

# Broadband Active Filters Solve Signal Processing Accuracy and Matching Problems

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With tight control of performance and a small integrated circuit form factor, broadband active filters can replace large, complicated discrete designs

Few active filters on the market offer bandwidth higher than 2 MHz. Yet today's new generation broadband communication receivers require several to tens of MHz bandwidth, requiring very good noise and distortion performance. Additionally, I/Q channel or multichannel receivers have tight matching requirements that can be extraordinarily difficult to meet. For the most part system designers must resort to discrete designs, which are bulky and consume large amounts of board space. And if a high degree of filter accuracy is required, the design challenge is simply daunting.

To address these applications, Linear Technology has introduced a broad selection of wide bandwidth active filters building blocks intended as drop-in solutions to ease the design task. These single and dual

matched filters provide integrated, highly accurate filtering capability in small footprint. This article examines various application requirements, along with design considerations to extract the most performance out of these filters.

These devices have tight tolerance on their filter response while providing exceptional dynamic range performance. They are ideal for a wide range of applications such as anti-aliasing filters for high resolution A/D converters, reconstruction filters for D/A converters in wireless communication receivers and transmitters, industrial and medical signal processing of optical and image processing filters, instrumentation and testing, RFID demodulation baseband filters, and all types of filtering in signal processing applications.

## A Versatile Broadband Active Filter Building Block

Devices in this series of filters are listed in Table 1. The LTC6601-1 contains a low noise,

Part Number	Features
LTC6601-1	Configurable 5 to 27 MHz, 2-Pole differential, low noise, 0.5% tolerance lowpass filter building block
LTC6605-7	Dual Matched 7 MHz 2-pole differential lowpass filter
LTC6605-10	Dual Matched 10 MHz 2-pole differential lowpass filter
LTC6605-14	Dual Matched 14 MHz 2-pole differential lowpass filter
LT6604-2.5	Dual Matched 2.5 MHz 4th order linear-phase lowpass filter
LT6604-5	Dual Matched 5 MHz 4th order linear-phase lowpass filter
LT6604-10	Dual Matched 10 MHz 4th order linear-phase lowpass filter
LT6604-15	Dual Matched 15 MHz 4th order linear-phase lowpass filter
LTC6602	Dual Matched 900 kHz SPI Programmable 9th order bandpass/lowpass filter
LTC6603	Dual Matched 2.5 MHz SPI Programmable 9th order linear phase lowpass filter

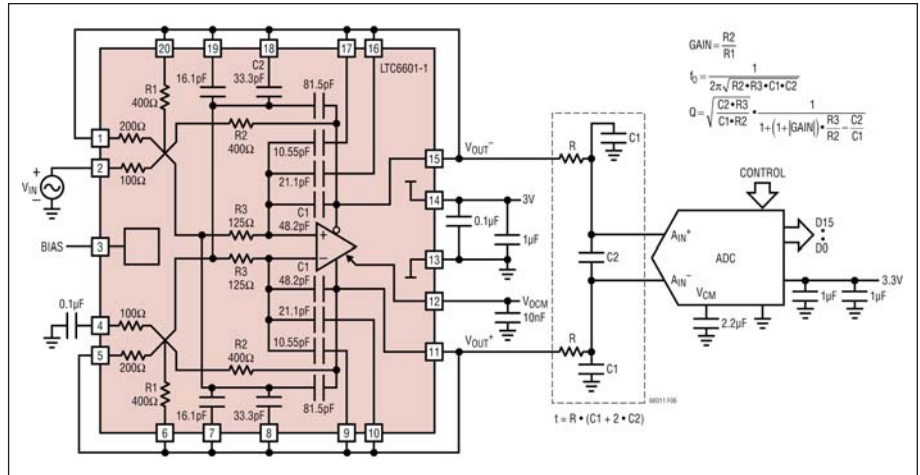
Table 1 · Features of the various devices in the LTC660x-series active filters.

wideband amplifier plus an assortment of on-chip resistors and capacitors to form a 2nd order differential input and output lowpass filter. The resistors and capacitors are available at the IC pins to allow the user to mix and match different combinations to obtain a wide range of lowpass responses from 5 to 27 MHz as well as to select filter gain. These internal resistors and capacitors are laser-trimmed at the factory to a tolerance of  $\pm 0.5\%$ . The amplifier's bandwidth is also laser trimmed. The combination provides a lowpass filter response with unparalleled accuracy that is difficult to replicate in a discrete design, ensuring excellent repeatability and saving significant board space. Figure 1 shows the filter topology by pin-strapping different resistors and capacitors to form varying filter responses. Higher order filters with precise response can be easily created by cascading multiple stages of the filter. The high precision also simplifies the task of creating matched performance in a multi-channel environment.

From the basic building block come dual matched filters with fixed bandwidth of 7, 10 and 14 MHz cut-offs, corresponding to the LTC6605-7, -10, and -14, respectively. These dual channel filters are tested and guaranteed for their matched gain and phase performance. They are intended to be drop-in, small form-factor solutions with minimum external components.

**Broadband Pre-ADC Driver/Filter Makes a Tough Application Easy**

High speed, high resolution ADC inputs are difficult to drive, owing to their inherently wide input bandwidth and their abrupt changes in input impedances resulting from the switching of the input sampling circuit. Particularly troublesome is the instantaneous current glitches generated when the input is switched from hold mode to sample mode, during which the hold capacitor sees a sud-



**Figure 1 · The LTC6601-1 2nd order differential filter topology. Both bandwidth and gain are pin-configurable by pin-strapping the appropriate internal resistors and capacitors based on the equations provided.**

den change in voltage. The filter output amplifier can source or sink more than 20 mA load current and is short-circuit protected at  $\pm 65$  mA current limiting. This combines with the device's high amplifier gain-bandwidth helps to provide low impedance drive to absorb the current glitches inherent in many high speed ADCs with minimum disturbance. Moreover, the LTC6601-1 output stage is a rail-to-rail design that can drive  $\pm 1V_{p-p}$  differential into an external 50 ohm load.

Figure 1 also shows the filter driving differentially into an ADC. It is a good idea to add a RC network to decouple the LTC6601-1 filter outputs from the ADC inputs. The shunt capacitors provide the bulk of the transient charge during ADC sampling, while the series resistors provide attenuation and decoupling of the transient noise. The value of the R1 and C1 depend on the bandwidth of the signal and the desired noise band-limiting. A good starting point is a 25 ohm series resistance. Too high a resistance could unnecessarily lengthen settling time and increase attenuation through the dynamic input resistance of the ADC. Too little resistance may not provide sufficient damping. Then the RC filter pole

should be chosen to be higher than the LTC6601-1 filter corner so that it does not significantly alter the phase shift and attenuation to the desired filter response. At the same time, the RC pole should be low enough to provide some broadband noise roll-off. A good rule of thumb is to set the RC pole 3 to 4 times higher than the desired filter corner.

In Figure 1, the LTC6601-1 is DC coupled to the ADC. The DC common-mode voltage must satisfy both the filter and the ADC. The LTC6601-1's output common-mode rejection ratio is fairly robust at 70 dB, but the ADC's input common-mode range is more limited and its conversion performance depends on a relatively narrow common-mode voltage range. So the ADC's input common-mode of 1.250V at the  $V_{CM}$  pin is used to drive the LTC6601-1's output common-mode pin (pin 12) which has relatively high impedance.

On the input side, the LTC6601-1 has a balanced differential arrangement. But it can be driven from a single-ended source if desired. To do so, one side of the differential input should be AC-grounded as shown in Figure 1. Then the other differential input can be driven with a single-ended source.

LPF1	LPF0	Divider Ratio	Lowpass BW (kHz)	HPF1	HPF0	Divider Ratio	Highpass BW (kHz)
0	0	1/600	150	0	0	1/6000	15
0	1	1/300	300	0	1	1/2000	45
1	0	1/100	900	1	0	1/1000	90
1	1	1/100	900	1	1	—	Bypass HPF

Table 2 · LTC6602 cutoff frequency control,  $R_{BIAS} = 54.9\text{ k}$ ,  $f_{CLK} = 90\text{ MHz}$ .

LPF1	LPF0	Divider Ratio	Lowpass BW (kHz)
0	0	1/512	156.25
0	1	1/128	625
1	0	1/32	2500
1	1	1/32	2500

Table 3 · LTC6603 cutoff frequency control,  $R_{BIAS} = 30.9\text{ k}$ ,  $f_{CLK} = 80\text{ MHz}$ .

### Dual Broadband Filters Have Matched Performance To 15 MHz

The LT6604 family of dual broadband filters is designed to provide tight matching of phase and amplitude performance over its rated frequency bandwidth. The family is available in fixed 2.5, 5, 10 and 15 MHz cutoff bandwidths. Their responses have a 4th order approximate Chebyshev roll-off skirt while maintaining a tight 0.6 dB gain flatness in the passband up to the specified cutoff frequencies. They are designed for today's new generation of advanced communications receivers, instrumentation, and signal process-

ing equipment requiring exacting multichannel filtering and matching characteristics.

Configured as single supply (3V and 5V) differential input and output filters, the LT6604 family can also operate single-ended inputs, and can be powered from  $\pm 5\text{V}$  supplies. The designers can set their filter gain using two external resistors without altering the filters' frequency response.

The LT6604 filters have an internally biased output DC common-mode voltage that is one-half of the supply voltage which automatically biases the part regardless of the sup-

ply voltage used. But when driving into an A/D converter that has an input bias voltage other than the mid-supply, it is best to override the filter's internal common-mode voltage with the ADC's so the interface is seamless—as long as the driving source impedance is low ( $<100\Omega$ ).

### Higher Order Software Programmable Filters Offer System Flexibility

LTC6602 and LTC6603 are dual, matched filters with software programmability which enhances system flexibility. Both filters are 9th order designs. The LTC6602 combines a 5th order lowpass cascaded with a 4th order highpass to form a bandpass response. The highpass filter can be bypassed under software control, providing a lowpass-only function. Maximum operating frequency is 900 kHz, suitable for RFID readers and lower frequency communications receiver uses. In contrast, the LTC6603 has higher bandwidth with maximum cutoff up to 2.5 MHz. It is a true 9th order lowpass filter. So its roll-off skirt is significantly sharper, providing more than 45 dB rejection at one octave above the corner frequency. Figure 2 shows the filter characteristics of the two filters.

Both the LTC6602 and LTC6603 are switched capacitor designs. Each has an internal oscillator whose frequency is set by an external bias resistor. Once set, this free-running oscillation frequency is used to divide down to one of three software-settable filter cutoff frequencies for each the highpass and lowpass sections,

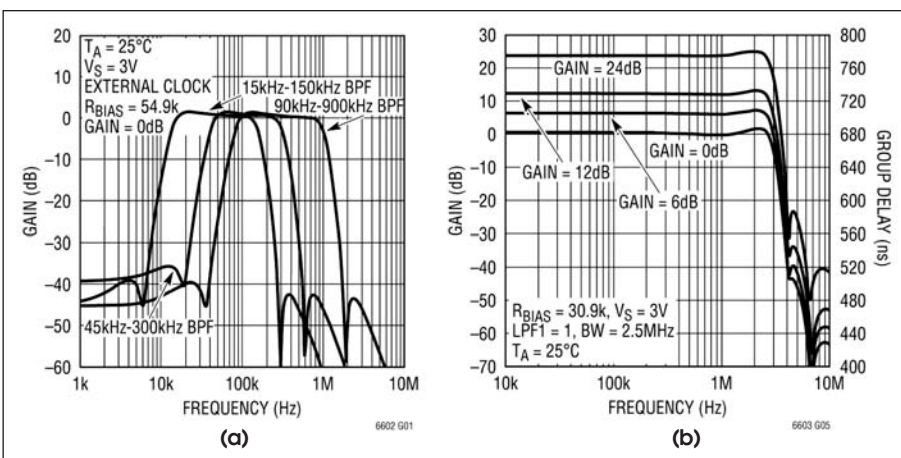
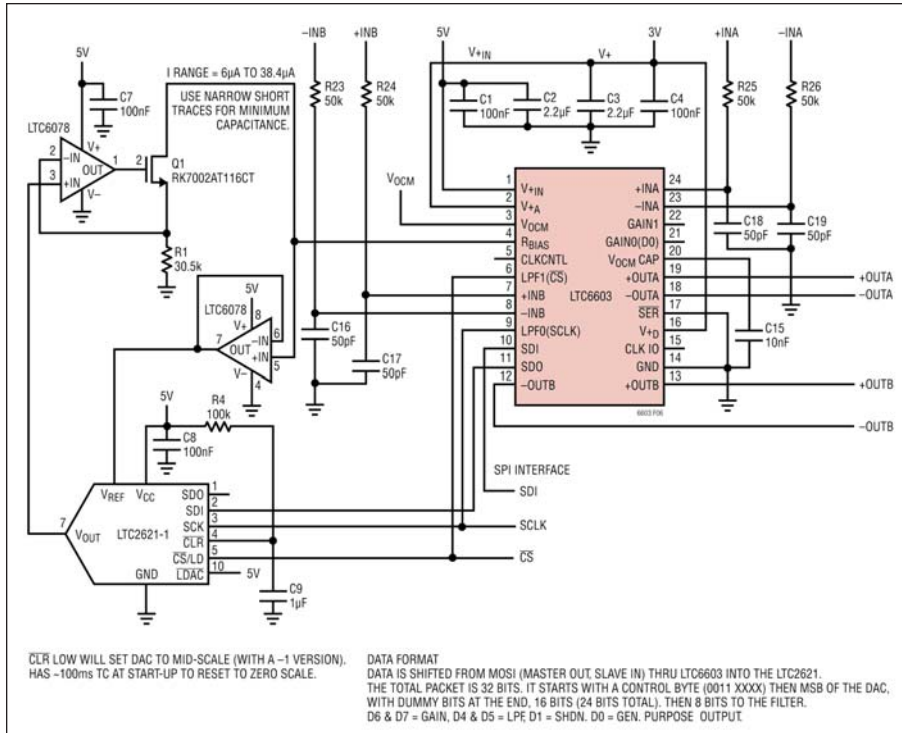


Figure 2 · (a) The left-hand plot shows the LTC6602 frequency response that can be controlled by the SPI bus. (b) The right-hand plot shows LTC6603 frequency response steps using the SPI interface.



**Figure 3** · An 8-bit D/A converter provides versatile programmability of the filter bandwidth.

where each section is controlled by a 2-bit (four discrete states), user-settable register accessible via a SPI serial bus. Table 2 and Table 3 show the LTC6602 and LTC6603 bandwidth mapping, respectively, the filter divider ratios at each filter state, and the corresponding filter cutoff frequencies.

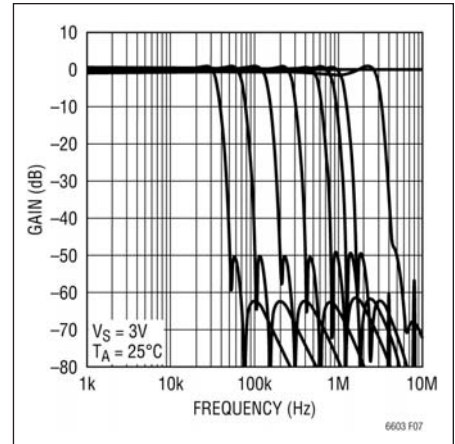
This method provides a fairly coarse but predictable control of the frequency resolution. If finer frequency control is needed, an external clock can be applied to override the internal one. The  $f_{CLK}$  can vary within a range of 25 to 90 MHz. Combined with the SPI control, one can easily place the filter corner or its notch at a precise determined location.

Users can also implement an alternative digital control with fine frequency increments over 2 decades range with an 8-bit DAC as shown in Figure 3. The figure shows a serial input 8-bit DAC, the LTC2621-1 which powers up and resets to one-half of the  $V_{REF}$  voltage, biasing the

DAC output conveniently within the linear region of the subsequent amplifier stage. The LTC6603's internal  $R_{BIAS}$  DC voltage is buffered by one-half of the LTC6078 dual op amp that sets the DAC's  $V_{REF}$ . In turn, the DAC's output voltage drives a voltage-to-current converter formed by the other half of the LTC6078 driving an output FET in a feedback loop. This way, the DAC meters the current precisely into the LTC6603  $R_{BIAS}$  pin, and hence the filter cutoff frequency. Figure 4 shows the frequency response range under DAC control. This implementation provides nearly 2 decades of filter bandwidth control ranging from 30 kHz to 2.5 MHz.

### Conclusion

The new family of broadband filters provides a higher level of programmability, versatility, accuracy and matching performance to a wide range of wireless communications equipment, industrial signal process-



**Figure 4** · The DAC provides nearly 2 decades of filter bandwidth control for the LTC6603, in 1/256 increments.

ing, high performance instrumentation, and many other signal processing systems.

### References

1. LTC6601-1 datasheet, available at: <http://www.linear.com>
2. LTC6602 datasheet, available at: <http://www.linear.com>
3. LTC6603 datasheet, available at: <http://www.linear.com>

### Author Information

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