# LT6604-5



Dual Differential Amplifier with 5MHz Lowpass Filters

Approximates Chebyshev Response

Fully Differential Inputs and Outputs

Dual Differential ADC Driver and Filter

Single-Ended to Differential Converter

Adjustable Output Common Mode Voltage

Small  $4mm \times 7mm \times 0.75mm$  QFN Package

Matched, Dual, Differential Gain or Filter Stage

Common Mode Translation of Differential Signals

High Speed Test and Measurement Equipment

High Speed ADC Antialiasing and DAC Smoothing in

Wireless Infrastructure or Networking Applications

Guaranteed Phase and Gain Matching

**Resistor-Programmable Differential Gain** 

>82dB Signal-to-Noise (3V Supply, 2V<sub>P-P</sub> Output)

Low Distortion (1MHz,  $2V_{P-P}$  Output, 800 $\Omega$  Load)

Specified for Operation with 3V, 5V and ±5V Supplies

**FEATURES** 

4th Order Filters

HD2: 93dBc

HD3: 96dBc

APPLICATIONS

Medical Imaging

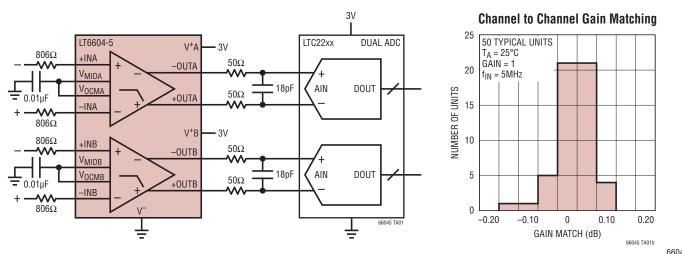
### Dual Very Low Noise, Differential Amplifier and 5MHz Lowpass Filter DESCRIPTION

The LT®6604-5 consists of two matched, fully differential amplifiers, each with a 4th order, 5MHz lowpass filter. The fixed frequency lowpass filter approximates a Chebyshev response. By integrating a filter and a differential amplifier, distortion and noise are made exceptionally low. At unity gain, the measured in-band signal-to-noise ratio is an impressive 82dB. At higher gains, the input referred noise decreases, allowing the part to process smaller input differential signals without significantly degrading the signal-to-noise ratio.

Gain and phase are well matched between the two channels. Gain for each channel is independently programmed using two external resistors. The LT6604-5 enables level shifting by providing an adjustable output common mode voltage, making it ideal for directly interfacing to ADCs. The LT6604-5 is fully specified for 3V operation. The differential design enables outstanding performance at a  $2V_{P-P}$  signal level for a single 3V supply.

See the back page of this datasheet for a complete list of related single and dual differential amplifiers with integrated 2.5MHz to 20MHz lowpass filters.

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# TYPICAL APPLICATION



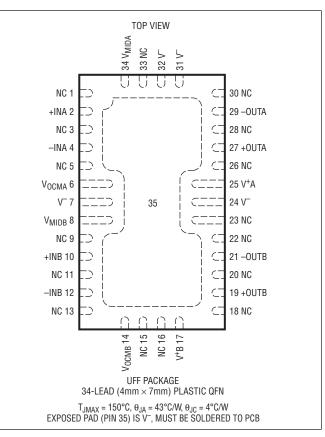
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# **ABSOLUTE MAXIMUM RATINGS**

(Note 1)

Total Supply Voltage11V
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 Range65°C to 150°C
Input Current
+IN, -IN, V <sub>OCM</sub> , V <sub>MID</sub> (Note 8)±10mA

# PIN CONFIGURATION



# ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	SPECIFIED TEMPERATURE RANGE
LT6604CUFF-5#PBF	LT6604CUFF-5#TRPBF	66045	34-Lead (4mm × 7mm) Plastic QFN	0°C to 70°C
LT6604IUFF-5#PBF	LT6604IUFF-5#TRPBF	66045	34-Lead (4mm $\times$ 7mm) Plastic QFN	–40°C to 85°C

Consult LTC Marketing for parts specified with wider operating temperature ranges. \*The temperature grade is identified by a label on the shipping container. Consult LTC Marketing for information on non-standard lead based finish parts.

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  $T_A = 25^{\circ}$ C. Unless otherwise specified  $V_S = 5V$  (V<sup>+</sup> = 5V, V<sup>-</sup> = 0V),  $R_{IN} = 806\Omega$ , and  $R_{LOAD} = 1k$ .

PARAMETER	CONDITIONS		MIN	ТҮР	MAX	UNITS
Filter Gain Either Channel, V <sub>S</sub> = 3V	$ \begin{array}{l} V_{IN}=2V_{P-P},f_{IN}=DC\ to\ 260 \text{kHz} \\ V_{IN}=2V_{P-P},f_{IN}=500 \text{kHz} \ (\text{Gain Relative to}\ 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=2.5 \text{MHz} \ (\text{Gain Relative to}\ 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=4 \text{MHz} \ (\text{Gain Relative to}\ 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=5 \text{MHz} \ (\text{Gain Relative to}\ 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=15 \text{MHz} \ (\text{Gain Relative to}\ 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=15 \text{MHz} \ (\text{Gain Relative to}\ 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=15 \text{MHz} \ (\text{Gain Relative to}\ 260 \text{kHz}) \\ \end{array} $	•	-0.5 -0.15 -0.4 -0.7 -1.1	0 0 -0.1 -0.1 -0.2 -28 -44	0.5 0.1 0.3 0.6 0.8 –25	dB dB dB dB dB dB dB dB
Matching of Filter Gain, V <sub>S</sub> = 3V	$ \begin{array}{l} V_{IN}=2V_{P-P},f_{IN}=DC \ to \ 260 \text{kHz} \\ V_{IN}=2V_{P-P},f_{IN}=500 \text{kHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=2.5 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=4 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=5 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=15 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=15 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P},f_{IN}=25 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ \end{array} $	•		0.05 0.005 0.01 0.03 0.05 0.15 0.1	0.7 0.1 0.2 0.5 0.6 1.8 2.8	dB dB dB dB dB dB dB
Matching of Filter Phase, $V_S = 3V$	$V_{IN} = 2V_{P-P}, f_{IN} = 2.5MHz$ $V_{IN} = 2V_{P-P}, f_{IN} = 4MHz$	•		0.2 0.5	2 3	deg deg
Filter Gain Either Channel, V <sub>S</sub> = 5V	$ \begin{array}{l} V_{IN} = 2V_{P-P}, \ f_{IN} = DC \ to \ 260 \text{kHz} \\ V_{IN} = 2V_{P-P}, \ f_{IN} = 500 \text{kHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN} = 2V_{P-P}, \ f_{IN} = 2.5 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN} = 2V_{P-P}, \ f_{IN} = 4 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN} = 2V_{P-P}, \ f_{IN} = 5 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN} = 2V_{P-P}, \ f_{IN} = 15 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN} = 2V_{P-P}, \ f_{IN} = 15 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN} = 2V_{P-P}, \ f_{IN} = 25 \text{MHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ \end{array} $	•	-0.5 -0.15 -0.4 -0.7 -1.1	0 -0.1 -0.1 -0.2 -28 -44	0.5 0.1 0.3 0.6 0.8 –25	dB dB dB dB dB dB dB dB
Matching of Filter Gain, V <sub>S</sub> = 5V	$ \begin{array}{l} V_{IN}=2V_{P-P}, f_{IN}=DC \ to \ 260 \text{kHz} \\ V_{IN}=2V_{P-P}, f_{IN}=500 \text{kHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P}, f_{IN}=500 \text{kHz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P}, f_{IN}=4M \text{Hz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P}, f_{IN}=5M \text{Hz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P}, f_{IN}=15M \text{Hz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P}, f_{IN}=5M \text{Hz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P}, f_{IN}=15M \text{Hz} \ (\text{Gain Relative to } 260 \text{kHz}) \\ V_{IN}=2V_{P-P}, f_{IN}=25M \text{Hz} \ (\text{Gain Relative to } 260 \text{kHz}) \end{array} $	•		0.05 0.005 0.01 0.03 0.05 0.15 0.1	0.7 0.1 0.2 0.5 0.6 1.8 2.8	dB dB dB dB dB dB dB dB
Matching of Filter Phase, $V_S = 5V$	$V_{IN}$ = 2V <sub>P-P</sub> , $f_{IN}$ = 2.5MHz $V_{IN}$ = 2V <sub>P-P</sub> , $f_{IN}$ = 4MHz	•		0.2 0.5	2 3	deg deg
Filter Gain Either Channel, $V_S = \pm 5V$	$V_{IN} = 2V_{P-P}$ , $f_{IN} = DC$ to 260kHz		-0.6	-0.1	0.4	dB
Filter Gain, R <sub>IN</sub> = 229Ω	$ \begin{array}{l} V_{IN} = 0.5 V_{P-P}, \ f_{IN} = DC \ to \ 260 \text{kHz} \\ V_S = 3 V \\ V_S = 5 V \\ V_S = \pm 5 V \end{array} $		10.4 10.3 10.1	10.9 10.8 10.7	11.5 11.4 11.3	dB dB dB
Filter Gain Temperature Coefficient (Note 2)	$f_{IN} = 260 \text{kHz}, V_{IN} = 2 V_{P-P}$			780		ppm/°C
Noise	Noise BW = 10kHz to 5MHz, $R_{IN}$ = 806 $\Omega$			45		μV <sub>RMS</sub>
Distortion (Note 4)	$ \begin{array}{l} V_{IN} = 2 V_{P\text{-}P}, \ f_{IN} = 1 MHz, \ R_L = 800 \Omega \\ 2 nd \ Harmonic \\ 3 rd \ Harmonic \end{array} $			93 96		dBc dBc
	$V_{IN}$ = 2V <sub>P-P</sub> , f <sub>IN</sub> = 5MHz, R <sub>L</sub> = 800 $\Omega$ 2nd Harmonic 3rd Harmonic			66 73		dBc dBc
Channel Separation (Note 9)	$V_{IN} = 2V_{P-P}, f_{IN} = 1MHz$			-117		dB
Differential Output Swing	Measured Between OUT+ and OUT-, $V_{OCM}$ Shorted to $V_{MID}$ $V_S$ = 5V $V_S$ = 3V	•	3.85 3.85	4.8 4.8		V <sub>P-P_DIFF</sub> V <sub>P-P_DIFF</sub>
Input Bias Current	Average of IN+ and IN-	•	-70	-30		μΑ



### **ELECTRICAL CHARACTERISTICS** The • denotes the specifications which apply over the full operating

temperature range, otherwise specifications are at  $T_A = 25^{\circ}$ C. Unless otherwise specified  $V_S = 5V$  (V<sup>+</sup> = 5V, V<sup>-</sup> = 0V),  $R_{IN} = 806\Omega$ , and  $R_{LOAD} = 1k$ .

PARAMETER	CONDITIONS		MIN	ТҮР	MAX	UNITS
Input Referred Differential Offset	$ \begin{array}{l} R_{IN} = 806\Omega \\ V_{S} = 3V \\ V_{S} = 5V \\ V_{S} = \pmSV \end{array} $	•		5 10 8	25 30 35	mV mV mV
	$ \begin{array}{l} R_{IN} = 229\Omega \\ V_{S} = 3V \\ V_{S} = 5V \\ V_{S} = \pm5V \end{array} $	•		5 5 5	13 16 20	mV mV mV
Differential Offset Drift				10		μV/°C
Input Common Mode Voltage (Note 3)	$ \begin{array}{l} \mbox{Differential Input} = 500 mV_{P-P}, \ \mbox{R}_{IN} = 229 \Omega \\ V_S = 3V \\ V_S = 5V \\ V_S = 5V \\ V_S = \pm 5V \end{array} $	•	0 0 -2.5		1.5 3 1	V V V
Output Common Mode Voltage (Note 5)	Differential Output = $2V_{P-P}$ , $V_{MID} = OPEN$ $V_S = 3V$ $V_S = 5V$ $V_S = \pm 5V$	•	1 1.5 –1		1.5 3 2	V V V
Output Common Mode Offset (with Respect to $V_{OCM}$ )	$V_S = 3V$ $V_S = 5V$ $V_S = \pm 5V$	•	-25 -30 -55	5 5 –5	50 45 35	mV mV mV
Common Mode Rejection Ratio				61		dB
Voltage at V <sub>MID</sub>	$V_S = 5V$ $V_S = 3V$	•	2.45	2.51 1.5	2.56	V V
V <sub>MID</sub> Input Resistance		•	4.3	5.5	7.7	kΩ
V <sub>OCM</sub> Bias Current	$V_{0CM} = V_{MID} = V_S/2$ $V_S = 5V$ $V_S = 3V$	•	-15 -10	-3 -3		μA μA
Power Supply Current (Per Channel)	$V_{S} = 3V, V_{S} = 5V$ $V_{S} = 3V, V_{S} = 5V$ $V_{S} = \pm 5V$	•		28 30	31 34 38	mA mA mA

**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  $R_{IN} \ge 229\Omega$ .

**Note 4:** Distortion is measured differentially using a differential stimulus. The input common mode voltage, the voltage at  $V_{OCM}$ , and the voltage at  $V_{MID}$  are equal to one half of the total power supply voltage.

**Note 5:** Output common mode voltage is the average of the +OUT and -OUT voltages. The output common mode voltage is equal to V<sub>OCM</sub>.

Note 6: The LT6604C-5 is guaranteed functional over the operating temperature range -40°C to 85°C.

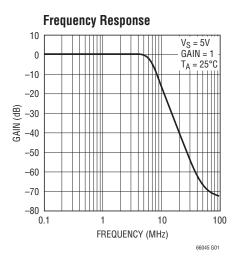
**Note 7:** The LT6604C-5 is guaranteed to meet 0°C to 70°C specifications and is designed, characterized and expected to meet the extended temperature limits, but is not tested at -40°C to 85°C. The LT6604I-5 is guaranteed to meet specified performance from -40°C to 85°C.

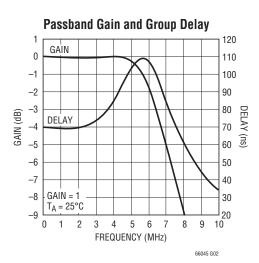
**Note 8:** Input pins (+IN, -IN, V<sub>OCM</sub> and V<sub>MID</sub>) are protected by steering diodes to either supply. If the inputs should exceed either supply voltage, the input current should be limited to less than 10mA. In addition, the inputs +IN, -IN are protected by a pair of back-to-back diodes. If the differential input voltage exceeds 1.4V, the input current should be limited to less than 10mA

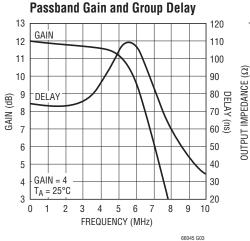
**Note 9:** Channel separation (the inverse of crosstalk) is measured by driving a signal into one input while terminating the other input. Channel separation is the ratio of the resulting output signal at the driven channel to the output at the channel that is not driven.



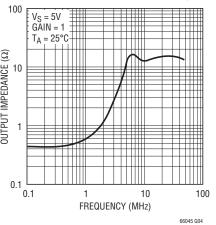
### TYPICAL PERFORMANCE CHARACTERISTICS



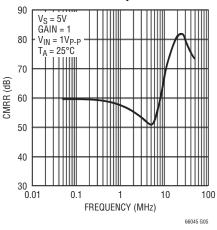


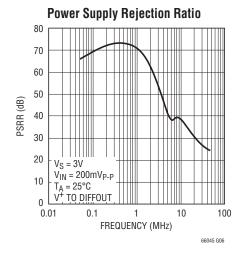


**Output Impedance vs Frequency** 

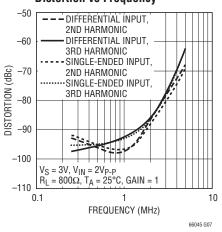


**Common Mode Rejection Ratio** 

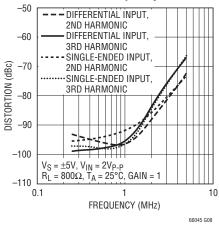




**Distortion vs Frequency** 

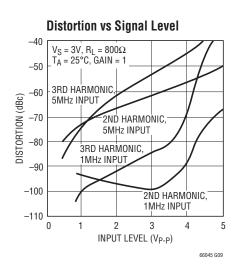


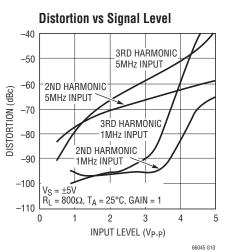
**Distortion vs Frequency** 





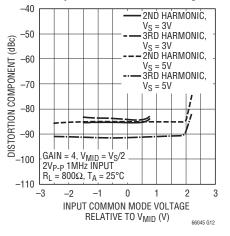
# TYPICAL PERFORMANCE CHARACTERISTICS



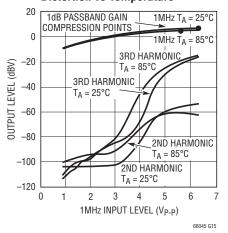


Distortion vs Input Common Mode Voltage -40 2ND HARMONIC, V<sub>S</sub> = 3V 3RD HARMONIC -50 DISTORTION COMPONENT (dBc)  $V_{\rm S} = 3V$ 2ND HARMONIC, -60  $V_{\rm S} = 5V$ 3RD HARMONIC, -70  $V_S = 5V$ -80 -90 GAIN = 1, V<sub>MID</sub> = V<sub>S</sub>/2 2V<sub>P-P</sub> 1MHz INPUT 100 R<sub>L</sub> = 800Ω, T<sub>A</sub> = 25°C -110 -3 -2 0 2 3 -1 1 INPUT COMMON MODE VOLTAGE RELATIVE TO V<sub>MID</sub> (V) 66045 G11

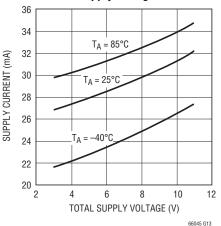
Distortion vs Input Common Mode Voltage



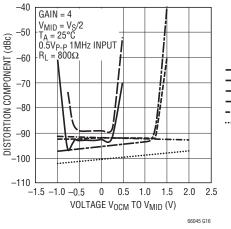
Distortion vs Temperature



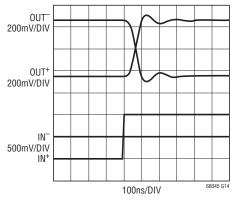
Single Channel Supply Current vs Total Supply Voltage

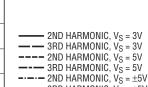


Distortion vs Output Common Mode Voltage



Transient Response, Differential Gain = 1, Single-Ended Input, Differential Output

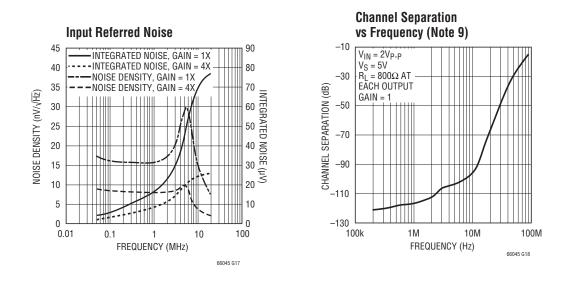




••••••••• 3RD HARMONIC,  $V_S = \pm 5V$ 



# **TYPICAL PERFORMANCE CHARACTERISTICS**



# PIN FUNCTIONS

**+INA**, **–INA** (**Pins 2, 4**): Channel A Input Pins. Signals can be applied to either or both input pins through identical external resistors,  $R_{IN}$ . The DC gain from the differential inputs to the differential outputs is 806 $\Omega/R_{IN}$ .

**V<sub>OCMA</sub> (Pin 6):** DC Common Mode Reference Voltage for the 2nd Filter Stage in channel A. Its value programs the common mode voltage of the differential output of the filter. Pin 6 is a high impedance input, which can be driven from an external voltage reference, or Pin 6 can be tied to Pin 34 on the PC board. Pin 6 should be bypassed with a  $0.01\mu$ F ceramic capacitor unless it is connected to a ground plane.

**V**<sup>−</sup> (**Pins 7, 24, 31, 32, 35):** Negative Power Supply Pin. Can be ground.

**V<sub>MIDB</sub>** (**Pin 8**): The V<sub>MIDB</sub> pin is internally biased at mid supply, see Block Diagram. For single supply operation the V<sub>MIDB</sub> pin should be bypassed with a quality  $0.01\mu$ F ceramic capacitor to V<sup>-</sup>. For dual supply operation, Pin 8 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 8 sets the output common mode voltage of the 1st stage of the filter in channel B. It has a 5.5k $\Omega$  impedance, and it can be overridden with an external low impedance voltage source. **+INB**, **–INB** (Pins 10, 12): Channel B 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  $806\Omega/R_{IN}$ .

 $V_{OCMB}$  (Pin 14): DC Common Mode Reference Voltage for the 2nd Filter Stage in Channel B. Its value programs the common mode voltage of the differential output of the filter. Pin 14 is a high impedance input, which can be driven from an external voltage reference, or Pin 14 can be tied to Pin 8 on the PC board. Pin 14 should be bypassed with a 0.01µF ceramic or greater capacitor unless it is connected to a ground plane.

**V<sup>+</sup>A, V<sup>+</sup>B (Pins 25, 17):** Positive Power Supply Pins for Channels A and B. For a single 3.3V or 5V supply (V<sup>-</sup> grounded) a quality  $0.1\mu$ F ceramic bypass capacitor is required from each positive supply pin (V<sup>+</sup>A, V<sup>+</sup>B) to the negative supply pin (V<sup>-</sup>). The bypass should be as close as possible to the IC. For dual supply applications, bypass the negative supply pins to ground and each of the positive supply pins (V<sup>+</sup>A, V<sup>+</sup>B) to ground with a quality  $0.1\mu$ F ceramic capacitor.

+OUTB, -OUTB (Pins 19, 21): Output Pins. Pins 19 and 21 are the filter differential outputs for channel B. With a typical short-circuit current limit greater than  $\pm$ 40mA, each pin can drive a 100 $\Omega$  and/or 50pF load to AC ground.

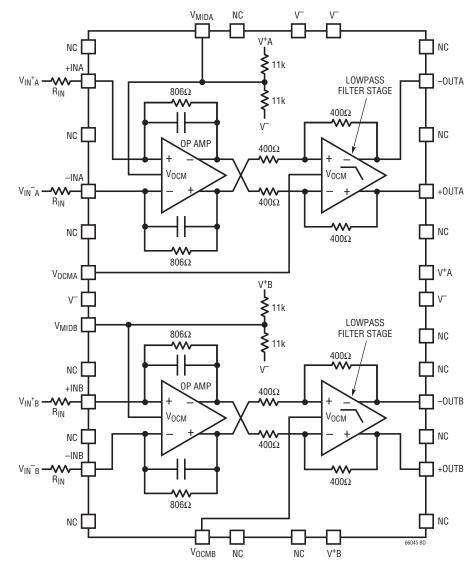


# PIN FUNCTIONS

+OUTA, – OUTA (Pins 27, 29): Output Pins. Pins 27 and 29 are the filter differential outputs for channel A. With a typical short-circuit current limit greater than  $\pm$ 40mA, each pin can drive a 100 $\Omega$  and/or 50pF load to AC ground.

 $V_{MIDA}$  (Pin 34): The V<sub>MIDA</sub> pin is internally biased at mid supply, see Block Diagram. For single supply operation the V<sub>MIDA</sub> pin should be bypassed with a quality 0.01µF ceramic capacitor to Pins V<sup>-</sup>. For dual supply operation, Pin 34 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 34 sets the output common mode voltage of the 1st stage of the filter in channel A. It has a  $5.5k\Omega$  impedance, and it can be overridden with an external low impedance voltage source.

**Exposed Pad (Pin 35):**  $V^-$ . The Exposed Pad must be soldered to PCB. If  $V^-$  is separate from ground, tie the Exposed Pad to  $V^-$ .



# **BLOCK DIAGRAM**





#### Interfacing to the LT6604-5

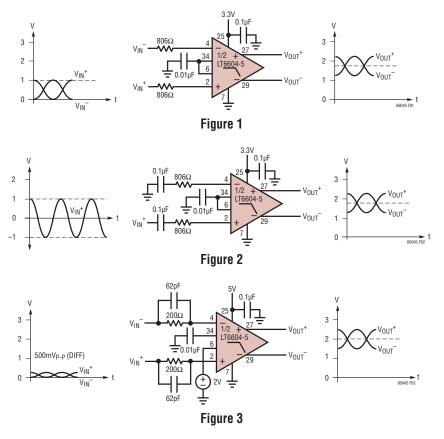
Note: The LT6604-5 contains two identical filters. The following applications information only refers to one filter. The two filters are independent except that they share the same negative supply voltage V<sup>-</sup>. The two filters can be used simultaneously by replicating the example circuits. The referenced pin numbers correspond to the A channel filter.

Each LT6604-5 channel requires two equal external resistors, R<sub>IN</sub>, to set the differential gain to  $806\Omega/R_{IN}$ . The inputs to the filter are the voltages V<sub>IN</sub><sup>+</sup> and V<sub>IN</sub><sup>-</sup> presented to these external components, Figure 1. The difference between V<sub>IN</sub><sup>+</sup> and V<sub>IN</sub><sup>-</sup> is the differential input voltage. The average of V<sub>IN</sub><sup>+</sup> and V<sub>IN</sub><sup>-</sup> is the common mode input voltage. Similarly, the voltages V<sub>OUT</sub><sup>+</sup> and V<sub>OUT</sub><sup>-</sup> appearing at Pins 27 and 29 of the LT6604-5 are the filter outputs. The difference between V<sub>OUT</sub><sup>+</sup> and V<sub>OUT</sub><sup>-</sup> is the differential output voltage. The average of V<sub>OUT</sub><sup>+</sup> and V<sub>OUT</sub><sup>-</sup> is the differential output voltage. The average of V<sub>OUT</sub><sup>+</sup> and V<sub>OUT</sub><sup>-</sup> is the differential output voltage. The average of V<sub>OUT</sub><sup>+</sup> and V<sub>OUT</sub><sup>-</sup> is the differential output voltage. The average of V<sub>OUT</sub><sup>+</sup> and V<sub>OUT</sub><sup>-</sup> is the common mode output voltage. Figure 1 illustrates the LT6604-5 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  $2V_{P-P}$ . The common mode output voltage is 1.65V, and the differential output voltage is  $2V_{P-P}$  for frequencies below 5MHz. The common mode output voltage is determined by the voltage at  $V_{OCM}$ . Since  $V_{OCM}$  is shorted to  $V_{MID}$ , 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  $V_{MID}$ .

Figure 2 shows how to AC couple signals into the LT6604-5. 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  $0.1\mu$ F coupling capacitor and the  $806\Omega$  gain setting resistor form a high pass filter, attenuating signals below 2kHz. Larger values of coupling capacitors will proportionally reduce this highpass 3dB frequency.

In Figure 3 the LT6604-5 is providing 12dB of gain. The gain resistor has an optional 62pF in parallel to improve the passband flatness near 5MHz. The common mode output voltage is set to 2V.





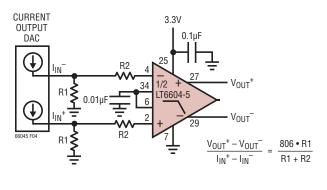


Figure 4

Use Figure 4 to determine the interface between the LT6604-5 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:

$$A = \frac{806 \bullet R1}{R1 + R2} \Omega$$

By setting R1 + R2 = 806 $\Omega$ , the gain equation reduces to A = R1( $\Omega$ ). The voltage at the pins of the DAC is determined by R1, R2, the voltage on V<sub>MID</sub> and the DAC output current. Consider Figure 4 with R1 = 49.9 $\Omega$  and R2 = 750 $\Omega$ . The voltage at V<sub>MID</sub>, for V<sub>S</sub> = 3.3V, is 1.65V. The voltage at the DAC pins is given by:

$$V_{DAC} = V_{MID} \bullet \frac{R1}{R1 + R2 + 806} + I_{IN} \frac{R1 \bullet R2}{R1 + R2}$$
  
= 51mV + I<sub>IN</sub> 46.8Ω

### Evaluating the LT6604-5

The low impedance levels and high frequency operation of the LT6604-5 require some attention to the matching networks between the LT6604-5 and other devices. The previous examples assume an ideal ( $0\Omega$ ) source impedance and a large (1k) load resistance. Among practical examples where impedance must be considered is the evaluation of the LT6604-5 with a network analyzer.

Figure 5 is a laboratory setup that can be used to characterize the LT6604-5 using single-ended instruments with  $50\Omega$  source impedance and  $50\Omega$  input impedance. For a unity

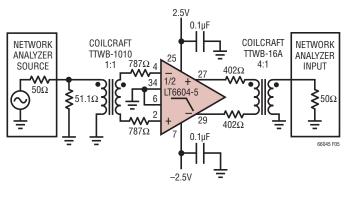


Figure 5

gain configuration the LT6604-5 requires an 806 $\Omega$  source resistance yet the network analyzer output is calibrated for a 50 $\Omega$  load resistance. The 1:1 transformer, 51.1 $\Omega$ and 787 $\Omega$  resistors satisfy the two constraints above. The transformer converts the single-ended source into a differential stimulus. Similarly, the output of the LT6604-5 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 LT6604-5 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 LT6604-5 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 LT6604-5 channel 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 supply rails, the input/output behavior of the IC shown in Figure 6 is relatively independent of the power supply voltage.



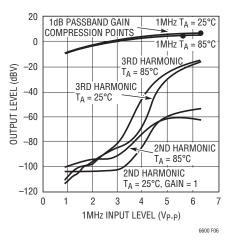


Figure 6. Differential Voltage Range

The two amplifiers inside the LT6604-5 channel have independent control of their output common mode voltage (see the Block Diagram section). The following guidelines will optimize the performance of the filter.

 $V_{MID}$  can be allowed to float, but it must be bypassed to an AC ground with a 0.01µF capacitor or some instability may be observed.  $V_{MID}$  can be driven from a low impedance source, provided it remains at least 1.5V above V<sup>-</sup> and at least 1.5V below V<sup>+</sup>. An internal resistor divider sets the voltage of  $V_{MID}$ . While the internal 11k resistors are well matched, their absolute value can vary by ±20%. This should be taken into consideration when connecting an external resistor network to alter the voltage of  $V_{MID}$ .

 $V_{OCM}$  can be shorted to  $V_{MID}$  for simplicity. If a different common mode output voltage is required, connect  $V_{OCM}$  to a voltage source or resistor network. For 3V and 3.3V supplies the voltage at  $V_{OCM}$  must be less than or equal to the mid supply level. For example, voltage  $(V_{OCM}) \leq 1.65V$  on a single 3.3V supply. For power supply voltages higher than 3.3V the voltage at  $V_{OCM}$  can be set above mid supply. The voltage on  $V_{OCM}$  should not be more than 1V below the voltage on  $V_{MID}$ . The voltage on  $V_{OCM}$  should not be more than 2V above the voltage on  $V_{MID}$ .  $V_{OCM}$  is a high impedance input.

The LT6604-5 was designed to process a variety of input signals including signals centered on the mid supply voltage and signals that swing between ground and a positive voltage in a single supply system (Figure 1). The allowable range of the 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 the Electrical Characteristics section).

#### **Common Mode DC Currents**

In applications like Figure 1 and Figure 3 where the LT6604-5 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. V<sub>MID</sub> sets the output common mode voltage of the 1st differential amplifier inside the LT6604-5 (see the Block Diagram section) at 2.5V. Since the input common mode voltage is near OV, there will be approximately a total of 2.5V drop across the series combination of the internal  $806\Omega$  feedback resistor and the external 200 $\Omega$  input resistor. The resulting 2.5mA common mode DC current in each input path, must be absorbed by the sources  $V_{IN}^+$  and  $V_{IN}^-$ .  $V_{OCM}$  sets the common mode output voltage of the 2nd differential amplifier inside the LT6604-5 channel, and therefore sets the common mode output voltage of the filter. Since, in the example of Figure 3,  $V_{OCM}$  differs from  $V_{MID}$  by 0.5V, an additional 1.25mA (625µA per side) of DC current will flow in the resistors coupling the 1st differential amplifier output stage to the filter output. Thus, a total of 6.25mA is used to translate the common mode voltages.

A simple modification to Figure 3 will reduce the DC common mode currents by 36%. If  $V_{MID}$  is shorted to  $V_{OCM}$  the common mode output voltage of both op amp stages will be 2V and the resulting DC current will be 4mA. Of course, by AC coupling the inputs of Figure 3 and shorting  $V_{MID}$  to  $V_{OCM}$ , the common mode DC current is eliminated.



#### Noise

The noise performance of the LT6604-5 channel can be evaluated with the circuit of Figure 7. Given the low noise output of the LT6604-5 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.

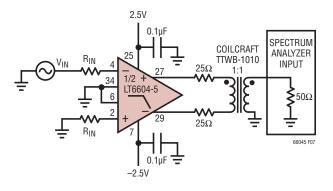
Example: With the IC removed and the  $25\Omega$  resistors grounded, Figure 7, measure the total integrated noise (e<sub>S</sub>) of the spectrum analyzer from 10 kHz to 5MHz. With the IC inserted, the signal source (V<sub>IN</sub>) disconnected, and the input resistors grounded, measure the total integrated noise out of the filter (e<sub>0</sub>). With the signal source connected, set the frequency to 1MHz and adjust the amplitude until V<sub>IN</sub> measures 100mV<sub>P-P</sub>. Measure the output amplitude, V<sub>OUT</sub>, and compute the passband gain A = V<sub>OUT</sub>/V<sub>IN</sub>. Now compute the input referred integrated noise (e<sub>IN</sub>) as:

$$e_{IN} = \frac{\sqrt{(e_0)^2 - (e_S)^2}}{A}$$

Table 1 lists the typical input referred integrated noise for various values of  ${\sf R}_{\sf IN}.$ 

PASSBAND Gain	R <sub>IN</sub>	INPUT REFERRED Integrated Noise 10kHz to 5MHz	INPUT REFERRED NOISE dBm/Hz	
4	200Ω	24µV <sub>RMS</sub>	-149	
2	402Ω	38µV <sub>RMS</sub>	-145	
1	806Ω	69µV <sub>RMS</sub>	-140	

#### Table 1. Noise Performance





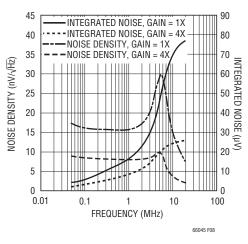


Figure 8. Input Referred Noise

Figure 8 is plot of the noise spectral density as a function of frequency for an LT6604-5 with  $R_{IN} = 806\Omega$  using the fixture of Figure 7 (the instrument noise has been subtracted from the results).

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

#### **Power Dissipation**

The LT6604-5 amplifiers combine high speed with large signal currents in a small package. There is a need to ensure that the die's junction temperature does not exceed 150°C. The LT6604-5 has an exposed pad (pin 35) which is connected to the lower supply (V<sup>-</sup>). Connecting the pad to a ground plane helps to dissipate the heat generated by the chip. Metal trace and plated through-holes can be used to spread the heat generated by the device to the backside of the PC board.

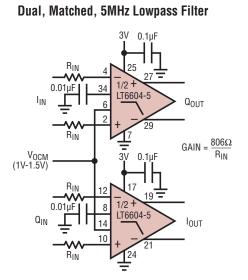


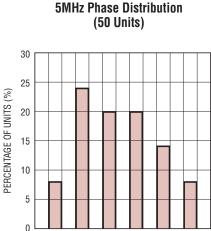
Junction temperature,  $T_J$ , is calculated from the ambient temperature,  $T_A$ , and power dissipation,  $P_D$ . The power dissipation is the product of supply voltage,  $V_S$ , and total supply current,  $I_S$ . Therefore, the junction temperature is given by:

 $\mathsf{T}_\mathsf{J} = \mathsf{T}_\mathsf{A} + (\mathsf{P}_\mathsf{D} \bullet \theta_\mathsf{J} \mathsf{A}) = \mathsf{T}_\mathsf{A} + (\mathsf{V}_\mathsf{S} \bullet \mathsf{I}_\mathsf{S} \bullet \theta_\mathsf{J} \mathsf{A})$ 

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, use 43°C/W as the package thermal resistance, then apply the equation for T<sub>J</sub>. For example, using the circuit in Figure 3 with DC differential input voltage of 250mV, a differential output voltage of 1V, 1k load resistance and an ambient temperature of 85°C, the supply current (current into V<sup>+</sup>) measures 32.2mA per channel. The resulting junction temperature is: T<sub>J</sub> = T<sub>A</sub> + (P<sub>D</sub> •  $\theta_{JA}$ ) = 85 + (5 • 2 • 0.0322 • 43) = 99°C. The thermal resistance can be affected by the amount of copper on the PCB that is connected to V<sup>-</sup>. The thermal resistance of the circuit can increase if the exposed pad is not connected to a large ground plane with a number of vias.

### TYPICAL APPLICATIONS





-134 -133.5 -133 -132.5

5MHz PHASE (DEG)

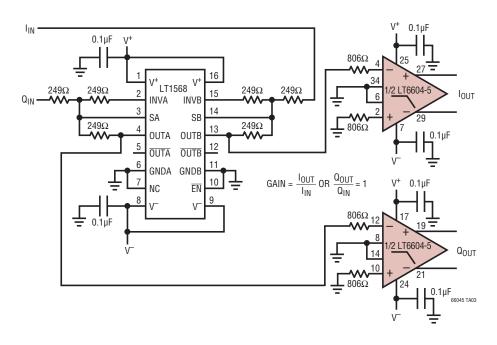
-132

66045 TA02

-134.5

LINEAR TECHNOLOGY

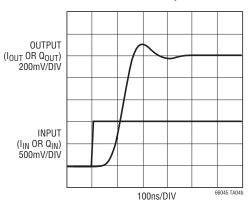
# TYPICAL APPLICATIONS



Dual, Matched, 6th Order, 5MHz Lowpass Filter Single-Ended Input ( $I_{IN}$  and  $Q_{IN}$ ) and Differential Output ( $I_{OUT}$  and  $Q_{OUT}$ )

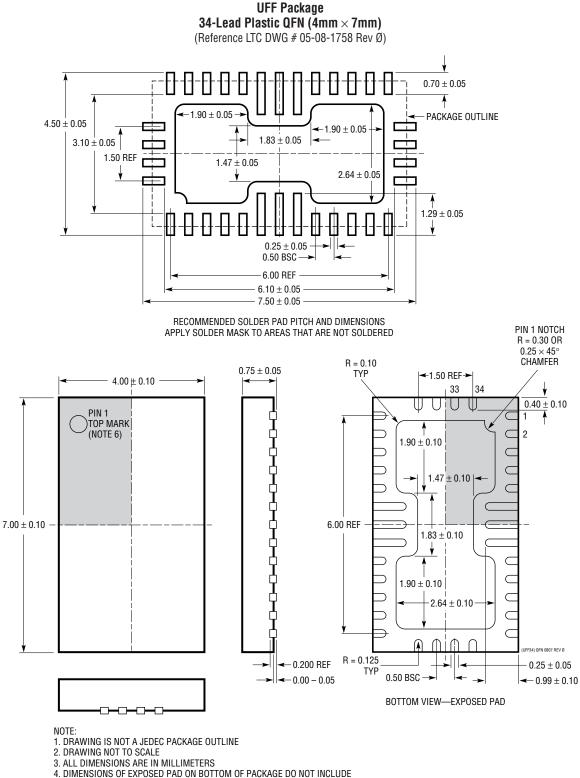
**Frequency Response** 12 0 GAIN (dB) 20 LOG (l<sub>0</sub>UT/l<sub>IN</sub>) 0R 20 LOG (Q<sub>0</sub>UT/Q<sub>IN</sub>) -12 -24 -36 -48 -60 -72 -84 -96 -108 0.1 10 40 1 FREQUENCY (MHz) 66045 TA04a

**Transient Response** 





### PACKAGE DESCRIPTION



- MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.20mm ON ANY SIDE
- 5. EXPOSED PAD SHALL BE SOLDER PLATED
- 6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION
  - ON THE TOP AND BOTTOM OF PACKAGE



# **RELATED PARTS**

PART NUMBER	DESCRIPTION	COMMENTS		
Integrated Filter	'S			
LTC1562-2	Very Low Noise, 8th Order Filter Building Block	Lowpass and Bandpass Filters up to 300kHz		
LTC1565-31	650kHz Linear Phase Lowpass Filter	Continuous Time, 7th Order, Differential		
LTC1566-1	Low Noise, 2.3MHz Lowpass Filter	Continuous Time, 7th Order, Differential		
LT1568	Very Low Noise, 4th Order Filter Building Block	Lowpass and Bandpass Filters up to 10MHz		
LTC1569-7	Linear Phase, Tunable 10th Order Lowpass Filter	Single-Resistor Programmable Cut-Off to 300kHz		
LT6600-2.5	Very Low Noise Differential 2.5MHz Lowpass Filter	SNR = 86dB at 3V Supply, 4th Order Filter		
LT6600-5	Very Low Noise Differential 5MHz Lowpass Filter	SNR = 82dB at 3V Supply, 4th Order Filter		
LT6600-10	Very Low Noise Differential 10MHz Lowpass Filter	SNR = 82dB at 3V Supply, 4th Order Filter		
LT6600-15	Very Low Noise Differential 15MHz Lowpass Filter	SNR = 76dB at 3V Supply, 4th Order Filter		
LT6600-20	Very Low Noise Differential 20MHz Lowpass Filter	SNR = 76dB at 3V Supply, 4th Order Filter		
LTC6601	Low Noise, Fully Differential, Pin Configurable Amplifier/Driver/2nd Order Filter Building Block			
LTC6602	Dual Adjustable Lowpass Filter for RFID			
LTC6603	Dual Adjustable Lowpass Filter for Communications			
LT6604-2.5	Dual Very Low Noise, Differential Amplifier and 2.5MHz Lowpass Filter	SNR = 86dB at 3V Supply, 4th Order Filter		
LT6604-10	Dual Very Low Noise, Differential Amplifier and 10MHz Lowpass Filter	SNR = 82dB at 3V Supply, 4th Order Filter		
LT6604-15	Dual Very Low Noise, Differential Amplifier and 15MHz Lowpass Filter	SNR = 76dB at 3V Supply, 4th Order Filter		





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