LTC1569-X, 10th Order, Linear-Phase Lowpass Filter Family is Tunable with a Single External Resistor

by Michael Kultgen

The new LTC1569-6/LTC1569-7 are the first monolithic filters in the industry to provide accurate control of the cutoff frequency without the need for an external clock. A single external resistor programs internal precision circuitry, enabling the user to vary the filter cutoff frequency over eight octaves with a typical accuracy of ±3% or better. Figure 1 shows a simplified block diagram of the LTC1569-6/ LTC1569-7.

The internal filter circuitry uses sampled-data techniques with a ratio of sampling frequency to filter cutoff frequency of 64:1 and 128:1 for the LTC1569-7 and LTC1569-6, respectively. This technology allows the realization of complex and accurate filter functions in a relatively small space.

Ease of tuning is just one of the many features of this linear-phase, DC-accurate, 10th order lowpass filter. Other features include:

- ❏ Up to 300kHz cutoff frequency operating on a single 5V supply or 150kHz cutoff frequency operating on a single 3V supply (LTC1569-7)
- ❏ Root raised cosine response (alpha = 0.5) with linear phase and steep selectivity
- ❏ DC accurate with a maximum offset of 5mV when powered with a 3V supply
- ❏ Differential or single-ended inputs
- ❏ Power consumption as low as 8mW (LTC1569-6, f_C = 4kHz)
- ❏ Small SO-8 package Operates from 3V to ±5V Supplies

An Outstanding Response

The frequency response of the LTC1569-6/LTC1569-7 is a 10th order approximation of the classical "root raised cosine" function with phase linearization. The result is an outstanding lowpass characteristic, ideal for data communications or data acquisition systems. This combination of precision and selectivity is *practically impossible to achieve with discrete filters.*

The filter attenuation is 50dB at 1.5 times the filter cutoff (f_C), 60dB at twice f_C, and in excess of 80dB at six times f_C. Thus, the LTC1569-6/ LTC1569-7 are excellent choices in applications with demanding specifications for rejection of frequency components outside the passband (Figure 2). Examples include a wireless communication system using a lowpass filter to limit the amount of energy transmitted outside of the desired channel or a sensor system that measures a low frequency signal in the presence of significant interference.

In data communications, designs are optimized to transmit the maximum amount of information in the allotted bandwidth. In systems using pulse amplitude modulation, pulse shaping is an important design consideration. The linear-phase, root raised cosine response (alpha = 0.5) of the LTC1569-6/LTC1569-7 lets users build matched filters with low intersymbol interference and a high tolerance of timing jitter. Figure 3 shows the eye pattern when the data rate is equal to twice the cutoff frequency (512kbps).

Easy, Accurate Tuning

Many commercially available monolithic filters using sampled data (switched capacitor) techniques require an external clock to set the cutoff frequency. The ratio of the internal sampling rate to filter cutoff frequency is usually fixed; the desired cutoff frequency will dictate the exact frequency of the external clock. For instance, if the sampling-rate to the filter-cutoff frequency ratio is 100:1 and the input signal is sampled at both rising and falling edges of the internal clock (this is commonly called a double-sampled filter), a 3.4kHz cutoff frequency will dictate a 170kHz external or internal clock. If the system already possesses a crystal-based master clock of several MHz, the desired clock frequency for the filter can be derived by using appropriate dividers. Clock division by conventional binary or decade counters will then provide enough resolution to fit the application. The clock generation task described above may be cumbersome but it yields stable and accurate clock frequencies. Because switched capacitor filters feature quite accurate clock-to-cutoff frequency ratios, the overall filter frequency/ phase accuracy will be superior to a that of discrete filter realization with active and/or passive components. Applications requiring narrow band filtering or strict control of the filter phase at given frequencies could justify such a complex clock-generation

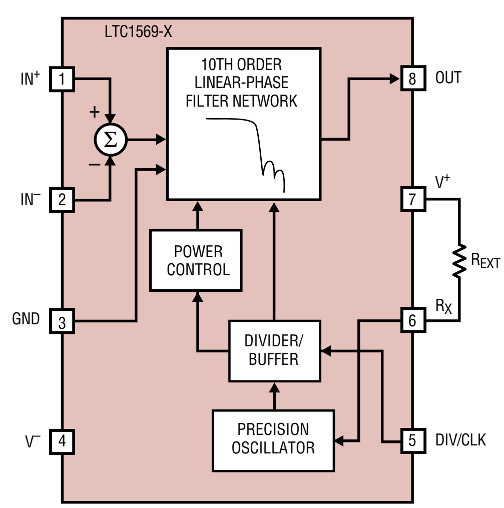

Figure 1. LTC1569-X block diagram

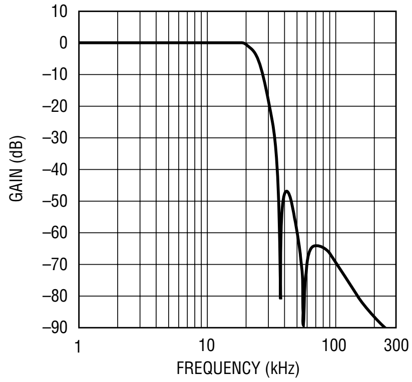

Figure 2. LTC1569-X frequency response characteristics

scheme, although many system designers strongly resist routing a "noisy" clock signal through an analog board.

Inexpensive and quite inaccurate clock generation (especially if the required clock frequency is below 1MHz) can also be realized with comparators or timers and discrete passive components. The clock frequency will show a tolerance of 5%–10%, especially if 5% discrete capacitors are used. This solution places the clock physically next to the sampled data filter, thus avoiding routing it throughout the PC board, but the wide tolerance of the clock can be objectionable.

Both clock generation methods above may fail if the required clock frequency is a few MHz and/or if the sampled data filter is intended to replace a discrete active filter design and there is no available clock in the system. In this case the clock generation becomes part of the filter design and the new clock/sampled-data-filter solution may be more complex than the existing discrete filter.

Clock Generation Made Easy

The LTC1569-6/LTC1569-7 solves the clock issues mentioned previously. An internal precision oscillator drives the sampled data filter. The frequency of the internal oscillator is set with an external resistor, which can have very low initial tolerance and can assume a large number of values. External capacitors or resistor-capacitor combinations are no longer required. The filter cutoff frequency is accurate to ±3% (for a given resistor value) for frequencies from 1kHz (LTC1569-6) to 256kHz (LTC1569-7); even higher cutoff frequencies are possible. Furthermore, the voltage across the external resistor is static, reducing EMI.

To set the cutoff frequency, place a resistor between pins 6 and 7 (Figure 4) and program the internal divider. The divider is programmed by tying pin 5 to pin 4 (divide by 1), floating pin 5 (divide by 4) or connecting pin 5 to pin 7 (divide by 16). These simple connections are illustrated in the application circuit of Figure 4, where the single-ended filter can have three different cutoff frequencies depending on the switch position: 8kHz, 32kHz or 128kHz.

By tying pin 6 to pin 4, the LTC1569-6/LTC1569-7 are placed in the external clock mode. The DIV/CLK pin becomes the input for an external clock signal and the LTC1569-6/LTC1569-7 can be tuned like traditional switched capacitor filters with a external-clock-frequency to filter-cutoff-frequency ratio of 64:1 (LTC1569-6) or 32:1 (LTC1569-7). Since the filter is double sampled, the effective oversampling ratio is 128:1

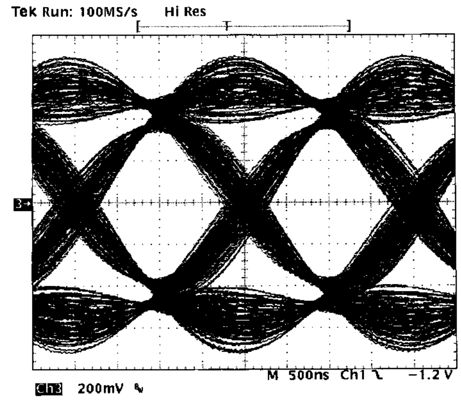

Figure 3. LTC1569-X eye diagram: data rate = 2× f_{CUTOFF} (512kbps)

(LTC1569-6) or 64:1 (LTC1569-7). External clocking is useful in applications where the cutoff frequency needs to be continuously variable or where the filter sampling needs to be synchronized to another element in the system, for example a second filter path or an A/D converter.

High Speed or Low Power

With cutoff frequencies as high as 300kHz (LTC1569-7, V_{SUPPLY} = 5V), the LTC1569-6/LTC1569-7 are the fastest switched capacitor filters on the market today, making them the ideal filtering solution for signal processing in the 200kHz to 300kHz range. Intelligent power management allows the IC to be configured for high speed or low power. For maximum cutoff frequencies, the 1569-7 typically requires 100mW when powered from a 5V supply. However, the power consumption can be reduced to as little as 8mW (LTC1569-6, V_{SUPPLY} = 3V, f_{CUTOFF} = 4kHz). In fact, there are several different power-speed combinations to choose from, allowing the user to tailor the filter to the requirements of the specific application.

Flexible Interface

Many applications require filtering a differential signal or translating the common mode voltage in a single-supply system. The flexibility of LTC1569-6/LTC1569-7's differential input solves these interfacing problems. For example, in Figure 5 the LTC1569-6/LTC1569-7 are used to pulse shape 256KB/s binary data in

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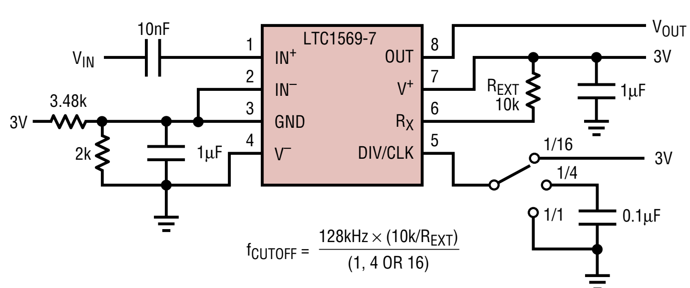

Figure 4. 3V AC-coupled, single-ended filter with multiple cutoff frequencies

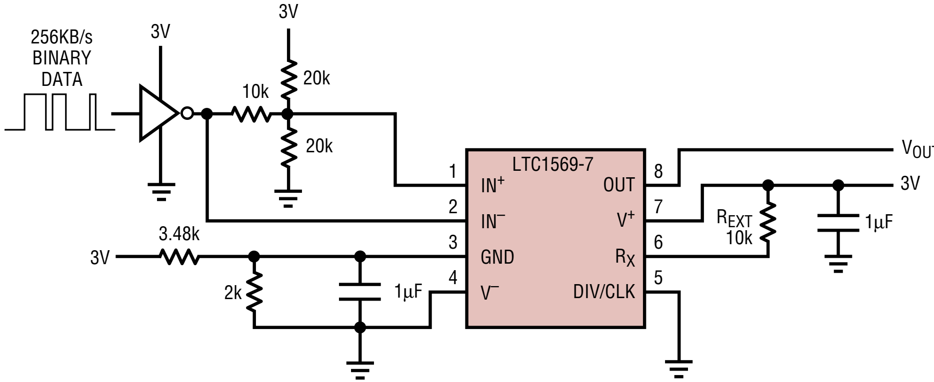

Figure 5. 3V DC-coupled, differential pulse-shaping filter

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a single-supply system. For maximum dynamic range, the GND reference for the filter is set to V+/3. The CMOS input data is attenuated by 3x, filtered and appears at the output as $1V_{P-P}$ signal centered about V+/3 .

By tying the IN^- input to GND, the LTC1569-6/LTC1569-7 accommodate single-ended AC- or DC-coupled interfaces. The signal range of each input includes the full power supply range. The output voltage range is typically (V^- + 50mV) to (V^+ – 0.8V).

DC Performance and Dynamic Range

The LTC1569-6/LTC1569-7 are well suited for systems requiring DC accuracy and dynamic range. The offset voltage is less than 5mV for 3V supplies, the DC linearity is 12 bits and the DC common mode rejection of the differential input is 80dB. Given the total integrated noise of $95\mu V_{RMS}$ (LTC1569-6), the filter has over 80dB of dynamic range for a 5V supply. For $1V_{P-P}$ signal levels, the filter has –80dB THD.

Differences Between the LTC1569-6 and the LTC1569-7

The LTC1569-6 is a lower power, lower noise version of the LTC1569-7. The LTC1569-7 is intended for systems needing the maximum bandwidth (150kHz/300kHz on a 3V/5V supply). The LTC1569-6 has twice the oversampling ratio, resulting in a 3dB reduction in the total integrated noise. The maximum sampling rate of the LTC1569-6 was reduced to realize as much as a 50% reduction in power consumption. The result is a high performance, low power filter suitable for 3V and 5V applications with cutoff frequencies up to 64kHz. All other features of the LTC1569-7 (response, accuracy, tunability) are retained in the LTC1569-6.

Conclusion

The LTC1569-X is the industry's first high performance monolithic filter with built-in precision tuning. The carefully chosen response is ideal for data communications or data acquisition in the 1kHz to 300kHz range. The small footprint, speed/power options, differential interface and 3V to ±5V operation make the LTC1569-6/LTC1569-7 an excellent solution for any lowpass filtering application.