LETTER

A Fully On-Chip Gm-Opamp-RC Based Preamplifier for Electret Condenser Microphones

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SUMMARY An on-chip CMOS preamplifier for direct signal readout from an electret capacitor microphone has been designed with high immunity to common-mode and supply noise. The Gm-Opamp-RC based high impedance preamplifier helps to remove all disadvantages of the conventional JFET based amplifier and can drive a following switched-capacitor sigma-delta modulator in order to realize a compact digital electret microphone. The proposed chip is designed based on 0.18 μm CMOS technology, and the simulation results show 86 dB of dynamic range with 4.5 μVrms of input-referred noise for an audio bandwidth of 20 kHz and a total harmonic distortion (THD) of 1% at 90 mVrms input. Power supply rejection ratio (PSRR) and common-mode rejection ration (CMRR) are more than 95 dB at 1 kHz. The proposed design dissipates 125 μA and can operate over a wide supply voltage range of 1.6 V to 3.3 V.

key words: *electret microphone, preamplifier, switched-capacitor, sigma-delta*

1. Introduction

Nowadays electret capacitor microphones (ECMs) are used in almost every telephony and multimedia application. The electrical model of the microphone is shown in the leftmost part of Fig. 1(a). C_S and C_P are equivalent capacitance of the electret capacitor (EC) and parasitic capacitance. The output signal swing of the ECM is typically small and needs to be amplified for further processing. A typical electret microphone preamplifier circuit uses an FET in a common source configuration [1]. Figure 1(a) shows an analog microphone consisting of a JFET based buffer along with the ECM and a following CODEC chip, which is not integrated in the ECM package. However, there are lots of disadvantages along with the JFET based analog microphone: inherent nonlinearity, poor PSRR, noise coupling due to single-ended analog signal transfer from the ECM to the CODEC, incompatible with standard CMOS processes. So far several techniques for better performance with JFET based architecture have been reported [2]. Others tried to replace the discrete JFET with a CMOS amplifier for better performance [3], [4]. However, previous trials still have disadvantages such as limited output swing and poor noise immunity from not being fully differential output [3], or in need of additional preamplifiers [4]. New advanced digital microphones, where the signal from the EC is A/D by an embedded A/D converter, can reduce all above problems [1].

Manuscript received November 4, 2008.
Manuscript revised December 21, 2008.
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DOI: 10.1587/transele.E92.C.587

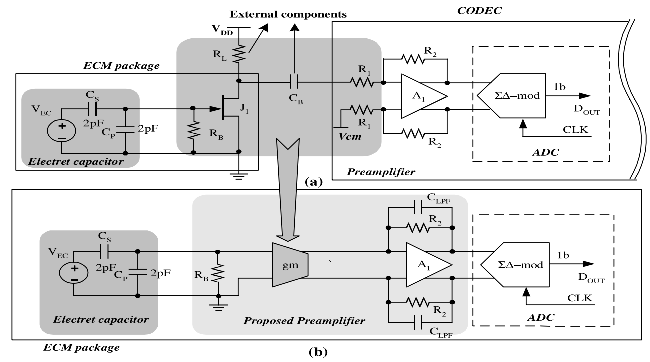
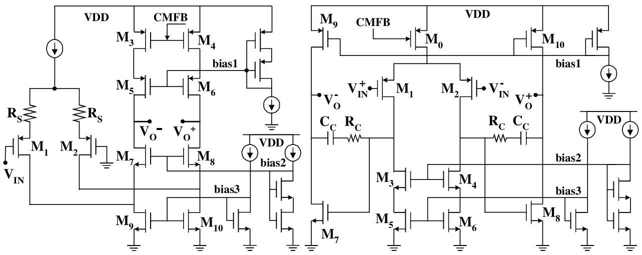


Fig. 1 A/D conversion system for ECMs (a) with JFET interface, (b) with proposed preamplifier.

In [1] the preamplifier is removed, and the EC is directly connected to the ADC by virtue of gm-C-integrator-based continuous-time (CT) sigma-delta modulator (SDM). This approach inherently provides high input-impedance and low power consumption. However, such configuration has drawbacks in the point of SNR with small input signal. This leads to higher order modulator design and larger capacitor size. Furthermore, CT modulators' filter coefficients depend on absolute value of resistance (or gm value) and capacitance, and operating frequency. Without extra tuning techniques, the performance and even the operation of the modulator are not guaranteed by the process and application variation. On the contrary, the coefficients of switched-capacitor (SC) modulators are functions of capacitor ratios, and they are very insensitive to the process variation. Also, the clock frequency change only makes the OSR change. Above considerations justify the use of SC SDM for the digital ECM.

2. Proposed Preamplifier

The proposed preamplifier has two key points: high input impedance for the ECM interface and wide swing differential output with low output impedance to drive the SDM for better noise immunity. The proposed preamplifier, thus, consists of 2 parts: a gm-cell for high-impedance interface, and a feedback amplifier for gain and output driving. From the conventional configuration in Fig. 1(a), one can recognize that the functions of JFET, R_L, and R_1 can be merged into a single transconductance amplifier (gm-cell). Figure 1(b) shows the total proposed preamplifier along with the following ADC in a digital microphone. A folded-cascode structure is used for the gm-cell (Fig. 2(a)). It has



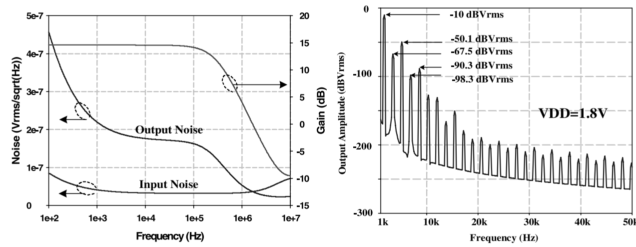
(a) (b)

Fig. 2 (a) Gm-cell, (b) Main amplifier (A1).

a PMOS input pair to deal with the input signal centered at ground level. Source degeneration resistors, R_S, help to enhance the linearity of the gm-cell. Output terminals are fully differential for noise immunity and better PSRR. The main amplifier shown in Fig. 2(b) has a two-stage configuration. First stage is telescopic structure to provide high DC gain with minimum power, and the second stage is common source configuration to drive the sampling capacitor of the SDM with enough signal swing. The capacitor C_{LPF} is used for anti-alias filtering. When $1/R_S \ll$ gm of the input transistors of the gm-cell, M_1/M_2 in Fig. 2(a), the voltage gain of the preamplifier is approximately R_2/R_S. But note that as R_S increase, R_2 should be increased also in order to keep the gain. In the point of low noise design, increasing R_2 is not desirable because it will also amplify the noise current from gm-cell and results in SNR degradation. Fortunately, the linearity requirement for large signal for ECM application is not so strict. Usually 1% THD at around 50 mVrms input signal is acceptable; hence R_S doesn't need to be too large. In this design, the ratio of 1/gm to R_S is 1 to 2. The input DC level of gm-cell is defined by two diodes in back-to-back configuration as a giga-omh resistor, R_B [3].

3. Simulation Results

Figure 3 shows the frequency response, the input/output noise (both flicker and thermal), and the FFT plot for 90 mVrms 2.1 kHz input sinusoidal signal (THD = 1%) of the proposed preamplifier. Voltage gain is 14.6 dB in signal bandwidth. The total simulated input-referred noise is 4.5 μVrms, and output noise is 25 μVrms from 100 Hz to 20 kHz. The maximum input/output voltages at 1% of THD are 90 mVrms/500 mVrms. This gives a dynamic range of 86 dB. The Monte-Carlo analyses show PSRR/CMRR of more than 95 dB at 1 kHz. The chip consumes 125 μA from a supply voltage of 1.6–3.3 V. The chip active die area is 240 μm × 320 μm in 0.18 μm CMOS technology. The performance summary and comparison is shown in Table 1.



(a) (b)

Fig. 3 (a) AC & noise response, (b) FFT Plot @ 1% THD.

Table 1 Performance summary and comparison.

Specifications	[2]	[3]	This Design
Type	JFET Based	CMOS amplifier	Gm-Opamp-RC Based
Process	CMOS 1.5μm	NA	CMOS 0.18μm
VDD	2.8V	±1.5V	1.6V – 3.3V
BW	10k	10k	20k
Input/Output Noise	5/52μV_{rms} (100Hz-10kHz)	30μV_{rms}/NA (100Hz-10kHz)	4.5/25μV_{rms} (100Hz-20kHz)
THD	1% @ Vin=52mV_{rms}	50dB @ Vin=20mV	1% @ Vin=90mV_{rms}
DR	80dB	56dB	86dB
PSRR/CMRR	50-90dB/NA (100Hz-10kHz)	NA	72-95dB/70-95dB (100Hz-20kHz)
Power	96μW	24μW	125μA
Size	2.2x2.2mm^2	NA	0.3x0.4mm^2

4. Conclusions

Small-sized and high-performance digital electret microphones promise a huge market. The proposed Gm-Opamp-RC based preamplifier with high DR of 86 dB for an audio bandwidth of 20 kHz, low distortion, high immunity to supply and common-mode noise, wide range of supply voltage, and very compact size helps to realize digital ECMs in a very small package and at a low cost.

Acknowledgement

This work was partially supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST) (No. R0A-2007-000-10050-0 and No. R11-2005-029-06001-0).

References

[1] O. Bajdechi and J.H. Huijsing, "A 1.8-V ΔΣ modulator interface for an electret microphone with on-chip reference," IEEE J. Solid-State Circuits, vol.37, no.3, pp.279–285, March 2002.
[2] M. Baker and R. Sarpeshkar, "A low-power high PSRR current-mode microphone preamplifier," IEEE J. Solid-State Circuits, vol.38, no.10, pp.1671–1678, Oct. 2003.
[3] C. Furst, "A low-noise low-power preamplifier for capacitive microphones," Proc. IEEE ISCAS, pp.477–480, May 1996.
[4] J. Silva-Martinez and J. Salcedo Suner, "A CMOS preamplifier for electret microphones," Proc. 38th Midwest Symp. Circuits and Systems, vol.2, pp.1018–1021, 1996.