The C-message filter, which simulates the frequency response of the human ear, is a commonly specified test and measurement filter for voice, audio, and telecommunication applications in the U.S. In Europe, a close relative is a psophometric noise-weighting filter. You can construct either type by cascading three 2nd-order bandpass sections with a 2nd-order lowpass section. The C-message filter, for example, is shown in Figure 1.

Dual universal, 2nd-order IC filters provide a compact and efficient means for implementing the circuit of Figure 1. If the IC filters are programmable, switched-capacitor types as shown, you can rapidly implement a C-message, psophometric, or other test filters on demand simply by loading the chips with different sets of coefficients. These coefficients set each 2nd-order section's filter mode, Q, and cutoff or center frequency $f_0$. The C-message filter has poles only, which are specified by the IEEE Standard 743-1984:

<table>
<thead>
<tr>
<th>Pole</th>
<th>Value in rad/sec</th>
<th>Value in Hz ($f_0$)</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP#1</td>
<td>-1502 j1267</td>
<td>312.741</td>
<td>0.6540</td>
</tr>
<tr>
<td>BP#2</td>
<td>-2439 j5336</td>
<td>933.761</td>
<td>1.2027</td>
</tr>
<tr>
<td>BP#3</td>
<td>-4690 j15267</td>
<td>2541.886</td>
<td>1.7026</td>
</tr>
<tr>
<td>LP#1</td>
<td>-4017 j21575</td>
<td>3492.778</td>
<td>2.7316</td>
</tr>
</tbody>
</table>

Figure 2 shows the external connections that configure two filter ICs in the architecture of Figure 1, along with a table of decimal equivalents for the digital coefficients associated with each filter section. These 2nd-order sections establish pole locations in accordance with the $f_0$ values listed. Each section contains two continuous-time Chebyshev filters whose center frequency can be digitally programmed in 128 steps over the range 1 to 25kHz. Passband ripple is 0.1dB. For maximum signal-to-noise ratio, the signal amplitude at
Signal swings are as follows: If you apply 4V to input INA on IC1, output BP_A swings 2.7V, output BP_B swings 1.85V, output BP_A of IC2 swings 1.6V, and the lowpass output (LP_A of IC2) swings 3.2V. IC2 operates in mode 4 instead of mode 1, which provides a gain of 2 instead of 1 for the LP and BP outputs (see data sheet).

You must bandlimit the filter's input signal to \( f_{CLK}/4 \) or less, where (in this case) \( f_{CLK} = 38.4\,kHz \). The uncommitted op amp in IC1 can provide second- or 3rd-order lowpass filter for this purpose. The uncommitted op amp in IC2 can provide a similar lowpass filter for smoothing the output signal.

As an alternative, you can realize the C-message function using one filter IC and an external op amp (Figure 3). This approach lacks flexibility, however. You can no longer switch to other filter functions by electrically reprogramming the circuit.

This circuit realizes the first bandpass (BP#1) in terms of external resistors and capacitors around the uncommitted opamp of IC1. BP#1, which also serves as an antialiasing filter for the sampling action of IC1, is an infinite-gain, multiple-feedback bandpass filter with \( f_0 = 312.74\,Hz \), \( Q = 0.654 \), and gain = 0.654. Design procedures for this configuration are available in the literature.

IC2 implements BP#2 and BP#3 with the same gain and signal levels as in Figure 1. The external op amp with resistors and capacitors implements LP#1, which also serves as the output smoothing filter. Like BP#1 you can design LP#1 as an infinite-gain, multiple-feedback circuit with \( f_0 = 3492.778\,Hz \), \( Q = 2.7316 \), and gain = 2.

The 125kHz clock frequency is arbitrary; other values require that you program IC1 for a different \( f_{CLK}/f_0 \) ratio.
Figure 4. Circuits in Figure 1 and Figure 2 produce the same frequency response.

In both filter circuits (Figure 1 and Figure 2) the coefficients for $f_{0A}$, $f_{0B}$, $Q_A$, $Q_B$ were calculated by software available from Maxim (see data sheet). Figure 4 shows the filter transfer function for either realization.

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