19-1147; Rev 0; 9/96

EVALUATION KIT AVAILABLE

MAXIM

High-Speed Differential Line Receivers

MAX4144/MAX4146

General Description

The MAX4144/MAX4146 differential line receivers offer unparalleled high-speed performance. Utilizing a three-op-amp instrumentation amplifier architecture, these ICs have fully symmetrical differential inputs and a single-ended output. The devices drive ±3.5V into a 150Ω load. The MAX4144 is internally set for a 2V/V closed-loop gain, while the MAX4146 can be externally set to gains from 10V/V to 100V/V.

These amplifiers use laser-trimmed, matched thin-film resistors to deliver a 70dB CMR at 10MHz. Using current-feedback techniques, the MAX4144 achieves a 130MHz bandwidth and 1000V/µs slew rate, while the MAX4146 maintains a 70MHz bandwidth at G = 10V/V and an 800V/µs slew rate. Excellent differential gain/phase and noise specifications make these amplifiers ideal in a variety of video and RF signal-processing applications.

For a complete differential transmission link, use the MAX4144/MAX4146 with the MAX4147 differential line driver (see the MAX4147 data sheet for more information).

Applications

- Differential-to-Single-Ended Conversion
- Twisted-Pair-to-Coax Converter
- High-Speed Instrumentation Amplifier
- Data Acquisition
- Medical Instrumentation

Features

MAX4144:

- **2V/V Fixed Gain**
- **130MHz Bandwidth**
- **1000V/µs Slew Rate**
- **70dB CMR at 10MHz**
- **-90 dBc SFDR (f_C = 10kHz)**
- **Low Differential Gain/Phase: 0.03%/0.03°**
- **800µA Shutdown**

MAX4146:

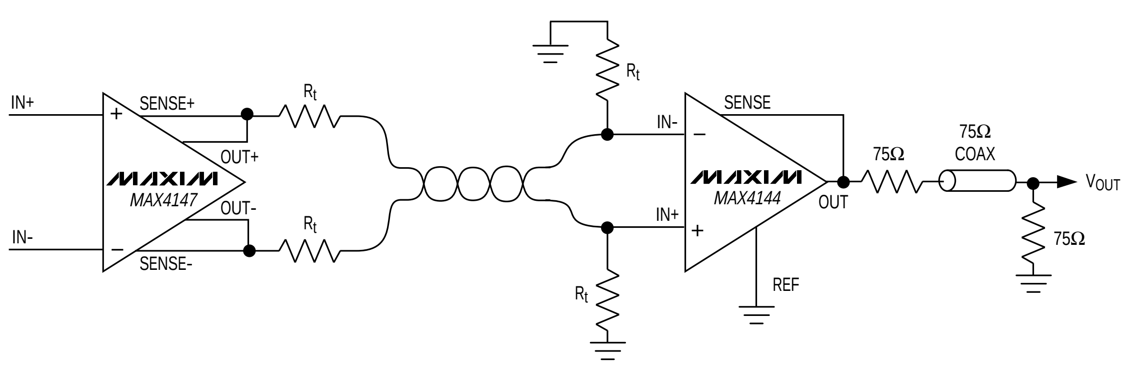
- **External Gain Selection**
- **70MHz Bandwidth (A_V = 10V/V)**
- **800V/µs Slew Rate**
- **90dB CMR at 10MHz**
- **-82dBc SFDR (f_C = 10kHz)**
- **Very Low Noise: 3.5nV/$\sqrt{Hz}$ (G = 100V/V)**
- **800µA Shutdown**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX4144ESD	-40°C to +85°C	14 SO
MAX4146ESD	-40°C to +85°C	14 SO

Pin Configurations appear on last page.

Typical Application Circuit



TWISTED-PAIR-TO-COAX CABLE CONVERTER

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V_{CC} to V_{EE})..12V
Voltage on IN_, SHDN, REF, OUT,
SENSE, RG_....................................(V_{CC} + 0.3V) to (V_{EE} - 0.3V)
Continuous Power Dissipation (T_A = +70°C)
SO (derate 8.33mW/°C above +70°C).........................667mW
Short-Circuit Duration to Ground.......................................10sec

Input Current (IN_, RG_)..±10mA
Output Current..±120mA
Operating Temperature Range
MAX414_ESD ....-40°C to +85°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10sec) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC ELECTRICAL CHARACTERISTICS

(V_{CC} = +5V, V_{EE} = -5V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS			MIN	TYP	MAX	UNITS
Input Offset Voltage	V_{OS}	V_{OUT} = 0V, R_L = ∞				0.6	8	mV
Input Offset Voltage Drift	TCV_{OS}	V_{OUT} = 0V, R_L = ∞				5		µV/°C
Input Bias Current	I_B	V_{OUT} = 0V, R_L = ∞, V_{IN} = $-V_{OS}$				9	20	µA
Input Offset Current	I_{OS}	V_{OUT} = 0V, R_L = ∞, V_{IN} = $-V_{OS}$				0.1	2.5	µA
Input Voltage Noise	e_n	f = 1MHz		MAX4144		12		nV/√Hz
				MAX4146		2.1 + (135 / G)		
Input Current Noise	i_n	f = 1MHz				1.7		pA/√Hz
Input Capacitance	C_{IN}					1		pF
Differential Input Resistance						1		MΩ
Differential Input Voltage Range		R_L = 150Ω		MAX4144	-1.55		1.55	V
				MAX4146	-3.1 / G		3.1 / G	
Common-Mode Input Voltage Range	V_{CM}	R_L = ∞			-2.8		2.8	V
Gain	A_V	-1V ≤ V_{OUT} ≤ +1V, R_L = 150Ω		MAX4144		2		V/V
				MAX4146		10 + (14kΩ / R_G)		
Gain Error		-1V ≤ V_{OUT} ≤ +1V, RL = 150Ω	MAX4144			0.02	2	%
			MAX4146	AV = 10V/V		0.5	2	
				AV = 100V/V		1.5	5	
Gain Drift		-1V ≤ V_{OUT} ≤ +1V, R_L = 150Ω		MAX4144		20		ppm/°C
				MAX4146		14 + 0.9G		
Common-Mode Rejection	CMR	V_C = ±2.8V	0°C ≤ T_A ≤ 85°C		70	80		dB
			-40°C ≤ T_A < 0°C		60			
Power-Supply Rejection	PSR	V_S = ±4.50V to ±5.50V			70	85		dB
Quiescent Supply Current	I_{SY}	R_L = ∞				11	16	mA
Shutdown Supply Current	I_{SHDN}	R_L = ∞				0.8	1	mA
Shutdown Output Impedance		V_{SHDN} ≥ 2.0V		MAX4144		1.4		kΩ
				MAX4146		2.0		
Output Voltage Swing	V_{OUT}	R_L = ∞			±3.4	±3.8		V
		R_L = 150Ω			±3.1	±3.5		
Output Current Drive	I_{OUT}	V_{OUT} = ±1.7V	0°C ≤ T_A ≤ 85°C		80	100		mA
			-40°C ≤ T_A < 0°C		60			

DC ELECTRICAL CHARACTERISTICS (continued)

(V_{CC} = +5V, V_{EE} = -5V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SHDN High Threshold	V_{IH}				2.0	V
SHDN Low Threshold	V_{IL}		0.8			V
SHDN Input Current (Note 1)	I_{SHDN}	V_{SHDN} ≤ 0.8V		-75	-150	µA
		V_{SHDN} ≥ 2.0V		±0.06	±2	

AC ELECTRICAL CHARACTERISTICS

(V_{CC} = +5V, V_{EE} = -5V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS			MIN	TYP	MAX	UNITS
-3dB Bandwidth	$BW_{(-3dB)}$	V_{OUT} ≤ 0.1V_{RMS}	MAX4144			130		MHz
			MAX4146	A_{VCL} = 10V/V		70		MHz
				A_{VCL} = 100V/V		30		MHz
Full-Power Bandwidth	FPBW	V_{OUT} = 2Vp-p	MAX4144			110		MHz
			MAX4146	A_{VCL} = 10V/V		70		MHz
				A_{VCL} = 100V/V		30		MHz
0.1dB Bandwidth	$BW_{(0.1dB)}$	V_{OUT} ≤ 0.1V_{RMS}		MAX4144		30		MHz
				MAX4146		10		
Common-Mode Rejection	CMR	f = 10MHz		MAX4144		70		dB
				MAX4146		90		
Slew Rate	SR	-2V ≤ V_{OUT} ≤ +2V		MAX4144		1000		V/µs
				MAX4146		800		
Settling Time	t_S	-1V ≤ V_{OUT} ≤ +1V	to 0.1%	MAX4144		23		ns
				MAX4146		17		
			to 0.01%	MAX4144		36		
				MAX4146		40		
Differential Gain	DG	f = 3.58MHz, R_L = 150Ω		MAX4144		0.03		%
				MAX4146		0.12		
Differential Phase	DP	f = 3.58MHz, R_L = 150Ω		MAX4144		0.03		degrees
				MAX4146		0.07		
Spurious-Free Dynamic Range	SFDR	f_C = 10kHz, V_{OUT} = 2Vp-p, R_L = 150Ω	MAX4144	A_V = 2V/V		-90		dBc
			MAX4146	A_V = 10V/V		-82		
		f_C = 5MHz, V_{OUT} = 2Vp-p, R_L = 150Ω	MAX4144	A_V = 2V/V		-66		
			MAX4146	A_V = 10V/V		-48		

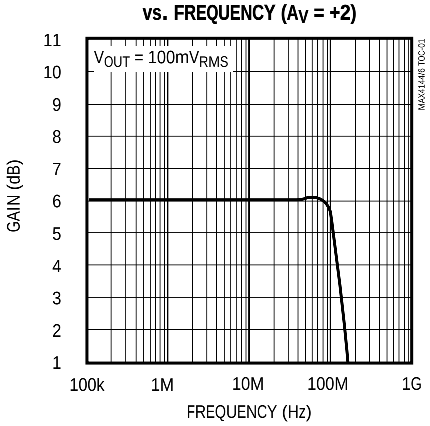
Note 1: The negative sign indicates that current is flowing out of the SHDN pin.
Note 2: Differential gain and phase are tested using a modulated ramp, 100 IRE (0.714V).

High-Speed Differential Line Receivers

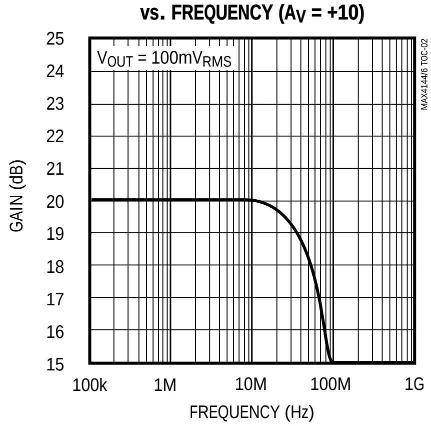
Typical Operating Characteristics

(T_A = +25°C, R_L = 150Ω, unless otherwise noted.)

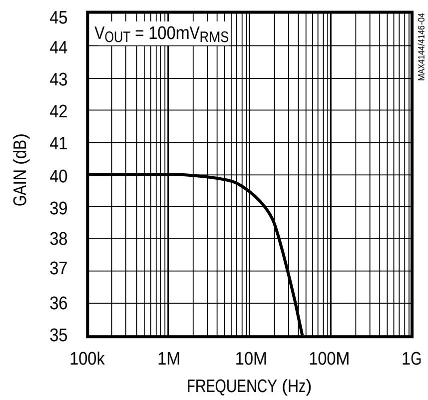
MAX4144
SMALL-SIGNAL GAIN
vs. FREQUENCY (A_V = +2)



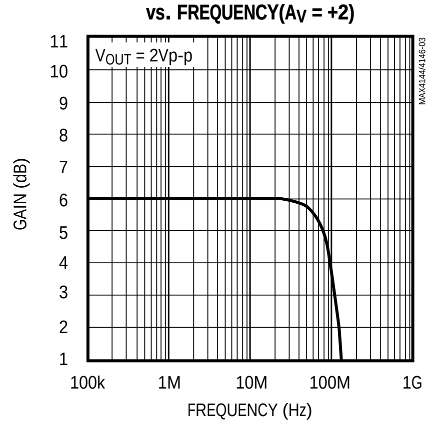
MAX4146
SMALL-SIGNAL GAIN
vs. FREQUENCY (A_V = +10)



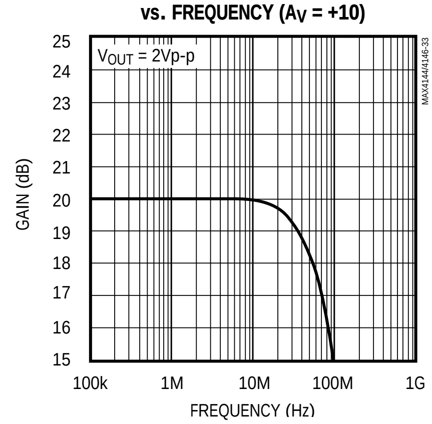
MAX4146
SMALL-SIGNAL GAIN
vs. FREQUENCY (A_V = +100)



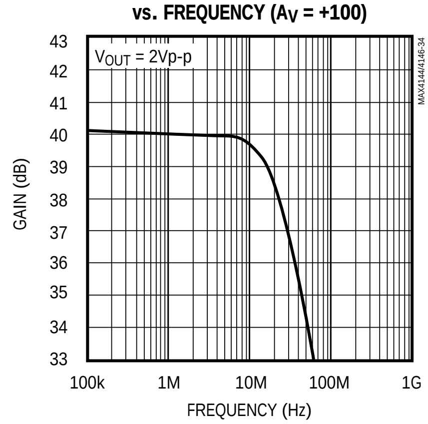
MAX4144
LARGE-SIGNAL GAIN
vs. FREQUENCY(A_V = +2)



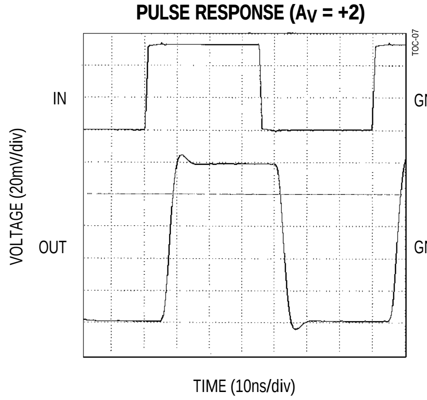
MAX4146
LARGE-SIGNAL GAIN
vs. FREQUENCY (A_V = +10)



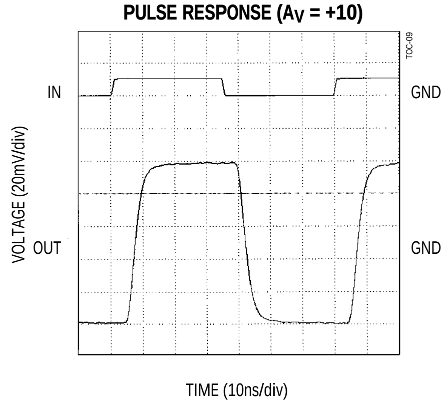
MAX4146
LARGE-SIGNAL GAIN
vs. FREQUENCY (A_V = +100)



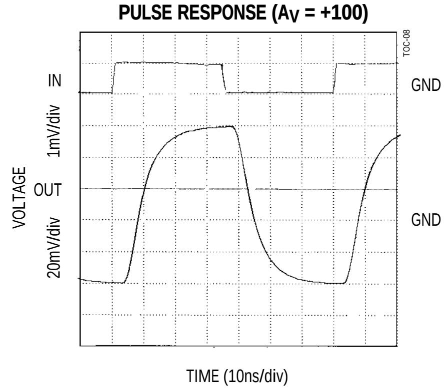
MAX4144
SMALL-SIGNAL
PULSE RESPONSE (A_V = +2)



MAX4146
SMALL-SIGNAL
PULSE RESPONSE (A_V = +10)



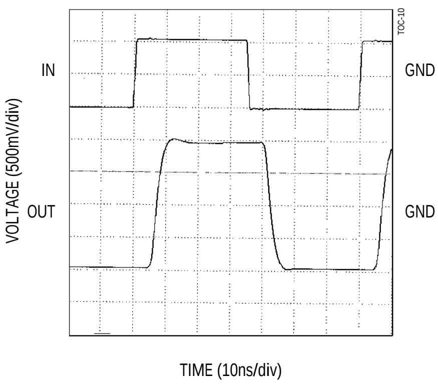
MAX4146
SMALL-SIGNAL
PULSE RESPONSE (A_V = +100)



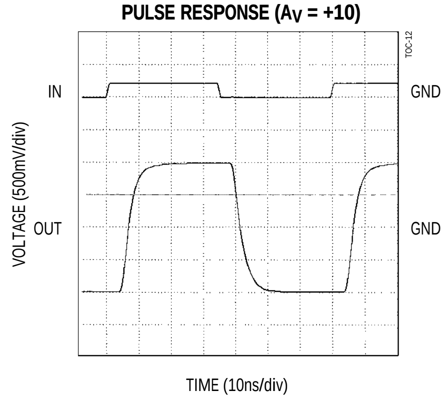
Typical Operating Characteristics (continued)

(T_A = +25°C, R_L = 150Ω, unless otherwise noted.)

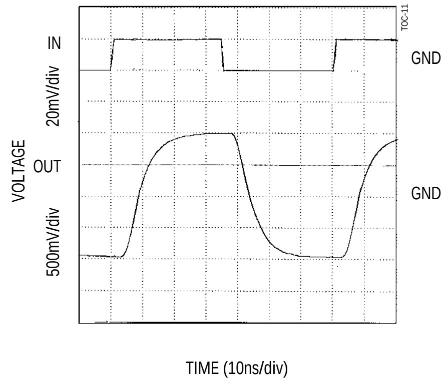
MAX4144 LARGE-SIGNAL PULSE RESPONSE (A_V = +2)



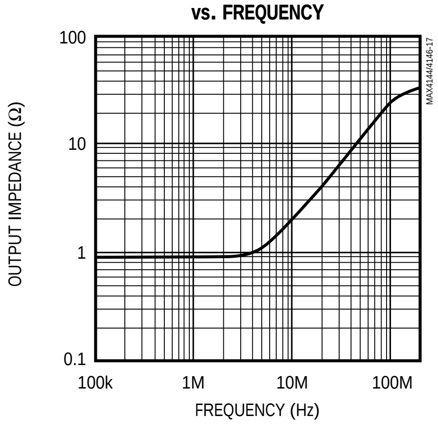
MAX4146 LARGE-SIGNAL PULSE RESPONSE (A_V = +10)



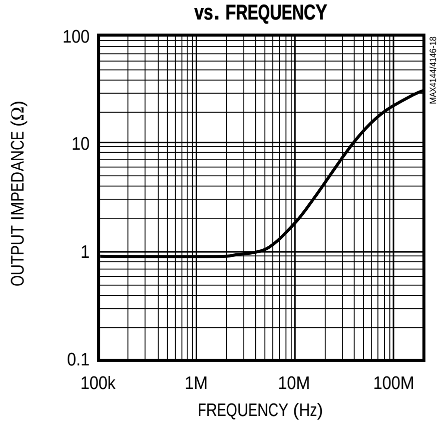
MAX4146 LARGE-SIGNAL PULSE RESPONSE (A_V = +100)



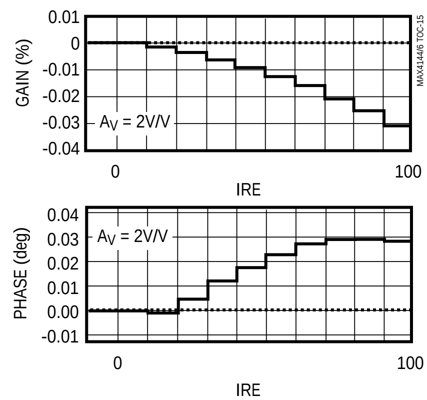
MAX4144 OUTPUT IMPEDANCE vs. FREQUENCY



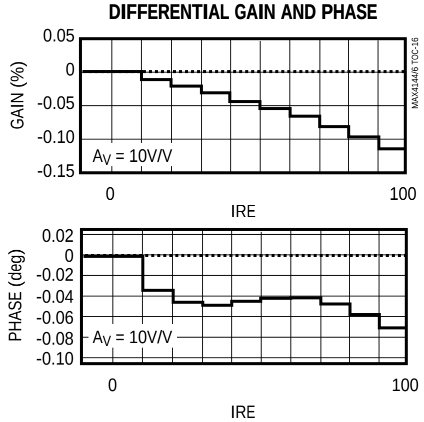
MAX4146 OUTPUT IMPEDANCE vs. FREQUENCY



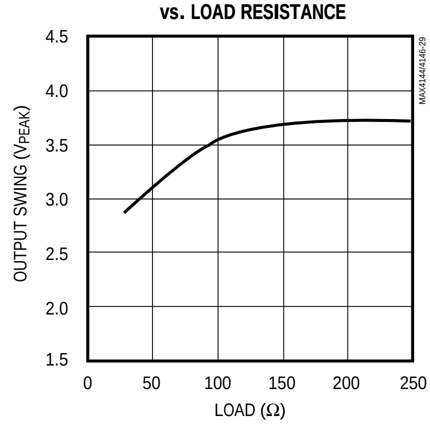
MAX4144 DIFFERENTIAL GAIN AND PHASE



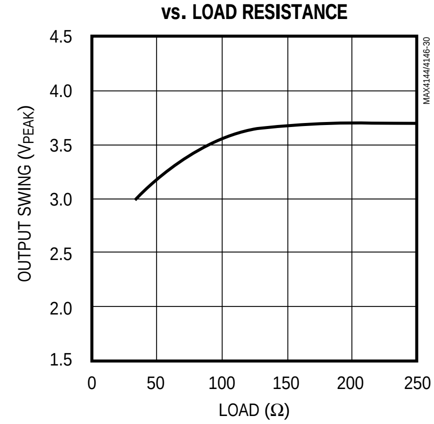
MAX4146 DIFFERENTIAL GAIN AND PHASE



MAX4144 OUTPUT SWING vs. LOAD RESISTANCE



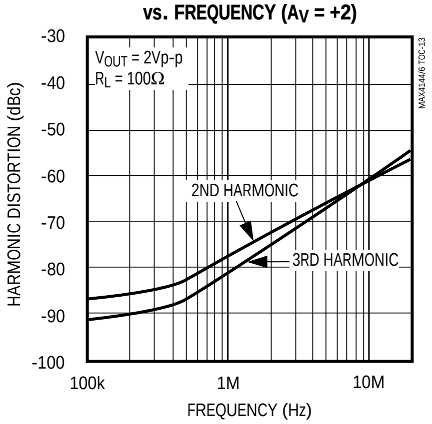
MAX4146 OUTPUT SWING vs. LOAD RESISTANCE



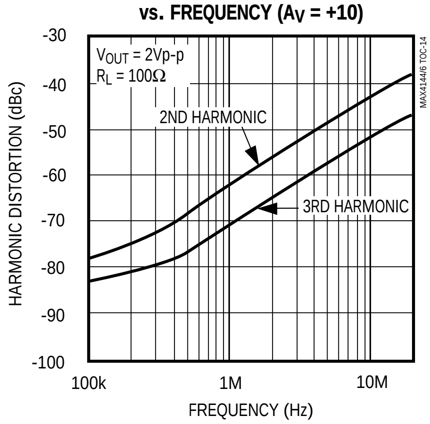
Typical Operating Characteristics (continued)

(T_A = +25°C, R_L = 150Ω, unless otherwise noted.)

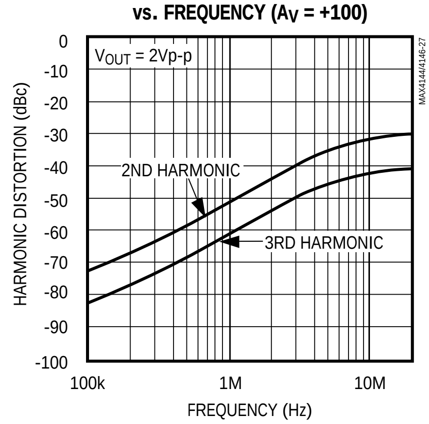
MAX4144
HARMONIC DISTORTION
vs. FREQUENCY (A_V = +2)



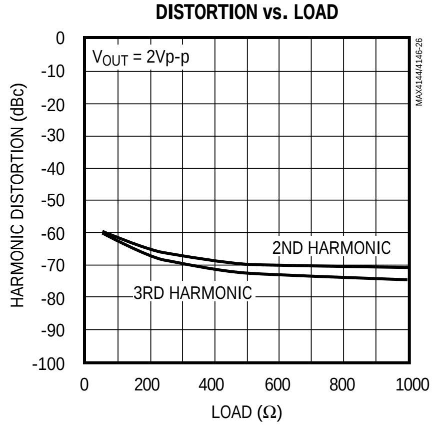
MAX4146
HARMONIC DISTORTION
vs. FREQUENCY (A_V = +10)



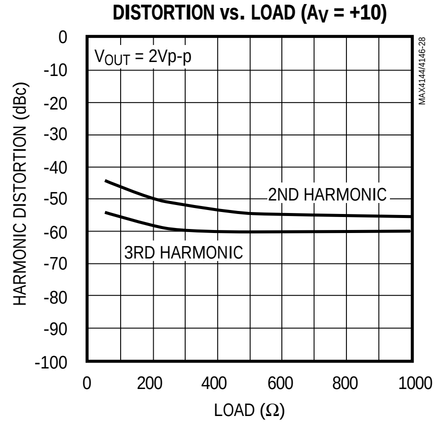
MAX4146
HARMONIC DISTORTION
vs. FREQUENCY (A_V = +100)



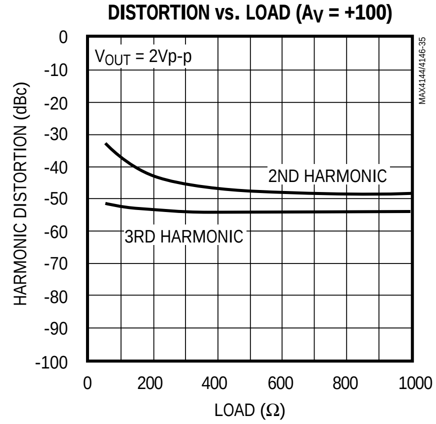
MAX4144
5MHz HARMONIC
DISTORTION vs. LOAD



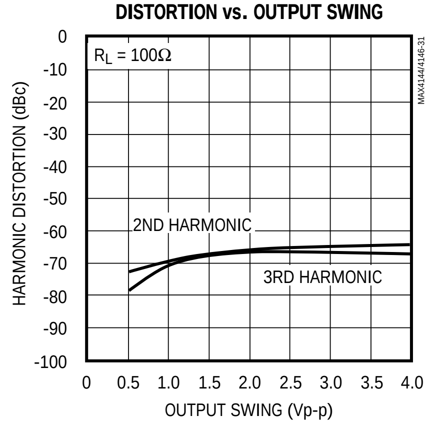
MAX4146
5MHz HARMONIC
DISTORTION vs. LOAD (A_V = +10)



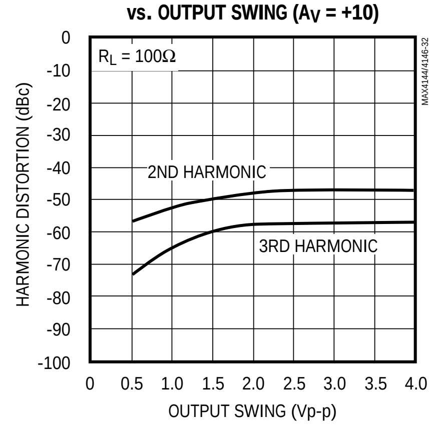
MAX4146
5MHz HARMONIC
DISTORTION vs. LOAD (A_V = +100)



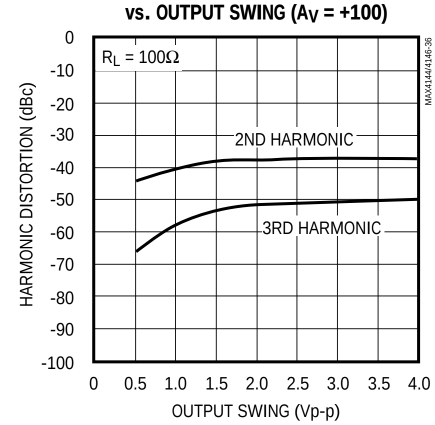
MAX4144
5MHz HARMONIC
DISTORTION vs. OUTPUT SWING



MAX4146
5MHz HARMONIC DISTORTION
vs. OUTPUT SWING (A_V = +10)



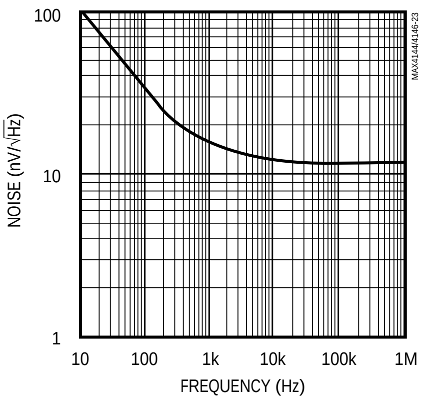
MAX4146
5MHz HARMONIC DISTORTION
vs. OUTPUT SWING (A_V = +100)



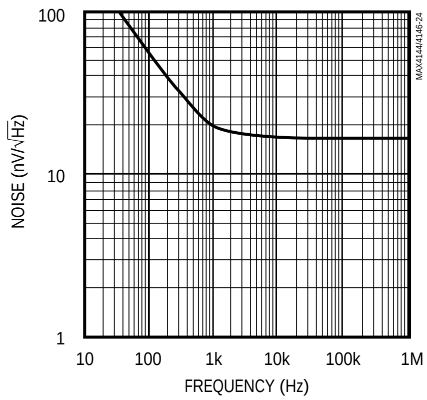
Typical Operating Characteristics (continued)

(T_A = +25°C, R_L = 150Ω, unless otherwise noted.)

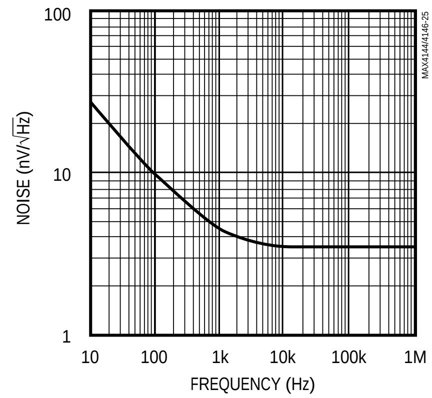
MAX4144 VOLTAGE NOISE vs. FREQUENCY



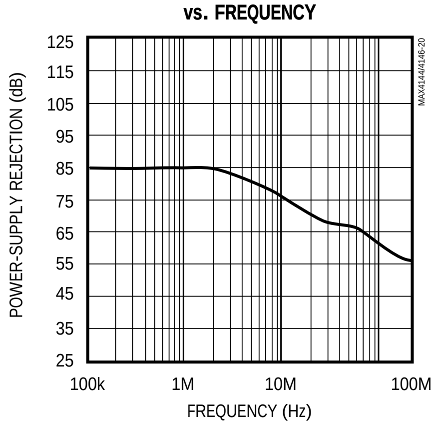
MAX4146 VOLTAGE NOISE vs. FREQUENCY (A_V = +10)



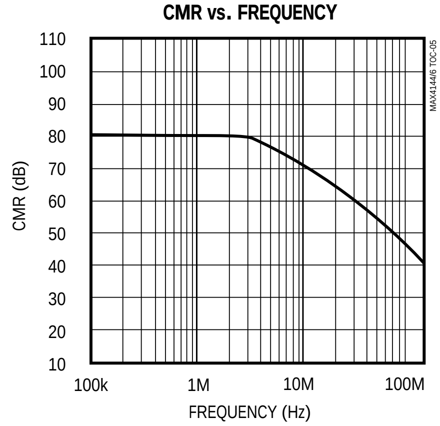
MAX4146 VOLTAGE NOISE vs. FREQUENCY (A_V = +100)



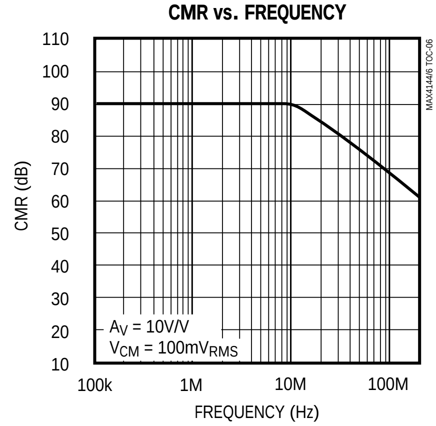
MAX4144 (A_V = 2) MAX4146 (A_V = 10) POWER-SUPPLY REJECTION vs. FREQUENCY



MAX4144 CMR vs. FREQUENCY



MAX4146 CMR vs. FREQUENCY



High-Speed Differential Line Receivers

Pin Description

PIN		NAME	FUNCTION
MAX4144	MAX4146		
1, 7	1, 7	V_{EE}	Negative Power Supply. Connect to -5V.
2	2	IN-	Inverting Input
3, 5, 10, 12	10, 12	N.C.	No Connect. Not internally connected.
—	3	RG-	Inverting Input for Gain-Set Resistor. A gain-setting resistor (R_G) between RG+ and RG- sets the gain (in V/V) according to the following equation: $G = 10 + \frac{14k\Omega}{R_G}$
4	4	SHDN	Logic Input for Shutdown Circuitry. A logic low enables the amplifier. A logic high disables the amplifier.
—	5	RG+	Non-Inverting Input for Gain-Set Resistor
6	6	IN+	Non-Inverting Input
8, 14	8, 14	V_{CC}	Positive Power Supply. Connect to +5V.
9	9	REF	Output Reference. Connect to ground for normal operation.
11	11	OUT	Output
13	13	SENSE	Output Sense. Connect to OUT close to the pin for normal operation.

Detailed Description

The MAX4144/MAX4146 differential line receivers feature 130MHz and 70MHz (A_V = 10V/V) bandwidth, respectively, and 70dB and 90dB common-mode rejection (CMR) at 10MHz. The parts feature a 1000V/µs slew rate, and power dissipation is a mere 110mW. The MAX4144 is internally set for a 2V/V closed-loop gain, while the MAX4146 can be set to gains from 10V/V to 100V/V using a single resistor. The amplifiers are ideal as line receivers. They have fully symmetrical differential inputs and a single-ended output, and can drive ±3.5V into a 150Ω load.

The differential inputs make the MAX4144/MAX4146 ideal for applications with high common-mode noise such as receiving T1 or XDSL transmissions over a twisted-pair cable. Excellent gain and phase, along with low noise, also suit them to video applications and RF signal processing.

For a complete differential transmission link, use the MAX4144/MAX4146 amplifiers with the MAX4147 line driver, as shown in the *Applications Information* section.

Applications Information

Grounding, Bypassing, and PC Board Layout

High-frequency design techniques must be followed when designing the PC board for the MAX4144/MAX4146.

- The printed circuit board should have at least two layers: the signal layer and the ground plane.
- Do not use wire-wrap boards—they are too inductive.
- Do not use IC sockets—they increase parasitic capacitance and inductance.
- Use surface-mount power-supply bypass capacitors instead of through-hole capacitors. Their shorter lead lengths reduce parasitic inductance, leading to superior high-frequency performance.
- Keep signal lines as short and as straight as possible. Do not make 90° turns; round all corners.
- The ground plane should be as free from voids as possible.

Output Short-Circuit Protection

Under short-circuit conditions to ground, the output current is typically limited to 100mA. This level is low enough that a moderate-duration short to ground will not cause permanent damage to the chip. However, a short to either supply will significantly increase power dissipation, and will cause permanent damage. The high output current capability is an advantage in systems that transmit a signal to several loads.

Input State Circuitry

The MAX4144/MAX4146 include internal protection circuitry that prevents damage to the precision input stage from large differential input voltages. This protection circuitry consists of five back-to-back Schottky protection diodes between IN+ and R_G+, and IN- and R_G- (Figure 1). The diodes limit the differential voltage applied to the amplifiers' internal circuitry to no more than $10V_F$, where V_F is the diode's forward voltage drop (about 0.4V at +25°C).

For a large differential input voltage (exceeding 4V), the MAX4146 input bias current (at IN+ and IN-) increases according to the following equation:

$$\text{Input Current} = \frac{(V_{IN+} - V_{IN-}) - 10V_F}{R_G}$$

The MAX4144 has an internal gain-setting resistor equal to 1.4kΩ. A differential input voltage as high as 10V will cause only 4.3mA to flow—much less than the absolute maximum rating of 10mA. However, in the MAX4146, R_G can be as low as 150Ω. Under this condition, the absolute maximum input current rating might be exceeded if the differential input voltage exceeds 5.5V (10mA x 150Ω + $10V_F$). In that case, 510Ω resistors can be placed at IN+ and IN- to limit the current without degrading performance.

Shutdown Mode

The MAX4144/MAX4146 can be put into low-power shutdown mode by bringing SHDN high. The amplifier output is high impedance in this mode; thus the impedance at OUT is that of the feedback resistors (1.4kΩ and 2kΩ, respectively, for the MAX4144/MAX4146).

Setting Gain (MAX4146)

The MAX4146's gain is determined by a single external resistor, R_G. The minimum gain is 10V/V (R_G = open), and the maximum practical gain is 100V/V. The gain (in V/V) is given in the following equation:

$$G = 10 + \frac{14k\Omega}{R_G}$$

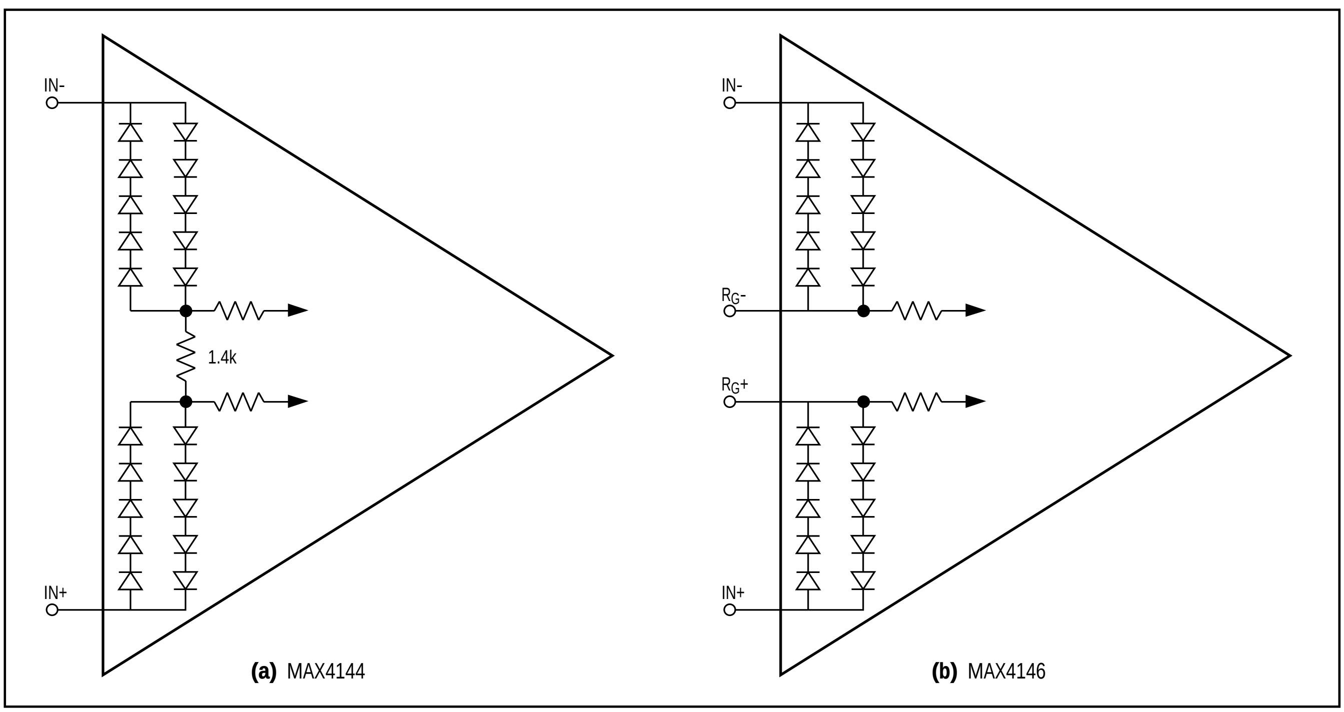


Figure 1. MAX4144/MAX4146 Input Protection Circuit

Figure 2 shows the connection for R_G. R_G might simply be a resistor, or it can be a complex pole-zero pair for filter and shaping applications (Figure 9). Use surface-mount gain-setting components to ensure stability.

Using REF and SENSE

The MAX4144/MAX4146 have a REF pin (normally connected to ground) and a SENSE pin (normally connected to OUT). In some long-line applications, it may be desirable to connect SENSE and OUT together at the load, instead of the typical connection at the part (Figure 3). This compensates for the long line's resistance, which otherwise leads to an IR voltage error.

When using this technique, keep the sense lines' impedance low to minimize gain errors. Also, keep capacitance low to maximize frequency response. The gain of the MAX4144/MAX4146 output stage is approximated by the following equation:

$$A_V = \frac{1}{2}\left[\frac{700\Omega + \Delta R_{SENSE}}{R}\left(1 + \frac{700\Omega + \Delta R_{REF}}{R + 700\Omega + \Delta R_{REF}}\right) + \frac{700\Omega + \Delta R_{REF}}{R + 700\Omega + \Delta R_{REF}}\right]$$

where ΔR_{SENSE} and ΔR_{REF} are the SENSE and REF trace impedances, respectively. R is 700Ω for the MAX4144 and 70Ω for the MAX4146.

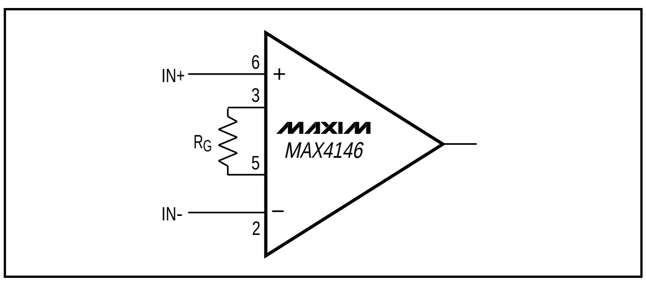


Figure 2. Connection of R_G in MAX4146

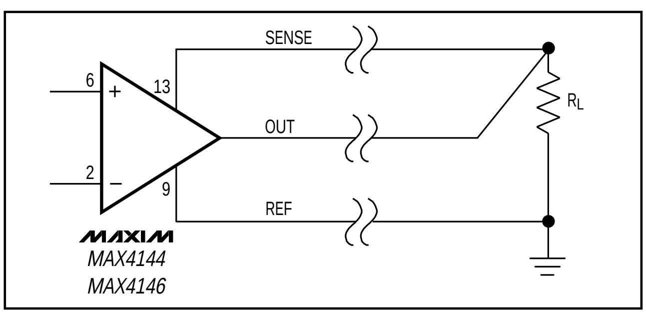


Figure 3. Connection of SENSE and REF to a Remote Load

Additionally, mismatches in the SENSE and REF traces lead to common-mode gain errors. Common-mode gain is approximated by the following equation:

$$A_{VCM} = \frac{\Delta R_{REF} - \Delta R_{SENSE}}{R + 700}$$

Substituting numbers for ΔR_{REF} and ΔR_{SENSE} into this equation, we can see that if changes in ΔR_{REF} and ΔR_{SENSE} are equal, CMR is not degraded.

Driving Capacitive Loads

The MAX4144/MAX4146 provide maximum AC performance when driving no output load capacitance. This is the case when driving a correctly terminated transmission line (i.e., a back-terminated cable).

In most amplifier circuits, driving large load capacitance increases the chance of oscillations. The amplifier's output impedance and the load capacitor combine to add a pole and excess phase to the loop response. If the pole's frequency is low enough and phase margin is degraded sufficiently, oscillations may occur.

A second concern when driving capacitive loads results from the amplifier's output impedance, which looks inductive at high frequencies. This inductance forms an L-C resonant circuit with the capacitive load. This causes peaking in the frequency response and degrades the amplifier's phase margin.

The MAX4144/MAX4146 drive capacitive loads up to 25pF without oscillation. However, some peaking may occur in the frequency domain (Figure 4).

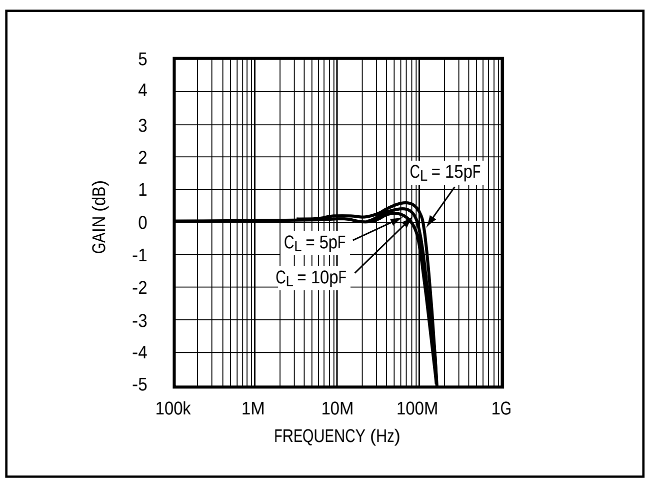


Figure 4. MAX4144 Small-Signal Response with Capacitative Load

To drive larger capacitance loads or to reduce ringing, add an isolation resistor between the amplifier's output and the load (Figure 5).

The value of R_{ISO} depends on the circuit's gain and the capacitive load (Figures 6 and 7). With higher capacitive values, bandwidth is dominated by the RC network formed by R_{ISO} and C_L; the bandwidth of the amplifier itself is much higher. Also note that the isolation resistor forms a divider that decreases the voltage delivered to the load.

Twisted-Pair Line Receiver

The MAX4144/MAX4146 are well suited as receivers in twisted-pair XDSL or NTSC/PAL video applications. The standard 24AWG telephone wire widely used in these applications is a lossy medium for high-frequency signals. The losses in NTSC video applications are almost 15dB per 1,000 feet (Figure 8). Losses are higher at higher frequencies, contributing to severe pulse-edge rounding in digital applications. The nominal impedance of twisted pair telephone wire is 110Ω.

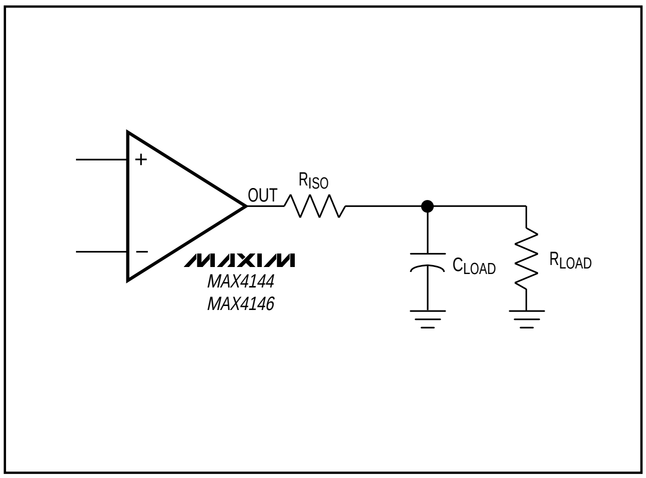


Figure 5. Addition of R_{ISO} to Amplifier Output

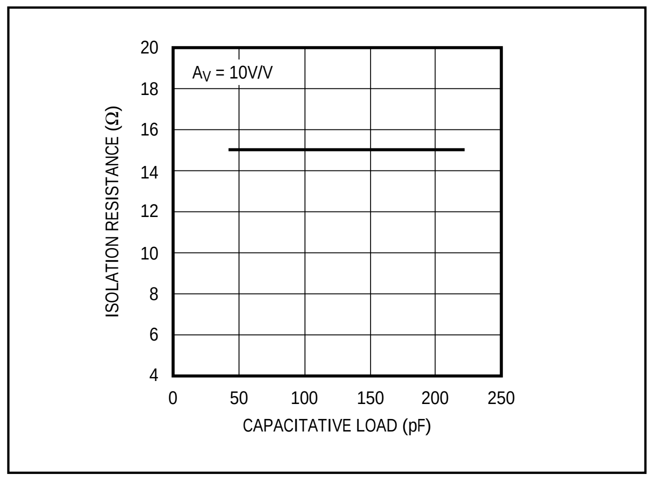


Figure 7. MAX4146 Isolation Resistance vs. Capacitative Load

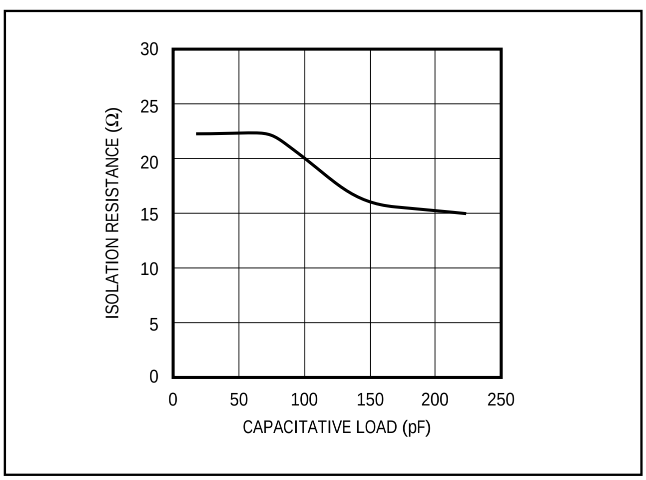


Figure 6. MAX4144 Isolation Resistance vs. Capacitative Load

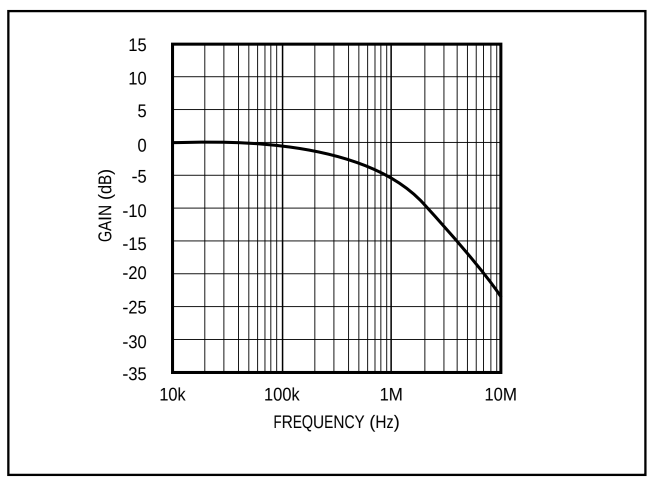


Figure 8. 1000 Feet of AWG24 Twisted-Pair Telephone Cable (Gain vs. Frequency)

High-Speed Differential Line Receivers

The MAX4146, with variable gain up to 100V/V, can be used to compensate for cable losses. In the circuit of Figure 8, the cable characteristics are such that the video-chroma frequency loss is almost 15dB greater than the low-frequency loss. The losses can be compensated for by using the RC-shaping network (Figure 9). A 560Ω resistance and a 100pF capacitance shape the MAX4146 gain to inversely match the frequency of the 1000 feet of telephone cable. The differential gain and phase, using the circuit of Figure 8, is 0.55% and 0.18°, respectively.

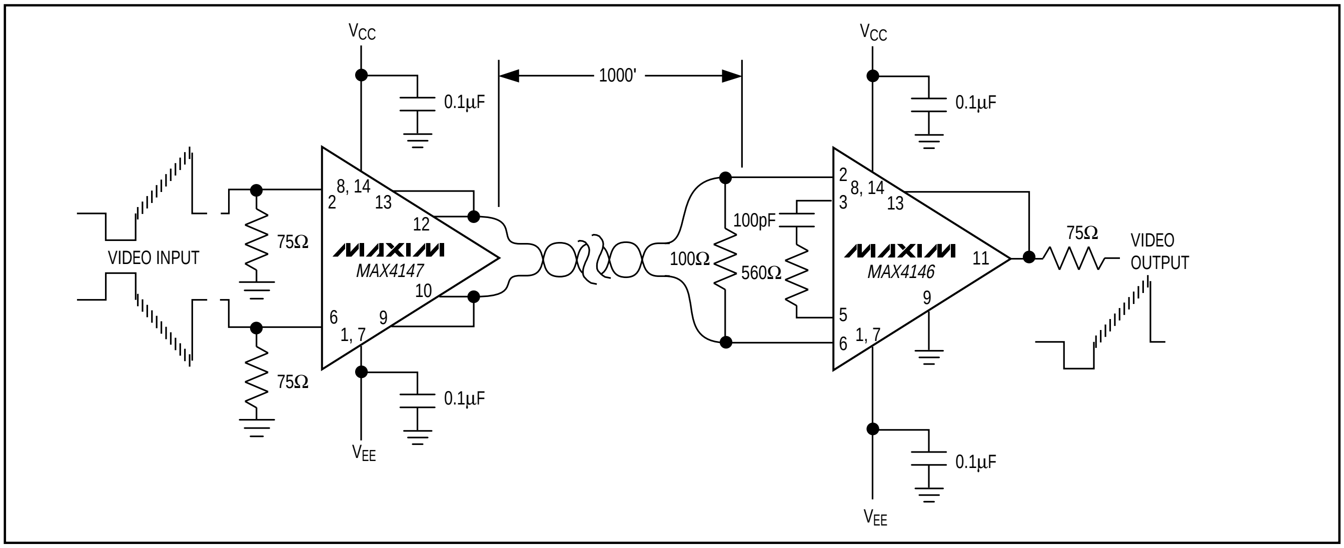


Figure 9. Circuit for Transmitting NTSC/PAL Video Over 1000 Feet of Twisted-Pair Telephone Line

Pin Configurations