

APPLICATION NOTE 1941

Third-Order Highpass Filter Has Synthetic Inductor

Inductors have a bad reputation as filter components. They not only transmit EMI, but they act as antennas for receiving EMI as well. To avoid these problems, you can simulate the impedance of an inductor with the combination of two wideband transconductance amplifiers (WTAs) and a capacitor (Figure 1). The circuit acts as a synthetic inductor (L_{SYN}) with one end connected to ground.

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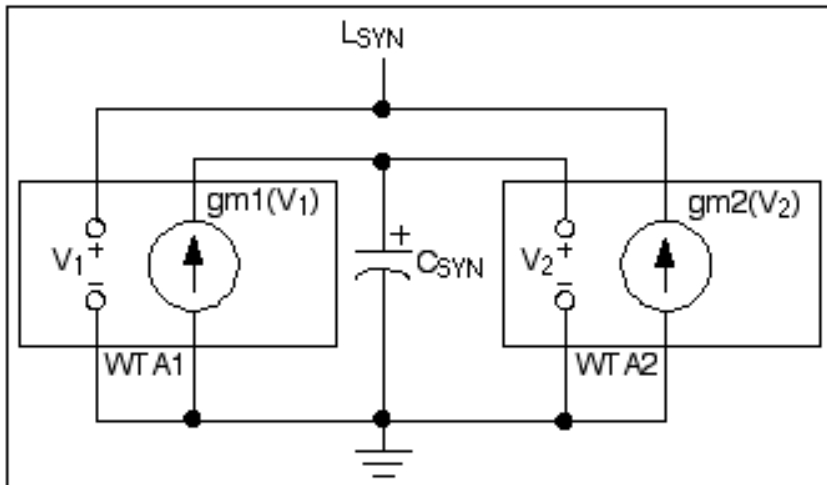


Figure 1. This single-port network simulates an inductor with two wideband transconductance amplifiers and a capacitor.

By forcing a current at L_{SYN} and measuring the resulting voltage, you can determine the equivalent impedance Z_{EQ}:

$$Z_{EQ} = \frac{sC}{(gm1)(gm2)},$$

where gm = transconductance.

The equivalent inductance, therefore, is:

$$L_{EQ} = \frac{C}{(gm1)(gm2)}.$$

This single-port network clearly offers the frequency-proportional impedance of an inductor, along with an advantage and a limitation: The inductance value can be large if (gm1)(gm2) << 1, but one end of the network must always connect to ground. Highpass, all-pole ladder filters make good applications, because all their inductors connect to ground. Two WTAs and a capacitor must be substituted for each one, so you should choose a configuration with the minimum number of inductors.

To be cost-effective, your design should feature a series capacitor at each end of the filter, with the simulated inductor acting as a shunt between them (Figure 2). The input capacitor blocks any DC applied to the filter, and the output capacitor blocks any DC offset introduced by the synthetic inductor. Though constructed with active components, the filter thus retains some of the advantages of a passive filter.

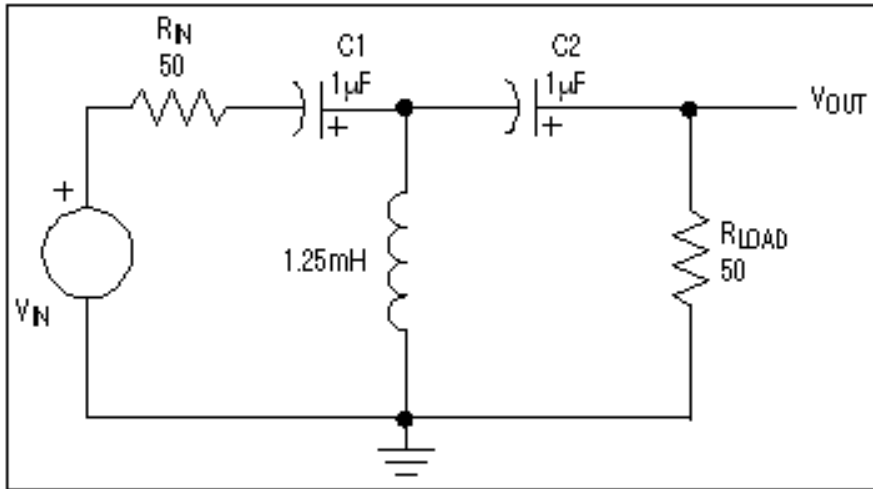


Figure 2. This simple ladder filter is a good application for the simulated inductor, which must have one end connected to ground.

In an actual circuit (Figure 3), C2 and C3 are bypass capacitors and C2 is part of the simulated inductor. The transconductance for each WTA is set by an external resistor (R1 or R3) according to the relationship $g_m = 8/R$. Because the simulated inductance depends on the product of these transconductances, it may appear that you have a range of choices for each. However, the optimum circuit for a given application allows the full range of output swing for each WTA, which restricts the g_m values.

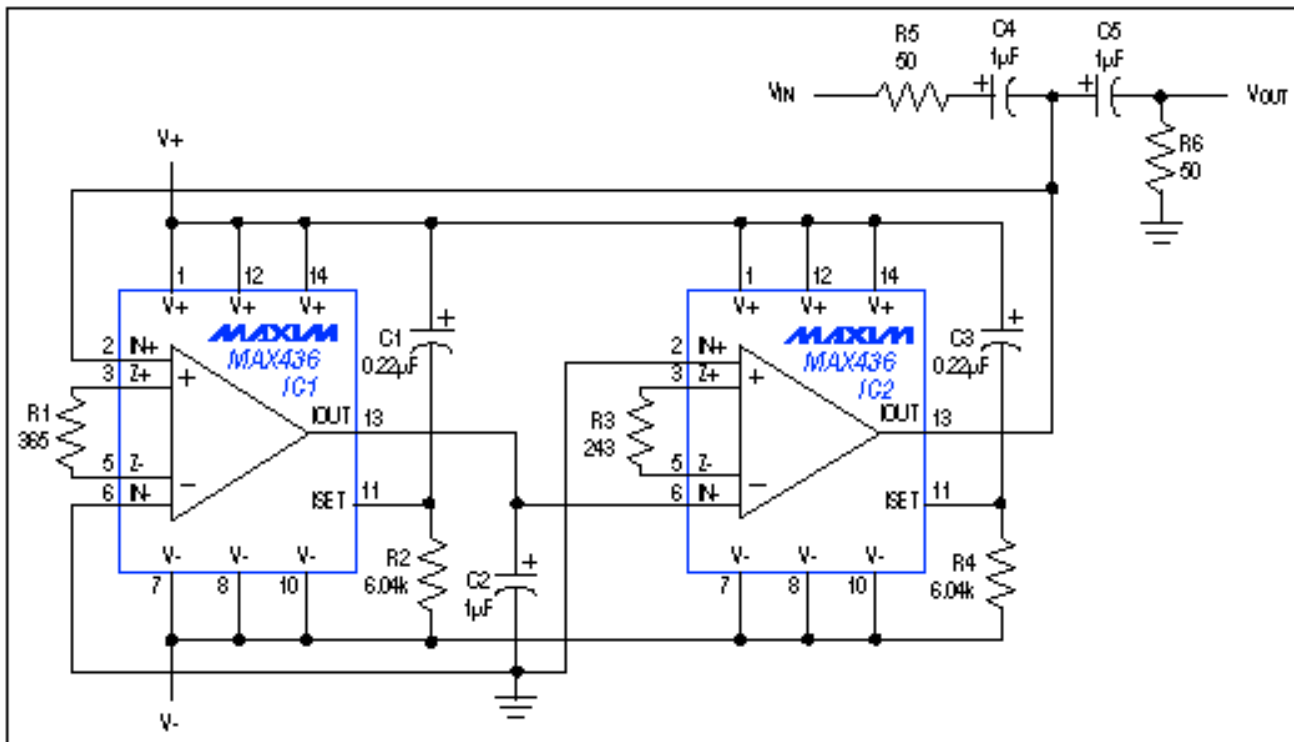


Figure 3. A 3rd-order Butterworth highpass filter is constructed by substituting the simulated inductor of Figure 1 in the

ladder filter of Figure 2. The filter has a 3.2kHz corner frequency and a -6dB loss due to the source and load impedances.

To determine these optimal gm values, start with equal transconductances and simulate the filter in SPICE using "g" elements for the amplifiers. While sweeping the frequency at least one decade above and below the filter's corner frequency, observe each WTA output for its peak voltage magnitude (the two peaks can occur at different frequencies).

At the synthetic inductor's port (pin 13 of IC2), the peak value is demanded by the filter and cannot be changed; a real inductor would produce the same peak. You therefore adjust the other peak to match. Let K equal the ratio of gm2 to gm1. Gain is proportional to transconductance, so you divide gm1 by K and multiply gm2 by K. Finally, rerun the SPICE simulation with these new gm values to verify that the peaks are equal and that the filter shape has not changed.

The filter exhibits a maximum attenuation of 58.6dB/decade (Figure 4). The slope decreases at a lower frequency, because the synthetic inductor's Q is affected by its series resistance. (Comparable 1.25mH inductors also have an appreciable resistance of 53Ω or so.) At 10Hz, for instance, the attenuation for an ideal filter is -90dB. For this circuit, the attenuation is -80dB.

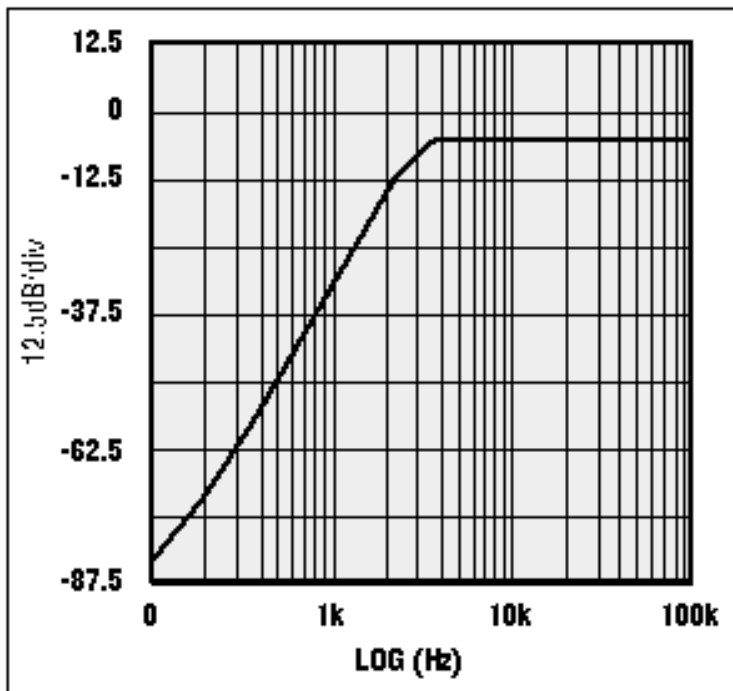


Figure 4. The Figure 3 filter has a maximum attenuation of 58.6dB per decade.

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More Information

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