A Chopper Modulated Instrumentation Amplifier Using Spike Shaping and Delayed Modulation Techniques for MEMS Pressure Sensor

N. P. Futane, C. Roychaudhuri and H. Saha

***Abstract*— A low-noise chopper modulated CMOS Instrumentation Amplifier intended for low frequency MEMS Pressure sensor applications is presented. The Chopper amplifier is designed using delayed modulation scheme and low pass filter spike shaping technique for achieving low residual offset. Compared to band pass technique performance of this technique is independent of sensor impedance and also relaxes the requirement of matched oscillator. The Instrumentation amplifier features a total dc gain of 40. The 1/f input noise is 450nv/√Hz. The measured CMRR is 100dB and the total power consumption is 3.5mw.The circuit has been designed using AMS0.35µm technology and simulated using ELDO simulator.**

***Index Terms*—residual offset , 1/f noise, OTA, Parasitic spike, Chopper technique, MEMS, Corner frequency, Piezo-resistive Pressure sensor.**

I. INTRODUCTION

Recent progress in development of MEMS & Integrated circuit technology based sensor not only led to the tremendous increase in performance of scaled down analog and digital VLSI circuits but also motivated the rapid development of signal processing circuit for silicon based micro-sensors. Monitoring low-amplitude signals necessitate using low noise amplifier such as implantable devices to record neuromuscular activities, MEMS based pressure, Gas , Flow sensors etc. It is well known that CMOS operational amplifier suffers from lot of imperfections such as 1/f noise, thermal noise and offset. The thermal noise occupies a wide frequency band, while 1/f noise , offset and input signals are narrow band signals. The two stage operational amplifier can be optimized for low frequency noise and offset performance by using circuit topology ,transistor selection and by designing the high gain input stage[5]; However the low frequency noise is significantly high of the order of micro volt and offset is in the order of mili volt .

There are two basic techniques that are used to reduce offset and 1/f noise of operational amplifier, namely Auto Zero(AZ) and chopper stabilization(CHS) technique . A noise analysis of both the technique is given in [1][2][3]. The AZ technique which is best suitable for the system which inherently uses sample-data system, and CHS is best suitable for pure analog system. The residual offset present in CHS mainly originates from modulator spikes, which after demodulation appears as residual offset at the output.

In this paper chopper modulated amplifier for MEMS pressure sensor is presented , which uses delayed chopping scheme in combination with low-pass filter for spike shaping to achieve low residual offset. Compare to BP filter technique this technique reduces the requirement of match oscillator and This technique is best suitable for high impedance sensor.

II. MEMS PIEZO-RESISTIVE PRESSURE SENSOR.

The designed chopper modulated instrumentation amplifier can sense the output signal of typical MEMS based piezoresistive pressure sensor in the range of 0 to 300millibar and indicate a change of 0.1mv /mbar The MEMS based pressure sensor have been fabricated and characterized in the laboratory. The schematic MEMS pressure sensor is shown in fig1.

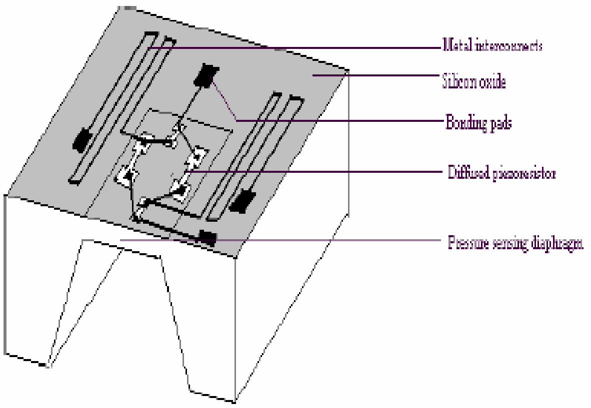

Fig 1: Piezo-resistive MEMS pressure sensor.

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III. CHOPPER TECHNIQUE (CHS)

Unlike Auto-zero technique, the CHS technique shown in fig. 2. does not use sampling, but rather applies modulation to transpose the signal to higher frequency where there is no 1/f noise and demodulates it back to the base band after amplification.

Suppose that the input signal has a spectrum limited to half of the chopper frequency so no signal aliasing occurs , and amplifier is ideal, with no noise or offset. This input signal is multiplied by the square-wave carrier signal m1(t) with the period $T=1/f_{chop.}$ After this modulation, the signal is transpose to the odd harmonic frequency of modulation signal. It is then amplified and demodulated back to original band.

Assuming that the input of chopper amplifier is a dc signal Vin the signal at the output of first modulator is square wave of period T and amplitude Vin refer fig. 2. If amplifier has a gain A_0, an infinite bandwidth and does not introduce any delay then the signal at the output is square wave with an amplitude A_0Vin. and the signal after demodulation is again dc signal of the value A_0Vin. This is ideal solution, but in reality the amplifier does not have infinite bandwidth and introduces the delay hence amplifier output will not be square wave. The dc value after low-pass filtering is $\left(8/\pi^2\right)A_0Vin$, corresponding dc gain of $0.8A_0$. This gain of chopper amplifier is also sensitive to the delay introduced by the main amplifier.

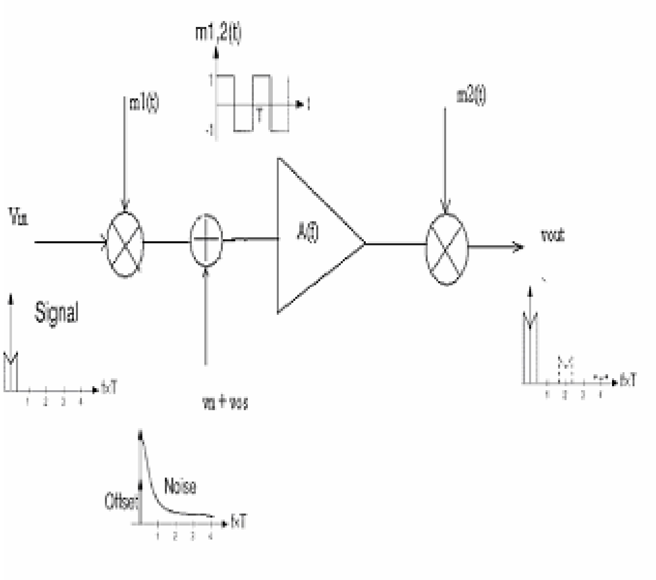

Fig 2: Basic chopper Modulation Technique

In contrast to the increased white noise component of auto-zero amplifier, the base band noise of chopper amplifier is almost equal to wideband thermal noise, at chopping frequency higher than 1/f noise corner frequency . The typical noise spectrum of chopper amplifier is shown in fig3. the lower 1/f noise of CHS technique is main reason to use this technique for readouts of MEMS sensor. However, the residual offset of chopper technique is high for some applications.

A. *Residual offset*

The residual offset is mainly due to the non-idealities of the chopper input modulator [3]. Any spikes caused by modulator non-idealities and appearing at the amplifier input will be amplified and demodulated by the output modulator , giving rise to residual offset. Since only odd harmonics of chopper frequency will contribute to the residual offset, the positive and negative spikes will have an odd symmetry.

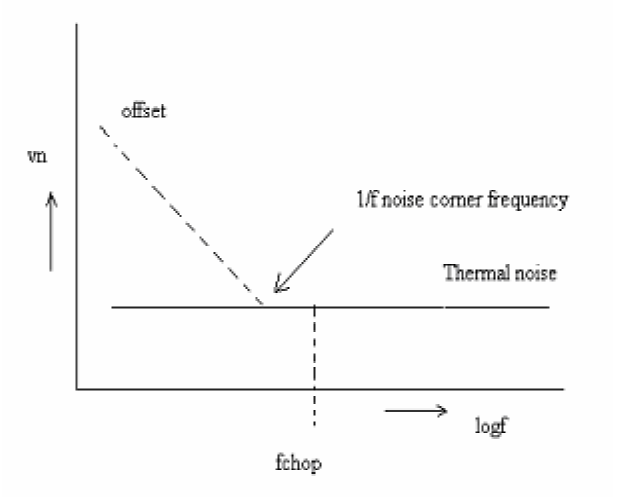

Fig 3: Typical Noise Spectrum of Chopper Amplifier.

The parasitic spike time constant τ is much smaller than half chopper period T/2, most of the spike energy appears at frequencies higher than the chopper frequency. The spectra of such spike is shown in fig-4. This spectra after amplification contributes to the residual offset voltage. The input referred offset can be calculated assuming $\tau << T/2$.

$$Vos = 2*(\tau/T)(Vspike)$$

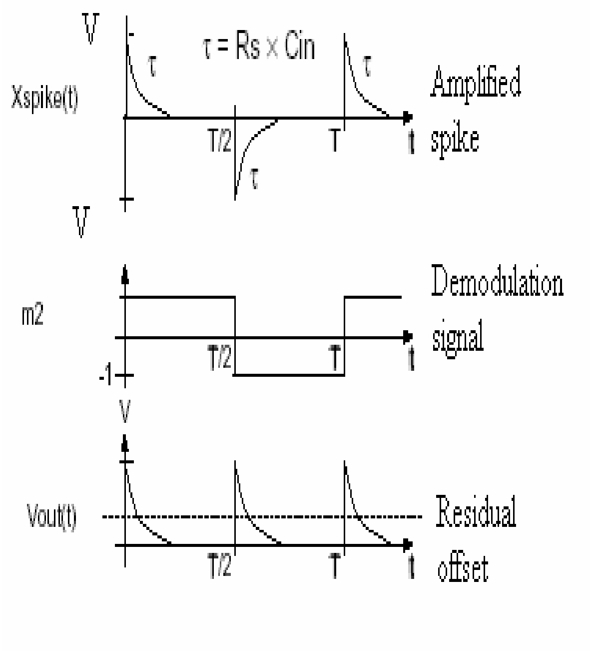

Fig 4: Amplified input spikes and residual offset caused by amplified spike.

here are three main options to reduce the residual offset lowering chopping frequency, lowering input impedance and lowering charge injection. However lowering chopping frequency is not real solution because chopping frequency should be higher than 1/f noise corner frequency to remove 1/f noise. The input resistance is dictated by input source. Charge injection is mainly dictated by the process choice and can be minimized by careful layout design. Hence it can not be improved in straight forward manner.

B. Techniques to reduce Residual offset.

The method to reduce the residual offset is shown by Menol [6]. The energy content of the spike is mainly located at higher harmonics of chopping frequency, while the energy of the modulated signal is mainly located at the fundamental of the chopping frequency if modulated signal that includes spike is band-pass filtered, almost all spikes are removed, while small part of signal is lost. This techniques significantly reduces the residual offset at the cost of reduced gain accuracy and needs match oscillator. The another technique to residual offset is low pass filter and delayed modulation scheme given in [6]. They remark that simply introducing delay in demodulation causes the chopping of the spike signal and hence dc content of output is minimized. The major weakness of this arrangement is that τ itself , that not only depends on sensor source resistance R, but also on amplifier input capacitance Cin hence it of little practical use. To solve this short-coming , shaping of spike can be introduced by addition of low-pass filter with time constant τc after the amplifier provided that $T >> \tau c >> \tau$, the shape of time response of filtered spike is primarily determined by τc and independent of impedance of connected sensor. The spike shipping is shown in fig 5.

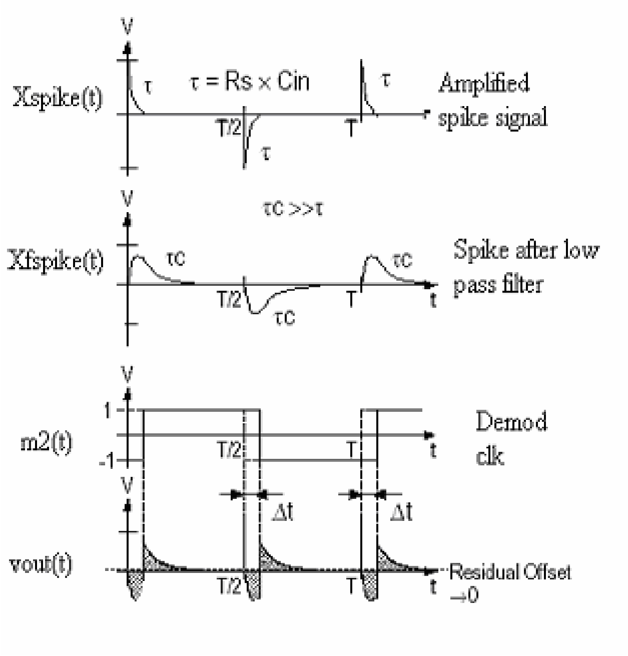

Fig 5: Spike after low-pass filter and reduced residual offset.

IV. CIRCUIT DESIGN

A Block diagram of proposed scheme is shown in fig-6. The whole path is fully differential modulation chopper amplifier.

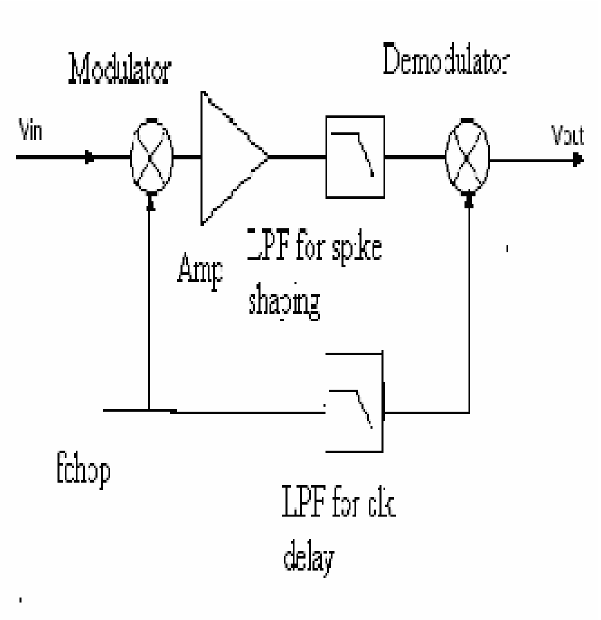

Fig 6: Block diagram of low-pass filter Delayed.

The chopper amplifier consists of Modulator and Demodulator which is designed using TG for low clock fed through. The input signal is chopped with 10kHz chopping frequency. The amplifier have been implemented using OTA [7]. The fully differential OTA with inherent CMBF is used for implementation of amplifier the PMOS OTA is used for low noise configuration. The schematic of fully differential OTA is shown in fig 7. [8]. The amplifier with 35dB gain is implemented using OTA based amplifier fig-8.The gain of amplifier is gm1/gm2 and output impedance is 1/gm2. This amplifier structure is attractive since it does not uses passive component. The Gain adjustment can be attained with either gm1 or gm2. The total adjustment range of the gain of the structure is double that attainable with single OTA. The OTA based structures uses OTAs and capacitors ,hence are attractive for integration. Component count of these structure is often very low with compared to VCVS design. The spike shaping low –pass filter of 50kHz cut-off frequency and low-pass filter fig.8. of 60kHz cut-off frequency for introduction of delay in demodulator clock have been implemented using OTA technique. The ac analysis of OTA amplifier is shown in fig 11. The noise analysis of OTA amplifier and CHS amplifier is shown in fig 10.

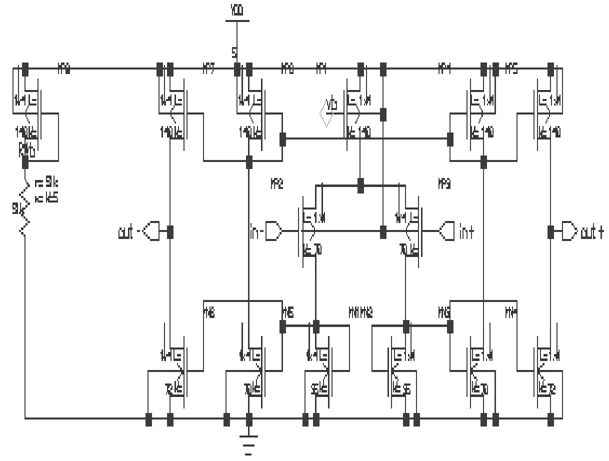

Fig 7: Fully differential OTA with inherent CMBF.

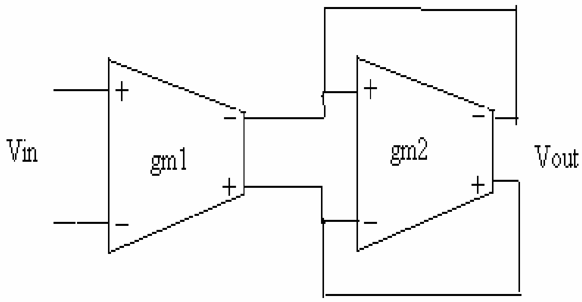

fig-7.

Fig 8: OTA amplifier.

V. RESULT & CONCLUSION

The CHS instrumentation amplifier for piezo-resistive MEMS sensor circuit has been designed with the CMOS AMS0.35 µm technology and simulated using Mentor Graphics ELDO simulator. The results of simulation are
PD= 3.5mw.
Noise= 450nv/√Hz.
DC gain of amp =40.
CMRR =100dB.

For larger sensor resistance better offset performance can be achieved compared to a design with Match oscillator and Band-pass filter technique. It also relaxes the requirement of Match oscillator.

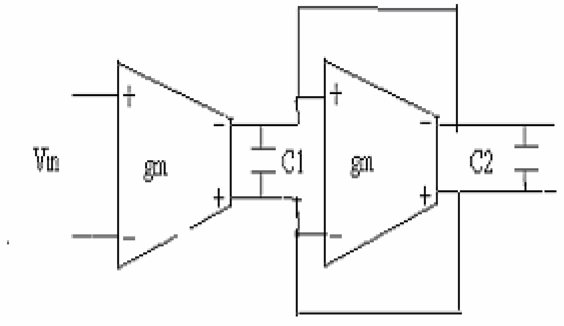

Fig 9: OTA Based low-pass filter

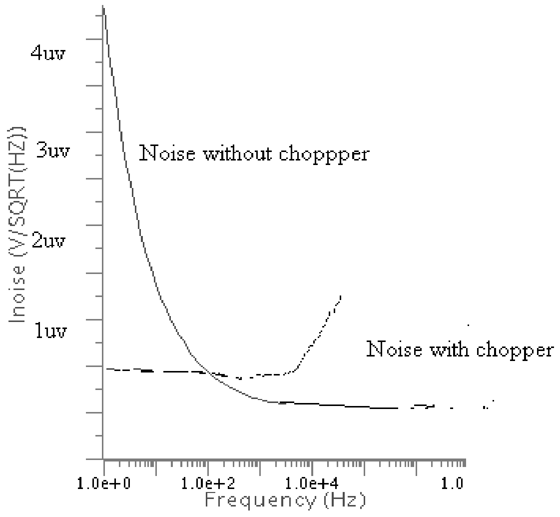

Fig 10: Noise analysis.

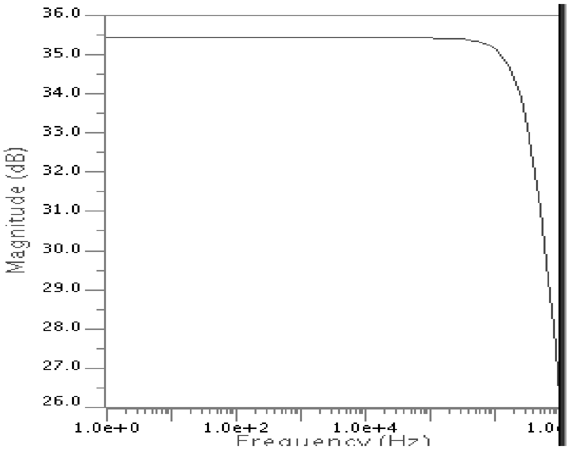

Fig 11: Gain of OTA Amplifier.

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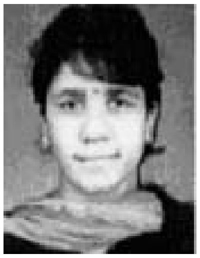

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