

2.3MHz Monolithic, Continuous Time, Differential Lowpass Filter Provides Solutions for Wide Band CDMA Applications

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Introducing the LTC1566-1: 2.3MHz Lowpass in SO-8

The LTC1566-1 is a new monolithic 7th order continuous time lowpass filter featuring differential input and output terminals; it operates from a single 5V supply and dual supplies of up to $\pm 5V$ and it is packaged in an 8-pin surface mount SO-8 package. The LTC1566-1 requires no external components other than power supply decoupling capacitors. It replaces bulky discrete designs built from differential amplifiers, op amps, precision resistors and capacitors. The filter is designed to have a flat passband from DC to 2MHz and a steep transition band. The $-3dB$ cutoff frequency is 2.3MHz and the attenuation at 3.5MHz is in excess of 38dB. The filter gain gradually rolls off past 5MHz

and the 85dB attenuation floor extends beyond 100MHz. This gain performance cannot be obtained with discrete components without trimming passive components. The filter cutoff is set at 2.3MHz to accommodate differential filtering needs in wide band CDMA base stations. Figure 1 shows the measured amplitude response and group delay.

The LTC1566-1 is a fully integrated, continuous time, differential filter; its passband, its cutoff frequency and its transition band are fixed. Depending on demand, other filter cutoff frequencies as well as other lowpass filter responses up to 7th order can be provided. The passband gain is internally set to 4V/V (12dB); it can be lowered with three external resistors.

Setting the Input and Output Common Mode Levels

Figure 2 shows the block diagram of the LTC1566-1. The high input impedance of "floating amplifiers" A1 and A2 allows external resistors R1

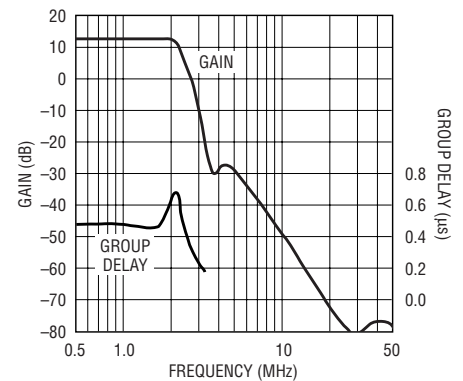
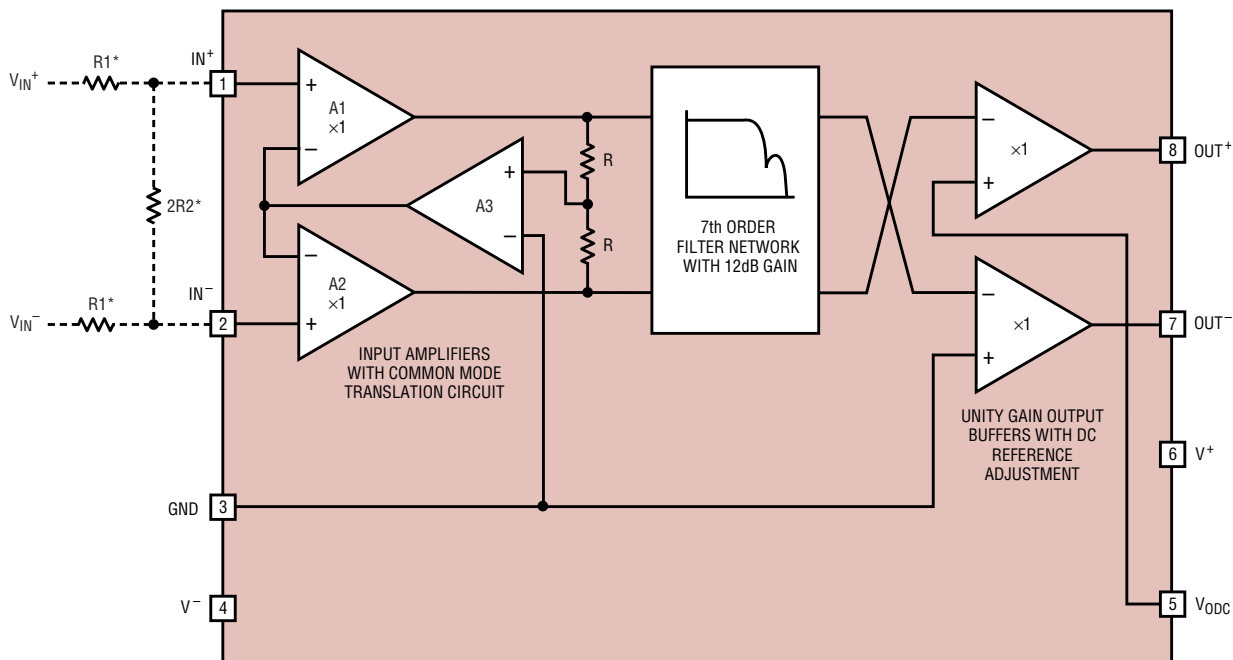


Figure 1. LTC1566-1 gain and group delay vs frequency



*NEEDED ONLY FOR PASSBAND GAIN < 12dB,

$$(IN^+ - IN^-) = (VIN^+ - VIN^-) \cdot \frac{R2}{R1 + R2}$$

Figure 2. LTC1566-1 block diagram

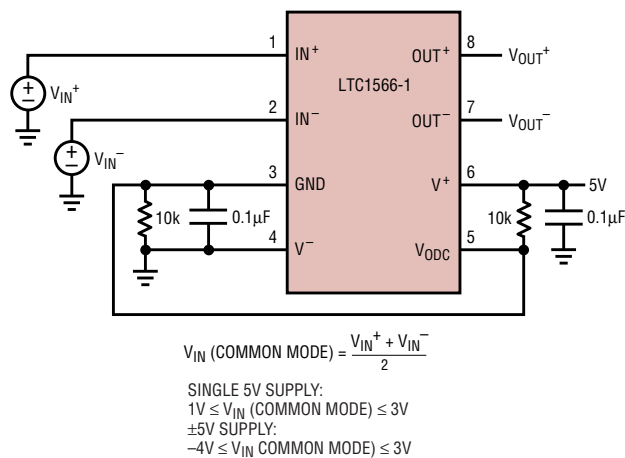


Figure 3. Single 5V supply operation, DC-coupled inputs

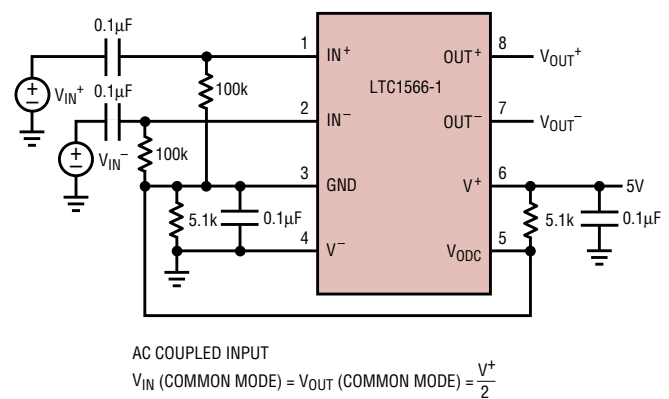


Figure 4. Single 5V supply operation, AC-coupled inputs

and 2R2 to be added to attenuate the differential input signal and to lower the effective passband gain of the circuit, if necessary. For example, if a gain of 2 (6dB) is desired, $R1 = R2$.

The LTC1566-1 is also capable of providing common mode voltage level shifting; that is, it can process differential input signals and provide filtered output differential signals with different common mode voltage levels. This is quite desirable, as components along a differential signal path may be optimized for a specific DC common mode level. For instance, the common mode output of a differential demodulator can be different than the required common mode input of a differential A/D converter.

The common mode translation is performed through unity-gain input buffers A1 and A2 and op amp A3 (Figure 2). Amplifier A3 forces the input amplifiers to operate with a common mode voltage dictated by the biasing of pin 3 (the ground pin) while

allowing floating amplifiers A1 and A2 to operate at an input common mode voltage dictated by the differential signal source driving the filter.

Another unique feature of the LTC1566-1 is the ability to introduce a differential offset voltage at the output of the filter. As seen in the block diagram, Figure 2, if a DC voltage is applied at pin 5 with respect to pin 3, it will be added to the differential voltage seen between pins 7 and 8. The DC output common mode voltage is therefore the arithmetic average of the DC voltages applied at pin 3 and pin 5. This output DC offset control can be used for sideband suppression of differential modulators, calibration of A/Ds or simple signal summation.

Figure 3 shows a typical connection for single-supply operation where the differential output is DC biased at one-half the power supply voltage. The input can be DC or AC coupled (Figure 3, Figure 4). AC coupling should be used if the common mode input voltage is outside the input range of the filter, as illustrated in Figure 4.

Dynamic Range

The total output in-band noise (DC to 2MHz) is typically $230\mu V_{RMS}$. Figure 5 shows the output signal-to-noise ratio vs differential output voltage. With a $1V_{RMS}$ output level ($2.8V_{P-P}$ differential) the filter features 73dB SINAD (S/N and THD). Note that the maximum dynamic range of the IC is independent of its power supply volt-

age. With dual 5V supplies, however, the filter can accept differential signals with wider common mode levels. The out-of-band noise is almost negligible due to the steep roll-off of the filter transition band. Input referred, the noise at each input terminal of the filter (pins 1 and 2) is $41\mu V_{RMS}$ or $-138dBm/Hz$.

Intermodulation

The coexistence of AMPS (American Mobile Phone System), CDMA (Code Division Multiple Access), and wide-band CDMA (WCDMA) cellular systems has increased the need for linearity in the transmitter and receiver circuits. In a CDMA or WCDMA transmitters, intermodulation of components in the spread-spectrum signal creates spectral regrowth and, consequently, adjacent channel interference. CDMA and WCDMA must operate in the presence of AMPS signals in the same channel (cochannel interference). Intermodulation between the AMPS signal and the CDMA/WCDMA signal desensitizes the receiver. Intermodulation is reduced by making the circuit as linear as possible. Both receiver and transmitter linearity can be characterized by measuring the intermodulation of two tones in the passband.

When two tones of equal amplitude are simultaneously applied to a weakly nonlinear circuit, the output spectrum above the two fundamentals will include the second and third harmonics of the input sources, the sum

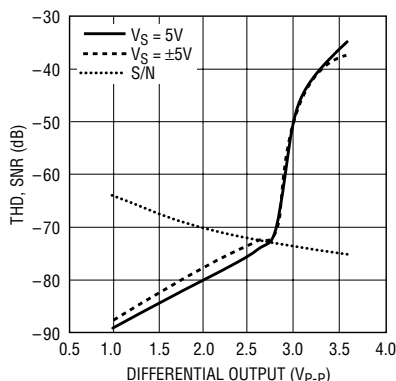


Figure 5. Total harmonic distortion and signal-to-noise ratio vs differential output voltage for single 5V and $\pm 5V$ supplies

and the difference frequencies of the two input sources (IM2) and the sum and differences of twice one input source and the other (IM3).

Furthermore, if the same two tones are applied to an LTC1566-1 lowpass filter, the filter selectivity will attenuate the out-of-band spurs. The 2nd order intermodulation products (IM2) and some 3rd order intermodulation

products (IM3), however, may fall within the passband or in the vicinity of the band edge of the circuit and their presence can limit system performance. Figure 6 shows the actual test circuit with 455kHz and 2MHz tones simultaneously applied at the filter's differential inputs. Figure 7 shows the measured IM3 products ($2 \times 2\text{MHz} - 455\text{kHz} = 3.55\text{MHz}$, and 2

$\times 450\text{kHz} - 2\text{MHz} = 1.1\text{MHz}$). The IM2 products, $2\text{MHz} + 455\text{kHz}$ and $2\text{MHz} - 455\text{kHz}$, are also shown and are weaker than the IM3s, as expected. The suppression of the IM2 products is due to the fully differential nature of the LTC1566-1, which tends to cancel them. Furthermore it can be proven that the IM3 products increase by approximately 3dB for each dB of

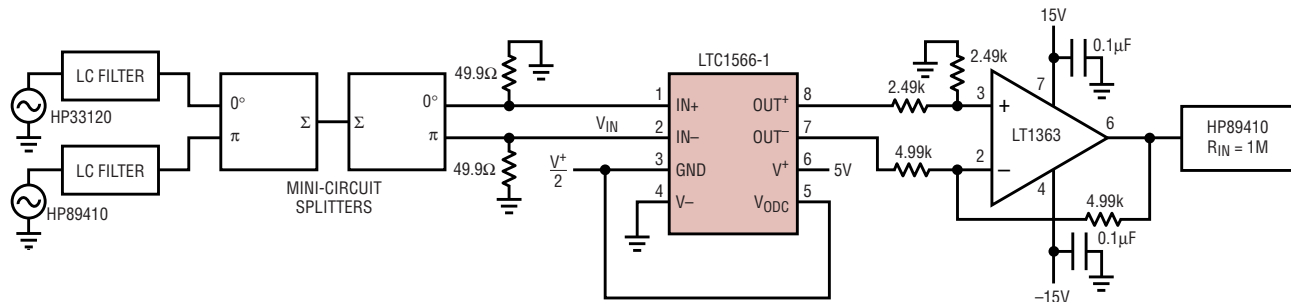


Figure 6. Test circuit for intermodulation distortion

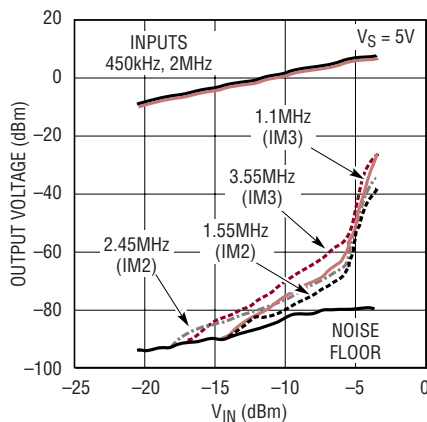


Figure 7. 450kHz/2MHz intermodulation, $V_S = 5V$

input signal increase, so their presence in the passband must be minimized or eliminated.

As shown in Figure 7, the excellent linearity of the LTC1566-1 provides an intermodulation ratio (IM) of better than 70dB for output levels of -3Bm or lower. The IM performance of the LTC1566-1 is better than some commercially available passive LC filter modules.

Out-of-Band Attenuation

The amplitude response of a filter is routinely tested with an input signal of varying frequency and constant amplitude; yet, a common requirement in communication systems is

the ability to process an in-band signal in the presence of large out-of-band interference. The active filter should be designed to meet these stringent requirements. Figure 8 shows a test circuit that simulates the case where the LTC1566-1 receives a constant-amplitude, in-band signal in the presence of strong out-of-band interference. Figure 9 shows the measured filter output. Three out-of-band tones (3MHz, 5MHz, 10MHz) are summed with a -2dBm (0.5V_{P-P}) 2MHz in-band signal. Figure 9 should be compared with the gain response of the filter shown in Figure 1. As can be seen in Figure 9, the LTC1566-1 can attenuate a 12dBm (2.52V_{P-P}) 10MHz out-of-band signal by 50dB, while amplifying an in-band 0.5V_{P-P} (-2dBm) 2MHz signal without gain error. The maximum allowable amplitude of the 10MHz out-of-band signal is 13dBm (2.82V_{P-P}); a larger signal will warp the passband gain. This excellent dynamic performance is attributable to the internal architecture of the LTC1566-1, which provides band-limiting at early stages.

Similar observations can be made for the 5MHz and 3MHz cases of Figure 9, although large 3MHz signals will warp the passband gain sooner; this is expected, because high ampli-

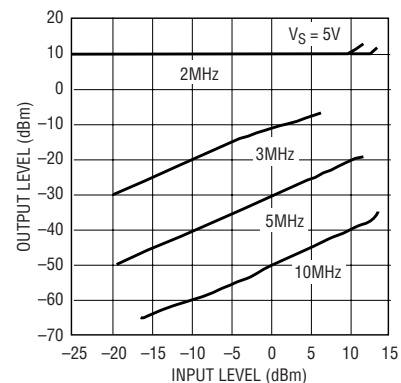



Figure 9. Out-of-band rejection, $V_S = 5V$

tude out-of-band 3MHz tones will also form in-band IM3 and IM2 products. To conclude, the LTC1566-1 attenuates out-of-band signals that are smaller than, equal to or larger than in-band signals.

Conclusion

The LTC1566-1 is a monolithic, self-contained, fully differential lowpass filter with outstanding linearity; it can process a wide spectrum of input signals and, in addition to filtering, it can provide common mode DC level shifting. 

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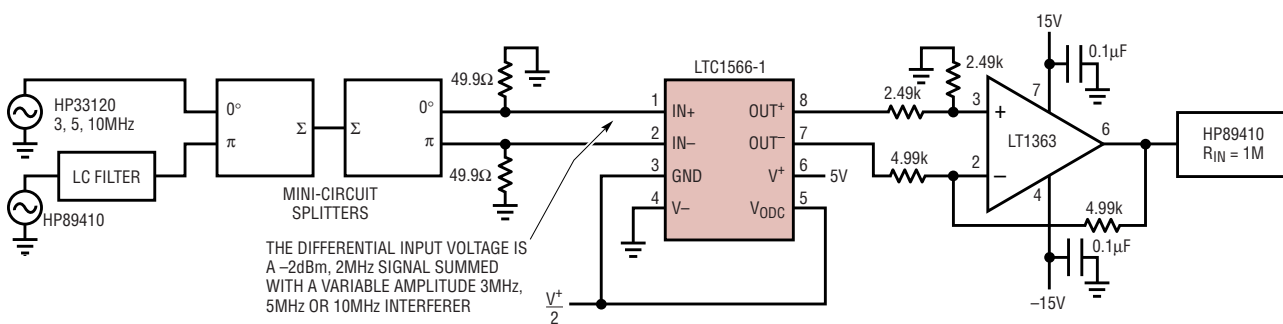


Figure 8. Test circuit for out-of-band rejection