresponds to color saturation. From Figure 1, Red has a saturation level of 30 IRE. If it has a higher saturation, it will appear pink. Fully saturated, it will be white. Those who have downloaded a full-color version of this document will see these gradients in color superimposed on the luminance pedestal. If a video circuit has inadequate bandwidth, the saturation levels of the colors will be limited. Pinks, for example, with a high saturation level, will be reddened. The viewer will notice that foreground colors, which are supposed to be lighted, are made harsher— fire-engine red instead of pink. This is counterintuitive in that the viewer may associate vivid color with a good video circuit; however, all it really means is that the signal is rolled off and cannot display pastels.

2.3 Video Op-Amp Phase

An op amp with poor phase response will produce a picture with incorrect colors. This is completely unacceptable because no one wants to see human faces with green coloration, for example. Most early discrete television sets had terrible color phase shifts. They compensated by using a hue control, which proved difficult to adjust. As the television warmed up, the adjustment drifted, requiring readjustment to avoid unpredictable hues. Newer all-electronic television chassis are a great improvement, but most of the improvement is in the reduction or elimination of color shift in the first place. The default setting can be perfect, and the user can be given a much smaller range of adjustment to compensate for real differences in color perception in some individuals.

2.4 Video Op-Amp Noise Margin

The voltage rail used by NTSC, PAL, and HDTV video (see Appendix B) is 1 V_{PP}. Only 0.714 V (0.7 V for PAL and HDTV) is used for luminance between black and white, with the remainder being used for synchronization. This creates a voltage margin problem similar to that experienced by high-resolution transducer-interface designers. When an infinite number of luminance steps are digitized over a 0.7-V range, each voltage step is small, as can be seen in Table 1.

Table 1. Video Converter Step Size

CONVERTER		VOLTAGE STEP (μs)	
Bits	States	NTSC	PAL
10	1 024	697	684
12	4 096	174	171
14	16 384	44	43

2.5 Differential Gain and Phase

Differential gain and phase are among the most important parameters for video design. Errors caused by poor differential gain and phase are visible at levels of about 3%, although this is a subjective value because some viewers are much more sensitive. Overall differential gain and phase errors of 3% are absolute maxima that cover all stages in the equipment. Each individual stage should have a much smaller error; otherwise, cumulative errors will overwhelm the equipment.

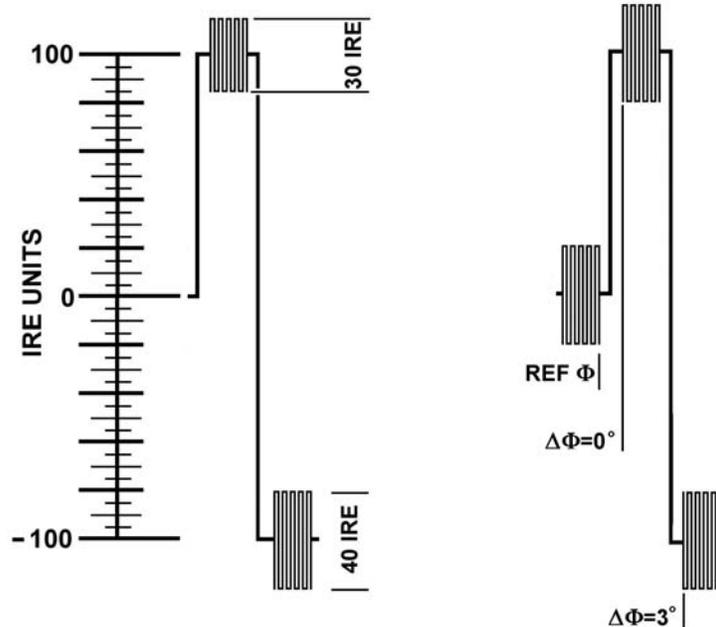


Figure 3. Differential Gain and Phase Error

The left-hand part of Figure 3 shows a completely unacceptable 25% differential-gain error. At a dc level of -100 IRE, a 3.58-MHz signal has a voltage swing of 40 IRE. At $+100$ IRE, it has a voltage swing of 30 IRE.

Differential gain errors are initially hard to detect, but they quickly become unacceptable. Colors that should be saturated at one level become either washed out with white, or darkened. Unfortunately, when this happens it is usually to sunlit scenes when the sky becomes white or shaded grassy areas turn gray. This is different from the errors due to inadequate bandwidth, which tend to produce colors having one saturation level.

The modification of the NTSC video standard in 1947 to include color was a significant advancement; unfortunately, the method chosen makes the signal very sensitive to differential phase response (different phases at different dc levels for the same frequency). The sensitivity is caused by the 3.58-MHz colorburst signal on the back porch of the waveform. The colorburst is a phase reference for the color information on the horizontal line. The NTSC system phase-modulates color information on a separate subcarrier operating at 3.58 MHz. The video modulation is then summed directly with the black and white signal. The video display generates an internal 3.58-MHz color time-base that must be phase-locked to the colorburst on the back porch.

The right-hand portion of the figure shows a differential phase error of 3° . At 100 IRE, the 3.58-MHz signal has zero phase shift from the colorburst at 0 IRE. At -100 IRE, there is a 3° phase shift from the 3.58-MHz color burst, or about 1%. High-speed op-amps usually specify differential phase error in degrees, not percent. The designer must be careful not to confuse the two. Any errors between the phase of the colorburst and the color information of the received video will result in the display of incorrect hues on the picture. At a level of about 3% phase differential, hue shifts in the yellowish-green region (the wavelengths at which the eye is most sensitive) begin to appear.

3 Video Circuits

The THS3201 is a high-speed current-feedback amplifier capable of operating in a unity-gain mode of almost 1 GHz. When used for video circuitry, it has flat amplitude response to at least ten times the video bandwidth. The phase response is within one degree to 6 MHz. It can form the basis of many high-performance video circuits. The availability of output-clamping op amps such as the OPA698 simplifies many design tasks such as sync stripping and restoration that were previously difficult.

3.1 Driving a Cable

Because of its gain and its phase characteristics at a gain of 2 (6dB), the THS3201 is an excellent video cable driver. The experienced designer will recognize that the circuit in Figure 4 has a noninverting gain of 2, but the load matching forms a 2:1 voltage divider. The overall circuit gain, therefore, is unity.

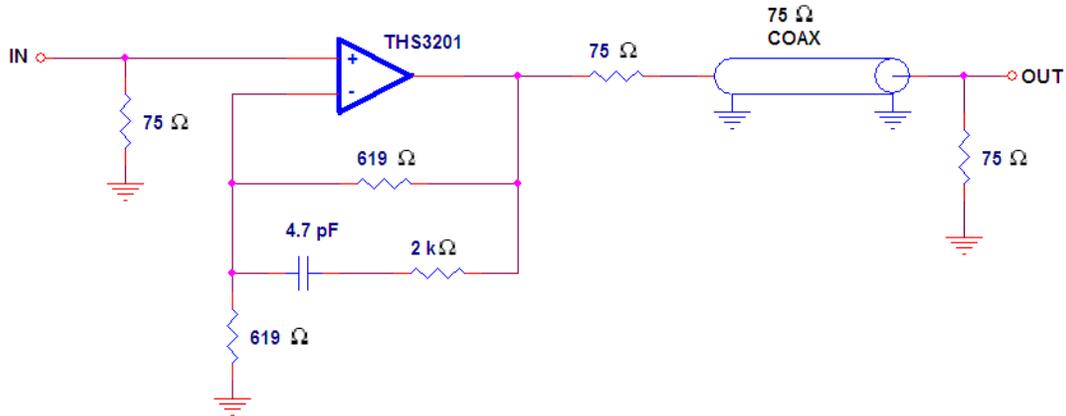


Figure 4. Video Cable Driver

The 4.7-pF capacitor and 2-kΩ resistor are added to compensate for capacitive loading in the coax. The designer will probably need to experiment with different values to find the correct combination to compensate for load capacitance.

The amplitude and phase response of this circuit are shown in Figure 5.

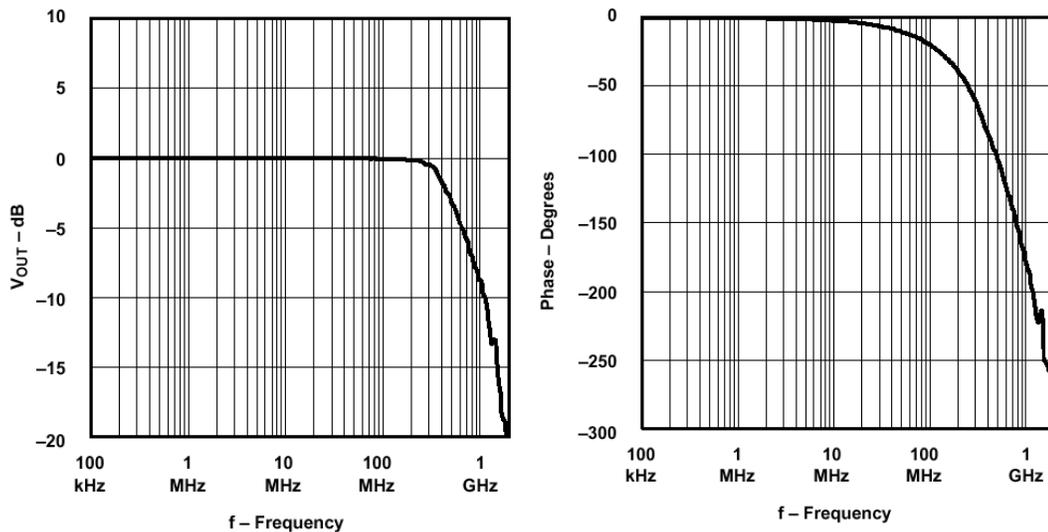


Figure 5. Amplitude and Phase Response of Video Cable Driver Circuit.

3.2 Sync Stripping

There are a number of reasons why the designer might want to design a video circuit that eliminates the horizontal sync pulse from the video signal. Two of the most common are:

- To increase the precision of A/D conversion of the waveform by eliminating the large dc sync component. This can result in an increase in precision of 30%.

- Cable companies often strip the horizontal sync from the waveform (or distort it) to prevent unauthorized reception of premium channels.

The traditional method of stripping the horizontal sync pulse from the video either uses diodes to create a half-wave rectifier circuit, or uses the negative-voltage rail of an op amp to clamp the waveform. These techniques, however, have some problems:

- If the traditional half-wave rectifier topology is used, the op amp must slew through two diode drops. No matter how low the diode forward voltage drop is, there is still a time when the op amp is open loop and slew-rate limited.
- If an op amp is allowed to hit its negative-voltage rail, its recovery time can be unpredictable.
- The colorburst waveform is also clipped by this technique. This can make proper color decoding difficult, or even impossible. Even if the sync-restoration technique is good, if the colorburst is not perfectly restored, the picture can suffer from poor color reproduction.

Figure 6 shows what happens with traditional sync strippers. The negative excursions of the colorburst, which extend to -20 IRE, are clipped. The sync-stripping level has been set at about -2 or -3 IRE, leaving a small residual sync. This was done to avoid clipping the zero crossings of the colorburst. If these zero crossings are lost, color phase information cannot be restored.

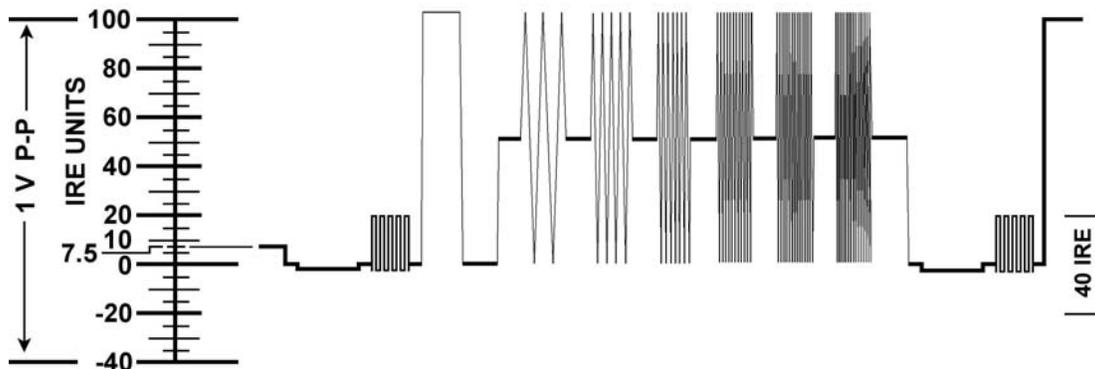


Figure 6. Traditional Horizontal Sync Stripping

Preferably, the designer should eliminate just the sync pulse without eliminating the negative excursions of the colorburst. The only real way that the designer has to differentiate between the sync and the colorburst is that the sync extends to a more negative voltage. A comparator circuit, therefore, can be used to detect this level, while ignoring the negative excursions of the colorburst. Figure 7 shows the schematic of an improved sync stripper.

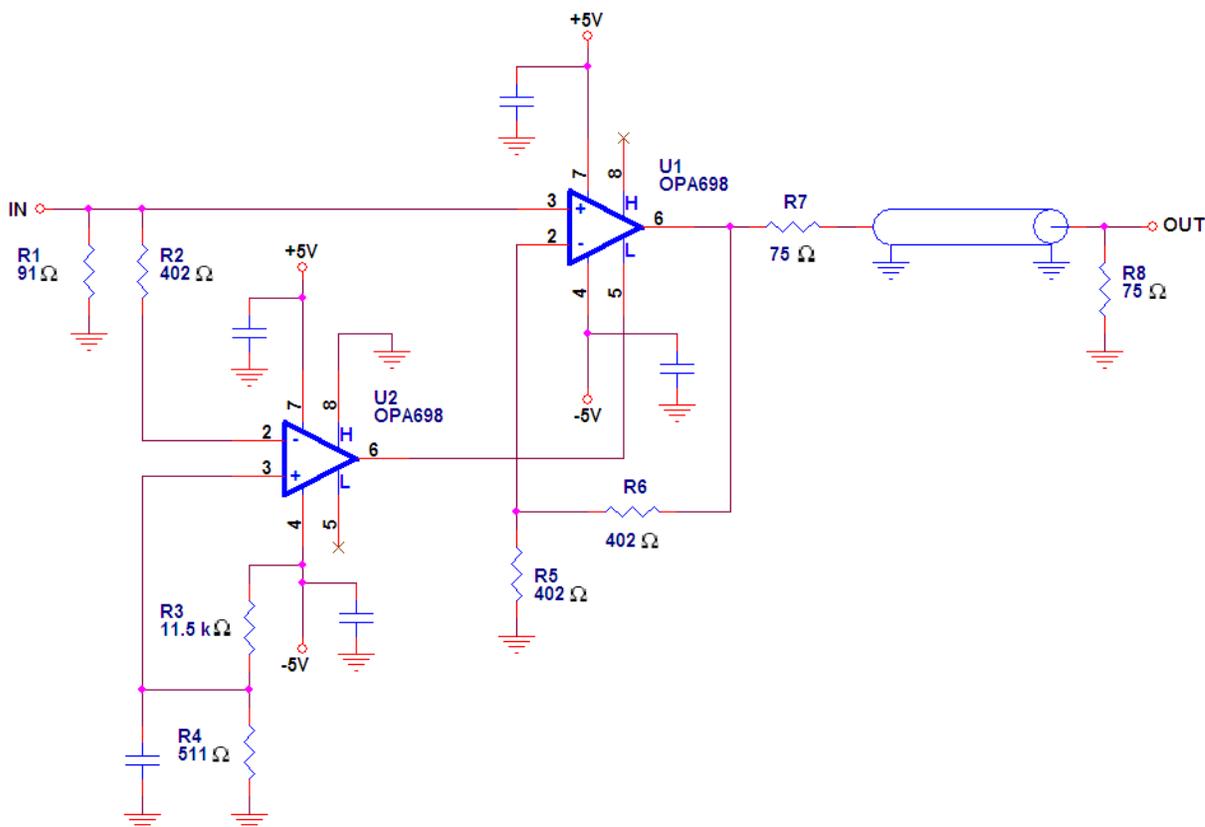


Figure 7. Improved Sync Stripper Circuit

This circuit uses two OPA698 output-limiting op amps: U1 is configured as a video buffer amplifier, and U2 is configured as a comparator.

The input circuit for U1 consists of R1 and R2, which forms a 75- Ω load for the previous stage. R5 and R6 form a noninverting gain of two for U1, followed by a 2:1 voltage divider formed by R7 and R8. With no intervention from U2, this circuit would pass the video waveform unchanged.

One of the capabilities of a voltage-limiting op amp is the capability to act as a comparator. U2 is operated as an open-loop comparator, with R3 and R4 setting the threshold at -0.213 V nominal. This is well below the -20 IRE (-0.141 V) excursions of the colorburst, which will be ignored by the comparator. The horizontal sync pulse, however, extends to -0.286 V and it will be detected. During normal video, including the colorburst, U2 will be at its default negative rail, the level generated internally when the L input is unconnected. This value (usually below -3 V) is supplied by U2 to the L input of U1, the video buffer stage. The value -3 V, of course, will not clamp the video, including the colorburst.

When the horizontal sync pulse is detected, the output of U2 switches to ground, as constrained by the H input of U2. This level is also applied to the L-clamping input to the video-buffer amplifier, clamping the video signal to GND, which is also 0 IRE, the blacker-than-black level. There may be short spikes as the circuit clamps, but these cannot be detected by the horizontal sync circuitry. Overall response of the circuit is shown in Figure 8.

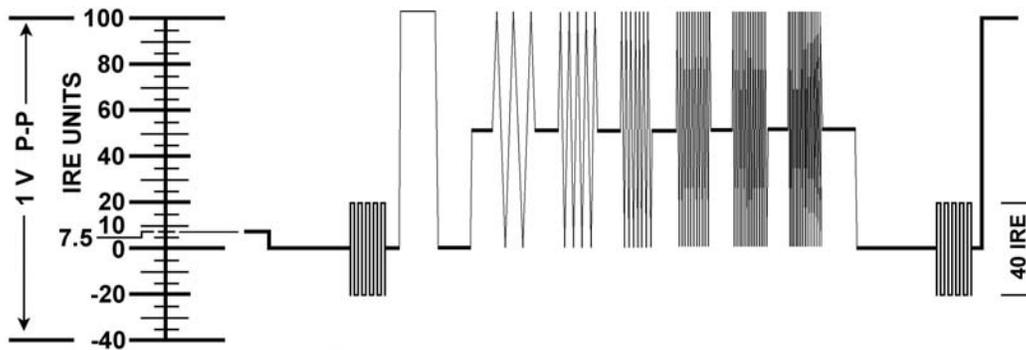


Figure 8. Improved Sync Stripper Response.

3.3 Sync Recovery

It is not the intention of this document to give complete schematics showing how to circumvent the video scrambling of cable companies. The techniques discussed here should be used only for legal purposes.

Sync-recovery circuits can also make use of output-limited op amps, such as the OPA698. The key to sync recovery is to make use of the handles that are left, to determine where to recreate a sync pulse. NTSC has two such handles.

3.3.1 Using the Pedestal

The pedestal for the black level creates a recognizable handle when it switches to blacker than black; that is, from 7.5 IRE to 0 IRE. This is a small change, however. A potentiometer would probably have to be used to fine-tune the detection level. Another disadvantage of this technique is that it is unusable with PAL, or any other format that does not use a pedestal.

To recreate the horizontal sync pulse use the pedestal, a window comparator is set to detect the transition from 7.5 IRE to 0 IRE. The window-comparator output triggers a 1.47- μ s front-porch delay. The conclusion of the front-porch delay is used to trigger a pulse 4.7- μ s wide.

3.3.2 Using the Colorburst

Using the colorburst from the previous line is a better detection technique. With this technique, a frequency detector tuned to 3.58 MHz detects the 8 to 11 cycles of colorburst, when it occurs at the blacker-than-black level. If the detector is allowed to operate at other times, it will detect the color information of the picture as a colorburst. The detection of 3.58 MHz triggers a delay of 58.42 μ s, which is the horizontal line time less the breezeway and back porch times. This is a much longer time interval and, therefore, much more prone to drift. It may require external adjustment. The end of the 58.42- μ s delay then generates a TTL sync pulse, as already described.

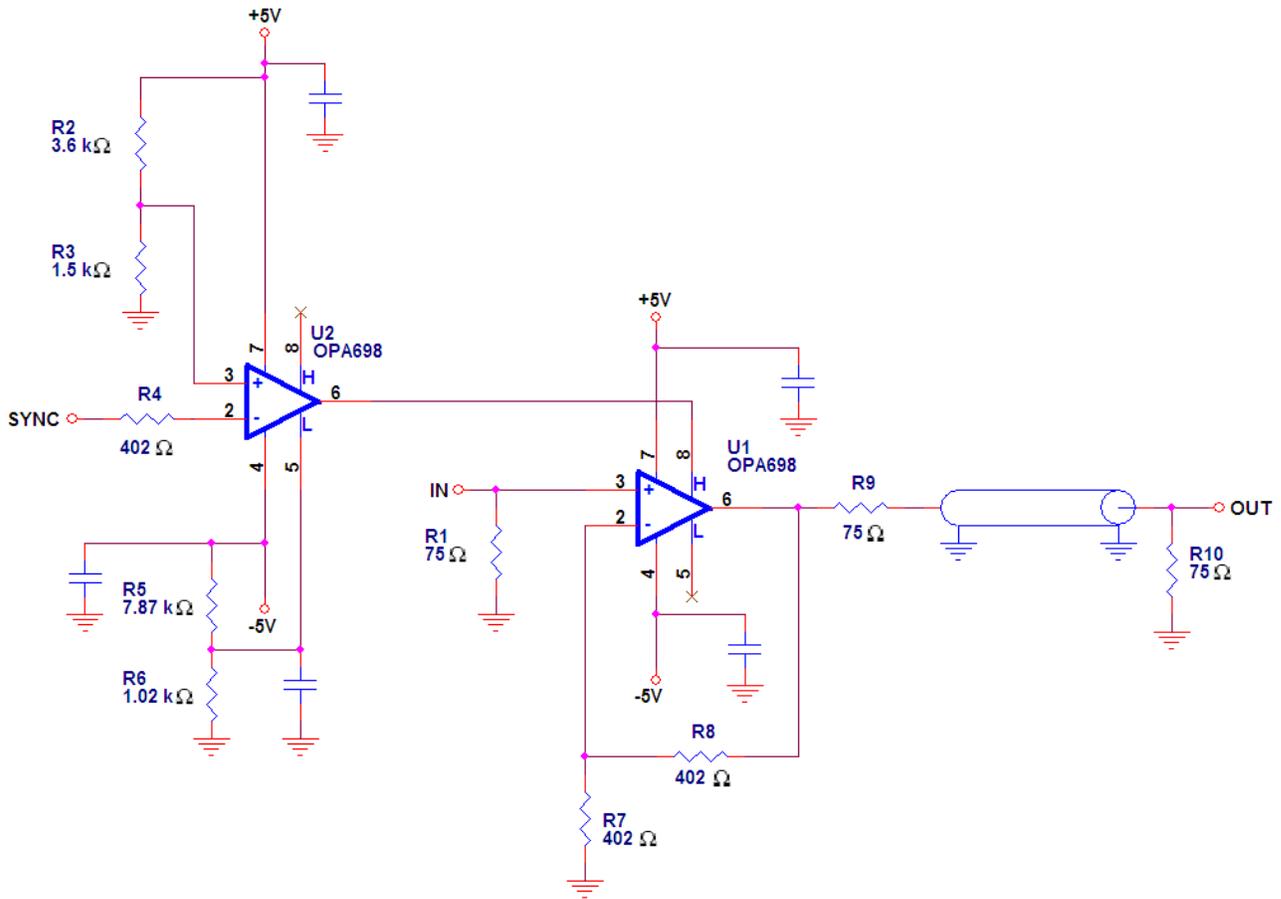


Figure 9. Partial Horizontal Sync Restoration Schematic

In Figure 9, the U1 is configured as a video buffer similar to the other circuits. With no intervention from U2, U1 passes the video signal unmodified. The restored horizontal sync pulse is TTL compatible. During the 4.7- μ s TTL sync pulse, U2 turns on and is constrained to a level of -0.572 V. This is applied to the VH input of U1, which is, therefore, clamped to an output voltage of -0.572 V. When the output of U1 is divided by two, the restored horizontal sync level is -0.286 V, or a level of -40 IRE. At the end of the 4.7- μ s sync pulse, U2 switches off and the video buffer amp can then pass video normally.

Appendix A: Video Glossary

Back Porch

The portion of the NTSC waveform between the trailing edge of the horizontal synchronization pulse and the beginning of the luminance / chrominance of the next video line.

Black level

Represents the darkest an image can get; defines what black is for a particular video system. For NTSC, this level is 7.5 IRE during the entire luminance portion of the video signal. It produces black on the screen.

Blacker-than-Black

The portion of the video signal that is below the black level of the format. For NTSC, blacker-than-black is anything lower than 7.5 IRE.

Blanking

The portion of the video signal that turns off the CRT during horizontal and vertical retrace / synchronization times. Blanking occurs when the scan line hits the right-hand-side and is about to be brought back to the left-hand-side of a CRT screen, or when the scan line hits the bottom of the screen and returns to the top. The video signal is blanked so that the return path of the scan beam is invisible as it travels from the right- to the left-hand edge or bottom to top of the screen. To blank the video signal, the video level is brought down to the blanking level, which is below the black level if a pedestal is used.

Blanking Level

The level of the video waveform at which the system defines blanking to occur. This can be the black level if a pedestal is not used, or below the black level if a pedestal is used.

Breezeway

The portion of the NTSC video waveform between the trailing edge of horizontal sync and the start of color burst.

Brightness

Another term for luminance. Brightness measures the luminance at each point on a screen.

Chrominance

The color part of the video signal. In NTSC, it is phase-shift modulated about a 3.58-MHz subcarrier. PAL encodes it at 4.43 MHz.

Color Burst

8 to 11 cycles of 3.58 MHz placed on the back porch of the NTSC composite video signal. The color burst is a phase reference for the color contained in the previous line of active video. By looking at the color burst, the color decoder can determine what is blue, orange, or magenta.

Color Phase

The difference in phase between the received 3.58-MHz color burst and the internally-generated 3.58-MHz color oscillator for NTSC.

Color Subcarrier

A signal used to control the color decoder. For NTSC the frequency is about 3.58 MHz; for PAL it is about 4.43 MHz. In the color decoder, the color burst is used to reconstruct a color subcarrier.

Composite Video

A single video signal including luminance, chrominance, and synchronization information. NTSC and PAL are examples of composite video.

Composite Sync

A signal containing both horizontal and vertical synchronization signals.

Contrast

The voltage span between the maximum white luminance and minimum black luminance.

DC Restoration

When a video signal has been ac-coupled, the exact voltage level of the sync tip is lost. By definition, ac coupling centers the waveform on zero volts. Therefore, the sync tip, and all other components of the video, must be referenced to a dc level to be digitized in an AD converter.

Differential Gain

Measures how much the color saturation changes with the luminance level. For a video system, an op amp with low differential gain is best. It is the change in ac gain with change in dc level. The ac signal is 40 IRE ($0.28 V_{PK}$) and the dc level change is ± 100 IRE (± 0.7 V). Typically tested at 3.58-MHz (NTSC) or 4.43-MHz (PAL) carrier frequencies.

Differential Phase

The change in ac phase with a change in dc level at a fixed frequency; how much the hue changes with the luminance level. For a video system, an op amp with low differential phase is best. The ac test signal is 40 IRE ($0.28 V_{PK}$) and the dc level change is ± 100 IRE (± 0.7 V). It is typically tested at 3.58-MHz (NTSC) or 4.43-MHz (PAL) carrier frequencies.

Front Porch

The portion of an NTSC waveform after the luminance and chrominance portions and before the horizontal sync pulse.

Gray Scale

The luminance portion of color video signals; a black-and-white video signal.

HDTV

High-definition television. A new video standard based on digital compression that improves picture quality.

Horizontal Blanking

Prevention of video signal display by keeping the video signal below 7.5 IRE while the electron beam sweeps across the CRT from right to left. The only exception is during the colorburst, which produces excursions above the blanking level, but is still time averaged to 0 IRE.

Horizontal Scan Rate

How fast the scanning beam in a display sweeps from side to side. In the NTSC system, this rate is 63.556 μ s, or 15.734 kHz.

Horizontal Sync

The portion of the video signal that tells the display where to place the image in the left-to-right dimension. The horizontal sync pulse tells the receiving system where the beginning of the new scan line is.

Horizontal Resolution

The number of white-to-black and black-to-white transitions that can be seen from the left to the right of the picture.

Hue

The distinction between color tones, carried in the chrominance part of the video signal. Hue is distinct from color intensity and color saturation. For example, a red hue could look brown at low saturation, bright red at a higher level of saturation, and pink at a high brightness level. All three of these colors have the same hue.

IRE

A video amplitude unit equal to 1 V_{PP} divided by 140. White is defined to be 100 IRE.

Luminance

In the NTSC and PAL video systems, the black-and-white part of a signal that contains both black-and-white and color parts. It is the luminance component that allows color TV broadcasts to be viewable by black and white TVs.

Monochrome

A video signal with no chrominance information.

NTSC

National Television Standards Committee; also the current United States video transmission standard. NTSC is a color-modulation scheme, but the term is used to describe a video format.

PAL

Phase-alternation line; the current video standard used in Europe and much of the world.

Pedestal

An offset used to separate the black level from the blanking level by a small amount. When a video system does not use a pedestal, the black and blanking levels are the same. NTSC uses a pedestal; PAL does not.

Resolution

A measure of the quality of a video device or signal. It is the dimension of the smallest discernable video unit in the horizontal and vertical dimensions. It may or may not be the same in the horizontal and vertical directions.

Phase Adjust

A method for adjusting the hue in a NTSC video signal. The phase of the color subcarrier is adjusted relative to the color burst. PAL and SECAM systems do not usually have a phase- (or hue-) adjust control.

Retrace

Motion of the electron beam between the times of its leaving the right-hand-edge and arriving at the left-hand edge of the CRT display. Retrace occurs during the horizontal blanking time.

RS-170A

Another term for NTSC video. RS-170 (no A) is another term for monochrome NTSC video.

Saturation

A measure of the amount of color. For example, a lightly saturated red looks pink, while a fully-saturated red is brilliant. Saturation does not mean the brightness of the color; just how much pigment is used to make the color. The less pigment, the less saturated the color is, effectively adding white to the pure color.

Scan Line

An individual line in the field or frame across the display. An NTSC frame contains 525 scan lines; a PAL frame has 625.

SECAM

An acronym for sequential video with memory. A video format, incompatible with NTSC and PAL, used in France and a few other countries.

Subcarrier

A secondary signal containing additional information that is added to a main signal.

Sync

A signal that tells the display where to put the picture. Horizontal sync tells the display where to put the picture in the left-right dimension. Vertical sync contains the vertical position information.

Vertical Blanking Interval

During the vertical blanking interval, the video signal is at the blanking level so that the electron beam does not display while returning from the bottom to the top of the CRT screen.

Vertical Resolution

The number of white-to-black and black-to-white transitions that can be seen from the top to the bottom of the picture. The maximum number is the number of active scan lines used by the image.

Vertical Scan Rate

For non-interlaced video, this is the same as the frame rate. For interlaced video, it is usually one-half the field rate.

Vertical Sync

The portion of the video signal that tells the decoder where the top of the picture is.

White Level

100 IRE during the entire luminance interval of the video; produces white on the screen.

Appendix B: NTSC Parameters

SIGNAL	STANDARD MEASUREMENT	COMMENTS
Composite NTSC video	1 V _{PP}	From maximum white to sync tip
Maximum video level	100 IRE	From 0 IRE baseline
Sync tip level	-40 IRE	From 0 IRE baseline
Black level	7.5 IRE	Optional under FCC rules
Color burst level	± 20 IRE	Centered on baseline
Subcarrier frequency	3.579545 MHz	± 10 Hz
Number of color-burst cycles	9 nominal	8 minimum to 11 maximum, zero crossing
Subcarrier cycles per line	227.5 cycles	For a 63.5 μs horizontal line
Total number of video lines	525	Complete top-to-bottom scan
Active-video lines	482 to 486	
Horizontal-sync time	4.7 ± 0.1 μs	At 50% rise time
Front-porch time	1.4 μs average	1.27 μs minimum
Breezeway time	0.38 μs	minimum
Back-porch time	4.8 μs average	
Number of equalizing pulses	10	5 in front, 5 in back of Vsync
Number of vertical separations	6	Contained in Vsync pulses
Vertical-blanking time	20 horizontal lines, 1271 μs	21 lines in common
Horizontal blanking	10.7 +0.7 / -0.2 μs	
Vertical-sync time	3 horizontal lines, 190.5 μs	3 * 63.5 μs horizontal intervals, 59.94 Hz
Subcarrier to horizontal sync conversion	15734.26 Hz	3.579545 / 227.5
Horizontal-line time	63.5 μs	

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