Application Report
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An Adaptable, Low Loss, Selective Filter And Gain Topology With Low Sensitivity To External Components

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ABSTRACT

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1 Introduction

Single supply electronics often require low current consumption in the few hundred picoamperes during shutdown mode. For example, battery operated ultrasonic gas flow meters also require amplifying a received signal of 200kHz by at least 20dB (in an acoustic path of length 40mm). In addition to gain, the filter must select only the frequency of the signal in interest to obtain the maximum possible accuracy and precision in time-of-flight measurements in presence of a noisy environment. TI's LMV881 23MHz low power CMOS EMI hardened operational amplifier with logic shutdown, 12 V/µs slew rate at 3.6V supply, input noise voltage of 5nV/√Hz at 200kHz, and rail-to-rail output voltage swing compliments the TDC1000-GASEVM for gas flow applications. The gain requirement at a transducer's resonant frequency becomes stringent when the acoustic path increases in a flow meter system architecture and amplifier GBW is fixed. The maximum possible selectivity factor of the filter suffers and so a trade-off with gain is unavoidable. Although a cascaded filter may provide the benefit of a high-order filter, factors such as pole-zero pairing, cascading sequence, and gain distribution require consideration or else the cascaded circuit will operate with intolerable specification errors. The Åckerberg-Mossberg topology is an alternative solution that provides the benefit of independently tuning the frequency of interest, the selectivity factor, an arbitrary notch, and the gain in the passband and stopband while being relatively insensitive to passive and active component tolerances compared to other 2^{nd} order filters. This provides the designer with the greatest flexibility to fine tune a filter for a specific ultrasonic transducer resonant frequency and acoustic distance.

2 The Åckerberg-Mossberg Topology

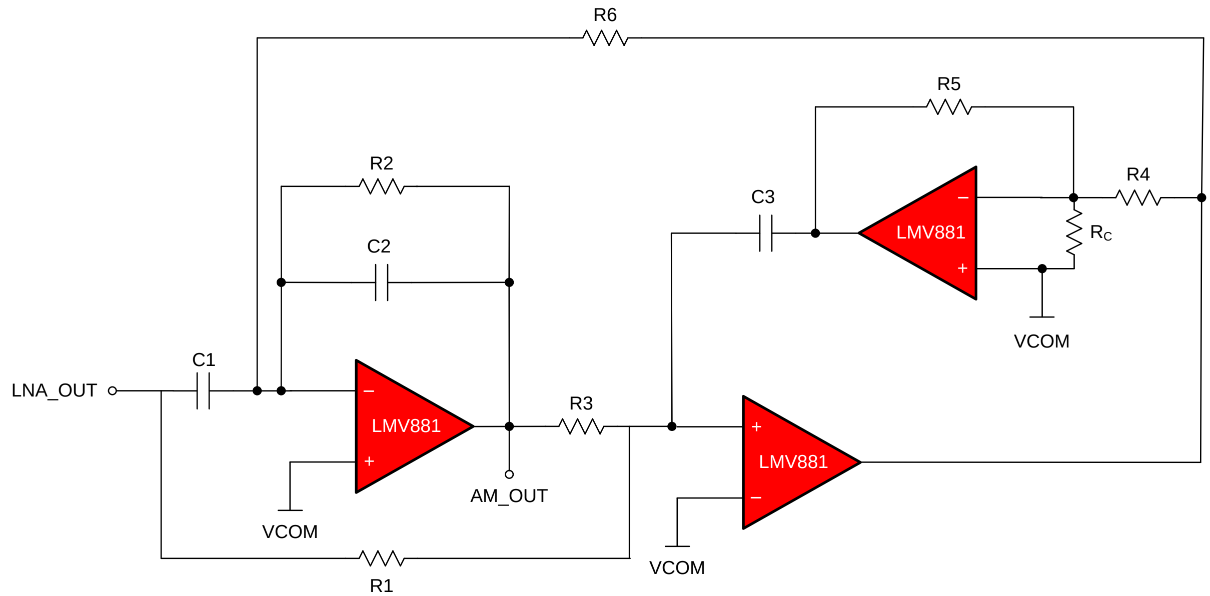

Figure 1. Åckerberg-Mossberg Topology with the Input Connected to TDC1000's LNA_OUT Pin.

The Åckerberg-Mossberg topology in Figure 1 consists of the inverting Miller Integrator and the non-inverting integrator with active compensation. These two integrators compensate each other by reducing the dependence of the selectivity factor Q to the finite GBW of the LMV881. This configuration extends the usability of the LMV881 when the resonant frequencies of typical ultrasonic transducers in the market may be different or the temperature of the system varies. The Åckerberg-Mossberg topology aims to keep the selectivity factor Q constant across different transducer resonant frequencies and temperatures for best filter performance.

3 Setup

Minimum selectivity factor Q dependence on a limited bandwidth requires that:

$$C_2=C_3=C \text{ and } R_3=R_6=R. \quad (1)$$

The gas sensor resonant frequency is:

$$f_0 = \frac{1}{2\pi RC} \quad (2)$$

The filter is stable when the input of the Miller integrator is fed by the negative feedback loop provided by the unity-gain inverter if:

$$R_4=R_5=R. \quad (3)$$

The Åckerberg-Mossberg topology in Figure 1 allows for an arbitrary notch below the resonant frequency of the ultrasonic transducer. A notch may be needed to filter out interference from a nearby source e.g. CCFL. This notch does not affect the poles of the transfer function and is applied by feeding a portion of the input signal into the virtual ground node of the Miller integrator and the non-inverting integrator. It is governed by:

$$C_1=aC \text{ and } R_1=R/c. \quad (4)$$

The notch frequency is:

$$f_{zero} = f_0\sqrt{\frac{c}{a}} \quad (5)$$

where:

a determines the high-frequency gain and c determines the low-frequency gain.

Resistor R_2=QR sets the selectivity factor. The component values are summarized in Table 1.

(6)

Table 1. Summarzied Component Values for the Åckerberg-Mossberg Topology.

Component	Value	For resonant frequency	Description
R	$\frac{1}{2\pi C f_0}$	7.860k	Set the cut-off frequency.
C	$\frac{1}{2\pi R f_0}$	100pF	
C_1	aC	1 nF	Sets the high-frequency gain.
f_{zero}	$f_0\sqrt{\frac{c}{a}}$	60kHz	notch for EMI of CCFL
R_1	R⁄c	7.00 kΩ	Sets the low-frequency gain.
R_2	QR	66 kΩ	Sets the selectivity factor.

4 Stability

In Figure 1, the non-inverting actively compensated integrator may become unstable due to the second parasitic pole of the LMV881. It is crucial to maintain the selectivity factor Q independent of the limited amplifier bandwidth while at the same time decreasing the phase-lead introduced by the non-inverting integrator. In this case, for the LMV881, let:

R_C=2.00 kΩ (7)

5 Interface with the TDC1000

Although the LMV881 introduces a maximum input offset voltage of 1mV, an AC coupling interface is recommended to ensure optimum performance of the zero-cross detect comparator in the TDC1000 as shown below:

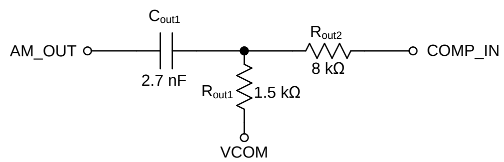

Figure 2. AC Coupling to Ensure Optimum Performance of the Zero-cross Detect Comparator in the TDC1000.

Figure 2 shows a high-pass filter that should not affect typical transducer resonant frequencies. Resistor R_out2 stabilizes the VCOM reference when the input capacitance of the zero-cross detect comparator discharges in the TDC1000.

6 Measured Results

Measured magnitude and phase responses are shown in Figure 3. The measured gain at 200kHz is 42.3dB with 3dB corners at 194kHz and 210kHz; the notch at 60kHz is at -40dB with 3dB corners deviating less than 1kHz away.

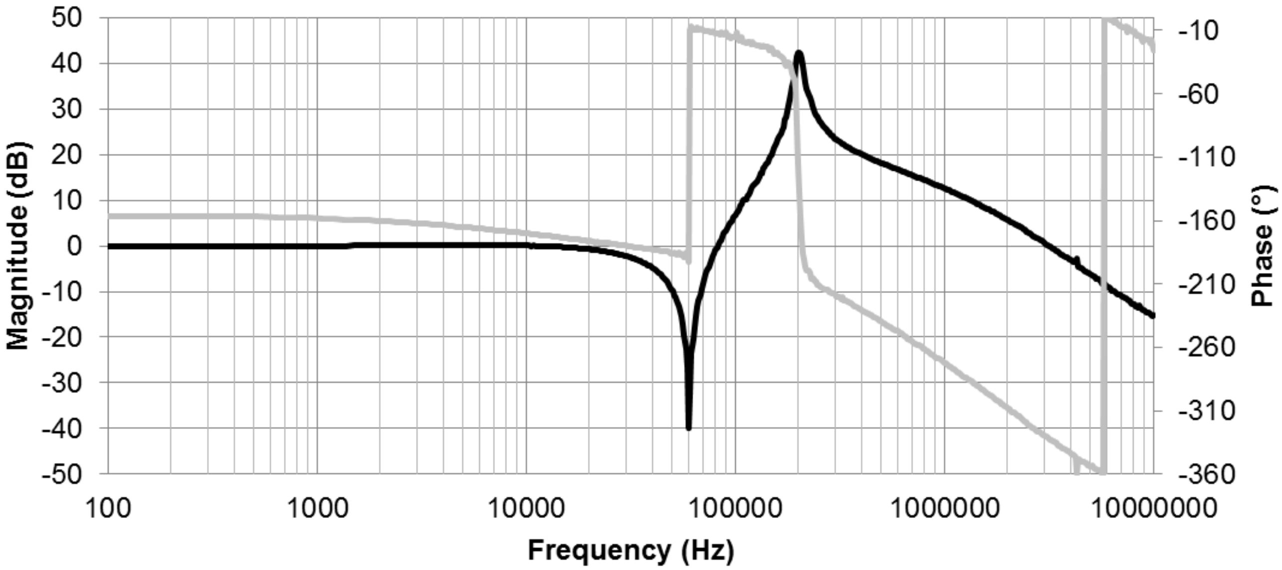

Figure 3. Measured Magnitude Response Using Component Values In Table 1

7 References

1. D. Akerberg and K. Mossberg, "A versatile active RC building block with inherent compensation for the finite bandwidth of the amplifier," IEEE Trans. on Circuits and Systems, vol. CAS-21, pp. 75-78, Jan. 1974.
2. Martin, Ken and S. Sedra, Adel, "On the Stability of the Phase-Lead Integrator," IEEE Trans. On Circuits and Systems, vol. CAS-24, NO. 6, June 1977.
3. Soderstrand, M. A. et al, "Modern Active Filter Design". John Wiley & Sons Inc. Dec 31. 1981.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (December 2015) to A Revision	Page
• Changed figure 1.	2

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