



High Speed Amplifiers for Video Applications

**Hooman Hashemi
Applications Engineer
Amplifier Products**

INTRODUCTION

MODERATOR:

Hello and welcome to today's National Semiconductor Online Seminar. I'm Michelle Miller and I will be your host. Before we begin, I'd like to go over the operation of your seminar interface. Slides will appear in the upper right section of your interface. If you wish the slides to be larger, click the "Enlarge" button. Slides will automatically advance or you can click on the slide title in the list on the left to jump to the place in the presentation. At the bottom of the interface is an interactive Web browser set to a Web page containing additional resources for this seminar. Questions may be submitted at any time and the presenter will respond via email. To ask a question, click the "Ask A Question" button, then fill in the form that appears, and then submit the form. Finally, National Semiconductor owns and is responsible for all the content in this seminar. Today's topic is High Speed Amplifiers for Video Applications. Today's seminar will be given by Hooman Hashemi, the Applications Engineer from the Amplifier Products line. Welcome, Hooman.

HASHEMI:

Thank you, Michelle. Hello, everyone. My name is Hooman Hashemi. I'm with the Amplifier Applications Group. Today, we'll be discussing Op Amp solutions to some common video applications.



What is covered

- **Analog Video Waveform**
- **Displaying the Video Signal**
- **Which Op Amp type fits video best?**
- **DC / AC Coupled Amplifiers, Single Supply Operation**
- **Video Multiplexing**
- **Video Transmission & Equalization over UTP**
- **Getting the heat out**



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Along the lines, we'll be going over some technical details necessary to understand the requirements of the amplifiers specified and used in analog video circuits. The discussion is limited to video applications only. First, we'll go over standard analog video signal and its characteristics. Then, we will consider what is involved in displaying that video signal on a display screen. Next, we shall show examples of DC coupled, AC coupled, and single supply amplifier designs. The output characteristics of the Op Amp are discussed as they pertain to driving a video-specific load. The task of switching between multiple sources is usually performed with video MUXs. We will explore a way to do this using a special Op Amp. Then, we will briefly discuss transmission of analog video over unshielded twisted pair, or UTP wire, which is often a low-cost approach. At the receiving end, you can do things to improve the received signal to remove some artifacts introduced by the cable and so on. And finally, we will briefly show you how to make sure a high-power device keeps its cool.



Next Topic

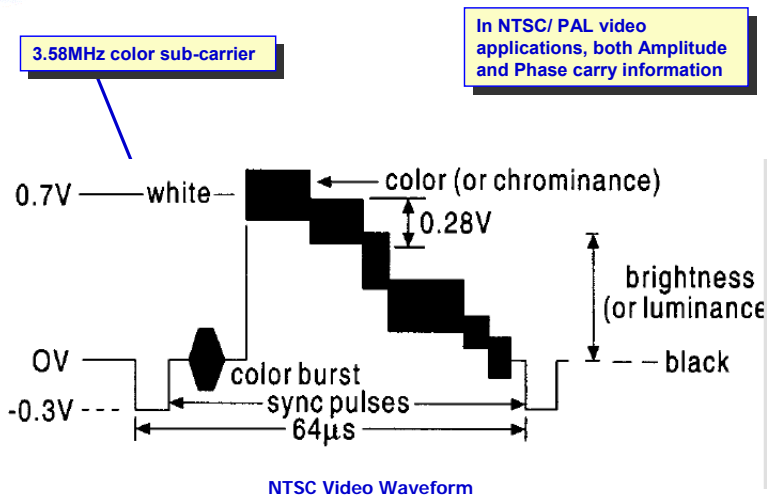
- **Analog Video Waveform**
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ANALOG VIDEO WAVEFORM

Composite Analog Video Waveform.



Composite Analog Video Waveform



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Here is the standard composite video waveform which is standard for both TV and standalone monitors. Timings and levels specified correspond to the NTSC standard which is not far from the values used in the PAL system. Note that to preserve color integrity the analog processing path should faithfully reproduce the 3.58 megahertz color modulation at any intensity or voltage level. The true reproduction of this modulation involves both amplitude and phase since these control the color depth and hue, respectively. This is what is referred to as Differential Gain and Differential Phase or Diff Gain, the DG and DP in the literature. Most professional video processing amplifiers require DG and DP to be less than .1% and .1 degrees, respectively.

In PC multimedia applications where the display information is in the form of analog red, green, blue or RGB voltage levels, the color sub-carrier is not used. In such a system, the sync and video levels for each color are the same as what is shown here minus the 3.58 megahertz carrier. We find that many designers of such systems still rely on the DG/DP specifications in their evaluations and their part selections even though, strictly speaking, the displayed image does not use this encoding scheme.



Next Topic

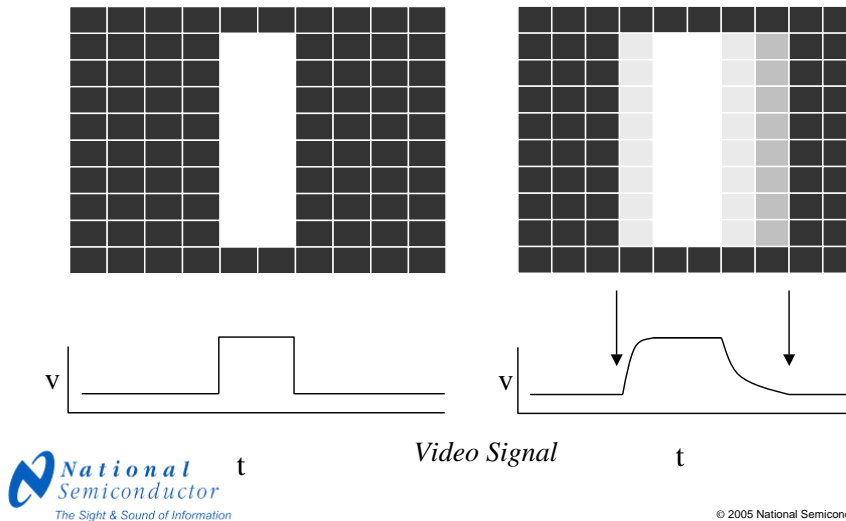
- *Analog Video Waveform*
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DISPLAYING THE VIDEO SIGNAL



High Speed Op Amp Applications

Video Raster Display



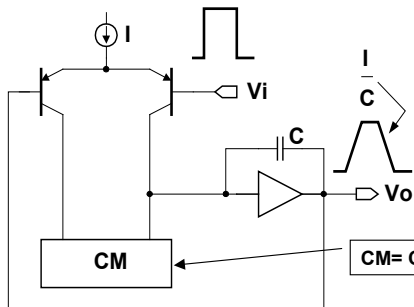
DISPLAYING THE VIDEO SIGNAL

High Speed Op Amp Applications, Video Raster Display. Rise and fall times are critically important to the faithful reproduction of video on a raster scan display. The black-to-white luminance signal, amplitude of a video signal is such that video amplifiers should be chosen for both bandwidth and slew rate performance. Video signals for distribution are in the range of 1.5 to two volts. To faithfully reproduce video signals of high quality, the overall speed and slew rate must be appropriate. Understanding the slew rate performance is important because in most video designs, the intent is to avoid slew rate limitation in the amplifier. A slew rate condition indicates the feedback control loop is unable to track the input signal for a portion of the input signal. Video circuits should be designed to avoid this condition, of course. Higher bandwidth, lower settling time, and higher slew rate are all factors in keeping the feedback in operation throughout the input cycle. The clean black-to-white and white-to-black transitions shown on the left-hand side, require the clean drive signal shown below the drawings. Failure to faithfully reproduce the signal on the left due to amplifier limitations will result in the degraded signal shown in the lower right. The signal applied to a video display will produce the degraded result shown in the screen drawing on the upper right-hand corner. A high-quality, high-speed amplifier with video speed, slew rate, and Diff Gain and Diff Phase is crucial to faithful video reproduction.



Slew Rate Analysis

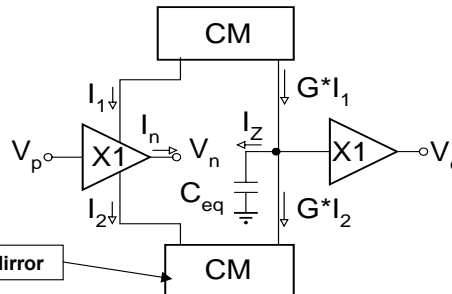
Voltage Feedback



All the current for charging and discharging C comes from current source I. This is the slew rate limitation in VFA.



Current Feedback



The current needed for slewing the node at Z comes from current mirrors $G \cdot I_1$ and $G \cdot I_2$. Larger step inputs causes greater I_1 - I_2 and produce larger output slew rates.

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One of the two important differences between voltage feedback, VFB, and current feedback, CFB, amplifiers is the capability of the CFB amplifier to produce higher slew rates than the VFB for the same quiescent current and process conditions. The other difference is the relative independence of gain bandwidth in the CFB amplifier. The VFB Op Amp is limited in slew rate by the ability of that circuit configuration to charge and discharge the inter-stage capacitor C in the voltage feedback schematic on the left-hand side. The current source I, which supplies the balancing currents to the input differential pair, is the sole source of current available to charge and discharge C when the circuit is under large signal, slew rate conditions. Since a current source supplies the same current under all conditions, charging and discharging are limited to I regardless of the magnitude of the input signal applied to the Diff Pair.

In the case of the CFB amplifier on the right-hand side C equivalent, C_{eq} , the gain node capacitance, is charged by the balanced current sources CM which produce current I_Z . By the way, CM is current mirror abbreviation. This becomes the charging and discharging current for C equivalent or C_{eq} . However, this current is not limited by the Diff Pair current source current as in the case of the VFB. Rather, this capacitance is charged and discharged by the delta current I_Z supplied by the current mirror. These matched current mirrors, CMs, are responding to the magnitude of I_N which is driven by the input signal. Thus, the charging current for the equivalent capacitance, which becomes the slew rate limitation in a CFB Op Amp is proportional to the input signal and would be theoretically limited only by the size of the current mirror transistors. This is different than the VFB design architecture.



Bandwidth and Slew Rates Needed for Various Monitor Line Rates

Line Rate (HXV)	Name	Refresh (Hz)	Pixel Time (ns)	Rise Time (ns)	BW (MHz)	SR (V/us)
451x483	TV_NTSC	29.97	118.09	39.36	9	36
640x480	VGA	60	44.05	14.68	24	95
1024x768	XGA	76	12.26	4.09	86	343
1600x1200	UXGA	76	4.88	1.63	215	860

$$\text{-3dB BW} = 0.35 / \text{Rise Time}$$

$$\text{SR} \sim 1.4\text{V} / \text{Rise Time (where 1.4V is the total voltage swing)}$$

Video BW and Slew Rate are defined by the number of pixels displayed in a horizontal line time



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These are some of the more common line rates in use today. As it can be seen from this chart, at higher line rates, the bandwidth and slew rate requirements on the Op Amp could be demanding. When used in a gain of +2 configuration amplifying and buffering a video signal, the amplifier output could see voltage excursions of up to 1.4 volt peak-to-peak. In every case shown here, it is assumed that the video could take as long as one-third the total pixel time in order to reach the final voltage. Another one-third is for keeping the pixel potential and the last one-third for reverting back to the original voltage level. Obviously, the worst case would be alternate white and black pixels or on and off pixels.

Assuming a single pole roll-off, the amplifier speed can be effectively related to the sine wave concept of bandwidth through the expression bandwidth is equal to .35 divided by rise or fall time. Even though most systems are not exactly single-pole, this relationship is a good approximation. The terms rise time is generally reserved for small signal and it refers to the time it takes the signal to travel between 10% and 90% of the final voltages. Generally speaking, an amplifier rise time would start to deteriorate as the amplitude is increased if the slew rate required is larger than what the amplifier is capable of. In a voltage feedback Op Amp, this is generally set by the amount of current available to charge the internal dominant pole capacitor as we have already seen in the previous foil. We can use the small signal rise time number to arrive at the amplifier slew rate because we know the total voltage swing to be around 1.4 volt peak-to-peak.



Calculation of BW and SR for a given Line Rate

Line Rate (HXV)	Name	Refresh (Hz)	Pixel Time (ns)	Rise Time (ns)	BW (MHz)	SR (V/us)
451x483	TV_NTSC	29.97	118.09	39.36	9	36
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1024x768	XGA	76	12.26	4.09	86	343
1600x1200	UXGA	76	4.88	1.63	215	860

Sample Calculation:
 Rate: 640 x 480 (HxV), 60Hz
 Refresh:
 Assume: 89% & 92% active time
 for Vert. & Horiz. Respectively
 Assume 1/3 pixel time devoted to
 rise/ fall times of the 1.4Vpp signal

$$Rise/Fall_Time = \frac{1}{60Hz} \times 0.89 \times 0.92 = 14.7ns$$

$$-3dB_BW = \frac{0.35}{Rise/Fall_Time} = 24MHz$$

$$SR(V/us) = \frac{1.4V}{Rise/Fall_Time} = 95(V/us)$$



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Here's a sample calculation done for the VGA line rate shown. For any line rate, you can plug the appropriate number in the equations shown here. But you must know the percentage of active times, the total time for both the horizontal and vertical scan, in order to do so. Here, you see the line rate information is plugged directly into the equation for rise/fall time to arrive at the 14.7 nanosecond value. This will then be used to come up with the 24 megahertz for bandwidth in the lower equation and 95 volt per microsecond for slew rate. That's how the values in the table are tabulated here.



Next Topic

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- *Displaying the Video Signal*
- ***Which Op Amp type fits video best?***
- *DC / AC Coupled Amplifiers, Single Supply Operation*
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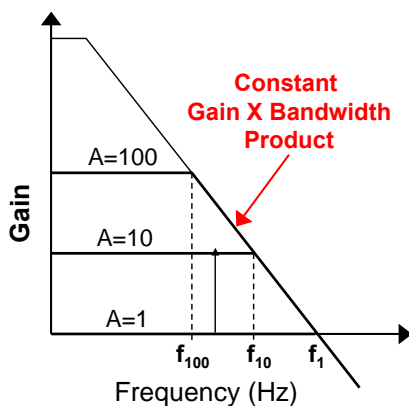
WHICH OP AMP TYPE FITS VIDEO BEST?

Which Op Amp type fits video best?

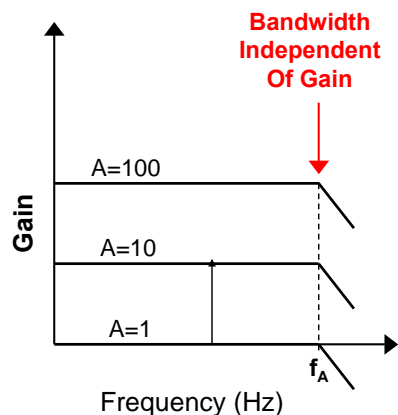


Gain Bandwidth Relationships (1st Order Approximation)

Voltage Feedback



Current Feedback



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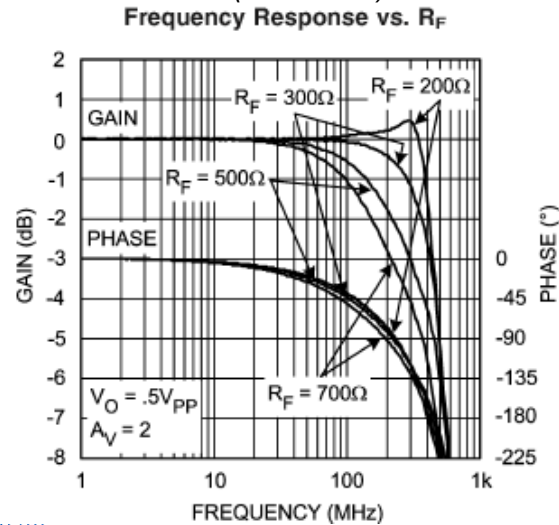
Another important difference between the VFB Op Amp and the CFB Op Amp is in the inherent relationship between gain and bandwidth. The VFB produces a constant gain times bandwidth product as diagrammed in the left-hand figure. If the external circuit is configured for a gain of 100, for example, the maximum frequency for which the circuit will faithfully reproduce a sine wave input is 1/100th of the frequency that such an input signal will be faithfully reproduced if the external configuration is for a gain of one. This relationship is easily remembered as the gain-bandwidth product for the IC. The point of inflection for an Op Amp is very low, of the order of a few hertz for low frequency VFB Op Amps and in the range of five to 10 kilohertz for high-speed VFB amplifiers. That's referring to that dominant pole shown on the left-hand side of your figure. The slope of the gain-bandwidth product is the familiar one pole roll-off or six db per octave or 20 db per decade that we all know.

In the case of the CFB Op Amp, the gain setting is based upon the external components is independent of the frequency over the meaningful range of the operation of the CFB. Beyond the commencement of roll-off at point f_A , the CFB amplifier exhibits the frequency attenuation characteristics of the VFB. This relationship allows for increased performance in terms of distortion and bandwidth per milliamp of supply current at high frequencies. The CFB amplifier is less flexible, however, in terms of external components than is the VFB amplifier. This will be seen in the limitations on the selection of the feedback resistor, R_F , as will be discussed in the next foils.



Optimum Performance Selecting a Feedback Resistor

(LMH6715)

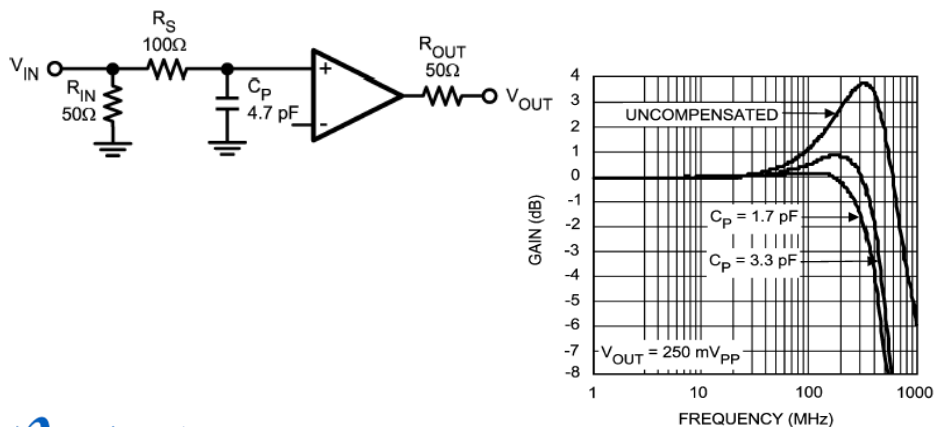


Unlike the VFB Op Amp which allows a very wide range of feedback resistor values, R_F in a CFB amplifier is specified as a design parameter. Within the allowable range, however, the equipment design engineer can control the response of the amplifier, particularly with regard to the amount of peaking needed in the circuit design. This chart shows the empirical data for one National Semiconductor CFB Op Amp, the LMH6715. The gain is fixed at +2 and the amplitude and phase is plotted here for a range of frequencies. Higher values of R_F such as 700 ohms result in the onset of amplitude roll-off at a lower frequency than does a lower value R_F such as 300 ohms. For example, a 700 ohm R_F produces a one db roll-off at 100 megahertz, whereas a 300 ohm resistor produces a one db roll-off at 300 megahertz, much higher. Notice the phase response for each does not change dramatically. Also, note that the R_F range is confined to the range of 200 ohms to about 700 ohms as shown here.



Programmable Gain Buffers

- Correct for Unity Gain Peaking!



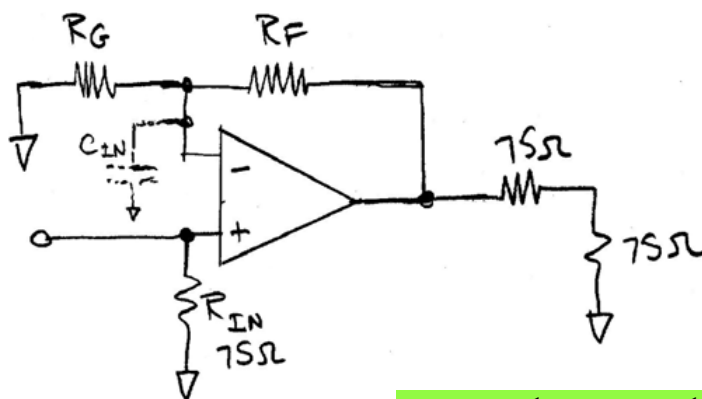
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Programmable Gain Buffers. These are – PGBs is what we call them – are Op Amps with the gain setting resistors built-in. With a current feedback PGB, like the LMH6739, the feedback resistor is a compromise between the value needed for stability at unity gain and the optimized value used at a gain of +2. The result of this compromise is substantial peaking in some cases at unity gain as you can see here. If this peaking is undesirable, a simple RC filter at the input of the buffer will smooth the frequency response as shown. The graph shows the results of a simple filter placed on the non-inverting input in the schematic to the left.



Resistor Value Limitations for VFB amplifiers



Pole Generated due to C_{in} :

$$f_p = \frac{1}{2\pi \frac{R_g \cdot R_f}{R_g + R_f} C_{in}} = \frac{1}{2\pi R_{eq} C_{in}}$$



Avoid high value resistors in high speed circuits

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In a voltage feedback amplifier, VFB, the user is free essentially to choose the value of the feedback resistor he chooses. However, for video, as well as any other high-speed, high-performance system, the higher order effects limit this selection. The amplifier, PC board layout, individual components around the Op Amp have inherent parasitic capacitances of which the input capacitance on the inverting input is shown here. In a video amplifier in a gain of +2 configuration with input terminated in 75 ohms, the inverting node capacitance is the one which dictates the maximum on R_F and R_G values.

In the case shown, the input capacitance, C_{IN} , will form a pole in the feedback. This pole is given by the expression shown and will have a tendency to increase the phase shift around the loop. With a typical input capacitance of around three pF using 2 kilo ohms for R_F and R_G , will result in this pole to be at around 53 megahertz. So, if the amplifier in use has a gain bandwidth product larger than 100 megahertz, it will have a phase margin less than 45 degrees. The result is that the overall amplifier will be less stable and tends to have overshoot in the time domain and frequency response peaking. Therefore, it's best to keep the value of resistors low to the point that for a given application, no significant poles are introduced to get the cleanest frequency response.



Choose Current Feedback for:

- *Better distortion for a given bandwidth*
- *Best slew rate*
- *Ability to change gain without changing bandwidth*

Choose Voltage Feedback for:

- *Best DC precision*
- *Low current bias applications*
- *Rail-to-rail performance is needed.*



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Which amplifier type would you choose? 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 exceptional 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 will be offered for high-speed applications, whereas VFB Op Amps are ubiquitous and used for low, medium, and high-speed applications.



Some High-Speed Op Amps & Buffers For Video Applications

National CFB Video Amps				National VFB Video Amps			
Slew Rate V/ μ S	BW	DG/DP		Slew Rate V/ μ S	BW	DG/DP	
LMH6714/20/22	1800	400	0.01/ 0.01	LMH6642/3/4	125	135	0.17/0.05
LMH6718%	600	110	0.04/ 0.03	LMH6654/5	200	130	0.01/ 0.03
LMH6715	1300	400	0.02/ 0.02	LMH6657/58	700	100	0.03/ 0.1
LMH6732*	2700	540	0.03/ 0.01	LMH6639	170	145	0.12/ 0.05
LMH6702	3100	720	0.03/ .007	LMH6609	1400	280	0.01/ 0.03
LM6181	1400	100	0.05/ 0.04				
LMH6559&	4580	1750	0.06/ 0.02				
LMH6560&	2700	680	0.1/ 0.03				
LMH6738/ 39%	3300	480	0.02/0.01				
LMH6723/24/25	600	260	0.03/0.11				
LMH6703	3000	450	0.02/0.02				
LMH6704	3000	450	0.02/ 0.02				

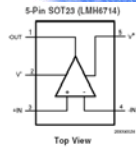
*: Programmable Supply Current
 &: Closed Loop Buffer
 %: Programmable Gain Buffer

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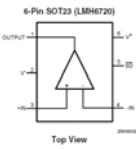
So the parameters of importance are bandwidth, slew rate, Diff Gain/Diff Phase in the case of NTSC or PAL video, and to some lesser extent output current capability, power dissipation, operating supplies, etc. Here is a list of parts with these characteristics in mind. As you can see, both CFB and VFB devices have been shown as they are both suitable for these applications. Also other devices, such as Programmable Gain Buffers, Closed Loop Buffers, etc. are included for completeness. Most of these devices are manufactured on National's VIP10 process which has trench isolation between transistors thereby improving speed by lowering capacitance especially at lower operating supply voltages.



A Family of Op Amps for High Performance Video Applications

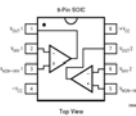


LMH6714 – Single



LMH6715 - Dual

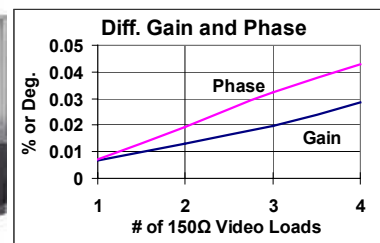
**LMH6720 – Single
w/ Shutdown**



LMH6722 - Quad

Key Specifications

- DP of 0.01° and DG of 0.01%
- Wideband: 400 MHz SSBW, Av=+2
250 MHz 2Vpp BW, Av=+2
- Fast slew rate: 1800 V/μs
- 0.1 dB Gain Flatness: 120 MHz
- I_{supply} = 6mA per amplifier
- Available in SOIC and SOT23 Packages
- Applications: HDTV, NTSC & PAL video systems, Video switching, Wideband active filters, cable drivers, Set-top Boxes



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National Semiconductor makes high-performance video ICs in a variety of configurations and packages. The LMH6714, 6715, 6720, and the 22 family features excellent Diff Gain and Diff Phase specs of only .01 degrees and .01%, respectively. These devices exhibit gain flatness out to – .1 db out to about 120 megahertz. The single, dual and quad versions are the 6714, 15, and 22, respectively. The single device with shutdown is designated the LMH6720. These current feedback devices provide a two volt peak-to-peak bandwidth of 250 megahertz typically and a slew rate of 1,800 volts per microsecond which is adequate for most video applications. These ICs are well suited for middle and high-end video applications in video switching, cable systems, and set-top boxes.

Note the graph in the lower right-hand corner. This is a plot of Diff Gain/Diff Phase as function of number of 150 ohm loads being driven by this device. Note that this device family can be used as a video distribution amplifier where one device could drive up to four video loads with Diff Gain/Diff Phase under .01% and .05 degrees, respectively.



Multiple Op Amps (& Other Amplifier Configurations) Best Suited to RGB Video

Device	Large Signal BW (LSBW) (MHz)	# of Devices/Package	Description
LMH6683	120	3	VFB Op Amp
LMH6738/ LMH6739*	400	3	CFB Op Amp / PGB*
LMH6722	250	4	CFB Op Amp
LMH6725	95	4	CFB Op Amp
LMH6644	30	4	VFB Op Amp

Large Signal Bandwidth (LSBW) combines Small Signal BW & SR into one number

*: Programmable Gain Buffer

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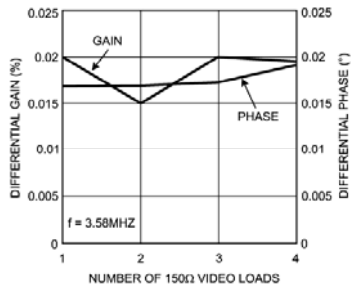
When dealing with RGB, red, green, blue signals, as would be the case with PC or multimedia applications, there are triple and quad devices in a package which simplify signal routing and making for a compact bank of amplifiers in a small space. The devices listed here are good choices to be considered in these instances.

You will note the arrow pointing to the device in the bottom middle of the slide. This is a Programmable Gain Buffer, in this case for the LMH6739. As you can see, with a device like this, the gain setting resistors are built into the package and manufactured right on the die. What does this buy for you? Well, this allows you to eliminate some external components in tight layouts and in the case of the 6739, with three devices inside, this offers a great advantage. In addition, this maximizes speed as it reduces the capacitance on the critical input junction which could otherwise slow the overall response. Finally, because the resistors are in intimate contact with the die and they have closer temperature coupling, better temperature tracking is obtained and also the individual amplifiers inside would have better matching as well.

You will note that the Large Signal Bandwidth, LSBW, is highlighted in this slide. This parameter is specified for many of the higher-speed amplifiers that National manufactures. It is generally measured at two volts peak-to-peak. LSBW is a good measure of attainable speed when you're dealing with video signals since, as we have already discussed, analog video is generally at around the two volt peak-to-peak level in the video pre-amp stages.



National's "Multiple Load" Cable Driver Offerings



LMH6715 DG/DP Performance as a function of number of loads

Device	DG (%)	DP (deg.)	# of 150ohm loads	Description
LMH6715	0.02	0.02	4	Dual 400MHz (Av=+2) Op Amp
LMH6714/ LMH6720/ LMH6722	0.03	0.045	4	Single (shutdown option) & Quad 250MHz Op Amp



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On the left-hand side of this slide, you see the graph from the LMH6715 data sheet. This plot shows what kind of Diff Gain/Diff Phase the 6715 is capable of even when driving more than one load or four to be exact in this case. You can see that the Diff Gain/Diff Phase numbers are less than .02% and .02 degrees for all loads shown. On the right, you see the Op Amps produced by National which meet the requirement of having low Diff Gain/Diff Phase errors with multiple loads.