DESIGN NOTES

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Switched-Capacitor Low Pass Filters for Anti-Aliasing Applications

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INTRODUCTION

Many signal processing applications require a front end low pass filter to bandwidth limit the signal of interest. This filter is often crucial to the system designer since it determines the number of bits which the system can resolve by its noise and dynamic range. Until now, the designer rejected the use of switched-capacitor filters as being too noisy, having too much distortion, or because they were not usable at a high enough frequency. The LTC1064-1 8th order Cauer filter can compete directly with the discrete operational amplifier design. Not only that, but the cost and performance advantages are tremendous.

The LTC1064-1 is a complete 8th order, clock tunable Cauer (also known as elliptic) low pass switched-capacitor filter *with internal thin film resistors*. The passband ripple is ±0.1dB and the stopband attenuation at 1.5 times the cutoff frequency is 72dB. The device is available in a 14-pin DIP or 16-pin surface mount package.

The LTC1064-1 boasts internal thin film resistors factory adjusted to optimize the Cauer 8th order response. The LTC1064-1 attains wideband noise (2kHz–102kHz) of $150\mu V_{RMS}$ and a total harmonic distortion of 0.03% for $V_{IN} = 3V_{RMS}$. No external components are required for cutoff frequencies up to 20kHz. For cutoff frequencies over 20kHz two small value capacitors are required to maintain passband flatness.

By way of comparison, older switched-capacitor filters had noise in the millivolts, THD in the percents, and maximum corner frequencies limited to <20kHz.

This note compares the performance of the LTC1064-1 8th order Cauer filter with internal thin film resistors to that of the equivalent filter built with operational amplifiers. The LTC1064-1 quad switched-capacitor filter competes favorably with op amp RC designs in most parameters of interest to the designer and wins easily when printed circuit board space is considered. *Since it is tunable*, the LTC1064-1 can replace not just one, but many op amp RC designs, if multi-frequency filtering is required. The specification comparisons become even more favorable to the LTC1064-1 as the frequencies become higher.

COMPARING THE LTC1064-1 WITH RC ACTIVE FILTERS UTILIZING OPERATIONAL AMPLIFIERS

Performance

The Cauer filter has target design specifications as follows: a cutoff frequency of 40kHz, ±0.05dB passband ripple and a −72dB attenuation at 1.5 times the cutoff frequency. This filter is realized with stopband notches and it is considered a quite complex and selective filter realization. Figure 1 details the frequency response of this design.

An 8th order active RC was designed using a fully inverting state variable topology. This topology is considered "state-of-the-art" for active filters since all non-inverting inputs of the op amps are grounded. The discrete active RC version of the Cauer filter is quite complex requiring 16 op amps, 31 resistors and 8 capacitors. The op amps used for this comparison were TL084 quad FET input amplifiers. The circuit topology was optimized to yield the maximum useful input voltage swing.

Test Results

Figure 1 shows the frequency response of the LTC1064-1 connected as shown in Figure 3. The shape of the frequency response of the active RC state variable filter was very similar and its differences cannot

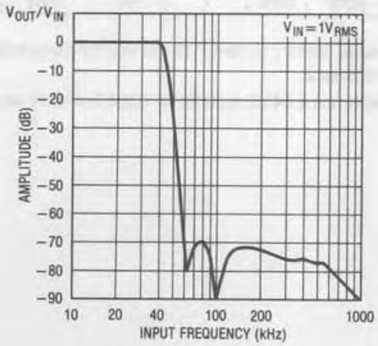

Figure 1. LTC1064-1 Frequency Response

be easily shown here. Figure 2, curve (a), details the TL084 state variable filter response near the 40kHz cutoff frequency. Laboratory "tweaking" of resistor values could not produce any better response than shown here. This is a passband ripple of approximately

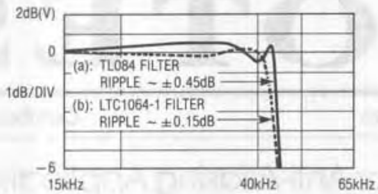

Figure 2. Passband Ripple

±0.45dB. For comparison, the LTC1064-1 passband ripple is ±0.15dB as shown in Figure 2, curve (b). This is for a clock to center frequency ratio of 100:1, or a 4MHz clock. The measured filter amplitude response at 1.5 times the cutoff frequency for the TL084 active RC filter was about −65dB while that of the LTC1064-1 was −68dB. The noise for the TL084 state variable implementation was $111\mu V_{RMS}$ while that for the LTC1064-1 was $145\mu V_{RMS}$. Second harmonic distortion measurements were also made on both filters and they are included on the summary chart, Table 1.

Table 1 compares the LTC1064-1, the switched capacitor implementation of the 8th order Cauer low pass filter, to the active RC. Both circuits operate with dual ±7.5V supplies or a single 15V supply.

System Considerations

Not only does the LTC1064-1 compare favorably on individual specifications, but it wins easily when system considerations are evaluated. Suppose four sharp cutoff frequencies are needed. The closest active RC solution is a 7th order single cutoff frequency Cauer filter. Four of these non-tunable devices (each a 2″ × 3″ hybrid) would be required for the four cutoff frequencies. This would be 24 square inches of PC board space. The discrete approach using operational amplifiers requires even more space. Since the LTC1064-1 is tunable, four frequencies can be selected merely by tuning the clock to the LTC1064-1. A complete LTC1064-1 system with tunable clock is estimated to occupy only 4 square inches of board space. This is a whopping savings of 6 times in board area. The LTC1064-1 wins easily in this category.

SUMMARY

In summary it can be seen from Table 1 that the LTC1064-1 is the equal of the active RC filter. In the pure specification battle there is no clear winner, but when the amazing difference in hardware complexity, the full clock tunability and the simple method of application of the LTC1064-1 device are all considered it is the sure winner.

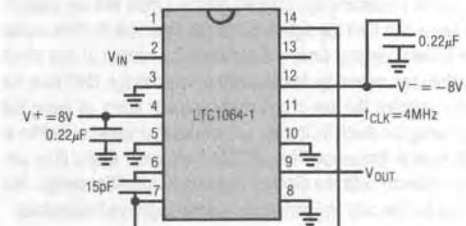

Figure 3. The LTC1064-1, Monolithic 8th Order Cauer Low Pass Filter Operating with a 4MHz Clock and Providing a 40kHz Cutoff Frequency

Table 1. 8th Order Cauer (Elliptic) LPF with a 40kHz Ripple Bandwidth

	# EXT OP AMPS	# EXT R's, 1%	# EXT CAPS, 5%	TUNABLE	WIDEBAND NOISE, RMS[4]	DISTORTION $V_{IN} = 1V_{RMS}, 3V_{RMS}$ (dB)	V_{OS} OUT (mV)[3]	I_{SUPPLY} (mA)	ATTENUATION AT 60kHz	MEASURED PASSBAND RIPPLE	TRIMMING[2]
RC Active TL084	16	31	8	No	111µV	−87, −87	55	33	65dB	±0.45dB	Yes
LTC1064-1	None[1]	None	1	Yes	145µV	−70, −70	30	18	68dB	±0.15dB	None

Note 1: An output inverting buffer (LT118) was used for driving cables during measurements.

Note 2: To obtain the ±0.45dB ripple for the TL084, 3 resistors were trimmed.

Note 3: The output offset voltage numbers are as measured by DVM with the input of the filter grounded.

Note 4: Measurement BW (2kHz-102kHz).

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