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APPLICATION NOTE 29

Multipurpose Filter Network Combines Anti-Aliasing and Sinc Compensation

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Abstract: In this application note a circuit with two switched-capacitor filters reconstructs the output of a digital-to-analog converter (DAC) while providing anti-aliasing and sinc-compensation functions. Filter IC prevents alias frequencies by excluding spectral energy above fs/2. The MAX265 filter is featured.

The dual-biquad filter chips and some external components (**Figure 1**) form a multipurpose filter for the reconstruction of D/A converter signals. Connected to a converter's output (**Figure 2**), the filter aids in generating the analog signal represented by digital-data samples at the converter's input. In addition, the filter provides anti-aliasing, (sinπx)/πx (sinc) compensation, and reduction of the D/A converter's quantization noise.

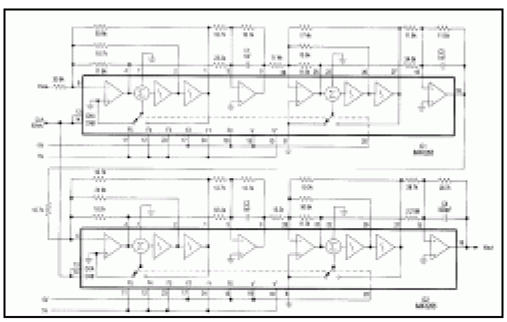

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Figure 1. Configured as shown, two filter ICs reconstruct the output of D/A converter while providing antialiasing and sinc-compensation functions.

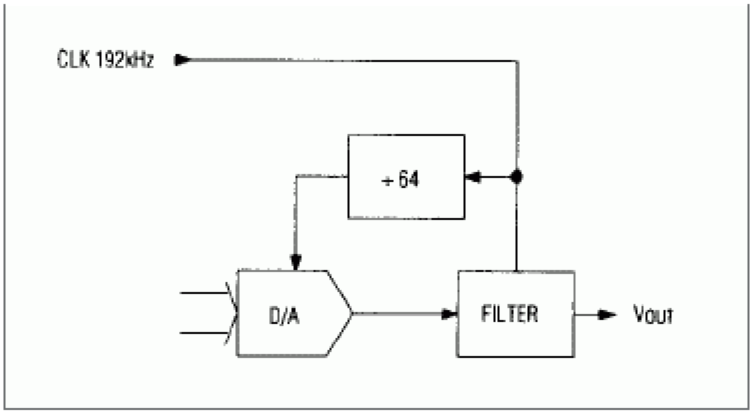

Figure 2. In a suggested application for the Figure 1 circuit, the applied clock signal and single-chip divider set the desired sample rate for the D/A converter.

At, DC, a D/A converter's output is easily predicted from it's data sheet specs. Time-varying signals, however, produce staircase-output waveforms whose reconstruction errors are best discussed in the frequency domain. The converter's output spectrum, for example, consists of spectra ($\pm f_1$, where f_1 is the spectrum represented by the digital input samples) that repeat at integral multiples of the sample rate f_S (**Figure 3**).

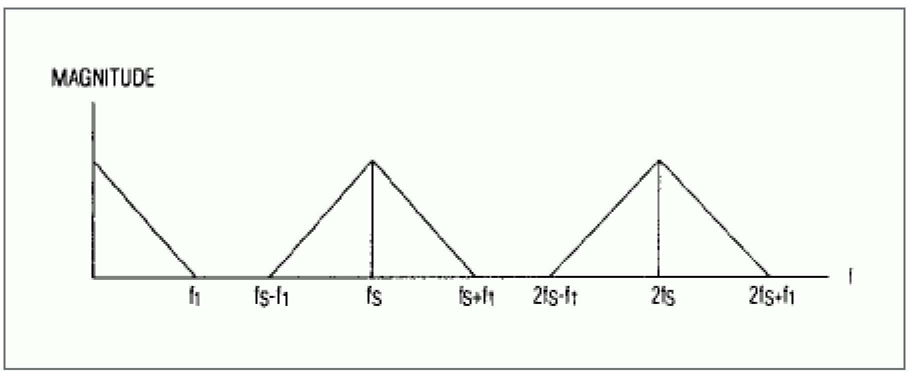

Figure 3. Figure 2's digital-input spectrum F_1 combines with the D/A converter's sampling rate f_S as shown, producing a $\pm f_1$ spectrum that repeats at integral multiples of f_S.

The filter's first job is to prevent alias frequencies by excluding spectral energy above $f_S/2$. In practice, $f_1 < f_S/2$. The filter should pass f_1 with an acceptably low error while sufficiently attenuating all frequencies above $f_S/2$.

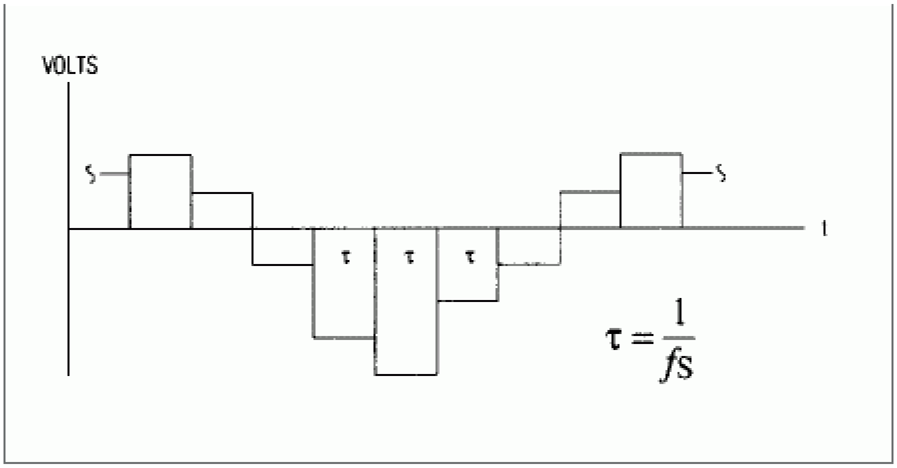

Figure 4. Before filtering, the D/A converter's output signal is a staircase waveform that can be regarded as a sequense of rectangular pulses.

A second filter requirement stems from the presence of sinc attenuation, introduced by the effect of rectangular-pulse components in the staircase waveform (**Figure 4**). These pulses have the same $1/f_S$ width, but differ in amplitude according to the digital-sample magnitudes. The spectrum of each pulse is the Fourier transform (the sinc function of f/f_S). These spectra combine with the f_1 spectrum to form an overall frequency response for the converter output. Note the sinc expression's variation in amplitude for various values of f:

Table 1.

f	$[(\sin)(\pi f/f_S]/(\pi f/f_S)$
0	1.0
$f_S/4$	0.9003 (-0.9dB)
$f_S/3$	0.8270 (-1.65dB)
$f_S/2$	0.6366 (-3.92dB)

Clearly, the staircase approximation causes an increase amplitude error as f approaches the Nyquist frequency $f_S/2$. To compensate for this attenuation, the Figure 1 circuit incorporates the inverse expression $(\pi f/f_S)/\sin(\pi f/f_S)$ in it's passband-magnitude response.

Ideally, the resulting filter response would provide sinc compensation to $f_S/2$, drop abruptly to zero, and maintain that infinite attenuation for all frequencies above $f_S/2$. But actual filters cannot provide abrupt transitions or infinite attenuation. As a practical compromise, the circuit makes its transition over a finite bandwidth (transition ratio), and then provides an out-of-band rejection comparable to the D/A converter's signal-to-noise ratio SNR.

SNR for an ideal D/A converter is about 6dB/bit, or 72dB for a 12-bit device. Quantization error further degrades this number, yielding about 68dB for a typical 12-bit converter. Thus a reasonable goal in Figure 1 is 70dB rejection above $f_S/2$.

To prevent aliasing, the stopband edge must be no greater than the Nyquist frequency ($f_S/2$). The passband edge must threrfore be less than $f_S/2$. To achieve 70dB stopband rejection in the 8th-order circuit of Figure 1, the required transition ratio ($f_{Stopband}/f_{Passband}$) is 1.5, which sets the passband edge at $f_S/3$. A rising amplitude response within this passband compensates for the converter's sinc attenuation.

Perfect sinc compensation would provide 1.65dB of gain at the Nyquist frequency, but tolerance uncertainties in the ±1% resistors and within the filter ICs limits the actual correction to about 1dB. The circuit does, however, achieve the 70dB stopband rejection and the 1.5 transition ratio. **Figure 5** compares the Figure 1 response with that of an ideal filter.

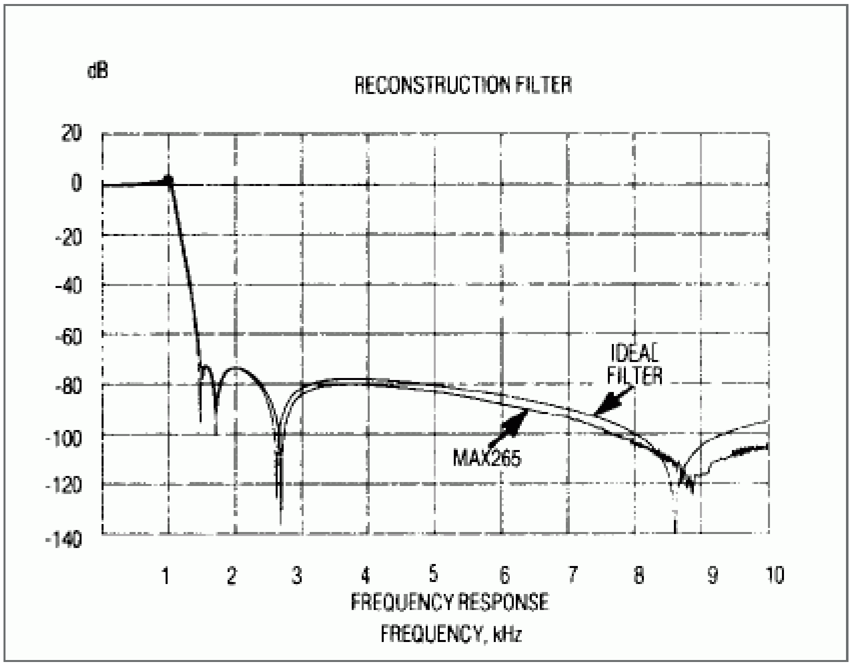

Figure 5. The circuit response of Figure 1 compares well with that of an ideal filter.

To assure maximum dynamic range, the four biquad-filter sections (two in each IC) exhibit increasing Q from input to output, The pole-zero pairs of each section also axhibit increasing frequency, which minimizes the spread in component values. The following pole and zero values produce a 1-rad/sec filter passband:

Table 2.

Section	f_{pole} (Hz)	Q_{pole}	f_{Zero}(Hz)
1	0.1005	0.5603	0.2397
2	0.1310	1.0540	0.2777
3	0.1564	2.3876	0.4273
4	0.1685	8.5145	1.4016

Note the feedback capacitors C1-C4 across each output op amp. These capacitors have two purposes; they improve the quality of transmission zeroes, and the form 1-pole lowpass filters that help to smooth out the discrete-level steps introduced by the filter's switched-capacitor action. The 1-pole filters have little effect on the passband shape because their high corner frequencies introduce only 0.1dB of loss at 1kHz.

Note also, that the applied clock frequency in Figure 2 (192kHz) allows use of a convenient binary-64 divider for setting the necessary 3X ratio betweeen the converter's sample rate and the filter's 1kHz corner frequency, f_0. Each chip is programmed for an f_{CLK}/f_0 ratio of 191.64 by V+ and V- connections to the filter inputs, F0-F5.

Related Parts		
MAX265	Resistor-Pin-Programmable, Universal Switched Capacitor Filter	Free Samples

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