19-1543; Rev 0; 10/99

**EVALUATION KIT AVAILABLE**

# Ultra-High-Speed, Low-Distortion, Differential-to-Single-Ended Line Receivers with Enable



## General Description

The MAX4444/MAX4445 differential line receivers offer unparalleled high-speed, low-distortion performance. Using a three op amp instrumentation amplifier architecture, these ICs have symmetrical differential inputs and a single-ended output. They operate from ±5V supplies and are capable of driving a 100Ω load to ±3.7V. The MAX4444 has an internally set closed-loop gain of +2V/V, while the MAX4445 is compensated for gains of +2V/V or greater, set by an external resistor. A low-power enable mode reduces current consumption to 3.5mA.

Using current-feedback techniques, the MAX4444/MAX4445 achieve a 550MHz bandwidth while maintaining up to a 5000V/µs slew rate. Excellent differential gain/phase and noise specifications make these amplifiers ideal for a wide variety of video and RF signal-processing applications. An evaluation kit is available to speed design.

## Features

- **5000V/µs Slew Rate (MAX4444)**
- **+2V/V Internally Fixed Gain (MAX4444)**
- **External Gain Selection (MAX4445, $A_{VCL} \geq$ +2V/V)**
- **550MHz -3dB Bandwidth**
- **-60dB SFDR at 5MHz**
- **Low Differential Gain/Phase: 0.07%/0.05°**
- **Low Noise: 25nV/$\sqrt{Hz}$ at $f_{IN}$ = 100kHz**
- **Low-Power Disable Mode Reduces Quiescent Current to 3.5mA**

## Applications

Differential-to-Single-Ended Conversion

Twisted-Pair to Coaxial Converter

High-Speed Instrumentation Amplifier

Data Acquisition

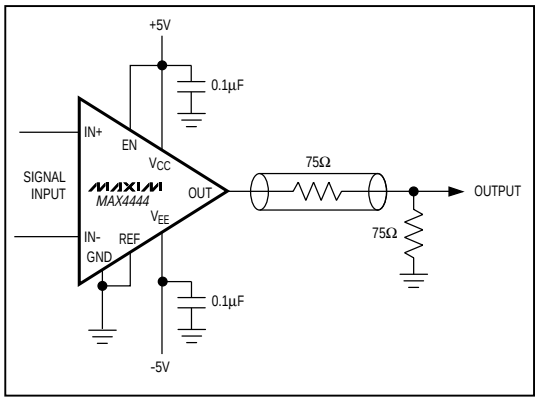
Medical Instrumentation

High-Speed Differential Line Receiver

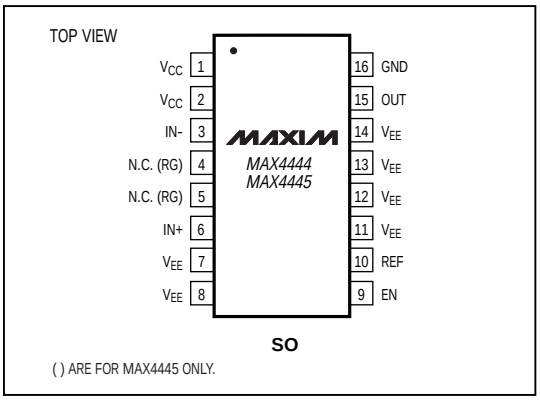
## Ordering Information

| PART | TEMP. RANGE | PIN-PACKAGE |
|---|---|---|
| **MAX4444**ESE | -40°C to +85°C | 16 Narrow SO |
| **MAX4445**ESE | -40°C to +85°C | 16 Narrow SO |

## Typical Operating Circuit




## Pin Configuration



## ABSOLUTE MAXIMUM RATINGS

$V_{CC}$ to $V_{EE}$ .....+12V
Voltage on IN+, IN-, EN, OUT+, OUT-, RG, REF.....($V_{EE}$ - 0.3V) to ($V_{CC}$ + 0.3V)
Current Into IN+, IN-, RG, EN .....20mA
Output Short-Circuit Duration .....Indefinite to GND
Continuous Power Dissipation ($T_A$ = +70°C)
16-Pin Narrow SO (derate 20mW/°C above +70°C) ...1600mW
Operating Temperature Range .....-40°C to +85°C
Storage Temperature Range .....-65°C to +150°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, $V_{EN}$ = ≥2V, $V_{CM}$ = 0 , $R_L$ = ∞, REF = GND, $A_{VCL}$ = +2V/V, $T_A$ = $T_{MIN}$ to $T_{MAX}$, unless otherwise noted. Typical values are at $T_A$ = +25°C.)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Operating Supply Voltage Range | | Guaranteed by PSRR test | | ±4.5 | | ±5.5 | V |
| Input Common-Mode Voltage Range | $V_{CM}$ | Guaranteed by CMRR test | | -2.9 | | 2.9 | V |
| Differential Input Voltage Range | $V_{DIFF}$ | Guaranteed by output swing test | | -1.7 | | 1.7 | V |
| Input Offset Voltage | $V_{OS}$ | | | | 15 | 65 | mV |
| Input Offset-Voltage Temperature Coefficient | $TC_{VOS}$ | | | | 12 | | µV/°C |
| Input Bias Current | $I_B$ | | | | 10 | 55 | µA |
| Input Offset Current | $I_{OS}$ | | | | 0.25 | 45 | µA |
| Differential Input Resistance | $R_{IN}$ | -2.9V ≤ $V_{IN}$ ≤ +2.9V | | | 82 | | kΩ |
| | | -2.9V ≤ $V_{CM}$ ≤ +2.9V | | | 170 | | |
| Gain | $A_V$ | -3V ≤ $V_{OUT}$ ≤ +3V | MAX4444 | | 2 | | V/V |
| | | | MAX4445 | | (1 + 600/$R_G$) | | |
| Gain Error | | -3V ≤ $V_{OUT}$ ≤ +3V, $R_L$ = 100Ω | MAX4444 | | 0.5 | 2 | % |
| | | | MAX4445 | | 2.6 | 8 | |
| Gain-Error Drift | | $R_L$ = 100Ω | | | 0.003 | | %/°C |
| Output Voltage Swing | $V_{OUT}$ | $R_L$ = 100Ω | | ±3.4 | ±3.7 | | V |
| | | $R_L$ = 50Ω | | ±3.3 | ±3.6 | | |
| Output Current Drive | $I_{OUT}$ | $R_L$ = 30Ω | | 90 | 120 | | mA |
| Power-Supply Rejection Ratio | PSRR | $V_S$ = ±4.5V to ±5.5V | | 53 | 70 | | dB |
| Common-Mode Rejection Ratio | CMRR | -2.9V ≤ $V_{CM}$ ≤ +2.9V | | 40 | 55 | | dB |
| Disable Output Resistance | $R_{OUT(OFF)}$ | $V_{EN}$ = 0, -3.5V ≤ $V_{OUT}$ ≤ +3.5V, MAX4444 | | | 1.8 | | kΩ |
| EN Logic Low Threshold | $V_{IL}$ | | | | | 0.8 | V |
| EN Logic High Threshold | $V_{IH}$ | | | 2 | | | V |
| EN Logic Input Low Current | $I_{IL}$ | $V_{EN}$ = 0 | | | 2.2 | 10 | µA |
| EN Logic Input High Current | $I_{IH}$ | $V_{EN}$ = 5V | | | 2.6 | 10 | µA |
| Quiescent Current | $I_Q$ | $V_{IN}$ = 0, $V_{EN}$ = 5V | | | 41 | 55 | mA |
| | | $V_{IN}$ = 0, $V_{EN}$ = 0 | | | 3.5 | 5.5 | |

## AC ELECTRICAL CHARACTERISTICS

($V_{CC}$ = +5V, $V_{EE}$ = -5V, $V_{EN}$ = 5V, $R_L$ = 100Ω, REF = GND, $A_{VCL}$ = +2V/V, $T_A$ = +25°C, unless otherwise noted.)

| PARAMETER | SYMBOL | CONDITION | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Small-Signal -3dB Bandwidth | $BW_{SS}$ | $V_{OUT}$ = 100mVp-p | | | 550 | | MHz |
| Large-Signal -3dB Bandwidth | $BW_{LS}$ | $V_{OUT}$ = 2Vp-p | | | 500 | | MHz |
| 0.1dB Gain Flatness | | $V_{OUT}$ = 100mVp-p | | | 80 | | MHz |
| Slew Rate (Note 1) | SR | $V_{OUT}$ = 4V step | MAX4444 | | 5000 | | V/µs |
| | | | MAX4445 | | 3800 | | |
| | | $V_{OUT}$ = 2V step | MAX4444 | | 2400 | | |
| | | | MAX4445 | | 2000 | | |
| | | $V_{OUT}$ = 1V step | | | 1200 | | |
| | | $V_{OUT}$ = 0.5V step | | | 600 | | |
| Rise Time (Note 1) | $t_{RISE}$ | | | | 650 | | ps |
| Fall Time (Note 1) | $t_{FALL}$ | $V_{OUT}$ = 4V step | | | 825 | | ps |
| | | $V_{OUT}$ = 2V step | | | 700 | | |
| | | $V_{OUT}$ = 1V step | | | 700 | | |
| | | $V_{OUT}$ = 0.5V step | | | 700 | | |
| Settling Time | | Settle to 0.1% , $V_{OUT}$ = 2V step | | | 12 | | ns |
| SFDR | | $V_{OUT}$ = 2Vp-p | $f_C$ = 100kHz | | -65 | | dBc |
| | | | $f_C$ = 5MHz | | -60 | | |
| | | | $f_C$ = 20MHz | | -55 | | |
| | | | $f_C$ = 100MHz | | -35 | | |
| 2nd-Harmonic Distortion | | $V_{OUT}$ = 2Vp-p | $f_C$ = 100kHz | | -65 | | dBc |
| | | | $f_C$ = 5MHz | | -62 | | |
| | | | $f_C$ = 20MHz | | -50 | | |
| | | | $f_C$ = 100MHz | | -35 | | |
| 3rd-Harmonic Distortion | | $V_{OUT}$ = 2Vp-p | $f_C$ = 100kHz | | -90 | | dBc |
| | | | $f_C$ = 5MHz | | -72 | | |
| | | | $f_C$ = 20MHz | | -62 | | |
| | | | $f_C$ = 100MHz | | -55 | | |
| Differential Phase Error | DP | NTSC, $R_L$ = 150Ω | | | 0.05 | | degrees |
| Differential Gain Error | DG | NTSC, $R_L$ = 150Ω | | | 0.07 | | % |
| Input Noise Voltage Density | $e_N$ | f = 100kHz (Note 2) | | | 25 | | $nV/\sqrt{Hz}$ |
| Input Noise Current Density | $i_N$ | f = 100kHz | | | 1.8 | | $pA/\sqrt{Hz}$ |
| Output Impedance | $Z_{OUT}$ | f = 10MHz | | | 0.7 | | Ω |
| Enable Time | $t_{SHDN(ON)}$ | $V_{IN}$ = 1V, $V_{OUT}$ settle to within 10% | | | 80 | | ns |
| Disable Time | $t_{SHDN(OFF)}$ | $V_{IN}$ = 1V, $V_{OUT}$ settle to within 10% | | | 200 | | ns |
| Power-Up Time | $t_{ON}$ | $V_{IN}$ = 1V, $V_{OUT}$ settle to within 10% | | | 0.5 | | µs |
| Power-Down Time | $t_{OFF}$ | $V_{IN}$ = 1V, $V_{OUT}$ settle to within 10% | | | 0.3 | | µs |

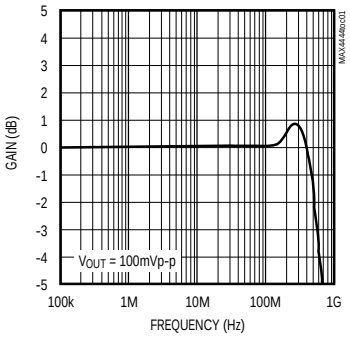
**Note 1:** Input step voltage has <100ps rise (fall) time. Measured at the output from 10% to 90% (90% to 10%) level.
**Note 2:** Includes the current noise contribution through the on-die feedback resistor.

# Ultra-High-Speed, Low-Distortion, Differential-to-Single-Ended Line Receivers with Enable

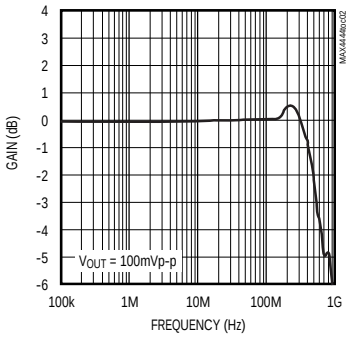
## Typical Operating Characteristics

($V_{CC}$ = +5V, $V_{EE}$ = -5V, $V_{EN}$ = 5V, $V_{IN}$ = $V_{IN+}$ - $V_{IN-}$, $R_L$ = 100Ω, REF = GND, $A_V$ = +2V/V, $T_A$ = +25°C, unless otherwise noted.)

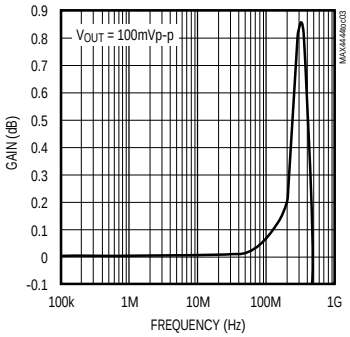
**MAX4444**
**SMALL-SIGNAL GAIN vs. FREQUENCY**



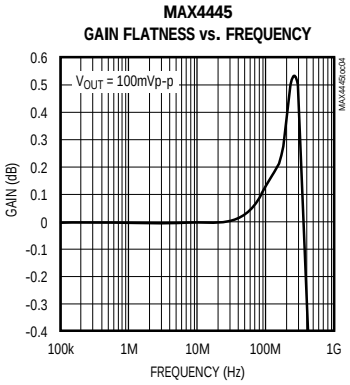

**MAX4445**
**SMALL-SIGNAL GAIN vs. FREQUENCY**



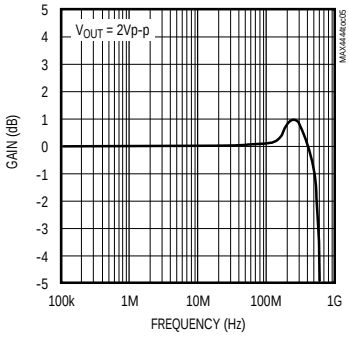

**MAX4444**
**GAIN FLATNESS vs. FREQUENCY**



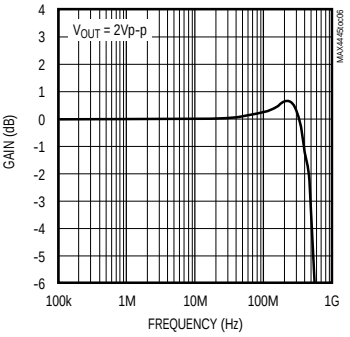

**MAX4445**
**GAIN FLATNESS vs. FREQUENCY**



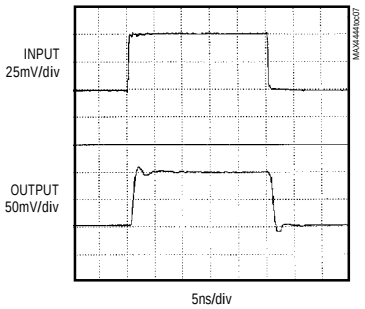

**MAX4444**
**LARGE-SIGNAL GAIN vs. FREQUENCY**



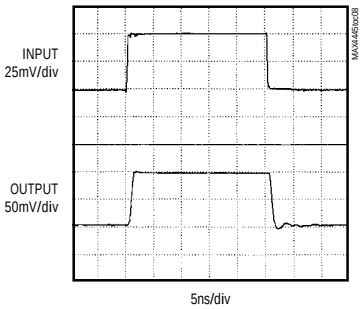

**MAX4445**
**LARGE-SIGNAL GAIN vs. FREQUENCY**



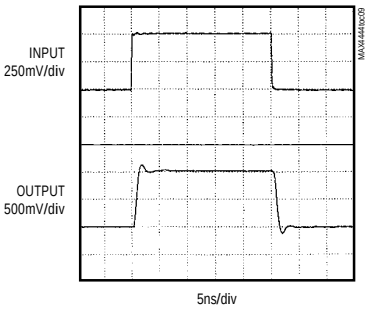

**MAX4444**
**SMALL-SIGNAL PULSE RESPONSE**




**MAX4445**
**SMALL-SIGNAL PULSE RESPONSE**



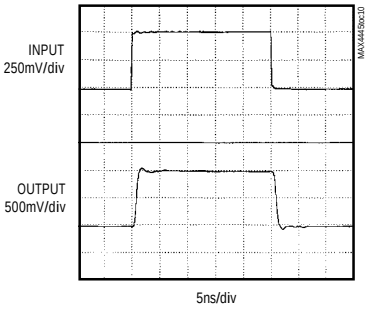

**MAX4444**
**LARGE-SIGNAL PULSE RESPONSE**



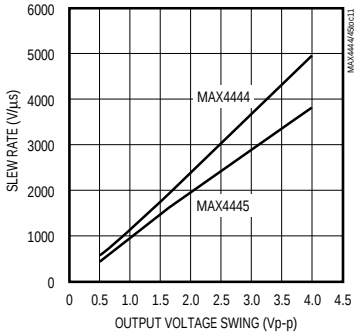
## Typical Operating Characteristics (continued)

($V_{CC}$ = +5V, $V_{EE}$ = -5V, $V_{EN}$ = 5V, $V_{IN}$ = $V_{IN+}$ - $V_{IN-}$, $R_L$ = 100Ω, REF = GND, $A_V$ = +2V/V, $T_A$ = +25°C, unless otherwise noted.)

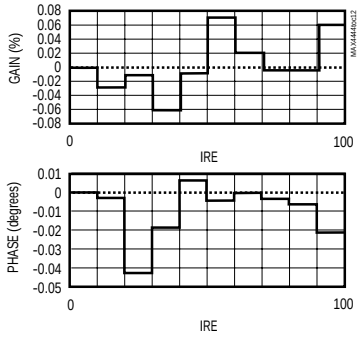
**MAX4445**
**LARGE-SIGNAL PULSE RESPONSE**



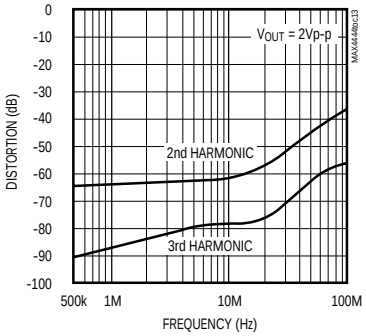

**SLEW RATE vs. OUTPUT VOLTAGE SWING**



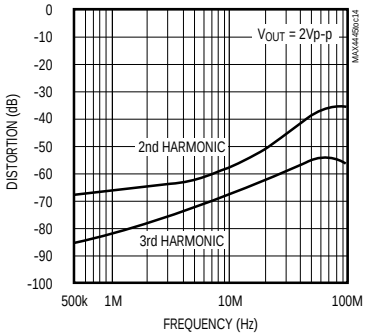

**MAX4444**
**DIFFERENTIAL GAIN AND PHASE**



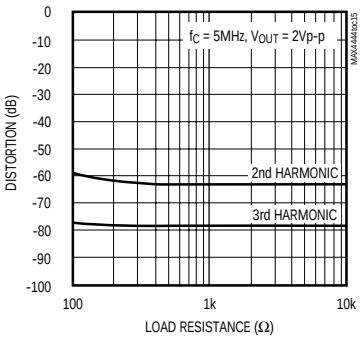

**MAX4444**
**HARMONIC DISTORTION**
**vs. FREQUENCY**



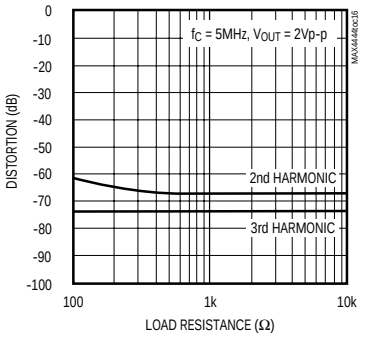

**MAX4445**
**HARMONIC DISTORTION**
**vs. FREQUENCY**



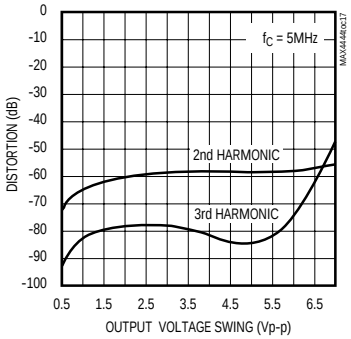

**MAX4444**
**HARMONIC DISTORTION**
**vs. LOAD RESISTANCE**



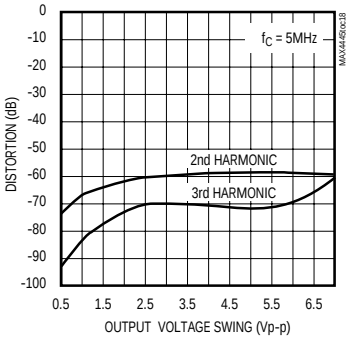

**MAX4445**
**HARMONIC DISTORTION**
**vs. LOAD RESISTANCE**




**MAX4444**
**HARMONIC DISTORTION**
**vs. OUTPUT VOLTAGE SWING**




**MAX4445**
**HARMONIC DISTORTION**
**vs. OUTPUT VOLTAGE SWING**

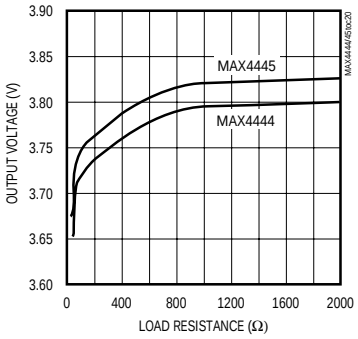


# Ultra-High-Speed, Low-Distortion, Differential-to-Single-Ended Line Receivers with Enable

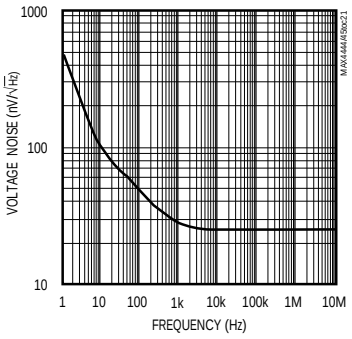
## Typical Operating Characteristics (continued)

($V_{CC}$ = +5V, $V_{EE}$ = -5V, $V_{EN}$ = 5V, $V_{IN}$ = $V_{IN}$+ - $V_{IN}$-, $R_L$ = 100Ω, REF = GND, $A_V$ = +2V/V, $T_A$ = +25°C, unless otherwise noted.)

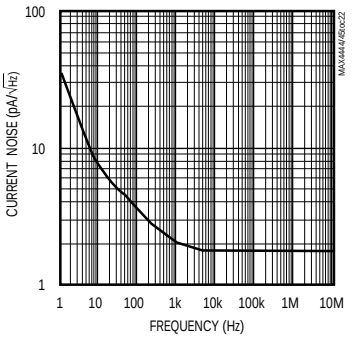
**VOLTAGE SWING vs. LOAD RESISTANCE**



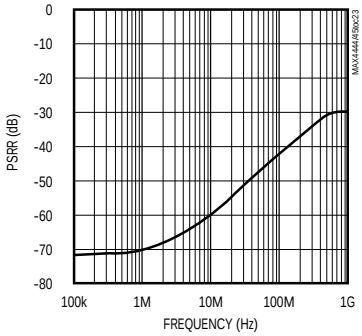

**INPUT VOLTAGE NOISE DENSITY vs. FREQUENCY**



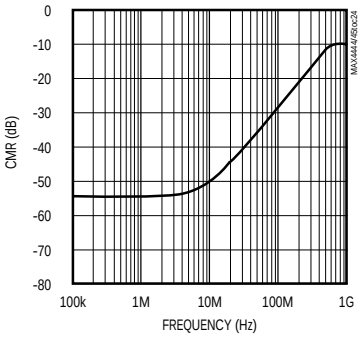

**INPUT CURRENT NOISE DENSITY vs. FREQUENCY**



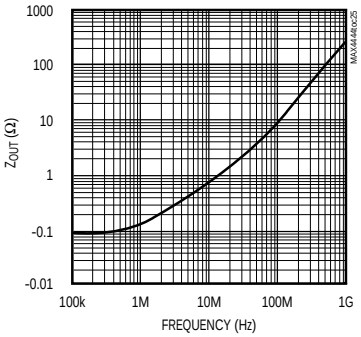

**POWER-SUPPLY REJECTION RATIO vs. FREQUENCY**



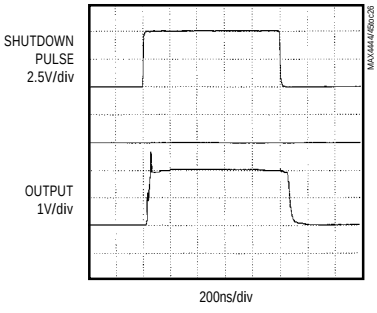

**COMMON-MODE REJECTION vs. FREQUENCY**



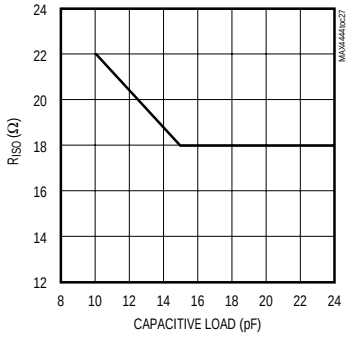

**MAX4444 CLOSED-LOOP OUTPUT IMPEDANCE vs. FREQUENCY**



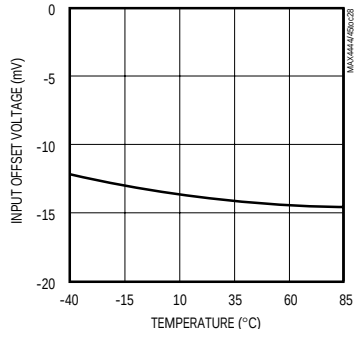

**SHUTDOWN RESPONSE**




**MAX4444 RECOMMENDED ISOLATION RESISTANCE vs. CAPACITIVE LOAD**



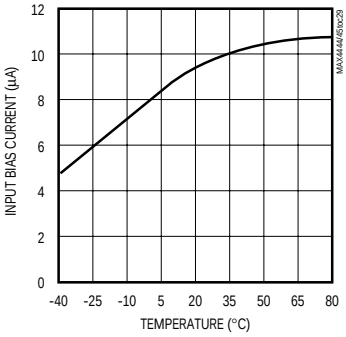

**INPUT OFFSET VOLTAGE vs. TEMPERATURE**



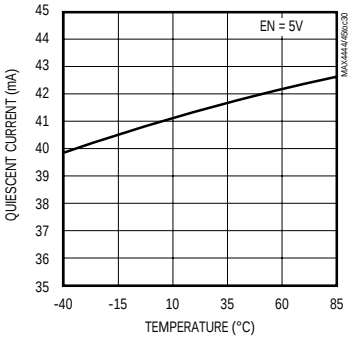
## Typical Operating Characteristics (continued)

($V_{CC}$ = +5V, $V_{EE}$ = -5V, $V_{EN}$ = 5V, $V_{IN}$ = $V_{IN+}$ - $V_{IN-}$, $R_L$ = 100Ω, REF = GND, $A_V$ = +2V/V, $T_A$ = +25°C, unless otherwise noted.)

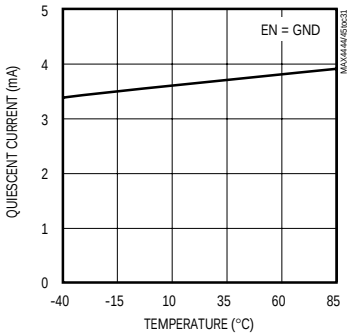
**INPUT BIAS CURRENT vs. TEMPERATURE**




**QUIESCENT CURRENT vs. TEMPERATURE**




**QUIESCENT CURRENT vs. TEMPERATURE**




## Pin Description

| PIN | | NAME | FUNCTION |
|---|---|---|---|
| MAX4444 | MAX4445 | | |
| 1, 2 | 1, 2 | $V_{CC}$ | Positive Power-Supply Input. Bypass with a 0.1µF capacitor to GND. |
| 3 | 3 | IN- | Inverting Amplifier Input |
| 4, 5 | — | N.C. | No Connection. Not internally connected. Connect to GND for best AC performance. |
| — | 4, 5 | RG | Resistor Gain Input. Connect a resistor between these pins to set closed-loop gain (Figure 1). |
| 6 | 6 | IN+ | Noninverting Amplifier Input |
| 7, 8, 11–14 | 7, 8, 11–14 | $V_{EE}$ | Negative Supply Input. Bypass with a 0.1µF capacitor. |
| 9 | 9 | EN | Active-High Enable Input. Connect to $V_{CC}$ for normal operation. Connect to GND for disable mode. |
| 10 | 10 | REF | Reference Input. Connect to midpoint of the two power supplies. |
| 15 | 15 | OUT | Amplifier Output |
| 16 | 16 | GND | Ground |

# Ultra-High-Speed, Low-Distortion, Differential-to-Single-Ended Line Receivers with Enable

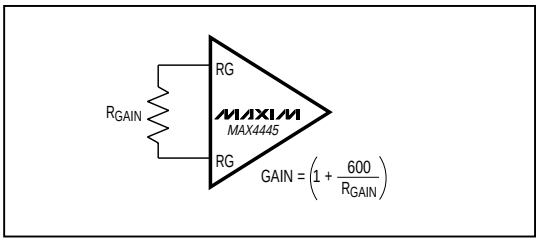



*Figure 1. Setting the Amplifier Gain*

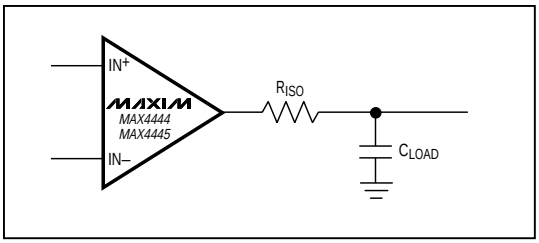



*Figure 2. Using an Isolation Resistor for High Capacitive Loads*

## Detailed Description

The MAX4444/MAX4445 differential-to-single-ended line receivers offer high-speed and low-distortion performance, and are ideally suited for video and RF signal-processing applications. These receivers offer a small-signal bandwidth of 550MHz and have a high slew rate of up to 5000V/µs. Their 120mA output capability allows them to be directly coupled to data acquisition systems.

## Applications Information

### Grounding Bypassing

Use the following high-frequency design techniques when designing the PC board for the MAX4444/MAX4445.

- Use a multilayer board with one layer dedicated as the ground plane.
- Do not use wire wrap or breadboards due to high inductance.
- Avoid IC sockets due to high parasitic capacitance and inductance.
- Bypass supplies with a 0.1µF capacitor. Use surface-mount capacitors to minimize lead inductance.
- Keep signal lines as short and straight as possible. Do not make 90° turns. Use rounded corners. Do not cross signal paths if possible.
- Ensure that the ground plane is free from voids.

### Low-Power Enable Mode

The MAX4444/MAX4445 are disabled when EN goes low. This reduces supply current to only 3.5mA. As the output becomes higher impedance, the effective impedance at the output for the MAX4444 is 1.8kΩ. The effective output impedance for the MAX4445 is 1.8kΩ plus $R_{GAIN}$.

### Setting Gain (MAX4445)

The MAX4445 is stable with a minimum gain configuration of +2V/V. $R_{GAIN}$, connected between the RG pins, sets the gain of this device as shown in Figure 1. Calculate the expected gain as follows:

$$Gain = (1 + 600 / R_{GAIN})$$

### Driving Capacitive Loads

The MAX4444/MAX4445 are designed to drive capacitive loads. However, excessive capacitive loads may cause ringing or instability at the output as the phase margin of the device reduces. Adding a small series isolation resistor at the output helps reduce the ringing but slightly increases gain error (Figure 2). For recommended values, see *Typical Operating Characteristics*.

### Coaxial Line Driver

The MAX4444/MAX4445 are well suited to drive coaxial cables. Their high output current capability can easily drive the 75Ω characteristic impedance of common coaxial cables. Adjust the gain of the MAX4445 to compensate for cable losses to maintain the required levels at the input of the next stage.

## Chip Information

TRANSISTOR COUNT: 254

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