

# Very Low Noise, Differential Amplifier and 15MHz Lowpass Filter

## FEATURES

- Programmable Differential Gain via Two External Resistors
- Adjustable Output Common Mode Voltage
- Operates and Specified with 3V, 5V,  $\pm 5V$  Supplies
- 0.5dB Ripple 4th Order Lowpass Filter with 15MHz Cutoff
- 76dB S/N with 3V Supply and 2V<sub>P-P</sub> Output
- Low Distortion, 2V<sub>P-P</sub>, 800 $\Omega$  Load,  $V_S = 3V$   
 1MHz: 86dBc 2nd, 90dBc 3rd  
 10MHz: 63dBc 2nd, 69dBc 3rd
- Fully Differential Inputs and Outputs
- Compatible with Popular Differential Amplifier Pinouts
- SO-8 Package

## APPLICATIONS

- High Speed ADC Antialiasing and DAC Smoothing in Networking or Cellular Base Station Applications
- High Speed Test and Measurement Equipment
- Medical Imaging
- Drop-In Replacement for Differential Amplifiers

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## DESCRIPTION

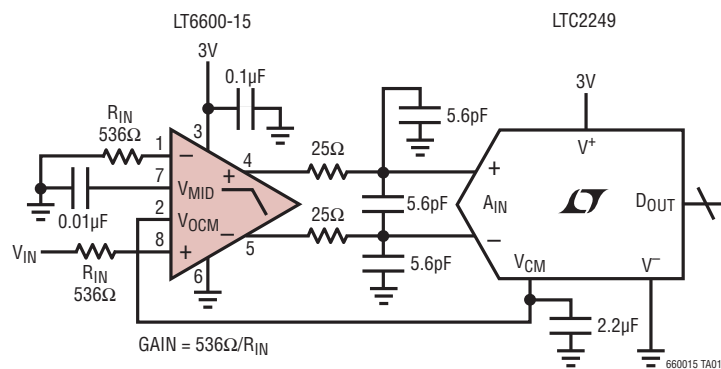
The LT<sup>®</sup>6600-15 combines a fully differential amplifier with a 4th order 15MHz lowpass filter approximating a Chebyshev frequency response. Most differential amplifiers require many precision external components to tailor gain and bandwidth. In contrast, with the LT6600-15, two external resistors program differential gain, and the filter's 15MHz cutoff frequency and passband ripple are internally set. The LT6600-15 also provides the necessary level shifting to set its output common mode voltage to accommodate the reference voltage requirements of A/Ds.

Using a proprietary internal architecture, the LT6600-15 integrates an antialiasing filter and a differential amplifier/driver without compromising distortion or low noise performance. At unity gain the measured in band signal-to-noise ratio is an impressive 76dB. At higher gains the input referred noise decreases so the part can process smaller input differential signals without significantly degrading the output signal-to-noise ratio.

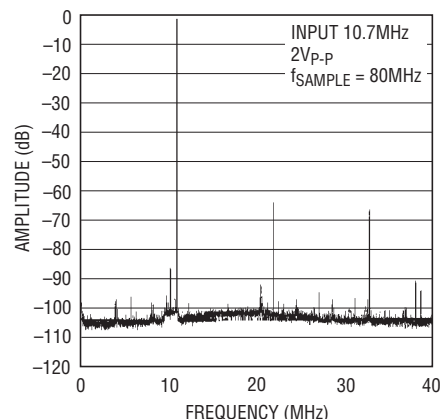
The LT6600-15 also features low voltage operation. The differential design provides outstanding performance for a 2V<sub>P-P</sub> signal level while the part operates with a single 3V supply.

The LT6600-15 is packaged in an SO-8 and is pin compatible with standalone differential amplifiers.

## TYPICAL APPLICATION



An 8192 Point FFT Spectrum

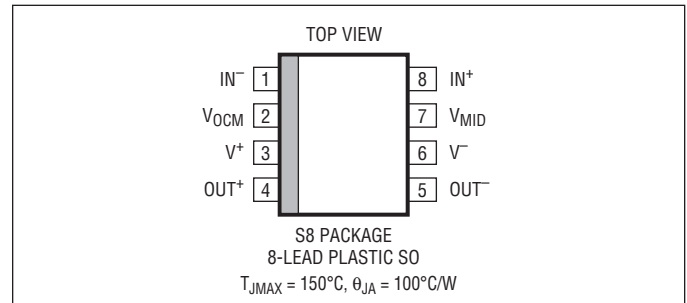


## ABSOLUTE MAXIMUM RATINGS

(Note 1)

|                                            |                |
|--------------------------------------------|----------------|
| Total Supply Voltage .....                 | 11V            |
| Input Current (Note 8).....                | ±10mA          |
| Operating Temperature Range (Note 6)....   | –40°C to 85°C  |
| Specified Temperature Range (Note 7) ....  | –40°C to 85°C  |
| Junction Temperature .....                 | 150°C          |
| Storage Temperature.....                   | –65°C to 150°C |
| Lead Temperature (Soldering, 10 sec) ..... | 300°C          |

## PIN CONFIGURATION



## ORDER INFORMATION

| LEAD FREE FINISH  | TAPE AND REEL      | PART MARKING | PACKAGE DESCRIPTION | TEMPERATURE RANGE |
|-------------------|--------------------|--------------|---------------------|-------------------|
| LT6600CS8-15#PBF  | LT6600CS8-15#TRPBF | 660015       | 8-Lead Plastic SO   | –40°C to 85°C     |
| LT6600IS8-15#PBF  | LT6600IS8-15#TRPBF | 600I15       | 8-Lead Plastic SO   | –40°C to 85°C     |
| LEAD BASED FINISH | TAPE AND REEL      | PART MARKING | PACKAGE DESCRIPTION | TEMPERATURE RANGE |
| LT6600CS8-15      | LT6600CS8-15#TR    | 660015       | 8-Lead Plastic SO   | –40°C to 85°C     |
| LT6600IS8-15      | LT6600IS8-15#TR    | 600I15       | 8-Lead Plastic SO   | –40°C to 85°C     |

Consult LTC Marketing for parts specified with wider operating temperature ranges.

For more information on lead free part marking, go to: <http://www.linear.com/leadfree/>

For more information on tape and reel specifications, go to: <http://www.linear.com/tapeandreel/>

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . Unless otherwise specified  $V_S = 5\text{V}$  ( $V^+ = 5\text{V}$ ,  $V^- = 0\text{V}$ ),  $R_{IN} = 536\Omega$ , and  $R_{LOAD} = 1\text{k}\Omega$ .

| PARAMETER                          | CONDITIONS                                                                              | MIN    | TYP  | MAX  | UNITS |
|------------------------------------|-----------------------------------------------------------------------------------------|--------|------|------|-------|
| Filter Gain, $V_S = 3\text{V}$     | $V_{IN} = 2V_{P-P}$ , $f_{IN} = \text{DC to } 260\text{kHz}$                            | –0.5   | 0.1  | 0.5  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 1.5\text{MHz}$ (Gain Relative to 260kHz)                | ● –0.1 | 0    | 0.1  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 7.5\text{MHz}$ (Gain Relative to 260kHz)                | ● –0.3 | 0    | 0.4  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 12\text{MHz}$ (Gain Relative to 260kHz)                 | ● –0.3 | 0.2  | 1.0  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 15\text{MHz}$ (Gain Relative to 260kHz)                 | ● –0.7 | 0    | 1.0  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 45\text{MHz}$ (Gain Relative to 260kHz)                 | ●      | –29  | –25  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 75\text{MHz}$ (Gain Relative to 260kHz)                 | ●      | –46  |      | dB    |
| Filter Gain, $V_S = 5\text{V}$     | $V_{IN} = 2V_{P-P}$ , $f_{IN} = \text{DC to } 260\text{kHz}$                            | –0.5   | 0    | 0.5  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 1.5\text{MHz}$ (Gain Relative to 260kHz)                | ● –0.1 | 0    | 0.1  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 7.5\text{MHz}$ (Gain Relative to 260kHz)                | ● –0.4 | 0    | 0.3  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 12\text{MHz}$ (Gain Relative to 260kHz)                 | ● –0.4 | 0.1  | 0.9  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 15\text{MHz}$ (Gain Relative to 260kHz)                 | ● –0.8 | 0    | 0.9  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 45\text{MHz}$ (Gain Relative to 260kHz)                 | ●      | –29  | –25  | dB    |
|                                    | $V_{IN} = 2V_{P-P}$ , $f_{IN} = 75\text{MHz}$ (Gain Relative to 260kHz)                 | ●      | –46  |      | dB    |
| Filter Gain, $V_S = \pm 5\text{V}$ | $V_{IN} = 2V_{P-P}$ , $f_{IN} = \text{DC to } 260\text{kHz}$                            | –0.6   | –0.1 | 0.4  | dB    |
| Filter Gain, $R_{IN} = 133\Omega$  | $V_{OUT} = 0.5V_{P-P}$ , $f_{IN} = \text{DC to } 260\text{kHz}$ , $V_S = 3\text{V}$     | 11.5   | 12.0 | 12.5 | dB    |
|                                    | $V_{OUT} = 0.5V_{P-P}$ , $f_{IN} = \text{DC to } 260\text{kHz}$ , $V_S = 5\text{V}$     | 11.5   | 12.0 | 12.5 | dB    |
|                                    | $V_{OUT} = 0.5V_{P-P}$ , $f_{IN} = \text{DC to } 260\text{kHz}$ , $V_S = \pm 5\text{V}$ | 11.4   | 11.9 | 12.4 | dB    |

660015fb

# ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . Unless otherwise specified  $V_S = 5\text{V}$  ( $V^+ = 5\text{V}$ ,  $V^- = 0\text{V}$ ),  $R_{IN} = 536\Omega$ , and  $R_{LOAD} = 1\text{k}\Omega$ .

| PARAMETER                                            | CONDITIONS                                                                               |                                            |        | MIN          | TYP          | MAX   | UNITS                                          |
|------------------------------------------------------|------------------------------------------------------------------------------------------|--------------------------------------------|--------|--------------|--------------|-------|------------------------------------------------|
| Filter Gain Temperature Coefficient (Note 2)         | f <sub>IN</sub> = 250kHz, V <sub>IN</sub> = 2V <sub>P-P</sub>                            |                                            |        | 780          |              |       | ppm/C                                          |
| Noise                                                | Noise BW = 10kHz to 15MHz                                                                |                                            |        | 109          |              |       | μV <sub>RMS</sub>                              |
| Distortion (Note 4)                                  | 1MHz, 2V <sub>P-P</sub> , R <sub>L</sub> = 800Ω, V <sub>S</sub> = 3V                     | 2nd Harmonic<br>3rd Harmonic               |        | 86<br>90     |              |       | dBc<br>dBc                                     |
|                                                      | 10MHz, 2V <sub>P-P</sub> , R <sub>L</sub> = 800Ω, V <sub>S</sub> = 3V                    | 2nd Harmonic<br>3rd Harmonic               |        | 63<br>69     |              |       | dBc<br>dBc                                     |
| Differential Output Swing                            | Measured Between Pins 4 and 5                                                            | V <sub>S</sub> = 5V<br>V <sub>S</sub> = 3V | ●<br>● | 3.80<br>3.75 | 4.75<br>4.50 |       | V <sub>P-P</sub> DIFF<br>V <sub>P-P</sub> DIFF |
| Input Bias Current                                   | Average of Pin 1 and Pin 8                                                               |                                            | ●      | −90          | −35          |       | μA                                             |
| Input Referred Differential Offset                   | R <sub>IN</sub> = 536Ω                                                                   | V <sub>S</sub> = 3V                        | ●      |              | ±5           | ±25   | mV                                             |
|                                                      |                                                                                          | V <sub>S</sub> = 5V                        | ●      |              | ±10          | ±30   | mV                                             |
|                                                      |                                                                                          | V <sub>S</sub> = ±5V                       | ●      |              | ±10          | ±35   | mV                                             |
|                                                      | R <sub>IN</sub> = 133Ω                                                                   | V <sub>S</sub> = 3V                        | ●      |              | ±5           | ±15   | mV                                             |
|                                                      |                                                                                          | V <sub>S</sub> = 5V                        | ●      |              | ±5           | ±17   | mV                                             |
|                                                      |                                                                                          | V <sub>S</sub> = ±5V                       | ●      |              | ±5           | ±20   | mV                                             |
| Differential Offset Drift                            |                                                                                          |                                            | 10     |              |              | μV/°C |                                                |
| Input Common Mode Voltage (Note 3)                   | Differential Input = 500mV <sub>P-P</sub> ,<br>R <sub>IN</sub> = 133Ω                    | V <sub>S</sub> = 3V                        | ●      | 0.0          | 1.5          | V     |                                                |
|                                                      |                                                                                          | V <sub>S</sub> = 5V                        | ●      | 0.0          | 3.0          | V     |                                                |
|                                                      |                                                                                          | V <sub>S</sub> = ±5V                       | ●      | −2.5         | 1.0          | V     |                                                |
| Output Common Mode Voltage (Note 5)                  | Differential Input = 2V <sub>P-P</sub> ,<br>Pin 7 = OPEN<br>Common Mode Voltage at Pin 2 | V <sub>S</sub> = 3V                        | ●      | 1.0          | 1.5          | V     |                                                |
|                                                      |                                                                                          | V <sub>S</sub> = 5V                        | ●      | 1.5          | 3.0          | V     |                                                |
|                                                      |                                                                                          | V <sub>S</sub> = ±5V                       | ●      | −1.0         | 2.0          | V     |                                                |
| Output Common Mode Offset<br>(with Respect to Pin 2) |                                                                                          | V <sub>S</sub> = 3V                        | ●      | −35          | 5            | 40    | mV                                             |
|                                                      |                                                                                          | V <sub>S</sub> = 5V                        | ●      | −40          | 0            | 40    | mV                                             |
|                                                      |                                                                                          | V <sub>S</sub> = ±5V                       | ●      | −55          | −10          | 35    | mV                                             |
| Common Mode Rejection Ratio                          |                                                                                          |                                            |        | 64           |              |       | dB                                             |
| Voltage at V <sub>MID</sub> (Pin 7)                  |                                                                                          | V <sub>S</sub> = 5V                        | ●      | 2.45         | 2.50         | 2.55  | V                                              |
|                                                      |                                                                                          | V <sub>S</sub> = 3V                        |        |              | 1.50         |       | V                                              |
| V <sub>MID</sub> Input Resistance                    |                                                                                          |                                            | ●      | 4.3          | 5.7          | 7.7   | kΩ                                             |
| V <sub>OCM</sub> Bias Current                        | V <sub>OCM</sub> = V <sub>MID</sub> = V <sub>S</sub> /2                                  | V <sub>S</sub> = 5V                        | ●      | −10          | −2           |       | μA                                             |
|                                                      |                                                                                          | V <sub>S</sub> = 3V                        | ●      | −10          | −2           |       | μA                                             |
| Power Supply Current                                 |                                                                                          | V <sub>S</sub> = 3V, V <sub>S</sub> = 5V   |        |              | 35           | 39    | mA                                             |
|                                                      |                                                                                          | V <sub>S</sub> = 3V                        | ●      |              |              | 44    | mA                                             |
|                                                      |                                                                                          | V <sub>S</sub> = 5V                        | ●      |              |              | 45    | mA                                             |
|                                                      |                                                                                          | V <sub>S</sub> = ±5V                       | ●      |              | 38           | 48    | mA                                             |
| Power Supply Voltage                                 |                                                                                          |                                            | ●      | 3            | 11           |       | V                                              |

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** This is the temperature coefficient of the internal feedback resistors assuming a temperature independent external resistor ( $R_{IN}$ ).

**Note 3:** The input common mode voltage is the average of the voltages applied to the external resistors ( $R_{IN}$ ). Specification guaranteed for  $R_{IN} \geq 100\Omega$ .

**Note 4:** Distortion is measured differentially using a differential stimulus. The input common mode voltage, the voltage at Pin 2, and the voltage at Pin 7 are equal to one half of the total power supply voltage.

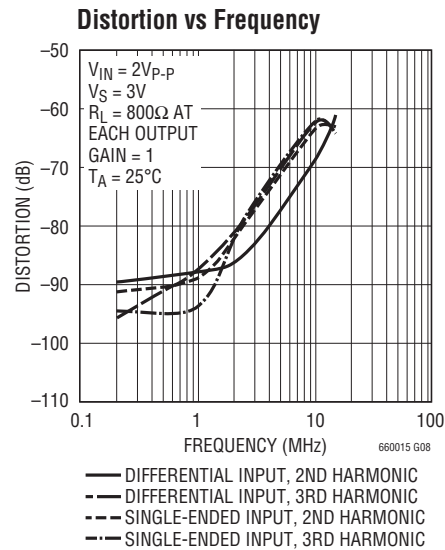
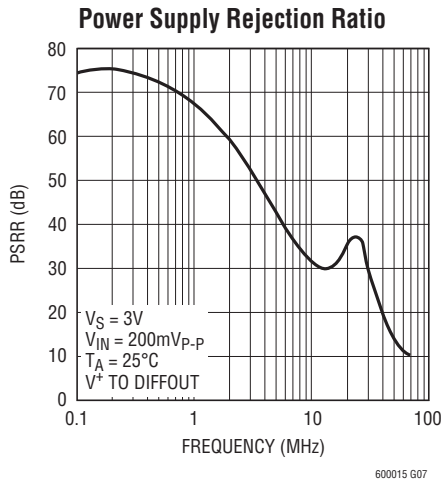
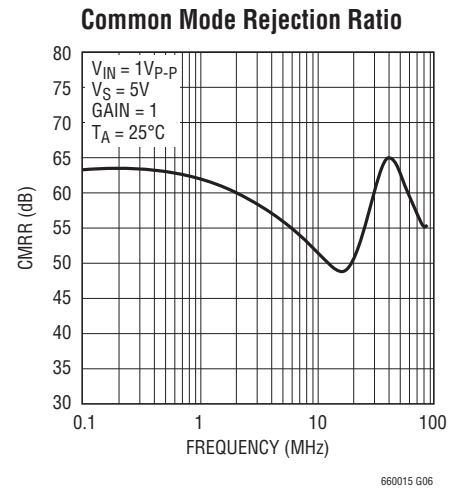
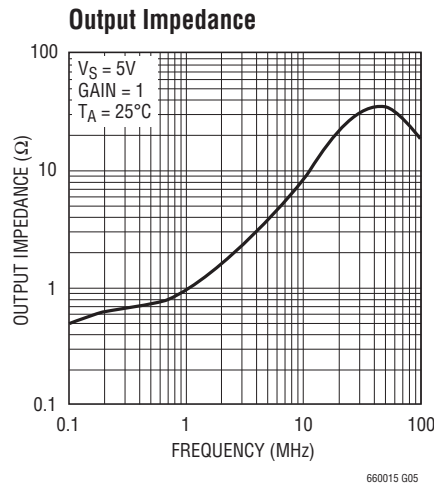
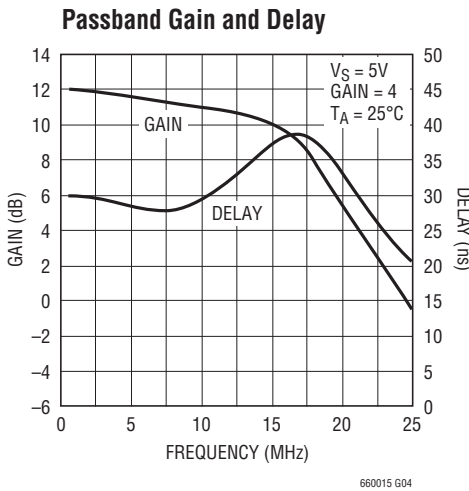
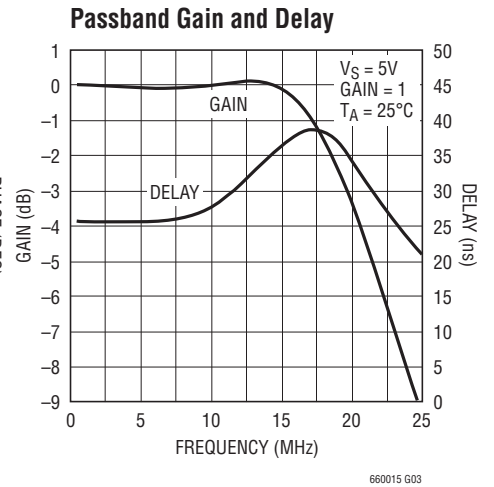
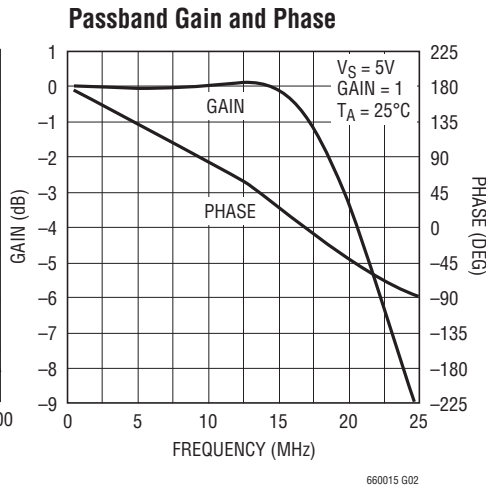
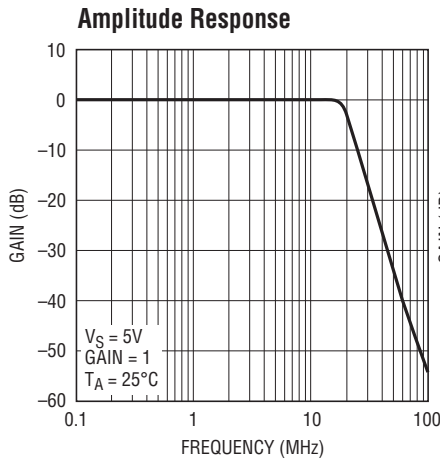
**Note 5:** Output common mode voltage is the average of the voltages at Pins 4 and 5. The output common mode voltage is equal to the voltage applied to Pin 2.

**Note 6:** The LT6600C-15 is guaranteed functional over the operating temperature range  $-40^\circ\text{C}$  to  $85^\circ\text{C}$ .

**Note 7:** The LT6600C-15 is guaranteed to meet  $0^\circ\text{C}$  to  $70^\circ\text{C}$  specifications and is designed, characterized and expected to meet the extended temperature limits, but is not tested at  $-40^\circ\text{C}$  and  $85^\circ\text{C}$ . The LT6600I-15 is guaranteed to meet specified performance from  $-40^\circ\text{C}$  to  $85^\circ\text{C}$ .

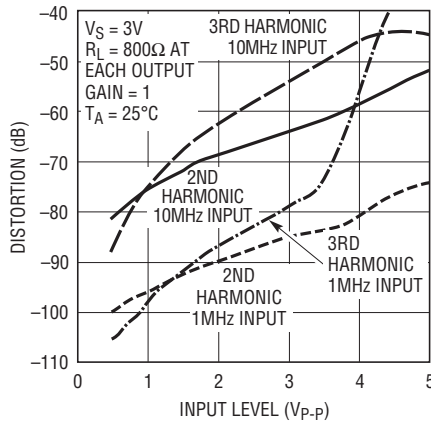
**Note 8:** The inputs are protected by back-to-back diodes. If the differential input voltage exceeds 1.4V, the input current should be limited to less than 10mA.

# TYPICAL PERFORMANCE CHARACTERISTICS

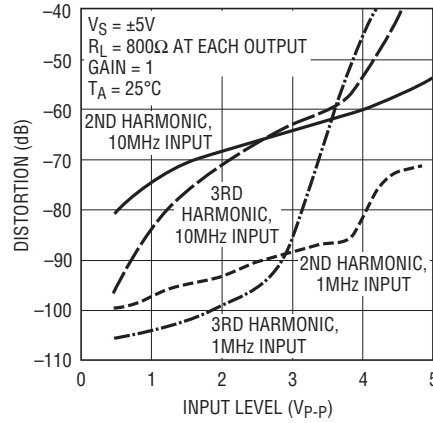


# TYPICAL PERFORMANCE CHARACTERISTICS

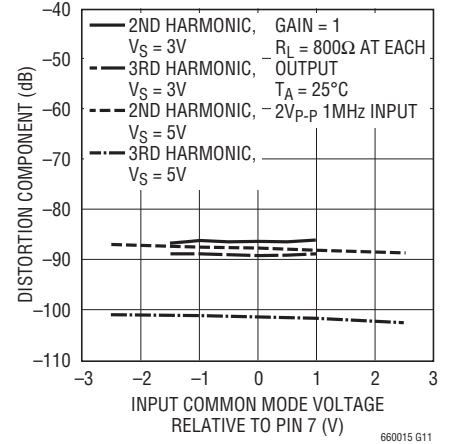
**Distortion vs Signal Level**



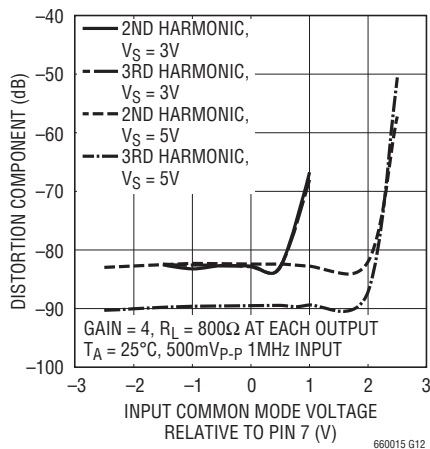
**Distortion vs Signal Level**



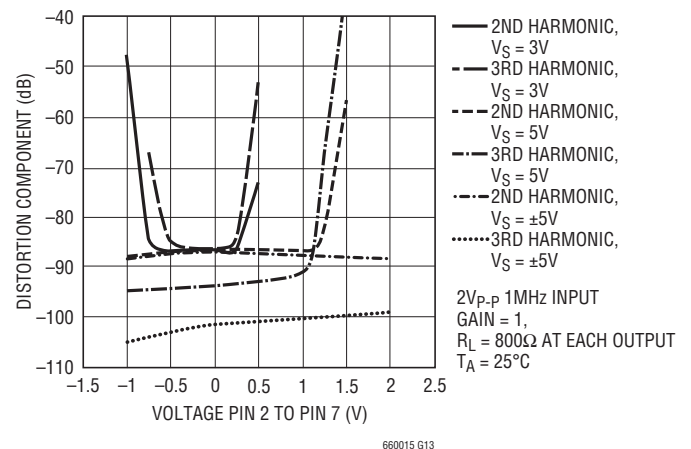
**Distortion vs Input Common Mode Level**



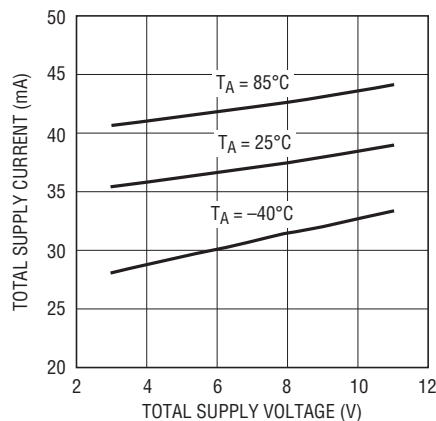
**Distortion vs Input Common Mode Level**



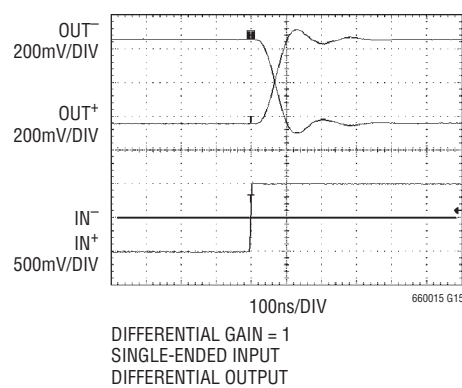
**Distortion vs Output Common Mode**



**Total Supply Current vs Total Supply Voltage**



**Transient Response**



## PIN FUNCTIONS

**IN<sup>-</sup> and IN<sup>+</sup> (Pins 1, 8):** Input Pins. Signals can be applied to either or both input pins through identical external resistors,  $R_{IN}$ . The DC gain from differential inputs to the differential outputs is  $536\Omega/R_{IN}$ .

**V<sub>OCM</sub> (Pin 2):** Is the DC Common Mode Reference Voltage for the 2nd Filter Stage. Its value programs the common mode voltage of the differential output of the filter. Pin 2 is a high impedance input, which can be driven from an external voltage reference, or Pin 2 can be tied to Pin 7 on the PC board. Pin 2 should be bypassed with a 0.01 $\mu$ F ceramic capacitor unless it is connected to a ground plane.

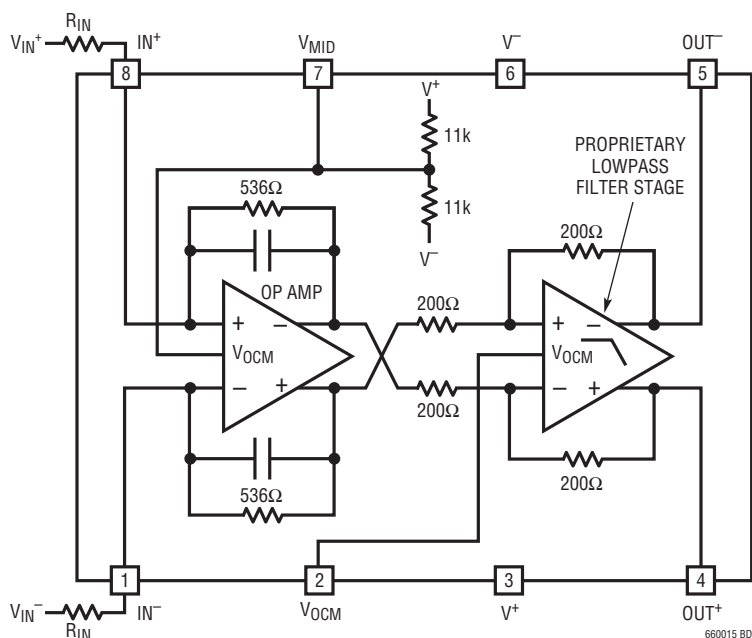
**V<sup>+</sup> and V<sup>-</sup> (Pins 3, 6):** Power Supply Pins. For a single 3.3V or 5V supply (Pin 6 grounded) a quality 0.1 $\mu$ F ceramic bypass capacitor is required from the positive supply pin (Pin 3) to the negative supply pin (Pin 6). The bypass should be as close as possible to the IC. For dual supply

applications, bypass Pin 3 to ground and Pin 6 to ground with a quality 0.1 $\mu$ F ceramic capacitor.

**OUT<sup>+</sup> and OUT<sup>-</sup> (Pins 4, 5):** Output Pins. Pins 4 and 5 are the filter differential outputs. Each pin can drive a 100 $\Omega$  and/or 50pF load.

**V<sub>MID</sub> (Pin 7):** The V<sub>MID</sub> pin is internally biased at mid-supply, see the Block Diagram section. For single supply operation, the V<sub>MID</sub> pin should be bypassed with a quality 0.01 $\mu$ F ceramic capacitor to Pin 6. For dual supply operation, Pin 7 can be bypassed or connected to a high quality DC ground. A ground plane should be used. A poor ground will increase noise and distortion. Pin 7 sets the output common mode voltage of the 1st stage of the filter. It has a 5.5k $\Omega$  impedance, and it can be overridden with an external low impedance voltage source.

## BLOCK DIAGRAM



# APPLICATIONS INFORMATION

## Interfacing to the LT6600-15

The LT6600-15 requires two equal external resistors,  $R_{IN}$ , to set the differential gain to  $536\Omega/R_{IN}$ . The inputs to the filter are the voltages  $V_{IN}^+$  and  $V_{IN}^-$  presented to these external components, Figure 1. The difference between  $V_{IN}^+$  and  $V_{IN}^-$  is the differential input voltage. The average of  $V_{IN}^+$  and  $V_{IN}^-$  is the common mode input voltage. Similarly, the voltages  $V_{OUT}^+$  and  $V_{OUT}^-$  appearing at Pins 4 and 5 of the LT6600-15 are the filter outputs. The difference between  $V_{OUT}^+$  and  $V_{OUT}^-$  is the differential output voltage. The average of  $V_{OUT}^+$  and  $V_{OUT}^-$  is the common mode output voltage.

Figure 1 illustrates the LT6600-15 operating with a single 3.3V supply and unity passband gain; the input signal is DC coupled. The common mode input voltage is 0.5V, and the differential input voltage is 2V<sub>P-P</sub>. The common mode

output voltage is 1.65V, and the differential output voltage is 2V<sub>P-P</sub> for frequencies below 15MHz. The common mode output voltage is determined by the voltage at Pin 2. Since Pin 2 is shorted to Pin 7, the output common mode is the mid-supply voltage. In addition, the common mode input voltage can be equal to the mid-supply voltage of Pin 7 (see the Distortion vs Input Common Mode Level graphs in the Typical Performance Characteristics section).

Figure 2 shows how to AC couple signals into the LT6600-15. In this instance, the input is a single-ended signal. AC coupling allows the processing of single-ended or differential signals with arbitrary common mode levels. The 0.1μF coupling capacitor and the 536Ω gain setting resistor form a high pass filter, attenuating signals below 3kHz. Larger values of coupling capacitors will proportionally reduce this highpass 3dB frequency.

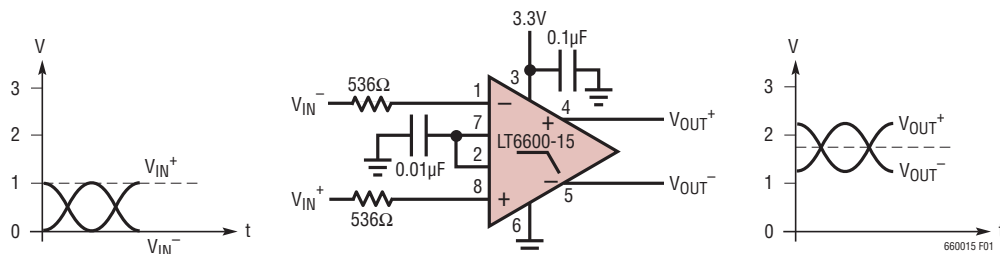


Figure 1

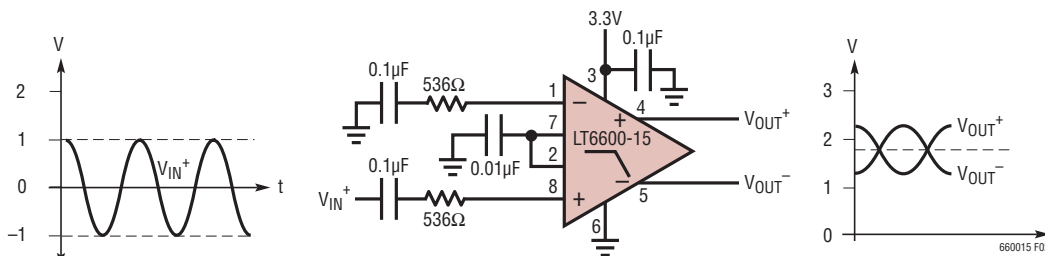


Figure 2

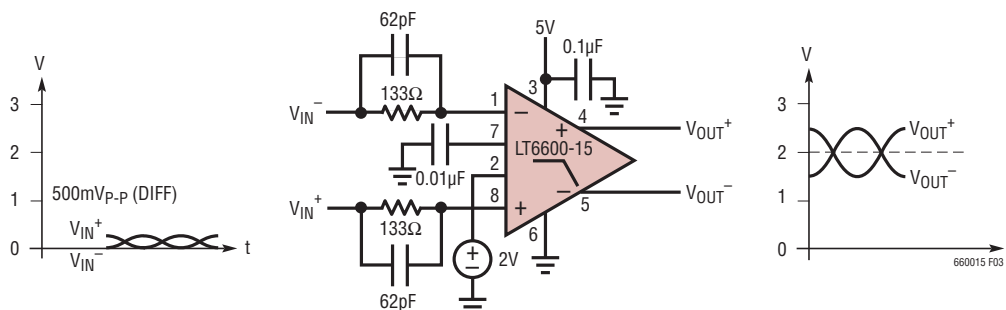


Figure 3

## APPLICATIONS INFORMATION

In Figure 3 the LT6600-15 is providing 12dB of gain. The gain resistor has an optional 62pF in parallel to improve the passband flatness near 15MHz. The common mode output voltage is set to 2V.

Use Figure 4 to determine the interface between the LT6600-15 and a current output DAC. The gain, or “transimpedance,” is defined as  $A = V_{OUT}/I_{IN}$ . To compute the transimpedance, use the following equation:

$$A = \frac{536 \cdot R1}{(R1 + R2)} (\Omega)$$

By setting  $R1 + R2 = 536\Omega$ , the gain equation reduces to  $A = R1(\Omega)$ .

The voltage at the pins of the DAC is determined by R1, R2, the voltage on Pin 7 and the DAC output current. Consider Figure 4 with  $R1 = 49.9\Omega$  and  $R2 = 487\Omega$ . The voltage at Pin 7 is 1.65V. The voltage at the DAC pins is given by:

$$\begin{aligned} V_{DAC} &= V_{PIN7} \cdot \frac{R1}{R1 + R2 + 536} + I_{IN} \cdot \frac{R1 \cdot R2}{R1 + R2} \\ &= 77mV + I_{IN} \cdot 45.3\Omega \end{aligned}$$

$I_{IN}$  is  $I_{IN+}$  or  $I_{IN-}$ . The transimpedance in this example is  $49.8\Omega$ .

### Evaluating the LT6600-15

The low impedance levels and high frequency operation of the LT6600-15 require some attention to the matching networks between the LT6600-15 and other devices. The previous examples assume an ideal ( $0\Omega$ ) source impedance and a large ( $1k\Omega$ ) load resistance. Among practical ex-

amples where impedance must be considered is the evaluation of the LT6600-15 with a network analyzer. Figure 5 is a laboratory setup that can be used to characterize the LT6600-15 using single-ended instruments with  $50\Omega$  source impedance and  $50\Omega$  input impedance. For a unity gain configuration the LT6600-15 requires a  $536\Omega$  source resistance yet the network analyzer output is calibrated for a  $50\Omega$  load resistance. The 1:1 transformer,  $52.3\Omega$  and  $523\Omega$  resistors satisfy the two constraints above. The transformer converts the single-ended source into a differential stimulus. Similarly, the output of the LT6600-15 will have lower distortion with larger load resistance yet the analyzer input is typically  $50\Omega$ . The 4:1 turns ( $16:1$  impedance) transformer and the two  $402\Omega$  resistors of Figure 5, present the output of the LT6600-15 with a  $1600\Omega$  differential load, or the equivalent of  $800\Omega$  to ground at each output. The impedance seen by the network analyzer input is still  $50\Omega$ , reducing reflections in the cabling between the transformer and analyzer input.

### Differential and Common Mode Voltage Ranges

The differential amplifiers inside the LT6600-15 contain circuitry to limit the maximum peak-to-peak differential voltage through the filter. This limiting function prevents excessive power dissipation in the internal circuitry and provides output short-circuit protection. The limiting function begins to take effect at output signal levels above  $2V_{P-P}$  and it becomes noticeable above  $3.5V_{P-P}$ . This is illustrated in Figure 6; the LT6600-15 was configured with unity passband gain and the input of the filter was driven with a 1MHz signal. Because this voltage limiting takes place well before the output stage of the filter reaches the

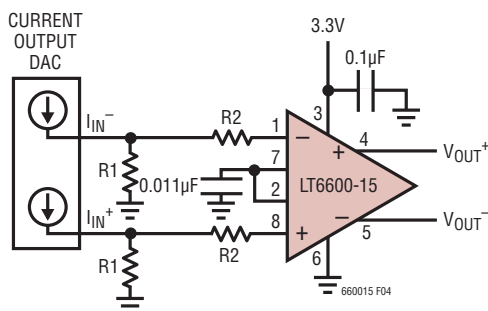


Figure 4

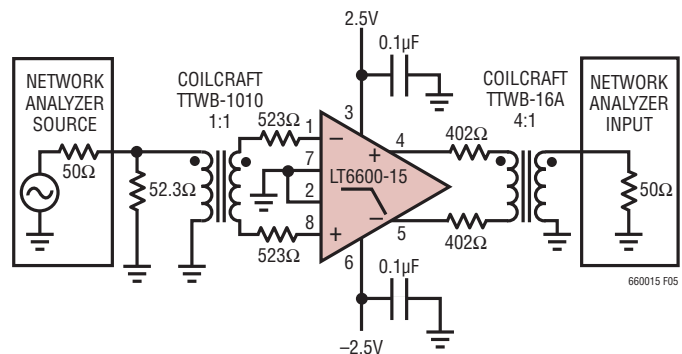
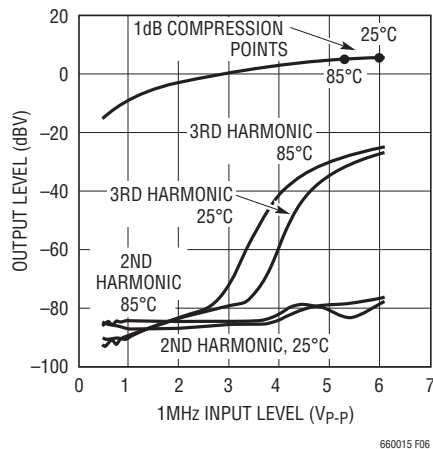


Figure 5

## APPLICATIONS INFORMATION



**Figure 6. Output Level vs Input Level, Differential 1MHz Input, Gain = 1**

supply rails, the input/output behavior of the IC shown in Figure 6 is relatively independent of the power supply voltage.

The two amplifiers inside the LT6600-15 have independent control of their output common mode voltage (see the Block Diagram section). The following guidelines will optimize the performance of the filter.

Pin 7 must be bypassed to an AC ground with a 0.01 $\mu$ F or larger capacitor. Pin 7 can be driven from a low impedance source, provided it remains at least 1.5V above  $V^-$  and at least 1.5V below  $V^+$ . An internal resistor divider sets the voltage of Pin 7. While the internal 11k resistors are well matched, their absolute value can vary by  $\pm 20\%$ . This should be taken into consideration when connecting an external resistor network to alter the voltage of Pin 7.

Pin 2 can be shorted to Pin 7 for simplicity. If a different common mode output voltage is required, connect Pin 2 to a voltage source or resistor network. For 3V and 3.3V supplies the voltage at Pin 2 must be less than or equal to the mid supply level. For example, voltage (Pin 2)  $\leq 1.65V$  on a single 3.3V supply. For power supply voltages higher than 3.3V the voltage at Pin 2 should be within the voltage of Pin 7 – 1V to the voltage of Pin 7 + 2V. Pin 2 is a high impedance input.

The LT6600-15 was designed to process a variety of input signals including signals centered around the mid-supply voltage and signals that swing between ground and a positive voltage in a single supply system (Figure 1). The range of allowable input common mode voltage (the average of  $V_{IN}^+$  and  $V_{IN}^-$  in Figure 1) is determined by the power supply level and gain setting (see Distortion vs Input Common Mode Level in the Typical Performance Characteristics section).

### Common Mode DC Currents

In applications like Figure 1 and Figure 3 where the LT6600-15 not only provides lowpass filtering but also level shifts the common mode voltage of the input signal, DC currents will be generated through the DC path between input and output terminals. Minimize these currents to decrease power dissipation and distortion.

Consider the application in Figure 3. Pin 7 sets the output common mode voltage of the 1st differential amplifier inside the LT6600-15 (see the Block Diagram section) at 2.5V. Since the input common mode voltage is near 0V, there will be approximately a total of 2.5V drop across the series combination of the internal 536 $\Omega$  feedback resistor and the external 133 $\Omega$  input resistor. The resulting 3.7mA common mode DC current in each input path, must be absorbed by the sources  $V_{IN}^+$  and  $V_{IN}^-$ . Pin 2 sets the common mode output voltage of the 2nd differential amplifier inside the LT6600-15, and therefore sets the common mode output voltage of the filter. Since, in the example of Figure 3, Pin 2 differs from Pin 7 by 0.5V, an additional 2.5mA (1.25mA per side) of DC current will flow in the resistors coupling the 1st differential amplifier output stage to filter output. Thus, a total of 9.9mA is used to translate the common mode voltages.

A simple modification to Figure 3 will reduce the DC common mode currents by 40%. If Pin 7 is shorted to Pin 2 the common mode output voltage of both op amp stages will be 2V and the resulting DC current will be 6mA. Of course, by AC coupling the inputs of Figure 3, the common mode DC current can be reduced to 2.5mA.

# APPLICATIONS INFORMATION

## Noise

The noise performance of the LT6600-15 can be evaluated with the circuit of Figure 7.

Given the low noise output of the LT6600-15 and the 6dB attenuation of the transformer coupling network, it is necessary to measure the noise floor of the spectrum analyzer and subtract the instrument noise from the filter noise measurement.

Example: With the IC removed and the 25Ω resistors grounded, Figure 7, measure the total integrated noise ( $e_s$ ) of the spectrum analyzer from 10kHz to 15MHz. With the IC inserted, the signal source ( $V_{IN}$ ) disconnected, and the input resistors grounded, measure the total integrated noise out of the filter ( $e_o$ ). With the signal source connected, set the frequency to 1MHz and adjust the amplitude until  $V_{IN}$  measures 100mV<sub>P-P</sub>. Measure the output amplitude,  $V_{OUT}$ , and compute the passband gain  $A = V_{OUT}/V_{IN}$ . Now compute the input referred integrated noise ( $e_{IN}$ ) as:

$$e_{IN} = \frac{\sqrt{(e_o)^2 - (e_s)^2}}{A}$$

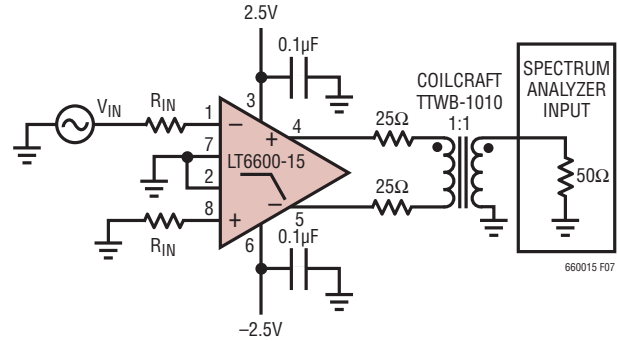
Table 1 lists the typical input referred integrated noise for various values of  $R_{IN}$ .

Figure 8 is plot of the noise spectral density as a function of frequency for an LT6600-15 using the fixture of Figure 7 (the instrument noise has been subtracted from the results).

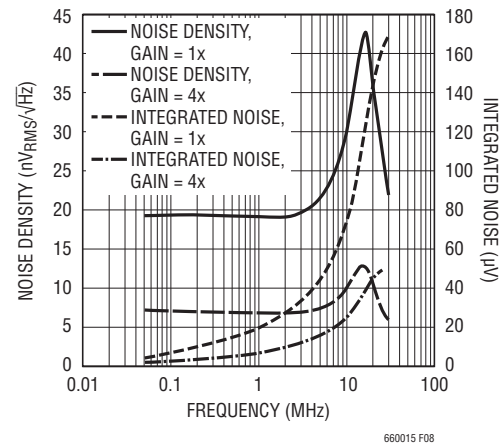
**Table 1. Noise Performance**

| PASSBAND GAIN (V/V) | $R_{IN}$ | INPUT REFERRED INTEGRATED NOISE 10kHz TO 15MHz | INPUT REFERRED INTEGRATED NOISE 10kHz TO 30MHz |
|---------------------|----------|------------------------------------------------|------------------------------------------------|
| 4                   | 133Ω     | 36μV <sub>RMS</sub>                            | 51μV <sub>RMS</sub>                            |
| 2                   | 267Ω     | 62μV <sub>RMS</sub>                            | 92μV <sub>RMS</sub>                            |
| 1                   | 536Ω     | 109μV <sub>RMS</sub>                           | 169μV <sub>RMS</sub>                           |

The noise at each output is comprised of a differential component and a common mode component. Using a transformer or combiner to convert the differential outputs to single-ended signal rejects the common mode noise and gives a true measure of the S/N achievable in the system. Conversely, if each output is measured individually and the



**Figure 7**



**Figure 8. Input Referred Noise, Gain = 1**

noise power added together, the resulting calculated noise level will be higher than the true differential noise.

## Power Dissipation

The LT6600-15 amplifiers combine high speed with large-signal currents in a small package. There is a need to ensure that the die junction temperature does not exceed 150°C. The LT6600-15 package has Pin 6 fused to the lead frame to enhance thermal conduction when connecting to a ground plane or a large metal trace. Metal trace and plated through-holes can be used to spread the heat generated by the device to the backside of the PC board. For example, on a 3/32" FR-4 board with 2oz copper, a total of 660 square millimeters connected to Pin 6 of the LT6600-15 (330 square millimeters on each side of the PC board) will result in a thermal resistance,  $\theta_{JA}$ , of about 85°C/W. Without the extra metal trace connected to the V<sup>-</sup> pin to provide a heat sink, the thermal resistance will be around 105°C/W. Table 2 can be used as a guide when considering thermal resistance.

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# APPLICATIONS INFORMATION

**Table 2. LT6600-15 SO-8 Package Thermal Resistance**

| COPPER AREA                   |                                | BOARD AREA<br>(mm <sup>2</sup> ) | THERMAL RESISTANCE<br>(JUNCTION-TO-AMBIENT) |
|-------------------------------|--------------------------------|----------------------------------|---------------------------------------------|
| TOPSIDE<br>(mm <sup>2</sup> ) | BACKSIDE<br>(mm <sup>2</sup> ) |                                  |                                             |
| 1100                          | 1100                           | 2500                             | 65°C/W                                      |
| 330                           | 330                            | 2500                             | 85°C/W                                      |
| 35                            | 35                             | 2500                             | 95°C/W                                      |
| 35                            | 0                              | 2500                             | 100°C/W                                     |
| 0                             | 0                              | 2500                             | 105°C/W                                     |

Junction temperature,  $T_J$ , is calculated from the ambient temperature,  $T_A$ , and power dissipation,  $P_D$ . The power dissipation is the product of supply voltage,  $V_S$ , and supply current,  $I_S$ . Therefore, the junction temperature is given by:

$$T_J = T_A + (P_D \cdot \theta_{JA}) = T_A + (V_S \cdot I_S \cdot \theta_{JA})$$

where the supply current,  $I_S$ , is a function of signal level, load impedance, temperature and common mode voltages.

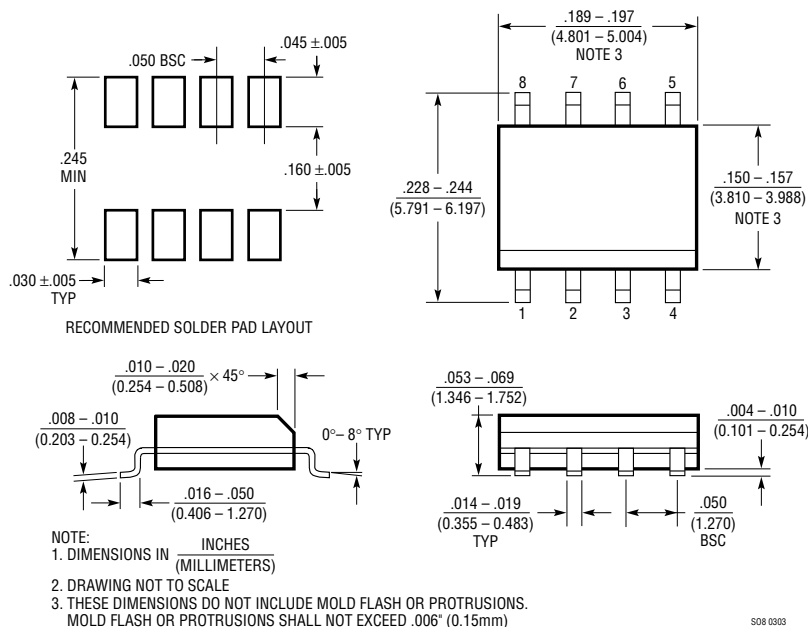
For a given supply voltage, the worst-case power dissipation occurs when the differential input signal is maximum, the common mode currents are maximum (see the Applications Information section regarding common mode DC currents), the load impedance is small and the ambient temperature is maximum. To compute the junction temperature, measure the supply current under these worst-case conditions, estimate the thermal resistance from Table 2, then apply the equation for  $T_J$ . For example, using the circuit in Figure 3 with a DC differential input voltage of 250mV, a differential output voltage of 1V, no load resistance and an ambient temperature of 85°C, the supply current (current into Pin 3) measures 50mA. Assuming a PC board layout with a 35mm<sup>2</sup> copper trace, the  $\theta_{JA}$  is 100°C/W. The resulting junction temperature is:

$$T_J = T_A + (P_D \cdot \theta_{JA}) = 85 + (5 \cdot 0.05 \cdot 100) = 110^\circ\text{C}$$

When using higher supply voltages or when driving small impedances, more copper may be necessary to keep  $T_J$  below 150°C.

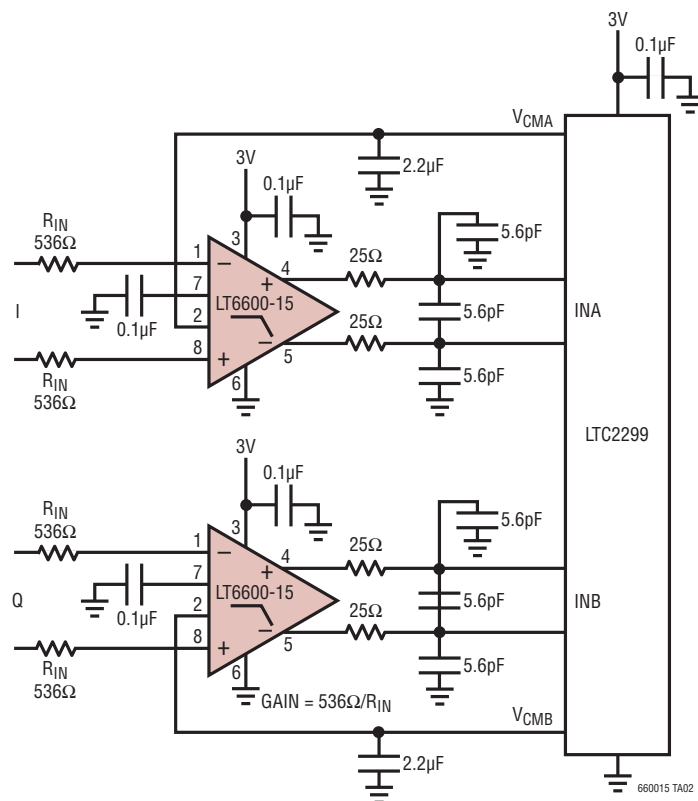
# PACKAGE DESCRIPTION

## S8 Package 8-Lead Plastic Small Outline (Narrow .150 Inch) (Reference LTC DWG # 05-08-1610)



S08 0303

## TYPICAL APPLICATION

Dual Matched I and Q Lowpass Filter and ADC  
(Typical Phase Matching  $\pm 1$  Degree)

## RELATED PARTS

| PART NUMBER              | DESCRIPTION                                                     | COMMENTS                                                              |
|--------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------------|
| LTC <sup>®</sup> 1565-31 | 650kHz Linear Phase Lowpass Filter                              | Continuous Time, SO8 Package, Fully Differential                      |
| LTC1566-1                | Low Noise, 2.3MHz Lowpass Filter                                | Continuous Time, SO8 Package                                          |
| LT1567                   | Very Low Noise, High Frequency Filter Building Block            | 1.4nV/ $\sqrt{\text{Hz}}$ Op Amp, MSOP Package, Fully Differential    |
| LT1568                   | Very Low Noise, 4th Order Building Block                        | Lowpass and Bandpass Filter Designs Up to 10MHz, Differential Outputs |
| LT1993-X                 | Low Distortion, Low Noise Differential Amplifier/ADC Driver     | Fixed Gain of 6dB, 12dB and 20dB                                      |
| LT1994                   | Low Distortion, Low Noise Differential Amplifier/ADC Driver     | Adjustable, Low Power, V <sub>S</sub> = 2.375V to 12.6V               |
| LT6600-2.5               | Very Low Noise Differential Amplifier and 2.5MHz Lowpass Filter | 86dB S/N with 3V Supply, SO-8                                         |
| LT6600-5                 | Very Low Noise Differential Amplifier and 5MHz Lowpass Filter   | 82dB S/N with 3V Supply, SO-8                                         |
| LT6600-10                | Very Low Noise Differential Amplifier and 10MHz Lowpass Filter  | 82dB S/N with 3V Supply, SO-8                                         |
| LT6600-20                | Very Low Noise Differential Amplifier and 20MHz Lowpass Filter  | 76dB S/N with 3V Supply, SO-8                                         |