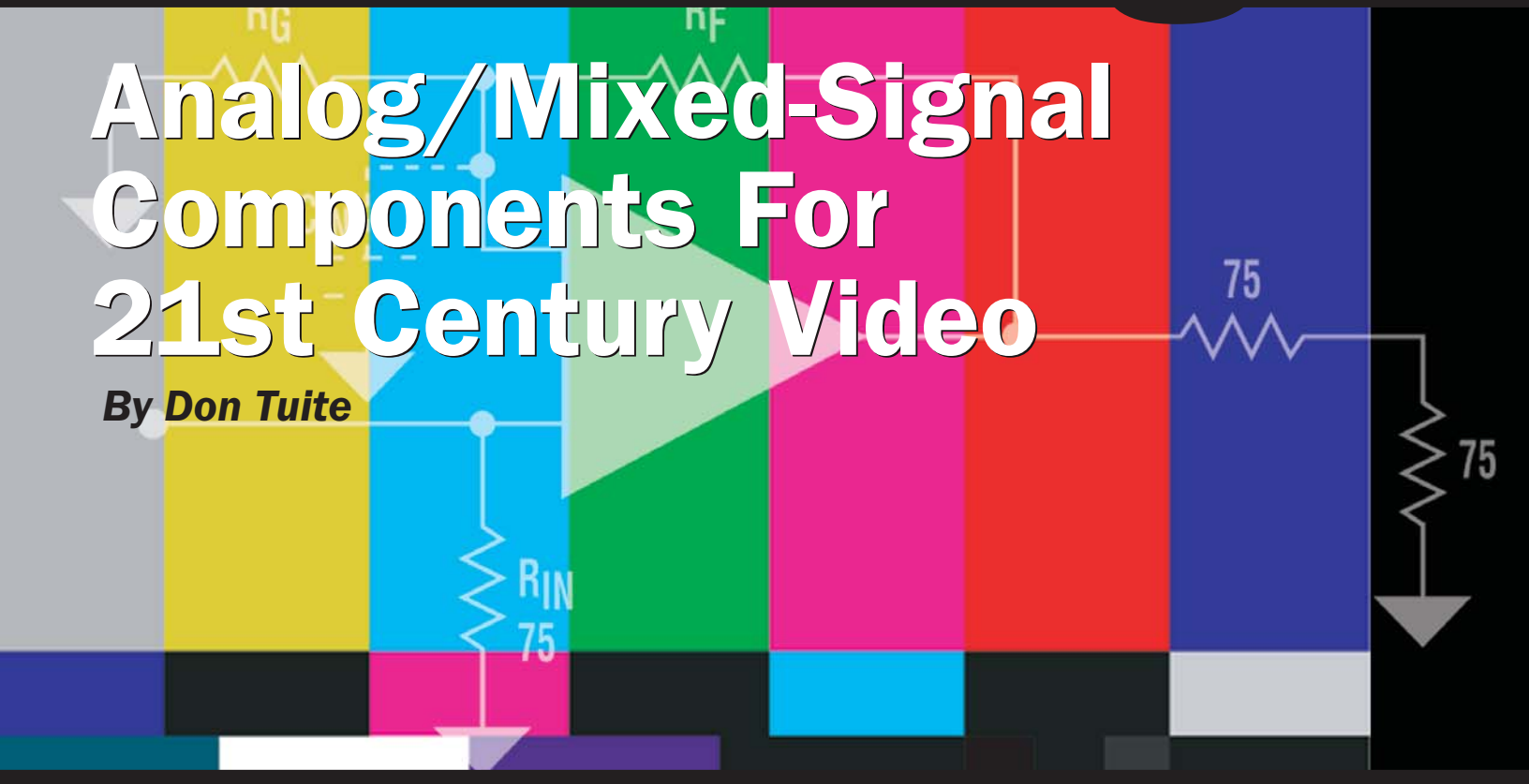


# electronic design

## Analog/Mixed-Signal Components For 21st Century Video

By Don Tuite



Sponsored by

 **National  
Semiconductor**  
*The Sight & Sound of Information*

 **Mouser**<sup>®</sup>

# Table of Contents

## Chapter 1. Basics

The Video Signal .....	3
Waveform Characteristics Relating to Op-Amp Selection .....	3
Color TV Encoding .....	4
Multimedia Color .....	4
Video Op-Amp Selection Criteria .....	4
DG and DP: Critical Characteristics for Composite Color .....	6
Amplifier Topology Considerations: VFB and CFB .....	6
Gain-Bandwidth Dependence in VFB Amplifiers .....	6
Practical Considerations in Designs Using VFB Op Amps .....	7
Current Feedback (CFB) Op Amps Are Different .....	8
CFB Slew Rate and Settling Time .....	8
Simpler Designs with CFB Programmable-Gain Buffers .....	9
VFB/CFB Tradeoffs .....	9

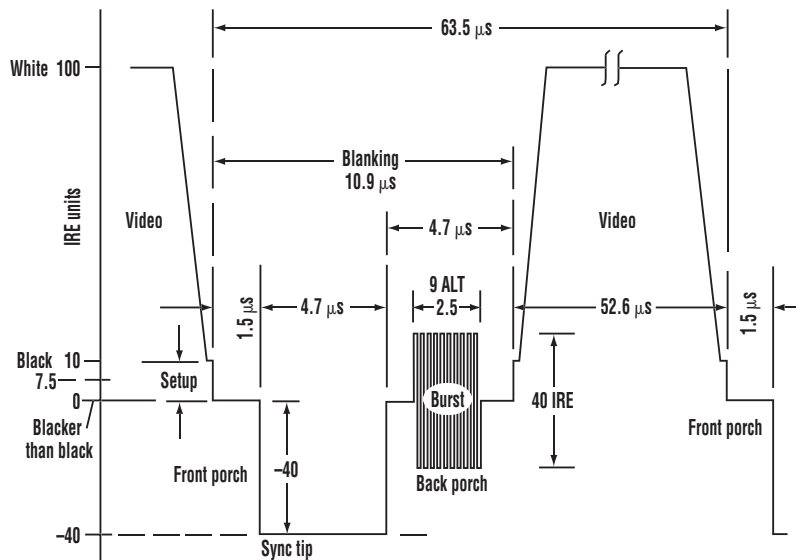
# Chapter 1

## THE VIDEO SIGNAL

In the analog domain, a video signal consists of a raster comprising a succession of amplitude-modulated scan lines. The number of scan lines containing picture data varies. North America's RS-170M/NTSC standard has 485 scan lines, while UXGA, a higher-resolution standard for computer displays, has 1600. The signal also contains synchronization pulses that add non-image lines.

Figure 1-1 shows the timing for one horizontal line of an RS-170M/NTSC signal. Waveforms in other standards are similarly broken up into an active picture area, a synchronizing pulse, and non-active areas. Called back and front porches, these non-active areas bracket the active pixel area.

The peak-to-peak signal level may lie between 0.7 and 2 V, depending on whether the signal is terminated or not. So, relative amplitudes are given in terms of IRE units, also called IEEE units. There are 100 IRE units from the reference level to peak white and 40 from the reference level to the tip of the synchronizing pulse. (Remember that for broadcast, the signal is inverted before it is applied to the modulator, so that the transmitter puts out maximum power only for sync tips. The signal is re-inverted in the baseband portion of the TV receiver. In computers and displays, the signal is never inverted, but some of the TV terminology lingers on.)



**1-1.** The voltage waveform of a single line of RS-170M/NTSC video comprises the amplitude- and phase-modulated video, synchronizing pulses, and a reference burst of color subcarrier. RS-170 is the International Standards Organization standard for monochrome video. The North American National Television Standards Committee (NTSC) protocol defines the color modulation characteristics. Because it encompasses both the amplitude-modulated black-and-white information and the phase- and amplitude-modulated color information, this is called a *composite* video signal. A number of schemes for *component* video exist. In these schemes, two or more signals carry the color information.

## WAVEFORM CHARACTERISTICS RELATING TO OP-AMP SELECTION

In a complete RS-170M/NTSC TV raster, each two-field frame has 525 lines, 485 of which are for display. The other lines carry vertical synchronizing pulses that

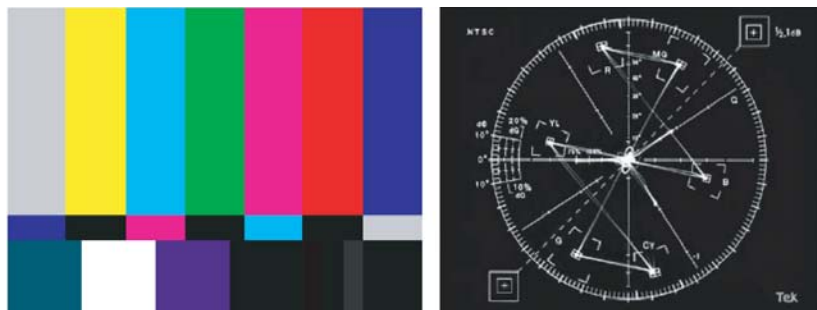
could be amplitude modulated with test signals or digital data. The line frequency is 15.734 kHz, with 30 frames consisting of 60 fields each second. One line sweep takes 63.56  $\mu$ s, and active video consumes 52.66  $\mu$ s of that. The other 10.9  $\mu$ s contain a synchronizing pulse (the “sync tip” in Figure 1-1) and eight cycles of color subcarrier (designated “burst” in Figure 1-1) that set the zero-phase reference for the line’s color information.

Although the picture information is analog, there are nominally 451 active pixels/line, as determined by the maximum transmittable video speed and the horizontal active time. Nominally, this suggests 52.7  $\mu$ s/451 pixels = 117 ns/pixel. Other video standards have their own specifications for these characteristics.

To minimize the transmit bandwidth required, RS-170 TV was limited to an update rate of 30 frames/s. But this was divided into 60 interlaced (alternating) fields/s, odd lines first, even lines next. (And yes, a 525-line frame means there is a half-line in each field.) Most computer display standards and many digital TV standards are non-interlaced or “progressive” scanned, so the field rate is the same as the frame rate.

### COLOR TV ENCODING

Analog TV standards encode color information on a monochrome video signal using a number of phase-modulation techniques (Fig. 1-2). When color was added to RS-170 monochrome, bandwidth did not have to increase, as the phase-modulated subcarrier’s frequency was selected to interleave the Fourier components of the phase-modulated color signal between the Fourier components of the monochrome signal. Where the monochrome components fall is determined by the horizontal and vertical timing characteristics of the signal.



**1-2. On the left is the standard Society of Motion Picture and Television Engineers (SMPTE) RS-170M/NTSC color-bar test pattern. On the right is a vector display of the chrominance (color) information on a Tektronix vectorscope display. (Hue is represented by angular displacement from the short vector that extends horizontally leftward from the center of the display. Vector length represents saturation.)**

### MULTIMEDIA COLOR

The alternative to phase-encoding color information, in composite video schemes, is to split the color signal into components. These may be Red, Green, Blue (RGB), and sometimes Luminance (Y), which corresponds to the monochrome video information. Alternatively, there may be two phase-shifted components, such as R-Y and B-Y. If the Rs, Gs, and Bs in any of these schemes are designated with primes (R', G', B'), that signal has been gamma-corrected for nonlinearities in the brightness characteristic of some particular type of display.

### VIDEO OP-AMP SELECTION CRITERIA

Designers who intend to use a particular op amp as a video cable driver or an “output” driver for

a back-panel connection on a TV or monitor must consider its small-signal half-power (–3 dB) bandwidth and its maximum slew rate. The required bandwidth and slew-rate characteristics depend on the video signals they must pass.

As noted earlier in this chapter, one can arrive at a rough estimate of pixel timing simply by dividing the time allotted by the video signal’s timing standards for a single pixel by the number of active pixels on the line. To refine that pixel time a little further, however, assume a video signal representing one white (full-scale) pixel, bracketed by two black pixels. Assume further that it will take as long as one-third of the total pixel time for the signal to ramp up to its final voltage and another third to ramp down, with a third of the pixel period spent maintaining the white level.

This implies that any op amp carrying the signal must deal with voltage transitions that occur in one-third the time allotted for a single pixel by the video-signal’s timing standards. The characteristic on the datasheet that affects this is the –3-dB bandwidth. Preferably, the datasheet should specify the op amp’s large-signal bandwidth. If it does not, use the small-signal bandwidth.

The internal op-amp design factors that influence –3-dB bandwidth are discussed later in this chapter. At this point, it is sufficient to say that assuming the op amp’s gain exhibits a single-pole (–6 dB/octave) roll-off, the required amplifier –3-dB bandwidth can be calculated using:

$$-3dBW = \frac{0.35}{pixeltime / 3}$$

Even though most systems aren’t exactly single-pole, this is an acceptable approximation.

A second and related datasheet characteristic, maximum slew rate, is equally important. While the –3-dB bandwidth is a measure of how fast the output can change for “small” input variations, the slew rate is a measure of speed when the output must make full output transitions (black to white or white to black). Assuming a 1.4-V maximum swing,

$$Slewrate \geq \frac{1.4}{pixeltime / 3}$$

The table lists characteristics of a number of video standards and calculates small-signal –3-dB bandwidths and slew rates for them in the two columns to the far right:

Standard	H pixels	V pixels	H% active	V% active	V frame rate (s <sup>-1</sup> )	Pixel time (ns)	1.3-pixel time (ns)	Required –3-dB bandwidth (MHz)	Required SR (V/μs)
<b>NTSC</b>	451	483	83	92	30	117.0	38.7	9	36
<b>PAL</b>	538	576	83	92	25	97.9	32.6	11	43
<b>DTV</b>	640	480	88	92	60	44.0	14.7	24	96
	704	480	82	92	60	37.1	12.4	28	114
	1280	720	78	96	60	13.5	4.5	78	314
	1920	1080	87	96	30	13.4	4.5	78	315
<b>VGA</b>	640	480	80	95	60	41.3	13.8	25	102
<b>SVGA</b>	800	600	76	96	76	20.0	6.7	53	212
<b>XGA</b>	1024	768	77	96	76	12.4	4.1	85	342
<b>SXGA</b>	1280	1024	75	96	76	7.2	2.4	146	587
<b>UXGA</b>	1600	1200	74	96	76	4.9	1.6	215	867

**DG AND DP: CRITICAL CHARACTERISTICS FOR COMPOSITE COLOR**

For composite, phase-modulated color-video applications, bandwidth and slew rate aren't the only limiting op-amp characteristics. To preserve color integrity in composite video, the analog processing path also must faithfully reproduce the subcarrier color modulation at any intensity or voltage level. True reproduction of this modulation involves both amplitude and phase, as they control the color saturation and hue, respectively. For an op amp, datasheet characteristics for these are differential-gain and differential-phase errors, or DG and DP.

Differential-gain errors occur when a video system doesn't process the chrominance signal amplitude consistently at all luminances. As a result, color saturation changes with luminance level. When a colored object moves from sunlight to shade, for example, the color intensity might increase or decrease abnormally.

Differential phase errors show up when luminance affects the chrominance phase angle so that colors change hue when picture brightness changes. In that case, when an object moves from sunlight to shadow, it might appear to change color.

In both DG and DP errors, the incorrect reproduction of color is most likely to occur in the high-luminance portions of the picture. Most professional video processing amplifiers require DG and DP to be less than 0.1% and 0.1°, respectively.

In computer applications, where the display information is represented by component voltage levels, system designers still may scrutinize DG/DP specifications in their evaluations and their part selections even though the displayed image doesn't use phase encoding.

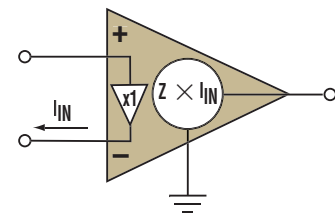
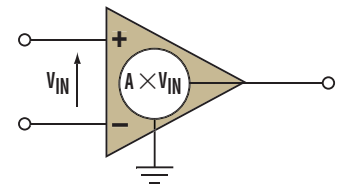
**AMPLIFIER TOPOLOGY CONSIDERATIONS: VFB AND CFB**

Internal architecture influences the critical op-amp characteristics for video applications. Operational amplifiers may be designed in one of two internal feedback topologies: voltage-feedback (VFB in Figure 1-3) or current-feedback (CFB in Figure 1-4). Each introduces some tradeoffs. The VFB topology is the more common, but the CFB architecture has certain advantages in some applications.

**GAIN-BANDWIDTH DEPENDENCE IN VFB AMPLIFIERS**

Though an ideal VFB op amp's open-circuit gain is very large and independent of input frequency, in a real-world VFB, the

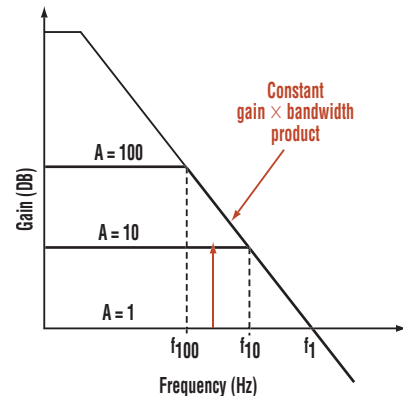
**1-3. In VFB amps, a voltage-gain stage in effect controls the output voltage. A very large dimensionless gain constant, A, multiplies the voltage difference between the two inputs. In a VFB amp, the output usually connects through a resistor to the inverting input to provide negative feedback. When that connection is made, the output changes to drive the voltage difference between the inverting and non-inverting input to zero.**



**1-4. Topologically, CFB amps differ from VFB amps in two important ways. For one thing, they have a unity-gain buffer between the non-inverting and inverting inputs. The buffer tends to have a very high input impedance and a very low output impedance. The other difference is that output voltage is controlled by a transfer function, operating on the current flowing through the buffer. This current is multiplied by a transfer impedance, Z, which is made large by design. In a CFB with negative feedback, the signal from the output will attempt to drive the error current (that is, the inverting input current) to zero (hence the term "current feedback").**

open loop gain is large at dc. But after a certain point, it rolls off at 6 dB/octave. As open-loop gain decreases with increasing frequency, the loop gain (essentially the difference in dB between the op amp's open-loop gain and its closed-loop gain) of the amplification stage is reduced. In an ideal inverting stage with a very high open-loop gain, the ratio of the feedback impedance to the input impedance (or 1 + that ratio in a non-inverting configuration) sets closed-loop gain. When increasing frequency causes the non-inverting open-loop gain of an op amp to fall off to the point at which it equals the closed-loop gain nominally set by the resistor ratio, the actual gain of the closed-loop configuration will be 0.707 times its dc value. The frequency at which this occurs is the datasheet characteristic called the -3-dB bandwidth.

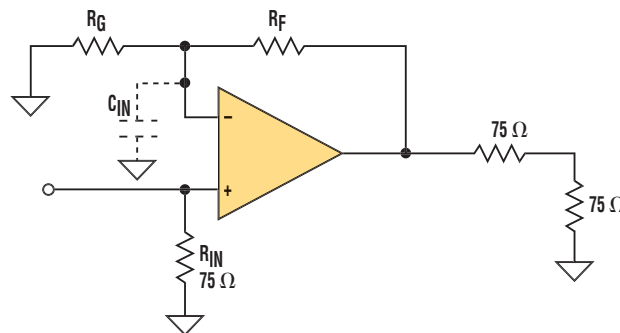
**1-5. In a VFB op amp, a circuit configured for a gain of 100 can only reproduce a sinewave input equal to 1/100th of the frequency reproduced by a configuration set for a gain of one. (The frequency of the inflection point in this figure is very low. It's on the order of a few hertz for low-frequency VFB op amps and in the range of 5 to 10 kHz for high-speed VFB amplifiers.)**



The product of a VFB op amp's closed-loop gain and the resultant bandwidth (called its gain-bandwidth product, or GBWP), does not vary for a certain range of frequencies. In consequence, for any given real-world VFB amplifier, one may design a circuit with high gain or high bandwidth, but not both (Fig. 1-5).

**PRACTICAL CONSIDERATIONS IN DESIGNS USING VFB OP AMPS**

With a VFB op amp, the circuit designer is essentially free to choose the value of the feedback resistor. But for video and any other high-speed, high-performance system, some higher-order effects limit this freedom. The amplifier, pc-board layout, and individual components around the op amp exhibit inherent parasitic capacitances. One example of what could happen is illustrated in Figure 1-6.



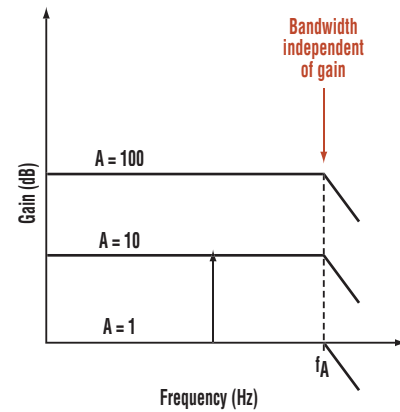
In the example in Figure 1-6, the input capacitance  $C_{IN}$ , which represents the combined input parasitic capacitance, creates a pole in the feedback network that will tend to increase the phase shift around the loop. The pole's frequency is given by:

**1-6. This is an example of the effect of parasitic input capacitance. For this video amp configured for a gain of +2, and with the input terminated in 75 Ω, the inverting node capacitance dictates the maximum resistor values as described in the text.**

$$F_P = \frac{1}{2\pi \frac{R_G R_F}{R_G + R_F} C_{IN}}$$

A typical input capacitance in such a case might be around 3 pF. So using values of 2 kΩ for  $R_F$  and  $R_C$ , this pole will occur at around 53 MHz. Therefore, if the amplifier has a GBWP wider than 100 MHz, it will have a phase margin less than 45°. Phase margin is the phase shift around the loop (measured relative to 180°) when the loop gain is unity. A large phase margin (~90° and higher) means the circuit is over-damped. Smaller phase margins (down to ~30°) will exhibit some degree of ringing.

In that case, the overall circuit will end up somewhat unstable and tend to exhibit overshoot in the time domain and peaking in its frequency response. This illustrates the need to keep the value of resistors low to ensure the cleanest frequency response for a given application.



**1-7. CFB op amps are compensated for maximally flat response with a specified feedback resistor.**

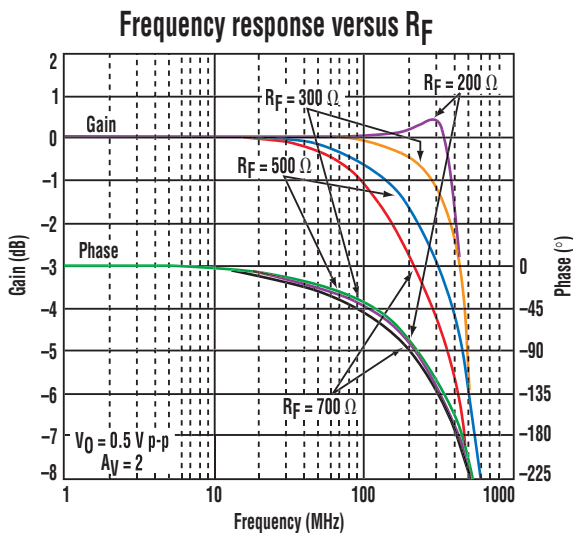
**CURRENT FEEDBACK (CFB) OP AMPS ARE DIFFERENT**

Like a VFB, a CFB op amp’s closed-loop gain is based upon the external components. But as Figure 1-7 illustrates, it is independent of frequency over the meaningful range of the operation of the CFB, as a first order approximation. Beyond the start of roll-off at point  $f_A$ , the CFB amplifier exhibits the frequency-attenuation characteristics of the VFB. At high frequencies, this relationship allows for increased performance in terms of distortion and bandwidth per milliamp of supply current.

In terms of external components, the CFB amp has less flexibility than the VFB amplifier. This shows up as a limited range for feedback resistors. Unlike the VFB op amp, which allows a very wide range of feedback resistor values,  $R_F$  in a CFB amplifier is specified as a design parameter. Within the allowable range, however, the equipment design engineer can control the frequency response of the amplifier. To illustrate, Figure 1-8 shows empirical data for a typical CFB op amp.

**CFB SLEW RATE AND SETTLING TIME**

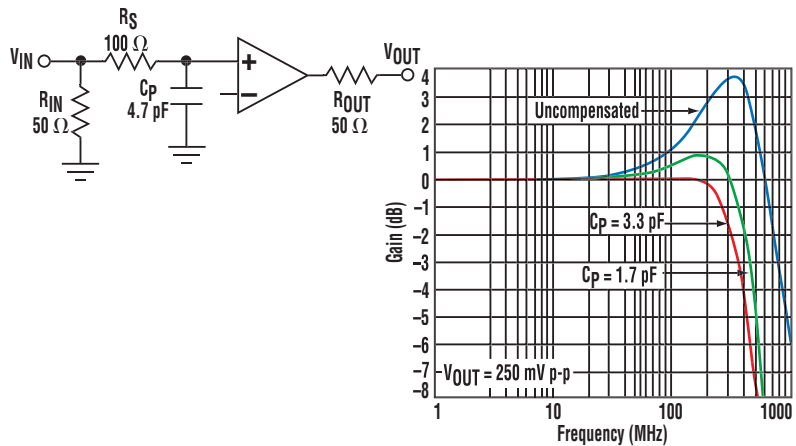
In addition to being free from GBWP limiting, CFB op amps do not experience slew-rate limiting. As with frequency response,  $R_F$  alone governs CFB transient response.



**1-8. This plot comes from the datasheet for National Semiconductor’s LMH6715. With gain fixed at +2, the graph plots amplitude and phase for a range of frequencies. Higher values of  $R_F$  result in the onset of amplitude roll-off at a lower frequency than does a lower value. In this case, a 700-Ω feedback resistor produces a 1-dB roll-off at 100 MHz, whereas a 300-Ω resistor produces a 1-dB roll-off at 300 MHz. Notice that the phase response for each value of  $R_F$  does not change dramatically. Also, note that the feedback-resistor is limited to a range from 200 Ω to about 700 Ω.**

**SIMPLER DESIGNS WITH CFB PROGRAMMABLE-GAIN BUFFERS**

Programmable-gain buffers, or PGBs, are op amps whose gain-setting resistors are built-in. Gains of +2, +1, or -1 are readily realizable by choosing the appropriate signal and ground connections. These devices allow for tighter layout, less parasitic capacitance, and better tracking between channels within a package (Fig. 1-9).



**1-9.** With a current-feedback PGB, like this LMH6739, the built-in feedback resistor is a compromise between the value needed for stability at unity gain and the optimized value used at a gain of +2. The result is substantial peaking in some cases at unity gain, as can be seen for the curve labeled “uncompensated.” If this peaking is undesirable, a simple RC filter at the input of the buffer will smooth the frequency response. This is shown in the figure by the curves labeled  $C_p = 1.7 \text{ pF}$  and  $C_p = 3.3 \text{ pF}$ .

**VFB/CFB TRADEOFFS**

Given their gain-bandwidth disadvantages, why do engineers continue to design circuits with VFB amplifiers? For one thing, VFBs offer lower noise and better dc performance than CFB op amps. Also, VFB amplifiers can be employed as integrators simply by using a capacitor as the feedback impedance. In contrast, CFB op amps must avoid a direct capacitance between the output and the inverting input. There are workarounds, but they add some circuit complexity.

Voltage-feedback op amps and current feedback op amps each have their own range of recommended applications. CFB op amps are chosen when slew rate and exceptionally low distortion are needed. VFB op amps excel for dc applications, for applications requiring low input bias current or high input impedance, and where rail-to-rail performance is critical. As a general rule, CFB amplifiers often are preferred for high-speed applications such as video. VFB op amps are ubiquitous and used for low, medium, and high-speed applications.