

Selecting video op amps

VIDEO AMPLIFIERS HAVE UNIQUE AND DEMANDING SPECIFICATIONS. UNDERSTANDING THEM WILL HELP YOU SELECT AN AMPLIFIER THAT CAN DO THE JOB.

Video op amps have improved significantly since their debut in the early 1990s. The first versions operated from $\pm 15V$ supplies, featured bandwidths of 50 MHz, and delivered slew rates in the low hundreds of volts per microsecond. Today's fastest amplifiers run on $\pm 5V$ supplies with bandwidths of 1.4 GHz and slew rates of 6000V/ μ sec. There are hundreds of versions available, and, to add to the challenge, many applications require the lowest possible supply voltage.

To simplify the design choices, it's important to identify major parameters of interest. Start with the kind of signal the op amp is passing, the available supply voltages, and the power dissipation that an application allows or tolerates. Important intangibles include ease of use and tolerance to board layout. This article covers the signal requirements and then reviews available amplifier topologies. **Table 1** suggests amplifiers for different signals.

VIDEO SIGNALS

The op-amp industry adopted the composite-video format in monochrome form in the early 1940s and the color standard in 1953 (**Figure 1**). White-level, color, and horizontal- and vertical-synchronous signals combine onto one conductor. The synchronous signals originally guided the electron beam's horizontal line-scan in early CRTs. In today's digital televisions they perform memory-mapped data-stream timing.

In US composite video, the synchronous pulses repeat at a 15,734-Hz rate. A flat region that represents a dark display and includes a chroma burst follows each horizontal synchronization. The burst is a number of 3.58-MHz sine waves that serves as a frequency reference for subsequent embedded color information. The composite-video receiver has its own chroma reference oscillator that resynchronizes each burst. The video-line-picture content follows the chroma burst. **Figure 1** shows a sample video content in which a steady color amplitude rides on a white level that increases across the line. Pictures contain fairly unpredictable color and intensity content. The figure does not show the vertical-synchronization patterns, which are the same amplitude as the horizontal synchronization but of complex pattern and durations.

The maximum amplitudes of the synchronization feature, the chroma, and the white part of the figure are 300, 100, and 707 mV, respectively. These amplitudes make the maximum peak-to-peak standard composite-signal amplitude approximately 1.05V p-p. Not all combinations of chroma and white amplitude exist in the color space of a particular video standard. The amplifier must be biased within its supplies to be able to handle the signal.

One source of video might be a DAC output, such as a ca-

ble-tuner box. These sources generally place the bottom of the synchronized signal at ground, with video details going positive. The boxes usually make output data samples at four times the chroma frequency but still have DAC-step artifacts that require filtering before use. Active filters using op amps frequently accomplish this task. Some op amps come with the appropriate filters and buffer the DAC output when you connect them to standard 75 Ω video cable. The amplifier typically drives a reverse-termination resistor in series with the cable to absorb any reflections, and this step loses one-half the output amplitude. The amplifier then has a gain of two to recover standard-output amplitude.

It also is important to consider the voltage excursions of the signal with respect to available power supplies. The synchronous amplitude is on ground at the DAC output, and an amplifier has no problem passing this amplitude with a negative-power supply. However, negative supplies are often unavailable. Some amplifiers' inputs can linearly go to ground and have allegedly rail-to-rail outputs, but neither MOS nor bipolar rail-to-rail amplifiers are completely linear closer than about 100 mV from the supply rails. **Figure 2** shows the differential gain measurement of a low-power bipolar op amp running on a single 5V power supply.

Differential gain is a measure of the deviation of ac gain over changing dc operating points. The output gain is stable only above an output dc level of 0.1V. Although the synchronizing level is not critical and may be distorted, forcing an amplifier into output overload incurs a recovery-time penalty when it has to rise back above ground. This recovery time could adversely affect synchronization. In single-supply applications, designers bias the output positive at approximately

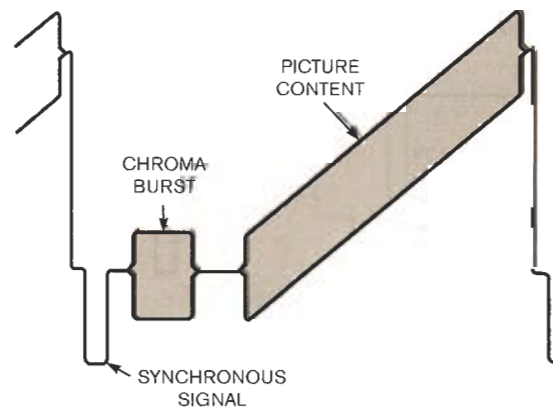


Figure 1 A composite-video waveform combines white-level, color, and horizontal- and vertical-synchronous signals onto one conductor.

200 mV by using offsetting circuitry.

The blue curve in the figure has a 150Ω load due to the 75Ω cable and termination in series with 75Ω back-match resistor. It exhibits large differential gain error as the output gets within 0.8V of the supply voltage. This situation occurs at a current of 28 mA, twice that of one standard load and amplitude. The proper way to bias this amplifier would be to offset the input by 100 mV. At a gain of two, this approach produces an output swing of 0.2 to 2.2V. With the positive head room of 0.8V, you establish a minimum supply voltage of 3V.

You use amplifiers to accomplish filtering, clamping, dc restoration, and buffering of the signal. Buffering provides input-termination quality and routes the signal to any manner of nonterminated loads.

Using ac coupling rather than dc restoration or clamping yields a larger peak-to-peak signal to pass. The average level of video signals varies between dark and fully white (Figure 3). The average level is the dc bias the amplifier's input pin receives from the input coupling capacitor. The peak negative excursion occurs during a static fully white signal, and the synchronous voltage is the dc bias minus 0.86V. When a long-term, fully dark signal changes to a fully white signal, the first white level is temporarily peaking at dc bias plus 0.64V and slowly sags down to the upper waveform of Figure 4. Thus, the amplifier must support a video signal of 1.5V p-p, not 1V p-p, as in the dc-coupled case. This situation can be problematic with low supply voltage.

Generalized methods exist for offsetting or stabilizing dc levels. Circuits that perform dc restoration observe the synchronized signals and use timers to gate the burst-time interval. During this interval, a feedback loop forces the burst's average amplitude to a reference—ground, for example—and the offset correction is in a sample-and-hold activity throughout the rest of the time. Circuits that clamp the synchronous signal's

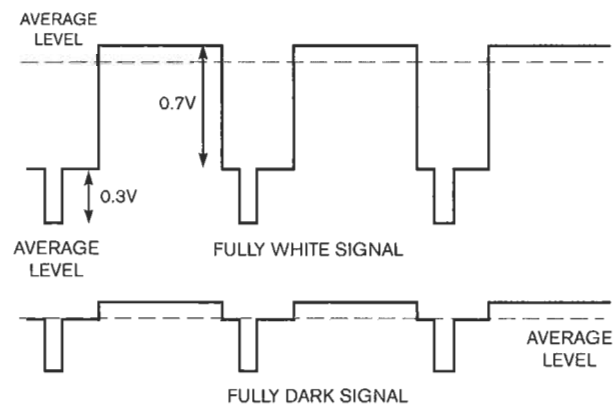


Figure 3 The average level of video signals varies between dark and fully white.

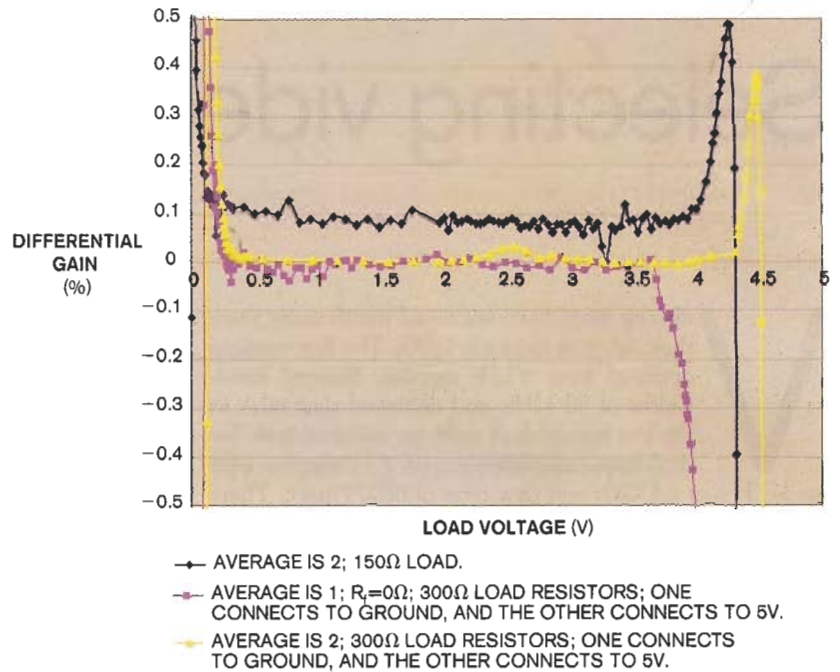


Figure 2 The differential gain measurement of a low-power bipolar op amp running on a single 5V power supply shows that the output gain is stable only above an output dc level of 0.1V.

negative-going extreme when you apply it through a capacitor also commonly establish offset.

The performance of composite-signal amplifiers has several metrics. The first is differential gain, the measure of stability of ac gain at 3.58 MHz over the video range of dc levels. The required performance is 0.05 to 1% stability, depending on quality level. The differential phase, the variation of phase lag through the amplifier at 3.58 MHz with dc variations through the video region, is similar to differential gain. An excessive deviation of phase manifests itself as color errors on the screen. The range of required performance is 0.05 to 1°. You can think of phase variation with dc level as the frequency response itself varying with output current and voltage. It is worst in low-quiescent-current amplifiers.

Another figure of merit in composite-video-reproduction quality is group delay, the change of delay of signal components at one frequency relative to another frequency within the signal spectrum. Although delay is harmless, variations of delay cause visual edges to smear as different spectral components arrive at different times. Within the moderate spectral content of 4.5 MHz, a group delay constancy of approximately 30 nsec is necessary. This delay is easy for most amplifiers that have at least 50-MHz bandwidth to achieve.

The S video standard places the luminance and synchronous parts of the composite signal onto a Y channel and the color and chroma parts onto a C channel. The C channel has no dc variation, and differential-phase performance is unnecessary. The Y channel has a slightly reduced 1V-p-p swing, and the C channel has a 286-mV-p-p swing. Dual combined DAC filters/amplifiers and DAC filters and combining amplifiers that merge the Y and C channels into a composite output are available.

TABLE 1 VIDEO SIGNALS' PERFORMANCE REQUIREMENTS

Signal type	Constraints	Performance	Amplifier type
Coaxial composite video	Portable: $V_s=3V$, cost, power	Differential gain: approximately 1%, differential phase: 1°	Single-supply, rail-to-rail output
	Nonportable: $V_s=5V$, cost, power	Differential gain: approximately 0.05%, differential phase: 0.05°	Single-supply, rail-to-rail output
	Nonportable: $V_s=5V$, high performance	Differential gain: approximately 0.01%, differential phase: 0.02°	Single-supply, rail-to-rail output
	Nonportable: $V_s=\pm 5V$, power	Differential gain: approximately 0.1%, differential phase: 0.1°	Dual-supply, current-feedback amplifier
	Nonportable: $V_s=\pm 5V$, high performance	Differential gain: approximately 0.01%, differential phase: 0.01°	Dual-supply, current-feedback amplifier
Coaxial component video	Consumer: cost, positive power supply only	-3-dB bandwidth of 200 MHz	Single-supply, rail-to-rail output
	Computer RGB, $\pm 5V$	-3-dB bandwidth of 600 to 1400 MHz, fast slew	Dual-supply, current-feedback amplifier
	Computer RGB, $\pm 5V$	-3-dB bandwidth of 350 to 700 MHz, fast slew	Dual-supply, slew enhanced
	Computer RGB, 5V	-3-dB bandwidth of 400 MHz, fast slew	Single-supply, slew enhanced, rail-to-rail output
Twisted-pair composite video	Differential driver	-3-dB bandwidth of 100 MHz, 1100V/ μ sec	Single-ended input/differential output
	Differential receiver	-3-dB bandwidth of 250 MHz, 800V/ μ sec	Differential input/single-ended output
Twisted-pair component video	Differential driver	-3-dB bandwidth of 450 MHz, 900V/ μ sec	Single-ended input/differential output
	Differential receiver	-3-dB bandwidth of 550 MHz, 900V/ μ sec	Differential input/single-ended output

You can capacitor couple the output to save power. Because no dc current goes through the capacitor, the offset current is zero, and the video content is both sourcing (drawing supply current) and sinking (drawing no supply current). This approach uses three times less supply current than dc coupling. One drawback is that the average video content causes a slow baseline wandering at the load. This wandering decalibrates the video level. To combat the problem, almost all video destinations have dc-restore circuitry that recalibrates baselines at synchronous or burst events.

The other drawback of capacitor coupling is that the capacitor must pass a lot of low-frequency content because the video picture repeats 30 times per second. With an effective 150 Ω load and approximately 5-Hz low-frequency cutoffs, you need a 200- μ F coupling capacitor, a large and somewhat expensive component.

Some video amplifiers incorporate so-called sag feedback paths that allow the use of substantially reduced coupling capacitors. They work by feeding back signal from the load side of the coupling capacitor. Feedback induces the amplifier output to rise for low frequencies. Although the coupling capacitor loses low-frequency signals, the amplifier boosts them, and the final output maintains low-frequency gain.

In many designs, you must offset the region around the chroma burst so that it is at ground, and the synchronous signal goes 300 mV below ground. This approach is practical with a negative supply and a dc-restoration or clamp circuit. Fortunately, some amplifiers come with charge-pump switching supplies that create a negative supply and dc-restore circuits that poise the burst interval at ground. Dual and quad devices

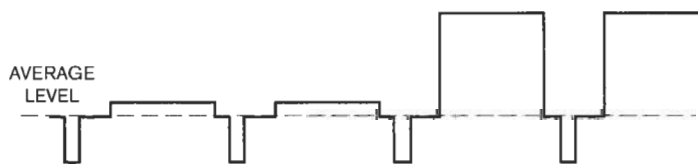


Figure 4 The peak negative excursion occurs during a static fully white signal.

are also available; they place the burst area of the Y channel of S video at ground and the C midvoltage at ground. These devices also have the appropriate DAC filters. Output-charge-pump noise of representative parts is only 0.3 IRE (Institute of Radio Engineers) p-p. An IRE unit is 1% of the peak video range, or 7 mV.

The other kind of analog-video transmission is component and has three color components. RGB (red/green/blue) is the common computer-monitor standard and offers the highest quality of component video. RGB achieves a fully white-to-fully dark transition on adjacent pixels to optimize font appearance. For a common 1280 \times 1024-pixel display with a 60-Hz scan-refresh rate, the pixel rate is nearly 100M pixels/sec. RGB components generally do not use DAC-reconstruction filters, instead transmitting the raw DAC output or a buffered version of it. Amplifier requirements are for a -3-dB bandwidth of 300 MHz, a slew rate of 1500V/ μ sec, and a settling time of 7 nsec to 1%.

The typical RGB amplifier is a triple with an internally set gain of two. Back-matching resistors are external because IC processes do not give accurate resistor values. Single-supply amplifiers typically have a slew rate of only approximately 500V/ μ sec and barely settle within a clock time. At the highest pixel counts, the amplifiers typically run on positive and negative supplies; are current-feedback or slew-enhanced, voltage-feedback designs; and have more than enough

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slew rate and bandwidth. Linearity for these devices should be 1% or better, and dc offsets are not generally important because almost all monitors have a dc-restoration feature for their inputs.

The other common component video is for HDTV (high-definition television), which uses the YPrPb standard. It has an overall luminance channel, Y; Pr, which contains red content minus Y; and Pb, which contains blue minus Y. You derive green from the weighted differences of them all. In 1080i television format, the video has a spectral content of 30 MHz, which a DAC typically generates when running at 135M or 270M samples/sec. An analog filter bandlimits and buffers the output-transmission line. Amplifiers should have better than 0.5-dB flatness at 30 MHz; greater-than-200-MHz, -3-dB bandwidth; a 200V/ μ sec minimum slew rate; and 0.3% linearity. Complete integrated filters and amplifiers have recently become available, but many designs still use discrete amplifiers as active filters or passive LC (inductance/capacitance) filters with supporting amplifiers.

Another variety of analog video is video over twisted-pair cable. Each component of this video is differential and transmits over Category 5 cable, which normally finds use in digital-network communications. Category 5 cable is less expensive and bulky than standard RGB coaxial cables. Category 5 cable is especially useful when video is concentrated, for instance, when users must access many computers in server clusters from a central control monitor and keyboard. Category 5 cable has four twisted pairs, three of which are for video; the remaining one is for keyboard or mouse signals in the KVM

(keyboard/video/mouse) function. Various twisted-pair lines can be single-ended synchronous and computer-control signals. The single-ended, bandlimited signals prevent radio emission, but the twisted-pair, self-shielded, differential signals can operate at full pixel speeds.

Single-supply, triple-Category 5-cable drivers are available that include common-mode synchronous encoding. Currently, all the differential receivers are $\pm 5V$ designs, but they effectively reject common-mode interference over wide frequency ranges. Integrated receivers with equalizers can undo the high-frequency losses the cables cause. Time equalizers are also available. Category 5 cable has twisted pairs with different winding pitches, and each pair is a slightly different length. The time equalizers can delay the signals coming in from the shorter lines to catch up with the delayed signals traversing the longer lines.

AMPLIFIER TOPOLOGIES

VFAs (voltage-feedback amplifiers) have noise-versus-slew-rate trade-offs. NTSC (National Television System Committee) video is forgiving of noise, having only approximately 5 MHz of signal bandwidth, and can tolerate a total noise of 50 nV/ \sqrt{Hz} p-p in the signal chain for one IRE. The slew-rate requirement is only 22V/ μ sec. Supply current need not be more than 2 mA for line drivers with filters. Thus, VFAs, including CMOS devices, are good candidates for many applications.

Component video has higher performance requirements, and you can use only the fastest VFAs in this application. These amplifiers require a bandwidth of 200 MHz or more,

a slew rate of at least 200V/ μ sec, and noise in the chain to 20 nV/ \sqrt{Hz} . CFAs (current-feedback amplifiers) and older slew-enhanced VFAs perform the best but need dual supplies because they require input and output head room. A new amplifier topology, a low-voltage, slew-enhanced VFA, is also now available. These devices can operate on a single supply as low as 3V, their input ranges from ground to the supply minus 1V, and they have rail-to-rail output. The output slew rate, however, is greater than 2000V/ μ sec, meaning that video waveforms cannot cause slew distortion in these amplifiers. Table 1 summarizes various signal tasks and recommends some part specifications. **EDN**

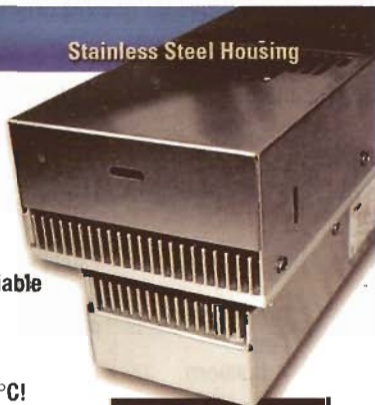
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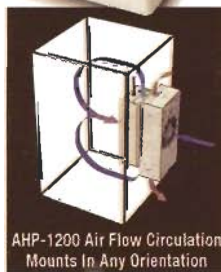
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