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MODELING AND SIMULATION OF SIGNAL CONDITIONING CIRCUIT FOR CLOSED LOOP MEMS ACCELEROMETER

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Abstract: *An Accelerometer is an Electro-mechanical device which measures Acceleration forces. These forces may be static like constant force of gravity pulling at our feet or dynamic like caused by moving or vibrating the accelerometer. Accelerometer measures the linear acceleration, integrating the acceleration the velocity can be derived, further integrating the velocity the position information can be derived. Hence it finds a solution to the important Engineering problem that is tracking the position of an object in the space. This paper describes the modelling and simulation of closed Loop Accelerometer which is targeted for space applications.*

Keywords: *MEMS, Accelerometer*

1. Introduction

High performance micro machined inertial sensors with µg resolution usually take the advantage of closed loop control in order to Increase the linearity, Resolution and Bandwidth [1].To avoid the electrostatic pull-in problems of purely analog force feedback control systems. The digital force feedback system is implemented. This paper reports on a high Performance inertial grade MEMS Accelerometer targeted at space applications. Reported results are for MEMS Capacitive sensor with +/- 1g. MEMS Accelerometer sensor having comb type structure with a capacitance of 6pF/g sensitivity will be used as the sensing element in the accelerometer. Capacitive sensing accelerometer provides a measure of acceleration by change in the capacitance of the MEMS sensor which gives the differential capacitance output ΔC. Hence for getting the resolution of 1µg we need to sense a change in capacitance of 6 x 10^{-18} F which requires a challenging task to develop read out electronics.

2. Sensor Model

The capacitive based MEMS Accelerometer sensor in Figure 1 consists of a movable plate (seismic mass) Supported by four beams and the Electrodes projecting sideways and fixed Electrodes realized as 'split' configuration to be inter-digitized with those from movable plate and support glass wafer on which fixed

Electrodes, anchors and stopper structure are bonded. In addition stoppers are provided to prevent the Failure of the structure on impact due to large mechanical shock acting on it. The sensor is a spring mass damper system hence the mathematical modelling is done and the modelling is done in pspice along with processing Electronics.

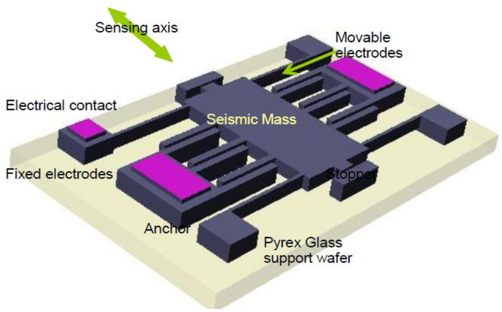

Fig. 1 Sensor Structure

To derive the motion equation of the system, mechanics principle is applied, where all real forces acting on the proof mass are equal to the inertia force of the proof mass. The sum of all the forces in Y direction is equal to the sum of all forces in X direction Sum of forces in Y direction= sum of forces in x direction

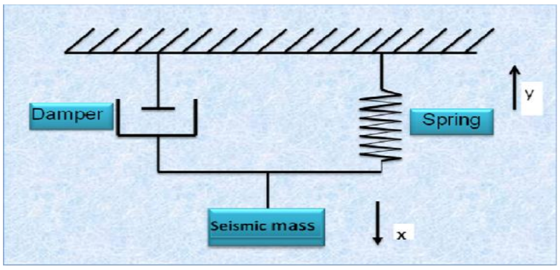

Fig.2 Mass Spring Damper system

Where, m = mass of proof mass, b = damping factor, k = spring constant.
Taking Laplace Transform,

$$m.A(s) = (M.s^2 + b.s + k).X(s) \quad (1)$$

$$X(S) = \frac{m.A(S)}{m.s^2 + b.S + k} \quad (2)$$

$$\frac{X(S)}{A(S)} = \frac{1}{S^2 + \frac{b}{m}S + \frac{k}{m}} \quad (3)$$

Using these Equations, the sensor model is built for simulation

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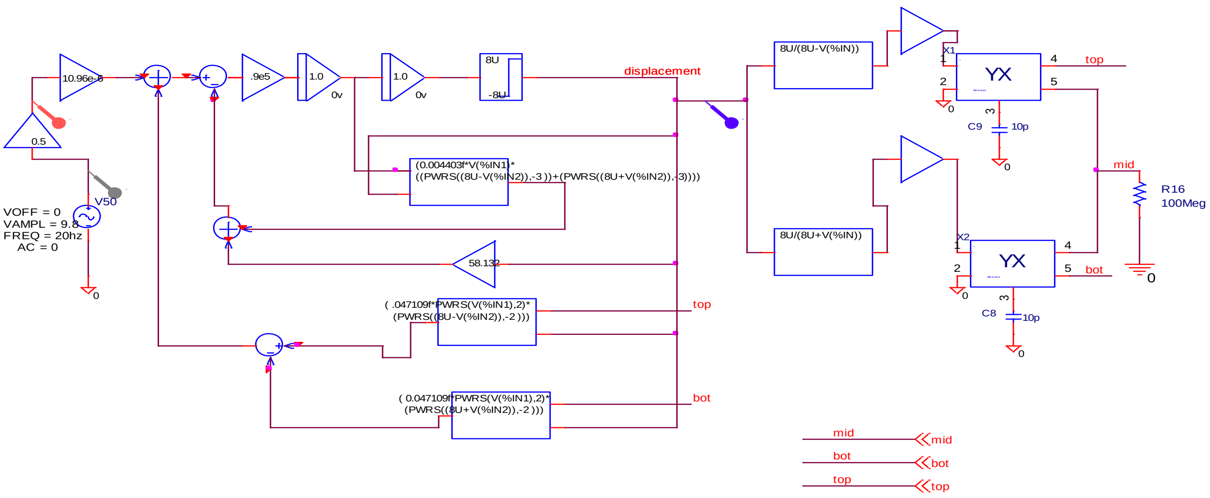

Fig.3 PSPice sensor Model

3. Signal conditioning circuit

At the beginning of the sensing phase, all charge is removed from the variable capacitors by grounding the electrodes. The sensing of the position of the seismic mass is realized by applying a voltage step to the top electrode and a step of the same magnitude but of opposite polarity to the bottom electrode. The resulting current from the seismic mass charges the feedback capacitor of an operational amplifier, the output voltage of which is proportional to the imbalance in capacitance. The output of this C/V converter is given to the sample and hold block, the output of which is given to the Comparator. The output of the comparator is given to the feedback circuitry consisting of the inverter and the analog switches. The logic state of the comparator corresponds to a positive or negative imbalance in the capacitance and determines the electrode that has to be energized by the feedback pulse. The feedback voltage pulse is applied to the electrode furthest away from the seismic mass and generates the electro static force that acts as a reset force for limiting the seismic mass movement. The output of the comparator which is in the form of the digital serial bit stream represents the average of the input acceleration and is given to the RC filter where the input (acceleration) waveform is regenerated from the digital bit stream.

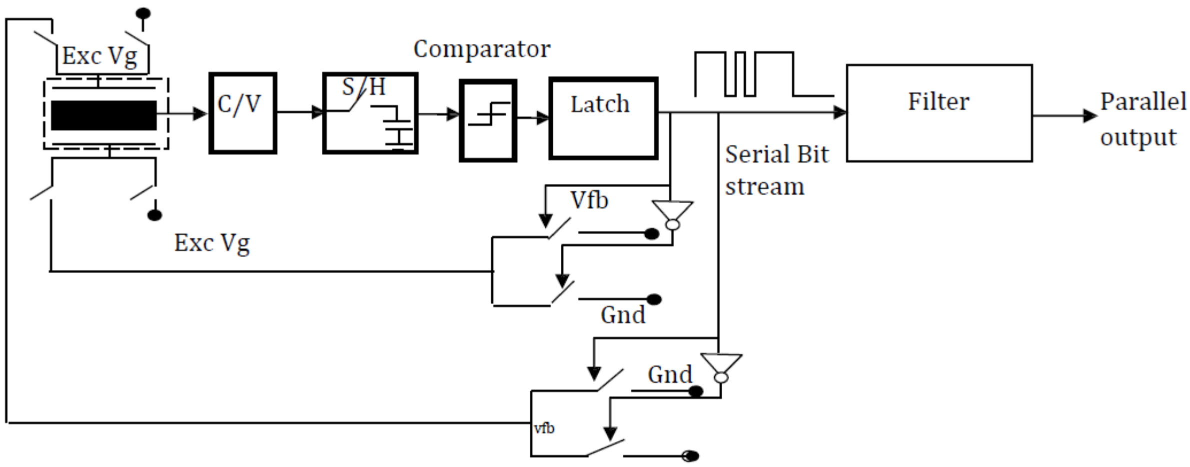

Fig. 4 signal conditioning circuit

4. Simulation Results

In the closed loop accelerometer simulation, an acceleration of 1g is applied to the sensor with the input frequency of 20 Hz. End to end simulation is done with the sensor model shown above and signal conditioning circuit.

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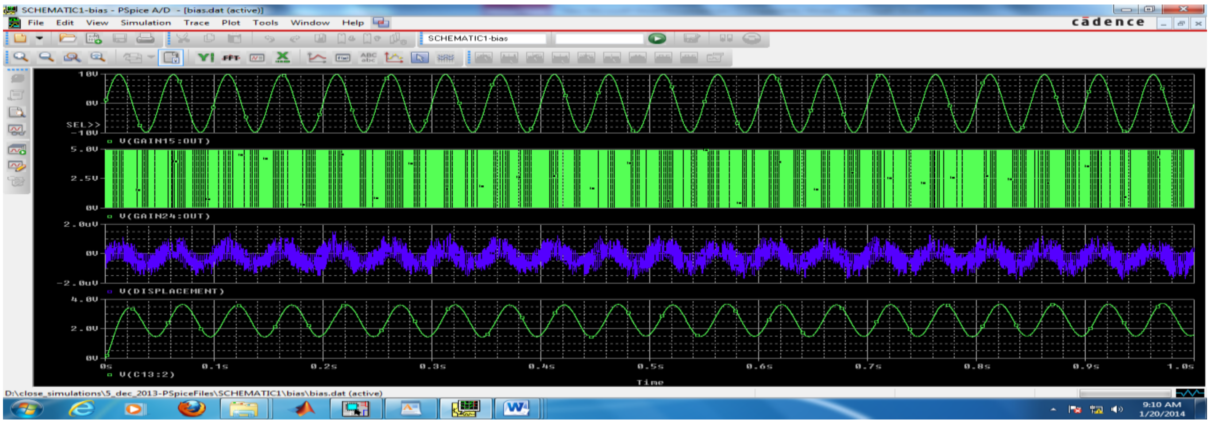

Fig. 5 simulation Results

5. Analysis of Simulation Results

In the analysis of the simulation results the scale factor,Range,second order non-linearity can be found out.Scale factor is the slope of of the input and output curve, which is in terms of volts/g.Range is the maximum acceleration the sensor can sense. Second order non-linearity is the ratio of second order coefficient to the first order coefficient in the data fit equation of the response curve.The sensor and signalconditioning circuit is simulated for the range of +/- 1g and the ouput voltage from the model is tabulated. From the values the Response curve is drawn.

Table 1 output voltage of varying acceleration (g)

Amplitude (g)	Amplitude (V)
-1	1.4636
-0.8	1.6504
-0.6	1.8692
-0.4	2.0541
-0.2	2.268
0	2.4762
0.2	2.7058
0.4	2.9019
0.6	3.1044
0.8	3.3211
1	3.5022

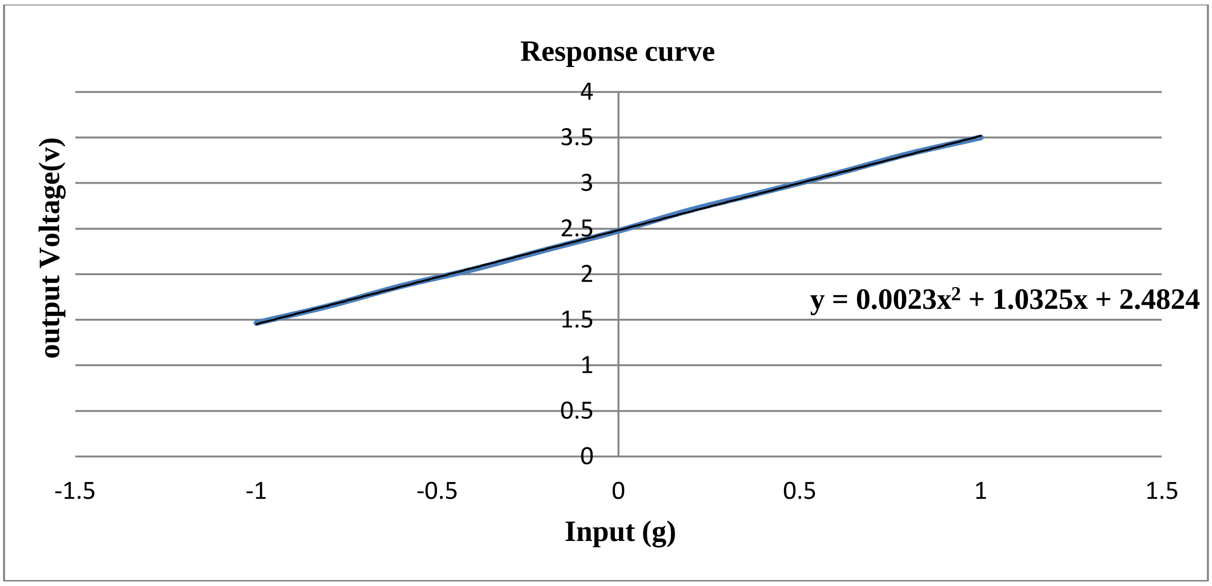

Fig. 6 Response curve (Input g Vs Output Voltage)

From the simulation, the following results are obtained. From the response curve it is found that:
Range: +/- 1g
Scale factor: 1.0325 v/g
Second order Non-linearity: 0.2 $\%g/g^2$

6. Conclusion

In this paper MEMS based capacitive acclerometer sensor is used for the development of inertial grade accelerometer.Along with the sensor the modeling the signal conditioning circuit is modelled and simulated in pspice simulation package. Hence the results from the simulation are tabulated. Inertial measuremen Unit, consists of gyros and accelerometers which forms the inertial navigation system and are used to control the launch vehicles and space crafts.By sensing the three components of acceleration in all the three directions, the IMU can control the path of the launch vehicles to high precision.

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