DESIGN NOTES

Design Low Noise Differential Circuits Using the LT1567 Dual Amplifier Building Block

Design Note 291

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Introduction

Many communications systems use differential, low level (400mV to 1V peak-to-peak), analog baseband signals where the baseband circuitry operates from a single low voltage power supply (5V to 3V). Any differential amplifier circuit used for baseband signal conditioning must have very low noise and an output voltage swing that includes most of the power supply range for maximum signal dynamic range. The LT®1567, a low noise operational amplifier (*1.4nV/√Hz voltage noise density*) and a unity-gain inverter, is an excellent analog building block (see Figure 1) for designing low noise differential circuits. The gain bandwidth of the LT1567 amplifier is 160MHz and its slew rate is sufficient for signal frequencies up to 5MHz. The LT1567 operates from 2.7V to 12V total power supply. The output voltage swing is guaranteed to be 4.4V and 2.6V peak-to-peak, at 1k load with a single 5V and 3V power supply, respectively. The LT1567 is available in an 8-lead MSOP surface mount package.

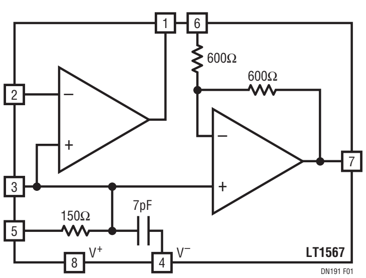
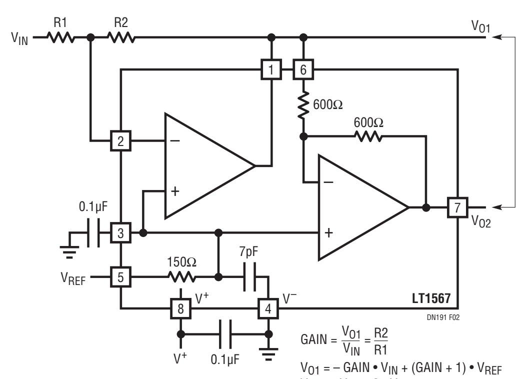


Figure 1. LT1567 Analog Building Block

A Single-Ended to Differential Amplifier

Figure 2 shows a circuit for generating a differential signal from a single-ended input. The differential output noise is a function of the noise of the amplifiers, the noise of resistors R1 and R2 and the noise bandwidth. For example, if R1 and R2 are each 200Ω, the differential output voltage noise density is 9.5 nV/√Hz and in a 4MHz noise bandwidth, the total differential output noise is 19µV_{RMS} (with a low level 0.2V_{RMS} differential signal, the signal-to-noise ratio is an excellent 80.4dB). The voltage on Pin 5 (V_{REF}) allows flexible DC bias for the circuit and can be set by a voltage divider or a reference voltage source (with a single 3V power supply, the V_{REF} range is 0.9V ≤ V_{REF} ≤ 1.9V). In a single supply circuit, if the input signal is DC coupled, then an input DC voltage (V_{INDC}) is required to bias the circuit within its linear region. If V_{INDC} is within the V_{REF} range, then V_{REF} can be equal to V_{INDC} and the output DC common mode voltage (V_{OUTCM}) at V_{O1} and V_{O2} is equal to V_{REF}. To maximize the unclipped LT1567 output swing however, the DC common mode output voltage must be set at $V^+/2$. The input signal can be AC coupled to the circuit's input resistor R1 and V_{REF} also set to the DC common mode voltage required by any following circuitry (for example the input of an I and Q modulator).



$$GAIN = \frac{V_{O1}}{V_{IN}} = \frac{R2}{R1}$$

$$V_{O1} = -GAIN \cdot V_{IN} + (GAIN + 1) \cdot V_{REF}$$

$$V_{O2} = -V_{O1} + 2 \cdot V_{REF}$$

$$V_{DIFF} = V_{O2} - V_{O1}$$

$$V_{DIFF} = 2 \cdot GAIN \cdot (V_{IN} - V_{REF})$$

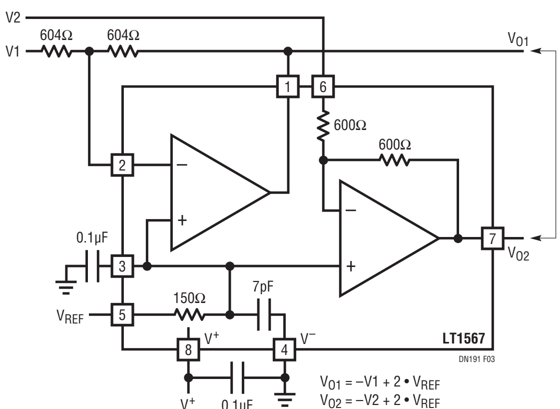
Figure 2. A Single-Ended Input to Differential Output Amplifier

A Differential Buffer/Driver

Figure 3 shows an LT1567 connected as a differential buffer. The differential output voltage noise density is $7.7nV/\sqrt{Hz}$. The differential buffer circuit of Figure 3, translates the input common mode DC voltage (V_{INCM}) to an output common mode DC voltage (V_{OUTCM}) set by the V_{REF} voltage ($V_{OUTCM} = 2 \bullet V_{REF} - V_{INCM}$). For example, in a single 5V power supply circuit, if V_{INCM} is 0.5V and V_{REF} is 1.5V then V_{OUTCM} is 2.5V.

A Differential to Single-Ended Amplifier

Figure 4 shows a circuit for converting a differential input to a single-ended output. For a gain equal to one ($R1 = R2 = 604\Omega$ and $V_{OUT} = V2 - V1$) the input referred differential voltage noise density is $9nV/\sqrt{Hz}$ and differential input signal-to-noise ratio is 80.9dB with $0.2V_{RMS}$ input signal in a 4MHz noise bandwidth. The input AC common mode rejection depends on the matching of resistors R1 and R3 and the LT1567 inverter gain tolerance (common mode rejection is at least 40dB up to 1MHz with one percent resistors and two percent inverter gain tolerance). If the differential input is DC coupled, then V_{REF} must be set equal to the input common mode voltage (V_{INCM}). If V_{REF} is greater than V_{INCM} then a peak voltage on Pin 7 may exceed the output voltage swing limit. The DC voltage at the amplifier's output (V_{OUT}, Pin 1) is V_{REF}.



$V_{O1} = -V1 + 2 \bullet V_{REF}$
$V_{O2} = -V2 + 2 \bullet V_{REF}$
$V_{DIFF} = V_{O2} - V_{O1} = V1 - V2$
OUTPUT DC COMMON MODE VOLTAGE, $V_{OCM} = 2 \bullet V_{REF} - VI_{NCM}$

Figure 3. A Differential Input and Output Buffer/Driver

LT1567 Free Design Software

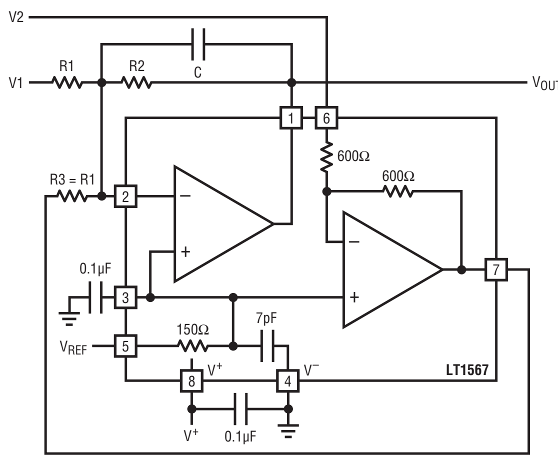
A spreadsheet-based design tool is available at www.linear.com for designing lowpass and bandpass filters using the LT1567.

The simple-to-use spreadsheet requires the user to define the desired corner (or center) frequency, the passband gain and a capacitor value for a choice of second or third order Chebyshev or Butterworth lowpass or second order bandpass filters.

The spreadsheet outputs the required external standard component values and provides a circuit diagram.

Conclusion

With one LT1567 and two or three resistors, it is easy to design low noise, differential circuits for signals up to 5MHz. The LT1567 can also be used to make low noise second and third order lowpass filters and second order bandpass filters with differential outputs.



$GAIN = \frac{R2}{R1}$, $R3 = R1$

$V_O = GAIN\,(V2 - V1) + V_{REF}$

f_{-3dB} BANDWIDTH AT $V_{OUT} = \frac{1}{2 \bullet \pi \bullet R2 \bullet C} \le 5MHz$

IF R1 = R3 = 604Ω, THEN

R2	V_η*	GAIN
604Ω	9.0	1
1.21k	8.4	2
2.43k	8.1	4

NOISE AT $V_{OUT} = GAIN \bullet V_\eta \bullet \sqrt{f_{\eta BW}}$ $f_{\eta BW} = 1.57 \bullet f_{-3dB}$

*V_η IS THE INPUT REFERRED DIFFERENTIAL VOLTAGE NOISE DENSITY IN $nV/\sqrt{Hz}$

Figure 4. A Differential Input-to-Single-Ended Output Amplifier

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