TEXAS INSTRUMENTS

AN-549 LM6361/LM6364/LM6365 Fast VIP Op Amps Offer High Speed at Low Power Consumption

ABSTRACT

The LM6361/LM6364/LM6365 family of op amps are wide-bandwidth monolithic amplifiers which offer improved speed and stability over many other op amps, at low cost, with little-to-no penalty in power supply consumption.

Contents

## List of Figures

1   Introduction

These advantages are due to a new process, developed by Texas Instruments, which provides lateral PNP transistors with nearly the gain and speed characteristic of NPN transistors—while the NPNs maintain their usual high performance. This allows the use of both NPN and PNP transistors in the signal path, where previously the PNP transistors severely limited the speed of linear devices. (Standard lateral PNPs have 1/10th the gain and 1/200th the bandwidth of standard NPN transistors.)

Traditional high-speed op amps often either used all-NPN circuitry, which usually severely limit the input, output, and power supply voltage ranges; used feed-forward techniques (which reduce stability); or resorted to costly hybrid design. Amplifiers made from this new process (dubbed VIP, for "Vertically-Integrated PNP") operate from a 5V to 30V (total) supply voltage, and have standard input and output voltage ranges. In addition, they require comparatively little supply current, and are available in standard 8-pin dual-in-line packages.

The first devices produced with this process are three op amps each with the same basic design but compensated to different degrees. The schematic of the unity-gain-stable LM6361 (see Figure 1) has a simple but effective form. The VIP transistors can now be used in the signal path, so a fairly traditional NPN differential input stage can be followed by a folded cascode wide-bandwidth gain stage. The input stage uses emitter-degeneration resistors to reduce its transconductance (G_m). The bandwidth of the amplifiers is then set by the ratio of G_m to compensation capacitance. This also determines the stability of the amplifier.

The compensation capacitance is stray capacitance (about 0.5 pF) that is seen lumped together at the front of the output stage. This output stage has a classic AB design, but since it contains a VIP transistor it has the speed necessary for a high speed amplifier. Additional capacitance on the output effectively increases the total compensation capacitance, increasing the stability of the amplifier but also reducing the bandwidth. This "compensation" is not ideal, however, so transient response may be degraded.

The step response (Figure 2) demonstrates the stability of the LM6361. The amplifier was set up as a unity-gain follower, with a 6V input step. The output has a small overshoot and settles quickly to its final value. This well-behaved response is due to the simplicity of the compensation, which can be seen in the frequency response (Figure 3). It shows a smooth one-pole rolloff beyond 50 MHz; where the gain has dropped to unity, with a phase margin of 45°; the next pole is introduced after 100 MHz.
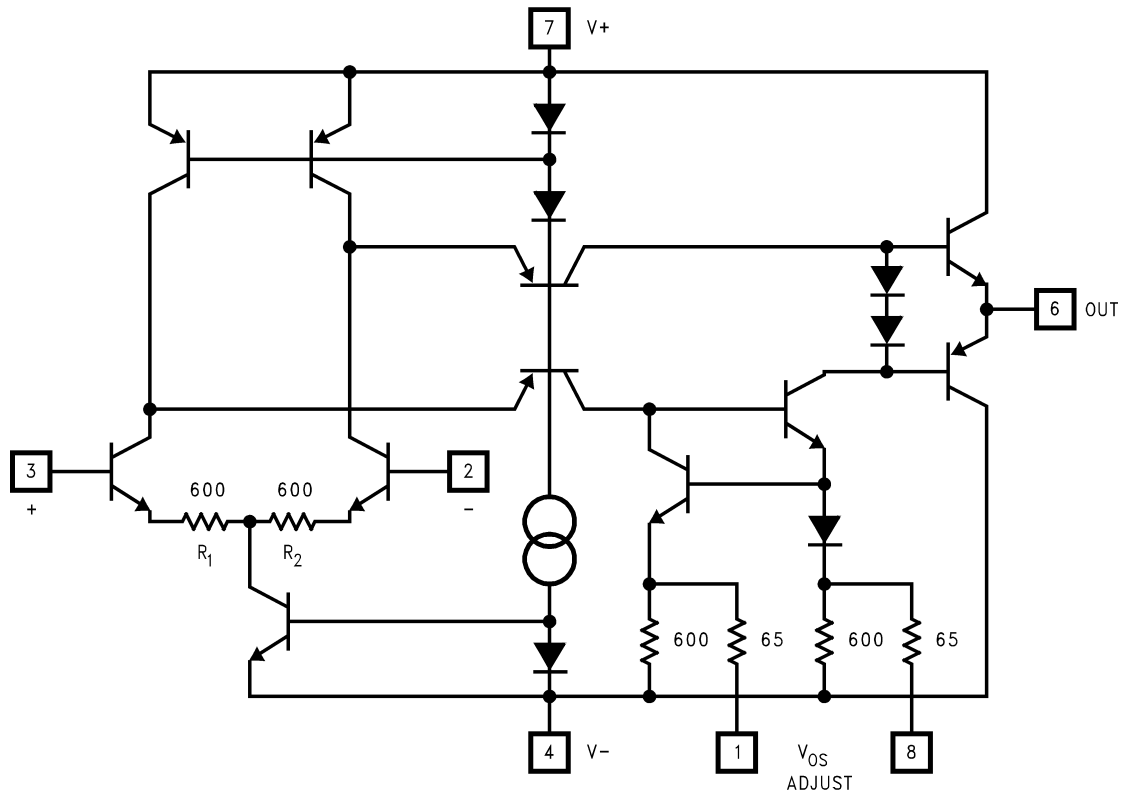
For LM6364, R1 and R2 are 150Ω; for LM6365, R1 and R2 are omitted.
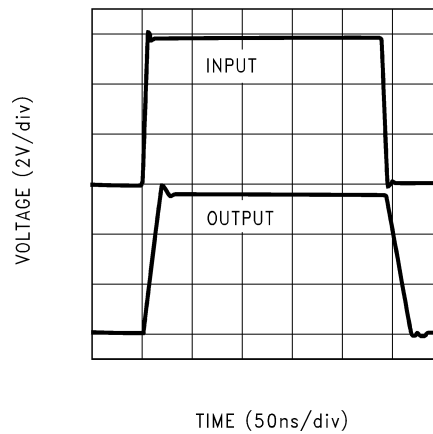
Figure 1. LM6361 Simplified Schematic

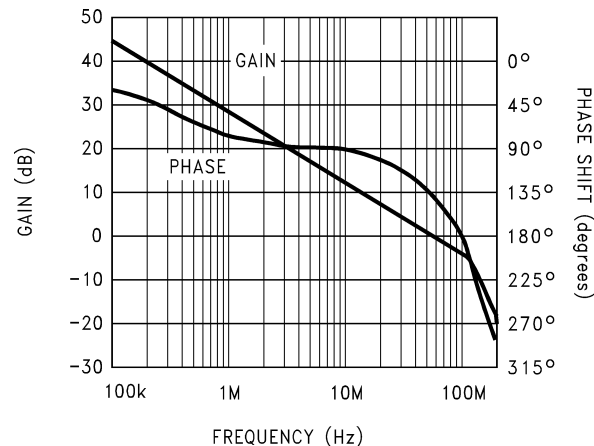**Figure 2. Step Response of LM6361 in Unity-Gain (Follower) Configuration**

Figure 3. Frequency Response of LM6361 (Closed Loop Gain = 45 dB)

The LM6364 and LM6365 are based on the LM6361 design. The LM6361's 600Ω emitter degeneration resistors are reduced to 150Ω in the 6364 to produce an op amp with gain-bandwidth product of 175 MHz, stable to a minimum gain of 5. In the 6365 the resistors are eliminated altogether, for a GBW of 725 MHz and minimum gain of 25. All three devices have slew rates ensured (and 100% tested) to be over 200 V/µs (the slew rates are typically 300 V/µs).

Since the emitter degeneration resistors contribute to offset voltage and input voltage noise, the device with the widest bandwidth also has the best DC specs. The high gain of the transistors used in the common design, combined with the configuration used, give these op amps their high speed without consuming a lot of power. Supply current is ensured to be less than 6.8 mA (with ±15V supplies) for each of the three devices.

The LM6361, LM6364, and LM6365 are ensured for operation over the commercial temperature range (0°C to 70°C). In addition, there are two other versions of each amplifier available: LM62XX, rated for operation over the industrial −25°C to +85°C range, and delivering improved DC input specifications over the LM63XX parts; and LM61XX, which is rated for the military temperature range (−55°C to +125°C), with the same improved DC specifications as the industrial versions.

These VIP amplifiers were optimized for high AC performance at low power consumption, while offering an ease of use previously found only in low speed parts. They are expected to bring a new level of performance and affordability to applications such as filtering, 8-bit data acquisition, video and communications, and general high frequency signal processing.

2   General High-Speed Circuit Design Techniques

The LM6361/LM6364/LM6365 op amp family can tolerate circuit-building techniques appropriate for op amps of much lower bandwidth. However, for best performance, any highspeed circuit (and many DC precision circuits) should be built using what is often called "good RF design." Power supply bypassing is very important: most op amps will require 0.01 µF to 0.1 µF good ceramic capacitors at each power supply pin, and an additional 2.2 µF to 10 µF tantalum nearby for extra noise reduction. These VIP op amps do not require as much bypassing as other op amps in their speed class; for most applications, 0.01 µF bypass capacitors are adequate. However, their stability (especially that of the wider gain-bandwidth LM6365) is enhanced when good bypassing is used.

Power supply bypassing is added to negate the effects of lead inductance from the power supply wires. This inductance causes "glitches" on the power supply lines every time the op amp has to deliver power to a transient load; these glitches normally work their way into other sensitive parts of your circuit. In addition, the inductance can create small tank circuits with stray capacitance, which often will cause a marginally stable circuit to oscillate.

For these reasons, keep all leads short (especially to the input pins), and make sure the ground paths are low-impedance, especially where larger currents will be flowing. Minimize stray capacitance (especially in the forms of sockets and parallel board traces). Stray capacitance allows signal coupling from one pin or input or lead to another, which can cause noise and/or oscillation.

All of the circuits shown here were built on copper-clad board (used as a ground plane), with the op amps in sockets for convenience—except for the input and output pins, which were soldered directly into the circuits.

3   1 MHz Voltage-to-Frequency Converter

The classic charge-pump voltage-to-frequency converter is limited in maximum frequency by the integrator amplifier. For example, op amps with 1 MHz gain-bandwidth products limit converters to a maximum frequency of about 10 kHz (for 0.1% accuracy or better). Higher-speed converters (500 kHz and up) must either incorporate the very-high-speed (usually hybrid) op amps, or turn to another, more complex, design.

The LM6365 can be used in the charge-pump V-to-F to produce a 1 MHz (at 10V) output signal, as shown in Figure 4. Offset and full-scale trims allow more than two-decade operation with 0.1% linearity, as shown in Figure 5. Careful power supply bypassing and layout are important to reduce noise and stray capacitance which will degrade performance.

The wide-bandwidth nature of the LM6365 provide the fast switching necessary for 1 MHz operation, with little degradation in accuracy for inputs up to 11V (10% overrange). Likewise, the 0.1% linearity holds for inputs down to 50 mV.

The circuit gain is described by Equation 1:

$$\frac{f}{V_{IN}} = 1/(2 \cdot V_z \cdot R_{in} \cdot C_{fb})$$
$$= 100\,kHz/V \tag{1}$$

where, V_Z is the output clamp voltage, 3.5V, and R_{in} and C_{fb} are the components noted on the schematic (Figure 4).
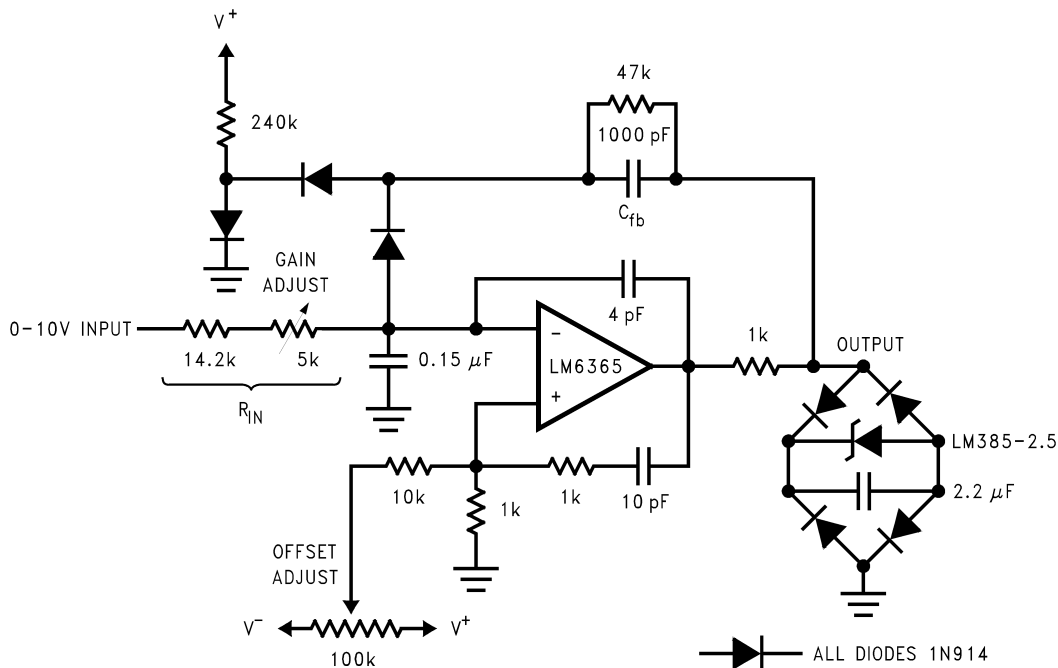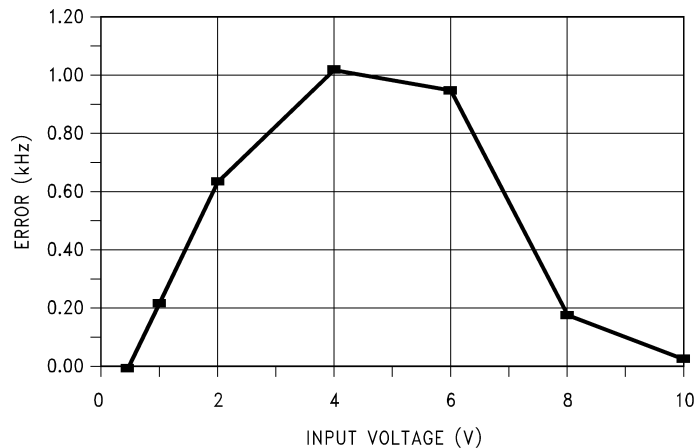

Figure 4. 1 MHz V-to-F Converter

Figure 5. Nonlinearity of LM6365 Voltage-to- Frequency Converter (of Figure 4) is 0.1%

To calibrate the circuit, first adjust the gain potentiometer until a 10.00V input produces a 1.000 MHz output. Then adjust the offset potentiometer until a 50 mV input produces a 5.0 kHz signal. Repeat adjustments until both ends of the input range produce the correct output frequencies. The 0.15 µF input capacitance improves the linearity of the circuit.

All leads must be kept very short, especially those connected to the inputs of the LM6365, to minimize stray capacitance which affects the gain and linearity. In addition, the LM6365 power supply pins must be bypassed with 4.7 µF tantalum and 0.01 µF ceramic capacitors to keep lead inductance from affecting the circuit's stability.

4   High-Frequency Active Filters

The LM6361 can be used in active filters at frequencies which often require special designs to achieve even adequate performance. For example, even though a 1 MHz low-pass filter could be constructed taking advantage of the natural bandwidth of an op amp such as a 741, the designer would find the cutoff varying with the unit-to-unit variation of 741 bandwidths, and the filter would only have a one-pole slope. A two-pole active filter with good performance at this frequency is difficult to realize with most standard op amps. Either the amplifier's own bandwidth is too low, or in the case of many de-compensated fast op amps, the low gain needed for the wide bandwidth may render the amplifier unstable. However, the LM6361 can easily be used to provide a 1 MHz cutoff with a 2-pole rolloff, as shown in Figure 6. And because the cutoff frequency is not set by amplifier bandwidth, but by the R-C network, it can be trimmed for accuracy.
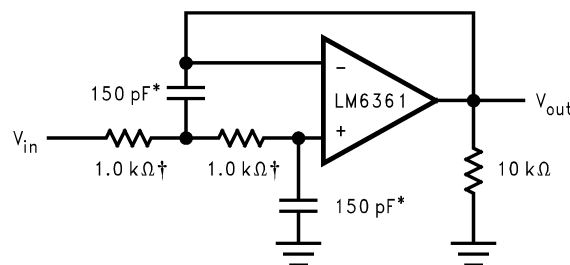
†1% tolerance
*matching determines filter precision

Figure 6. 1 MHz Low-Pass Filter

Figure 7 shows the frequency response of the low-pass filter. The gain rolls off at a steady 12 dB/octave until 6 MHz, where the gain is down 35 dB.
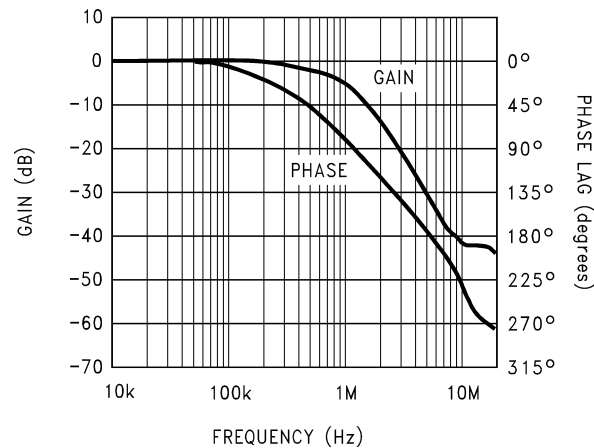
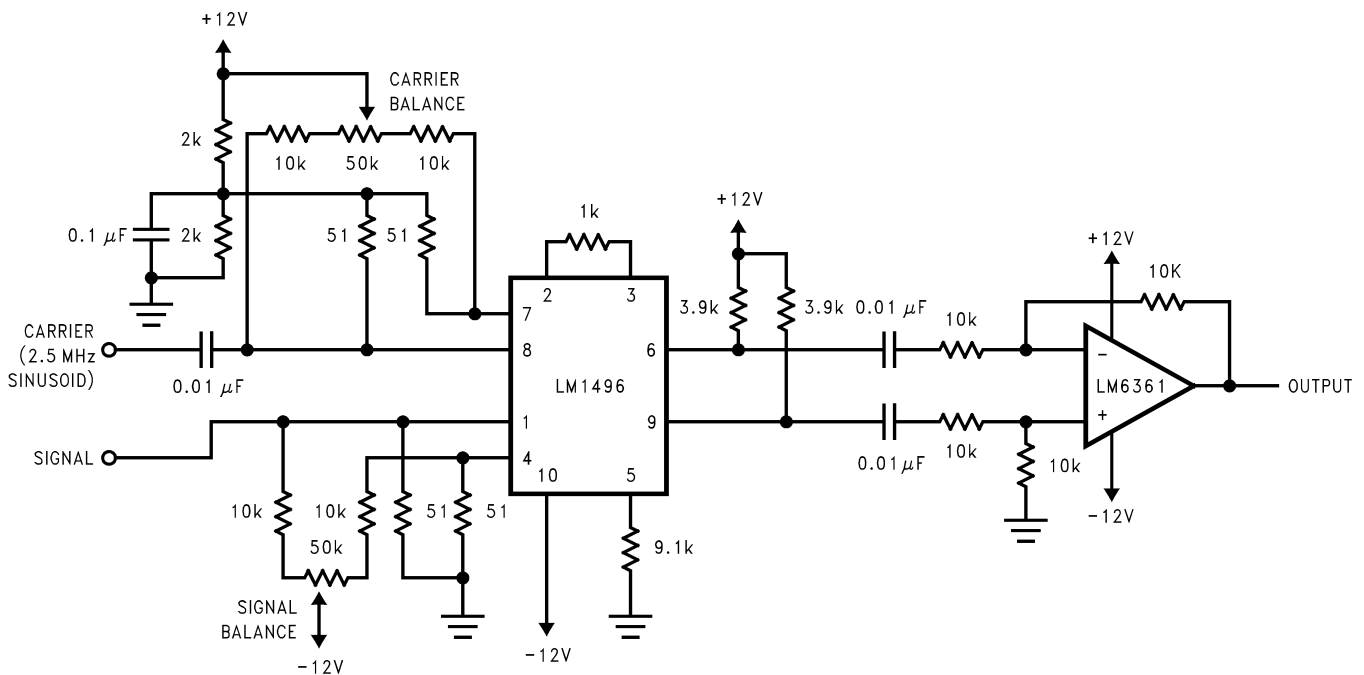**Figure 7. Frequency Response of Low-Pass Filter (Reference Figure 6)**

**Figure 8. Modulator with Single-Ended Output Centered about Ground**

5 Video/Communications Applications

In systems such as some local area networks, where a signal is modulated onto a carrier for transmission, and is demodulated for use, an amplifier may have to pass this multiplexed signal. The carrier frequency depends on the system in which it's used—some LANs have 10 MHz basebands, and radio and other broadcasting systems often use carriers of 10 MHz or less. Signals transmitted may be AM-audio, or perhaps some analog information from a transducer or sensor.

Special video circuits which are often used in these systems, such as the LM1496 modulator/demodulator and LM733/LM592 differential amplifiers, have differential outputs with common-mode voltage several volts above ground. This differential signal may be fine for transmitting on a twisted pair, but for sending through coax or for observation/monitoring, it would be better if it were single-ended. To convert the outputs to a signal which is single-ended, referenced to ground, requires a wide-bandwidth amplifier. Unity-gain stability is helpful if no additional gain is needed, but a less stable amplifier could be used if it is allowed sufficient noise gain. The LM6361 works well in this circuit, having a bandwidth of 50 MHz at unity gain. When higher gain is required, the LM6364 may be used.

TEXAS
INSTRUMENTS

In the circuit of Figure 8, an LM1496 is used to modulate an analog signal (lower trace, Figure 9) with a 2.5 MHz sine-wave carrier. The output of the LM1496 is a differential signal with a common-mode voltage of 8V. An LM6361 is used to convert this signal to a single-ended one centered about ground (upper trace, Figure 9).

The LM1496 requires quite a bit of balancing, using the two potentiometers shown, to obtain the lowest possible distortion. The LM1496 is the dominant source of distortion, which is caused by the application of an unbalanced carrier or modulating signal to the LM1496. The balance of the system can be checked on a scope, but for most accurate measurements a spectrum analyzer should be used.

TIME (2 μs/div.)
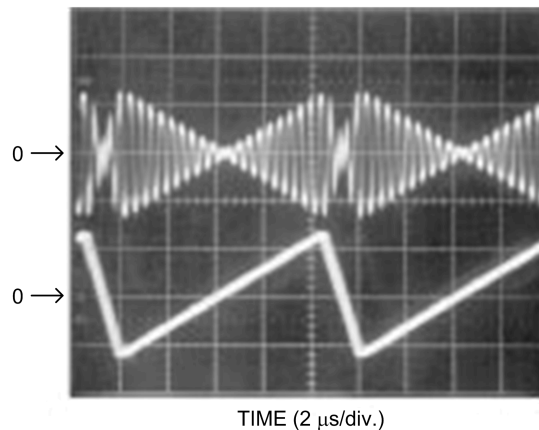
**Figure 9. Bottom Trace: Signal Input to Multiplexer of Figure 8 (200 mV/div)
Top Trace: Output of Multiplexer (2 V/div)**

6   Video Amplifier

The LM6361/LM6364/LM6365 series of amplifiers is also suitable for use in video amplifier systems. A key parameter of any amplifier used in video applications, especially NTSC color television systems, is the differential gain and phase it adds to the circuit . An NTSC Vectorscope can be used to check these parameters, analyzing the output of an amplifier whose input is from an NTSC signal generator.
[1]
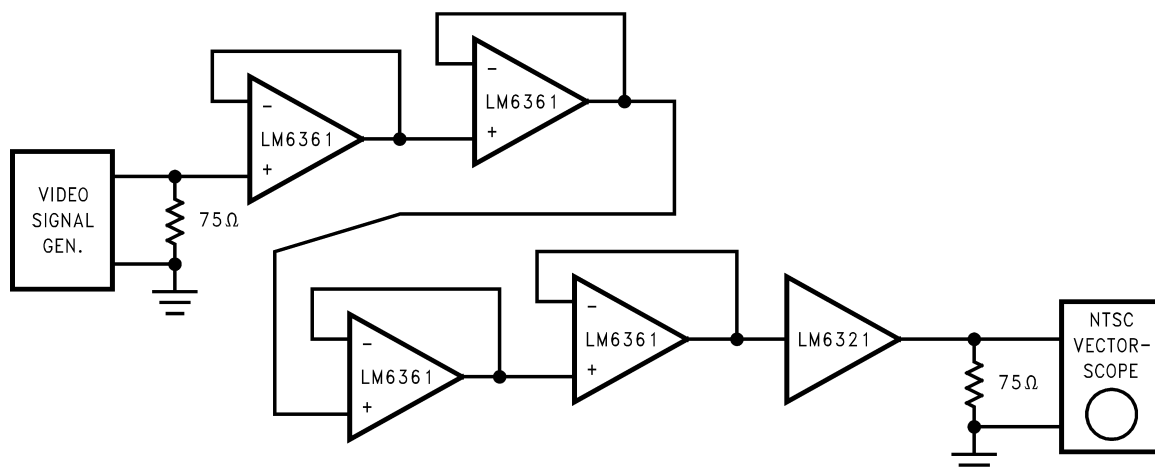
Figure 10. Test Circuit for Differential Gain, Differential Phase Measurements

[1]   Differential gain, in an NTSC color television system, is a change in color subcarrier amplitude due to a change in the luminance signal while hue and saturation of the original signal are held constant. In an amplifier, it relates to the variation of closed-loop gain with common-mode input voltage. It should be (ideally) zero.Differential phase is a phase change of the chrominance signal by the luminance signal while the original chrominance signal is held constant. In an amplifier, it relates to the variation of phase shift with common-mode input voltage. It should also be (ideally) zero.
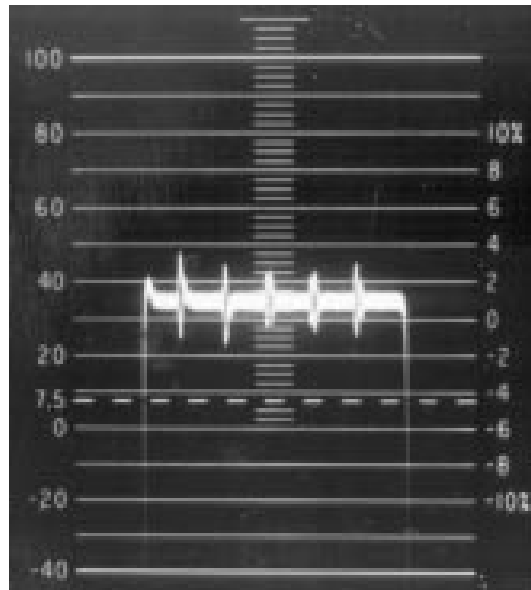
Differential gain, measured by change in level from the 1st (leftmost) horizontal bar to the 6th (rightmost), is less than 0.5% for the network.

Figure 11. Differential Gain of Four Cascaded LM6361s Plus Buffer (see Figure 10)
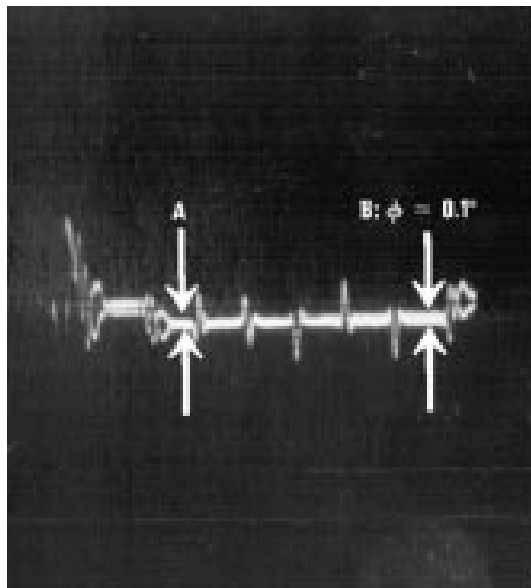
Differential phase, based on the spread in the two lines at point B when the spread at point A is nulled, is 0.1° for the network.

Figure 12. Differential Phase of Four Cascaded LM6361s Plus Buffer (see Figure 10)

To adequately measure the differential gain and phase of these op amps, the error produced by four LM6361 voltage followers, connected in series (see Figure 10), was measured. A Tektronix 144 NTSC Signal Generator provided the input signal, and a Tektronix 520 NTSC Vectorscope was used to monitor the error. Since the Vectorscope input needed 75Ω termination, an LM6321 buffer was added to prevent loading of the LM6361s. The LM6321 added less than 0.1% differential gain, and less than 0.02° differential phase, to the measurement.

Figure 11 shows the differential gain of the four LM6361 followers (plus buffer) of Figure 10 to be less than 0.5%, or an average of less than 0.12% for each LM6361. The differential phase measurement for the same circuit is made with the Vectorscope displaying the picture of Figure 12, with one side of the display zeroed as shown (point A). The spread of lines at point B represents the differential phase, which is 0.1° for the network (0.02° for each follower), as measured with the Vectorscope. These measurements indicate that a video signal will suffer very little degradation when amplied with one of these devices.

7   References

- "200 MHz PNP Transistors Spawn Fast Analog Chips," by Monticelli, Wright, Small and Geczy. *Electronic Design*, August 21, 1986, page 111.
- *Tektronix Type 520/R520 NTSC Vectorscope Instruction Manual,* 1969. Pages 2.2–2.20.

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