AMPLIFIER AND COMPARATOR CIRCUITS   VIDEO CIRCUITS

Application Note 692: Mar 15, 2000

Transconductance Amplifiers Simplify Wideband Techniques

This article describes the unique architecture used in the MAX435/MAX436 transconductance amplifier and how this applies to traditional applications as well as new ones. Sample circuits are shown using the MAX435/MAX436 as a phase splitter, an impedance transformer, a coaxial cable driver, and as a twisted pair cable driver for distances over 5000 feet.

Limited performance in transconductance amplifiers has hampered their acceptance for years, with exception of the few applications tailored to their capabilities. But two new products from Maxim promise to widen the scope of such amplifiers. The Maxim parts offer better specs for established circuits, and their unique architectures offer the prospect of entirely new applications.

MAX435/MAX436 amplifiers are open-loop devices that provide accurate gain without feedback. VOUT/VIN gain is the product of an internal current gain (4 ±2.5% in the MAX435; 8 ±2.5% in the MAX436), and the ratio of an output impedance ZL to the user-connected "transconductance network" Zt (**Figure 1**). Zt is a 2-terminal network connected across the amplifier's Z+ and Z- terminals. The MAX435 has differential outputs, and the MAX436 has a single-ended output.

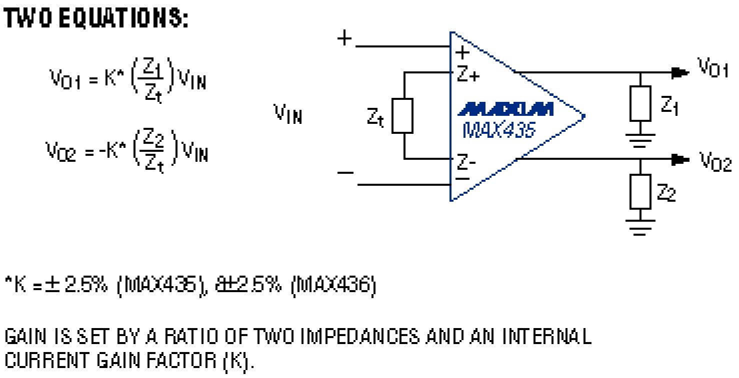


Figure 1.*Simple equations and freedom from instability ease the application of transconductance amplifiers.*

Because ZL or Zt (or both) can be frequency-shaping networks, the ZL/Zt ratio can implement some interesting transfer functions. A resistor ratio (times the internal current gain) simply sets a desired voltage gain. Replacing ZL with a parallel-RC network produces a lowpass response, and replacing Zt with a series-RC network produces a highpass response. Combining the parallel-RC ZL and series-RC Zt produces a bandpass filter. Or, by replacing Zt with a crystal or series-LC network you can create a high-Q tuned amplifier.

Each of these configurations is elevated to new levels of performance by the amplifiers' high speed: the MAX435 has a 275MHz bandwidth with 800V/µs slew rate, and the MAX436 has a 200MHz bandwidth with 850V/µs slew rate. Both offer 18ns settling times (±1%) for 0.5V step inputs, and both feature exceptional CMRRs of 53dB at 10MHz. Both have fully differential, symmetrical, high-impedance inputs. Input offset voltages (300µV typical) are much lower than those of most high-speed op amps.

The secret of high speed lies in the MAX435/MAX436 architecture. Consider the MAX435 (**Figure 2**). With zero volts across VIN+ and VIN-, the currents from I1 and I2 are mirrored and multiplied, producing 12mA in Q1 and Q2. These currents each match 12mA from a current source in the output stage, producing a zero differential output at IOUT+ and IOUT-.

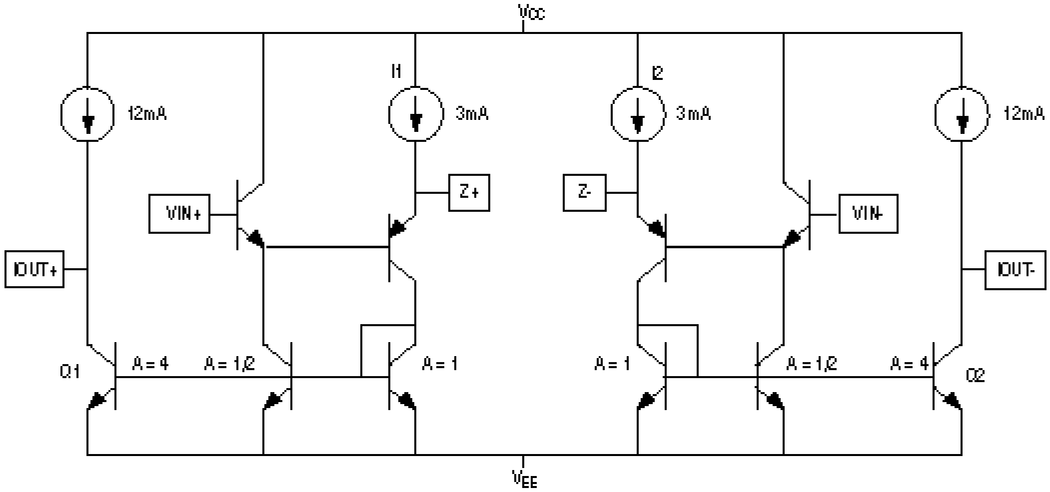


Figure 2.*This simplified schematic shows basic circuitry in the MAX435 differential-output transconductance amplifier. An external resistor (R_{SET}) controls the four current sources, and its nominal value of 5.9kW produces the current levels shown.*

Connecting a positive differential voltage across VIN+ and VIN- diverts some of the I1/I2 current through Zt (connected between Z+ and Z-), causing an imbalance in the Q1/Q2 currents. The result is a net differential output current at IOUT+ and IOUT-. Time delays are very short because the signals propagate as steered currents (rather than voltages), and because all stages in the signal path receive substantial bias currents. The following applications are made possible by these and other special capabilities in the MAX435/MAX436 amplifiers.

Because MAX435 and MAX436 outputs are high-impedance current sources, you can create a summing amplifier simply by tying two or more outputs together. No additional components are required except a load resistor to develop the output voltage. Another intrinsic function is that of phase splitter-the MAX435 differential outputs provide inverted and non-inverted (0° and 180°) versions of the input signal.

As phase splitter, the MAX435 offers a convenient, single-IC differential drive for balanced transmission lines (**Figure 3**). The IC's excellent common-mode rejection (90dB at dc; -53dB at 10MHz) assures reliable transmissions.

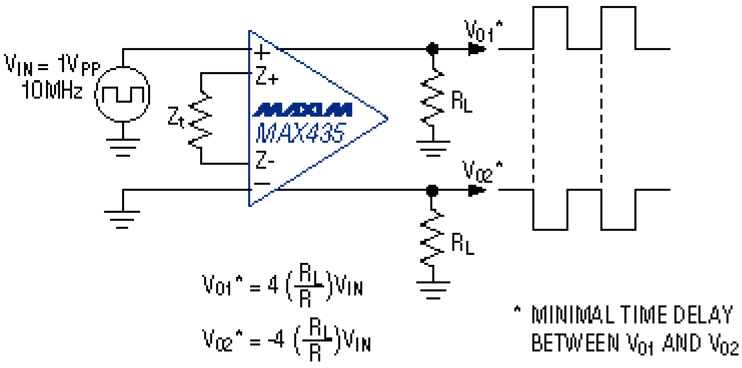
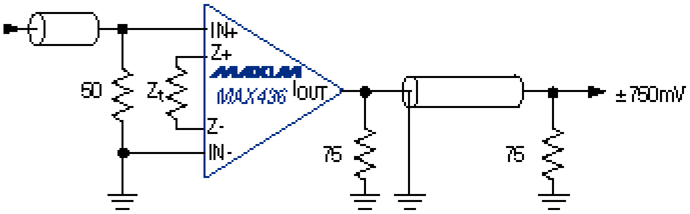
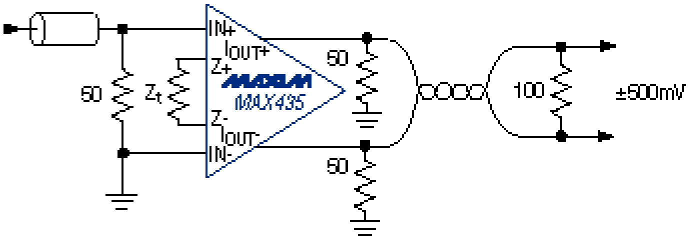


Figure 3. *Differential outputs make the MAX435 a convenient single-package phase splitter.*

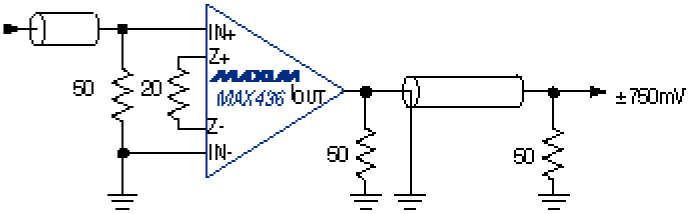
The amplifiers' high-impedance inputs and outputs allow them to operate as monolithic impedance transformers (**Figure 4**). The high-impedance, true-differential inputs (800kW typical) let you connect any reasonable value of input termination resistance. Similarly, the current-source outputs have a relatively high source resistance (3.2kW typical) that lets you connect any reasonable value of load resistance.



50Ω → 75Ω



50Ω → BALANCED PAIR



50Ω → 50Ω, GAIN = 20dB

Figure 4.*Independent settings for output current and load resistance enable MAX435/MAX436 amplifiers to act as impedance transformers. Supply voltages are ±5V, and the* R_{SET} *resistors (between the amplifiers'* I_{SET} *terminals and ground) are 5.9kW.*

The main advantage of these circuits over magnetic transformers is in their low-end frequency response, which extends to dc. Baseband video, for example, has frequency components ranging from 4.5MHz to below 60Hz. A line transformer with flat frequency response over that range would be very bulky and expensive! Flexibility is another advantage for the IC approach; by changing one or two resistors you can match the transmitter and receiver to a variety of cables in the same system.

As another illustration of the need for impedance matching, coaxial cables for high-speed signals must be carefully terminated in their characteristic impedance to ensure maximum power transfer and minimum distortion. To obtain optimum performance from 50W cable, therefore, you must terminate each end of the cable with 50W.

Further description

Voltage-mode amplifiers have low output impedance, so they require a series-resistor interface to coaxial cable. But MAX435/ MAX436 amplifiers have high-resistance current-source outputs that require a parallel connection of the termination resistor (i.e., in shunt with the cable). Note that back-terminating the cable this way reduces the circuit voltage gain by half (**Figure 5**).

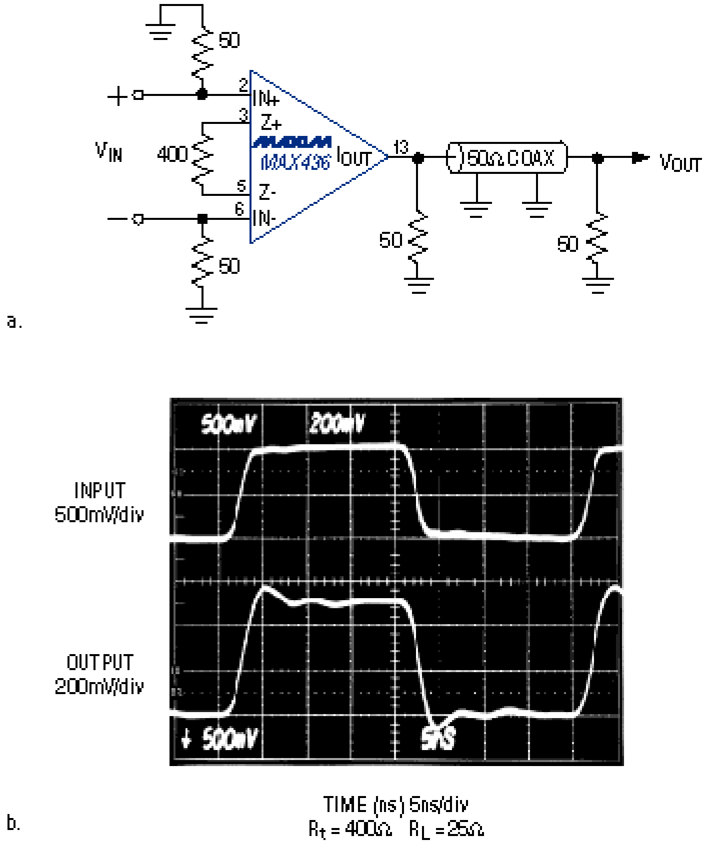


Figure 5. *As a coaxial-cable driver (a), the MAX436 transconductance amplifier handles fast pulses with minimal overshoot and ringing (b).*

MAX435/MAX436 amplifiers offer the user several "control handles." For top performance in this application and others, you should be aware of the amplifiers' shutdown capability, their adjustable load-current limits, and the factors that affect their dc accuracy.

First, the internal current sources are controlled by an external resistor (RSET) connected between the ISET terminal and the V- supply voltage (Figure 2). Both amplifiers operate on ±5V. The standard RSET value for which all specifications are guaranteed is 5.9kW, and this value sets the limit for maximum IOUT: ±20mA for the MAX436, and ±10mA per output for the MAX435. By connecting a larger-valued RSET, you can reduce the amplifiers' supply current and power dissipation (along with the maximum IOUT).

You can also increase the output current by decreasing RSET, but be careful to ensure that the higher current does not combine with a particular operating condition to exceed the package power-dissipation rating. Removing RSET altogether provides a partial shutdown of the amplifier. Without RSET, the room-temperature supply currents (normally 35mA) drop to 450µA ±25% for the MAX435 and 850µA ±25% for the MAX436.

DC accuracy in the MAX435 and MAX436 is affected by the input offset voltage (VOS), the output offset current (IOS), and tolerance on the internal current gain K, as well as tolerance on the external impedances Zt and ZL. VOS is caused by a VBE mismatch at the input stage (like the VOS in bipolar voltage amplifiers), and is measured between the Z+ and Z- terminals-with Zt removed and the inputs (IN+ and IN-) grounded. VOS produces a small error current in Zt during normal operation. Multiplied by K, it produces an output error current, even with no differential input voltage applied.

IOS is a separate and independent output error that is caused by imperfectly matched devices in the output current mirrors. Though measured under the same conditions as the VOS measurement, IOS does not vary with input voltage. Combining the IOS and VOS effects yields a net error in output voltage. The MAX435's differential output error VERR(DIFF), for instance, is the sum of each output error:

$VERR(DIFF) = (VERR+) - (VERR-)$, where

$VERR+ = (RL+)[(IOS+) + K(VOS/Rt)]$, and $VERR- = (RL-)$
$[(IOS-) - K(VOS/Rt)]$. IOS is -20µA typical (±100µA max),
and VOS is 0.3mV typical (3.0mV max).

Similarly for the MAX436,

$VERR = (RL)[IOS + K(VOS/Rt)]$,
where IOS is 6µA typical (±100µA max), and VOS is 0.3mA typical (3mA max).

Twisted-pair video

The MAX435 and MAX436 amplifiers provide a differential-out/differential-in combination that is well suited for one-way transmission of video signals over a twisted-pair cable (**Figure 6**). As a bonus, the MAX436 Zt network provides a means for line equalization and gain adjustment.

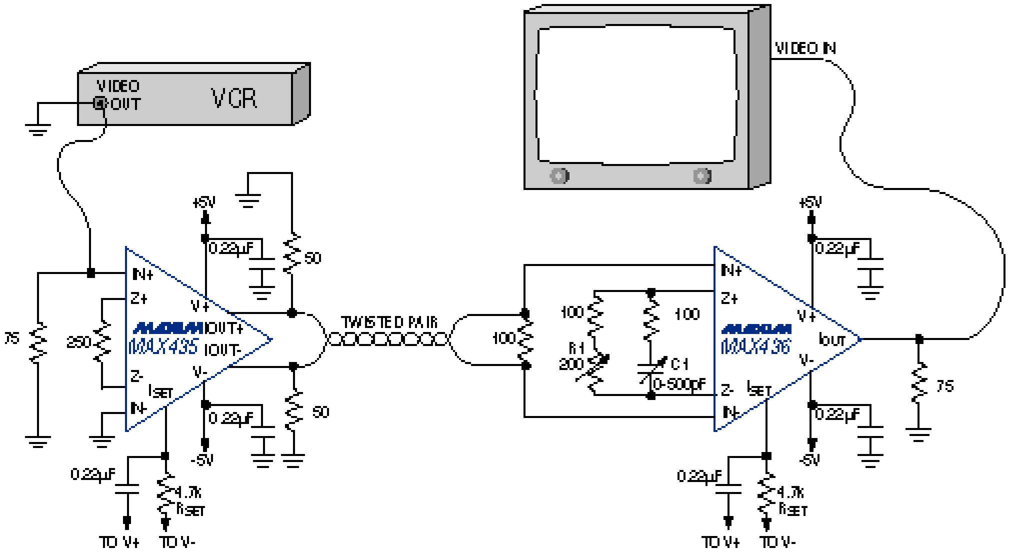


Figure 6. *Two transconductance amplifiers and a twisted-pair cable transmit baseband video for 5000 feet or more.*

Replacing coaxial cable with twisted-pair cable saves cost in many applications that don't require the higher bandwidth of coax. These applications have initially included LANs and LONs (local area networks and local operational networks). But twisted-pair cable is more compact than coaxial cable, and the miles of unused twisted-pair cabling that already reside in the phone systems of existing buildings may inspire additional applications. Baseband (composite) video can be transmitted over these cables as far as 5000 feet, with surprising quality.

Twisted-pair video transmission works best with a single channel of baseband video. Many applications require such transmissions within a building; an obvious example is the separate video channels routed from individual surveillance cameras back to a security office. Other closed-circuit TV (CCTV) systems are found in retail stores, supermarkets, airports, and schools.

Twisted pairs resist differential noise pickup; because a pair is twisted, any differential current induced by an interfering EM field in one loop gets cancelled in the following loop. Common-mode noise, on the other hand, must be rejected by a balanced (differential) circuit at the receiver. Twisted-pair cables must also be terminated in their characteristic impedance to minimize the reflections caused by line discontinuities.

For twisted pairs exceeding 200 feet (approximately), bandwidth falls short of the typical baseband-video bandwidths (4MHz to 5MHz). But these cables are satisfactory for baseband video if you equalize your receiver, provide an NTSC monitor with automatic gain compensation, and choose quality (wideband) cable.

Stranded and unstranded wires exhibit similar bandwidths, but the highest-bandwidth cables are unshielded, and have insulation of low dielectric constant between the conductors.

Polyethylene or polypropylene insulation is recommended for new installations. For twisted-pair video transmissions under 1000 feet, use common 24AWG telephone wire. For longer distances, you can improve the video fidelity by using larger wire.

The differential-output MAX435 of Figure 6 eliminates the need for a balun (balanced-to-unbalanced) transformer or the two-driver alternative-one single-ended inverting driver and one single-ended non-inverting driver. The MAX435 drives the balanced twisted-pair cable from a ground-referred input signal (in this case, from a VCR's VIDEO OUT baseband signal).

At the driver end of the cable, each conductor is terminated with a 50W resistor to ground. The resulting 100W between conductors is an appropriate match for the cable's characteristic impedance. A mismatch can degrade the video, but it cannot affect amplifier stability because the MAX435 has no feedback. Output amplifiers are ±0.5V.

At the receiver end, a MAX436 amplifier converts the balanced input channel to a single-ended output. Again, the proper line termination is 100W between cable conductors at the IN+, IN- inputs. The Zt impedance network across Z+ and Z- adds adjustable gain (approximately 6dB) to compensate for a 6dB loss introduced by the termination resistors. The network's adjustable capacitor also provides line equalization (frequency compensation) if required. Load resistance is 50W, consisting of the 75W resistor in parallel with 150W at the monitor's input port.

Test results

Operating with 500 feet of inexpensive, 22-gauge, twisted-pair burglar-alarm cable (approximately 4¢ per foot), the Figure 6 circuit attenuates the baseband video's 3.58MHz colorburst frequency about 6dB (**Figure 7**). Despite the distortion, no degradation of color saturation was observed at the NTSC monitor used in this test. No degradation was expected, however; this monitor compensates for signal attenuation by calibrating automatically against test patterns in the vertical interval test signal (VITS).

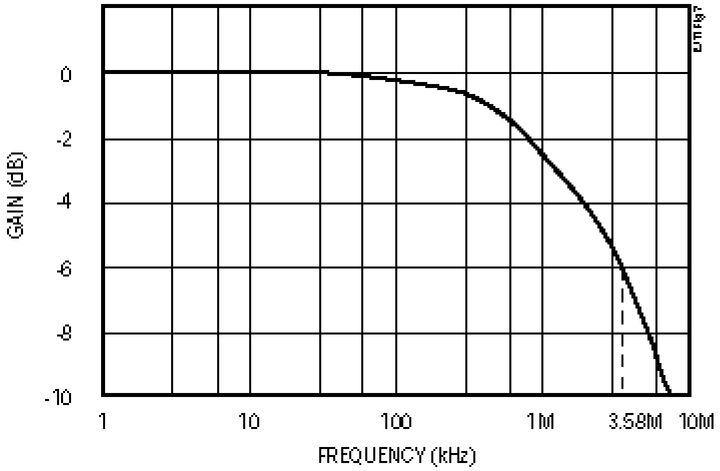
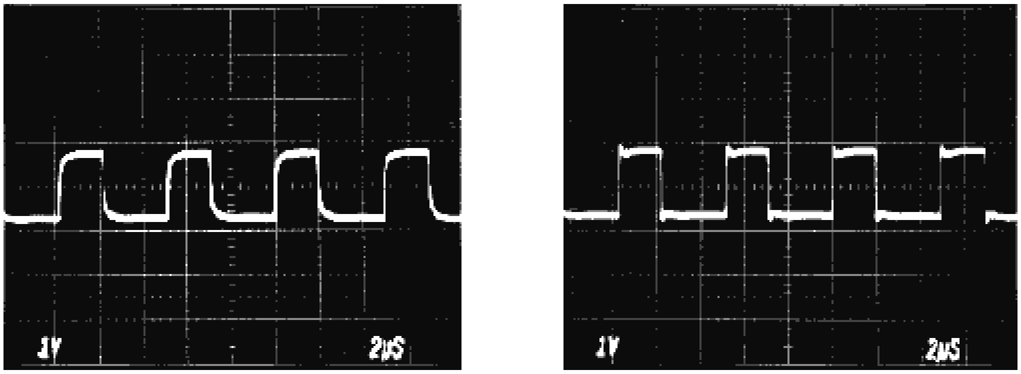


Figure 7. *Inexpensive burglar-alarm cable (twisted pair, 500 feet, 22AWG) attenuates the 3.58MHz colorburst frequency of baseband video by 6dB.*

The monitor's automatic loss equalization is robust; it compensates for colorburst attenuation as high as 10dB, displaying an excellent picture with no noticeable color fading or loss of horizontal resolution. Further attenuation, however, produces poor chroma and a horizontal fuzziness that makes it difficult to read displayed text.

Under that condition you can still achieve compensation via adjustments at the MAX436 Zt network: R1 adjusts brightness by boosting the overall gain to compensate for ohmic losses, and C1 introduces a pole/zero pair in the receiver circuit, which adjusts for color by extending the channel bandwidth. Because compensation is introduced at the receiver, you can simply view the display and adjust for the best picture. Before-and-after waveforms show the result of this equalization (**Figure 8**).



8a. BEFORE EQUALIZATION

8b. AFTER EQUALIZATION

Figure 8. *These before-and-after waveforms show the effect of adjusting for optimum brightness and color via R1 and C1 (Figure 6), while observing the monitor display.*

Next, consider the Figure 6 circuit operating with 1000 feet of twisted-pair telephone cable. The test setup included a length of unused twisted pair in a trunk cable between two Maxim buildings, two jumper connections in the phone-patch room, and additional twisted-pair cable that was routed through hallways to complete the transmission path.

This system easily transmitted baseband video from a VCR, producing an excellent picture with R1 and C1 at their nominal settings (no equalization required). High noise immunity was illustrated by coupling 60Hz common-mode noise to the line (**Figure 9**). The MAX436 CMRR (60dB at 60Hz) removed this noise with no evidence of beating in the display. On the other hand, driving the cable in an unbalanced mode produced poor results as expected.

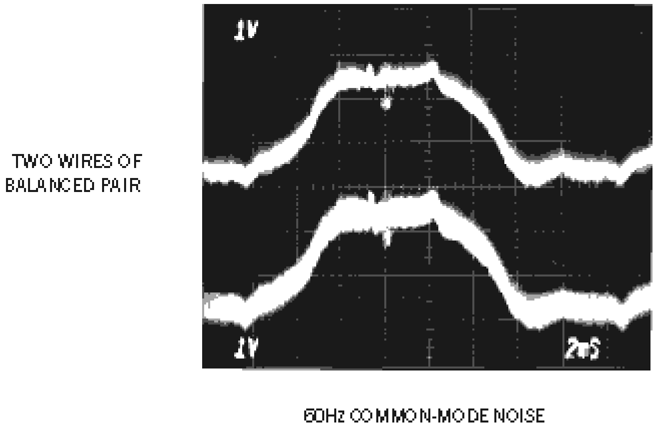
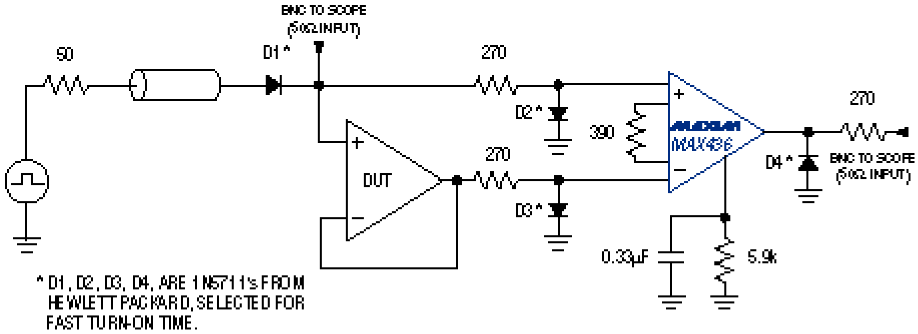


Figure 9. *Thanks to 60dB CMRR in the MAX436, the display in Figure 6 is unaffected when these 60Hz common-mode signals are deliberately added to each wire of the balanced cable.*

Although tests on the Figure 6 circuit involved only NTSC video signals, the circuit should provide comparable performance for PAL signals, which have a chroma carrier of 4.43MHz (vs. 3.58MHz).

Settling time measurements

Quick response and avoidable output saturation favor the MAX436 for use in measuring the settling time of slower amplifiers (**Figure 10**). In the test circuit, you configure the device under test (DUT) as a voltage follower and drive its inputs with a square wave. The MAX436 observes DUT settling time by comparing its input and output signals.



* D1, D2, D3, D4, ARE 1N5711's FROM HEWLETT PACKARD, SELECTED FOR FAST TURN-ON TIME.

Figure 10. *Wideband differential inputs and an absence of output saturation suit the MAX436 for use in settling-time fixtures.*

The applied square wave appears quickly at the MAX436's non-inverting input, but is delayed by propagation time through the DUT before reaching the inverting input. The result is a brief but high-amplitude signal (clamped by D2 and D3) that appears between the MAX436 inputs before the DUT can settle. If the MAX436 were a voltage-mode amplifier, this large differential input would cause the output transistors to saturate, thereby corrupting the settling-time measurement with overload-recovery time.

With properly chosen gain elements, however, the MAX436 can accommodate input signals that span its entire input common-mode range without saturation in the output stage. This characteristic suits the amplifier for settling-time measurements of D/A converters as well as high-speed op amps. (Following a 0.5V common-mode step, the MAX436 itself settles to ±0.1% in about 17ns.) Note that this common-mode response is faster than the response to a differential signal, in which the output response time is limited by the slew rate.

Figure 11 illustrates the response of a MAX442 (2-channel, 140MHz video multiplexer and amplifier) operating as a DUT in the circuit of Figure 6. The input step is 2V in this case. Note that the initial output level (40mV) should ideally be zero. It represents the difference in forward voltages for the Schottky clamp diodes D2 and D3, multiplied by voltage gain from the MAX436 to the scope (which is 8+50/390, i.e., near unity). This initial voltage has no effect on the settling measurement.

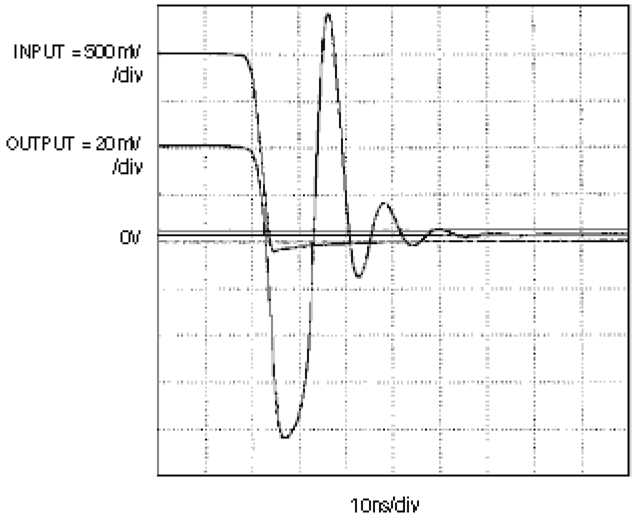


Figure 11. *Settling time for a MAX442 video amplifier in the Figure 10 circuit is 42ns.*

You can define settling time either from the beginning of the input's downward transition (which includes the DUT's propagation delay), or from the first output transition (a useful parameter in video applications). Because the MAX442's propagation delay is small, its ±0.1% settling time measures about 42ns either way. The mid-screen graticule line is 0V, the first cursor line is the final-settling level, and the next cursor line marks the boundary for ±0.1% settling.

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MORE INFORMATION

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