Electrical Analogue of Capacitive Force-Balanced Accelerometer Used in HSPICE Simulator

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Abstract

Analyzing mechanism of accelerometer, electrical analogue of capacitive force-balanced accelerometer used in HSPICE simulator has been developed. Comparing to the former equivalent circuit, we use acceleration instead of displacement as input variable. Thus we can easily simulate the accelerometer response, and analyze effects of feedback force without twice integration as in conventional model. Using the analogue, response of the sensor to input acceleration at different frequencies was simulated.

Introduction

The micromachining accelerometer is a kind of very useful microsensors, and has been studied theoretically and experimentally in depth. Capacitive interfaces and force-balanced feedback are good choices to get excellent sensitivity and wide measuring range. Timing simulation of the sensor with its measuring circuits is very important to determine performance of the accelerometer, but it is not easy, because all current VLSI simulators can not process mechanical signal, even do not contain time dependent capacitor model. In this paper, we have developed an electrical analogue used in HSPICE simulator to simulate response of the accelerometer to an input acceleration.

Modeling and Results

Fortunately, HSPICE(and many of other VLSI simulators) provides a model of Voltage Controlled Capacitor(VCCAP), so we can use time dependent voltage source and VCCAP to be a equivalent circuit of the sensor. Fig. 1 shows a typical deferential capacitive force-balanced accelerometer configuration with circuits[1]. In this case, the equivalent circuits are shown in Fig. 2, where Va_{in} is input voltage, equaling input acceleration, Vr reflects effects of feedback force, C_0, d_0, m, and K are parameters of the sensor. Here, we assume steady-state conditions for proof mass is always satisfied, so that circuits response to varying input acceleration with and without feedback can be simulated.

In fact, however, the proofmass does not instantaneously respond to input acceleration, but is in mass-spring-damper system(shown in Fig. 3(a))[2]. The differential equation is as

$$m\ddot{x}_{out} + b_m\dot{x}_{out} + Kx_{out} = -m\ddot{x}_{in}$$

For convenience, an equivalent circuit is widely used to analogize the accelerometer(shown in Fig. 3(b))[2]. The differential equation for the circuit can be derived as

$$C\ddot{V}_{out} + G\dot{V}_{out} + \frac{1}{L}V_{out} = -\frac{1}{L}\ddot{V}_{in}$$

where C, G and L are capacitance, conductance and inductance, respectively. The input voltage, Vin, is as an analogue of displacement. This treatment, however, is not convenient to analyze accelerator response, esp. when force-balance is used. Thus, we use the modified equivalent circuit shown in Fig. 4 to be an analogue of the proof mass. The differential equation for this circuit is as

$$C\ddot{V}_{out} + G\dot{V}_{out} + \frac{1}{L}V_{out} = -\frac{1}{L}(V_{in} - V_f)$$

where V_f reflects effects of feedback force. To compare these two equations, we can assume

$$\frac{1}{L}V_{in} = -ma \Rightarrow V_{in} = \frac{-ma}{K}$$

Different from the former equivalent circuit, we use acceleration instead of displacement as input variable, which is useful since what we interested in is the response of sensor to acceleration rather than to displacement. The more important advantage of this treatment is that we can easily analyze effects of feedback force without twice integration as in conventional model. We have simulated performances of deferential capacitive force-balanced accelerometer with measuring circuits. Fig. 5 showed the response of the sensor to input acceleration at frequencies of 100Hz, 1KHz and 10KHz with feedback force.

Conclusion

We have developed electrical analogue of capacitive force-balanced accelerometer used in HSPICE simulator. In the analogue, Voltage Controlled Capacitor(VCCAP) and time dependent voltage source are used to describe the capacitance change caused by accelerometer. Besides a new equivalent are developed to analogize mechanical response. Comparing to the former equivalent circuit, we use acceleration instead of displacement as input variable. Using this technique, we have simulated the accelerometer response, and analyzed effects of feedback force without twice integration as in conventional model.

[1] W. Kuehnel and S. Sherman, Snesors and Actuators, A(45), 1994, P7

[2]J. W. Gardner, Microsensors: principles and Applications", John Wiley & Sons, 1995

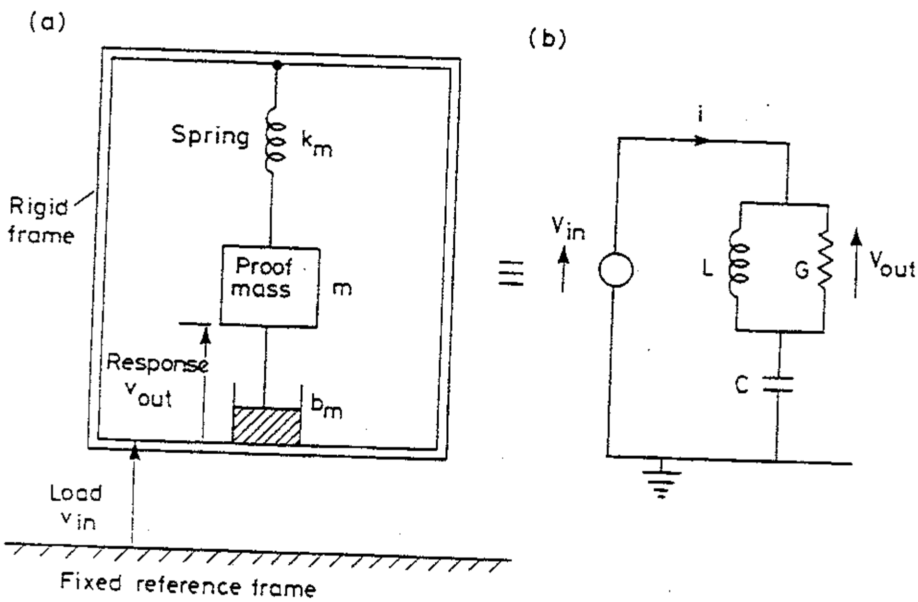

Fig. 1 (a) General layout of an accelerometer, and (b) equivalent circuit used for analogize the accelerometer widely. Reprint from Ref. [2].

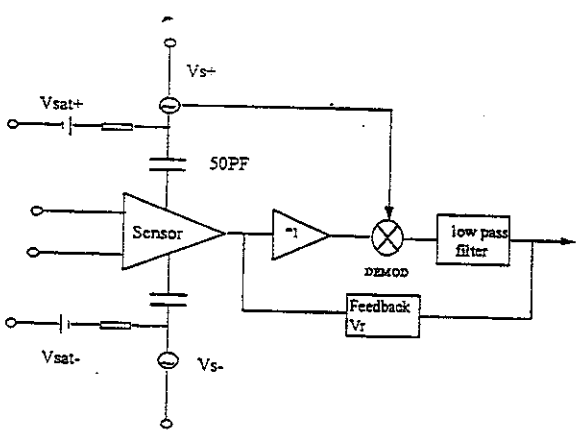

Fig.2 Simplified schematic of connection of a sensor and its measuring circuits with feedback voltage Vr.[1]

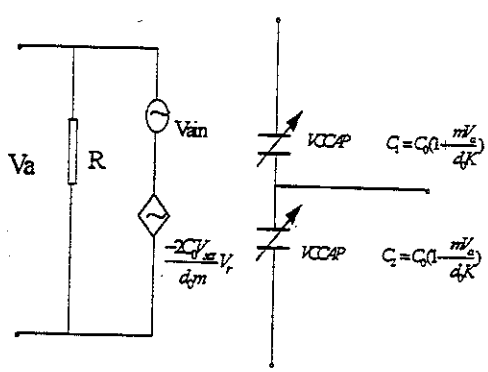

Fig.3 Equivalent circuits of capacitive force-balanced accelerometer. Here VCCAP is voltage controlled capacity.

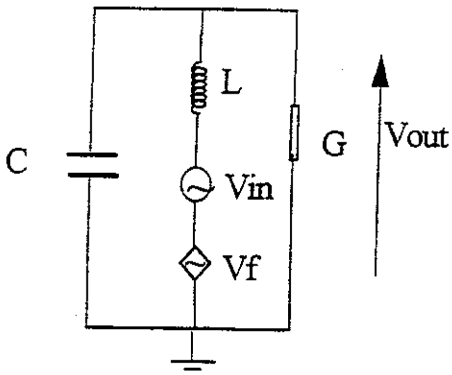

Fig. 4 The electrical analogue of force-balanced accelerometer. Here, *Vout* stands for *Xout*, and *(1/L)Vin* stands for input acceleration.

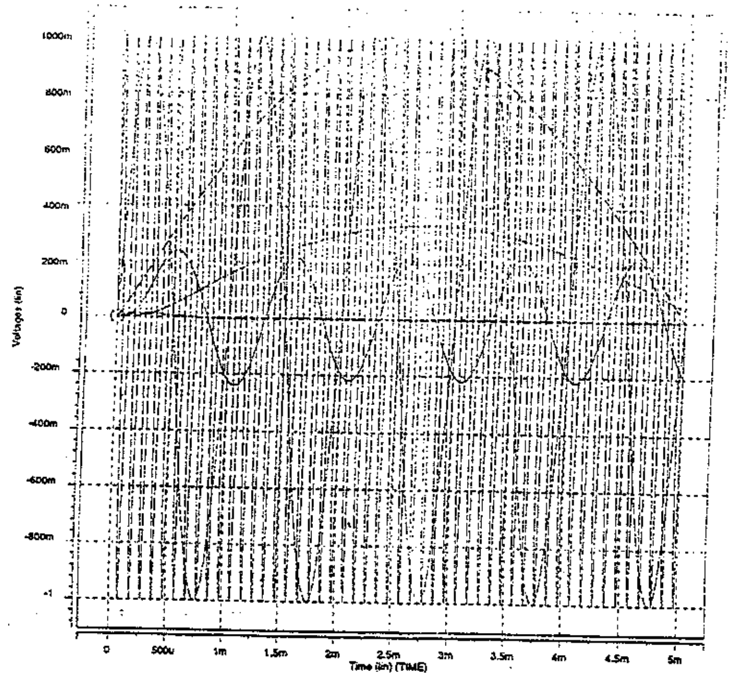

Fig. 5 Response of the accelerometer to input acceleration at frequencies of 100Hz, 1KHz and 10KHz with feedback force. The tree curves with amplitude of 1000m are for input set, the other ones are for output set.