A Novel MEMS Wireless Microphone

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Abstract:

A novel wireless microphone based on MEMS technique is presented in this paper. Microelectromechanical sensor and oscillator are utilized in the structure to reduce its overall size and power consumption. The basic theory, design principles and fabrication procedure are discussed and an FM modulated signal is finally obtained.

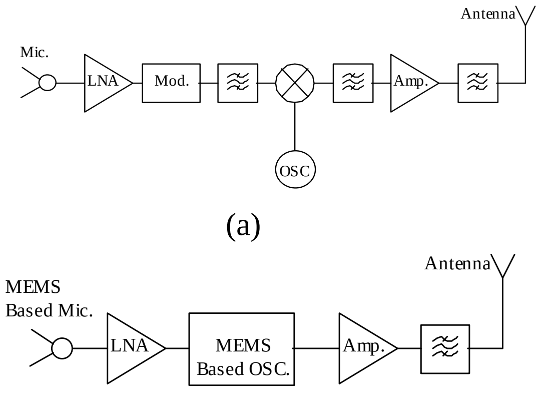
Introduction:

Nowadays, wireless microphone is widely used in human life such as communication, education and entertainment. However, the conventional wireless microphones suffer from the large size and high power consumption. Due to the fast development of CMOS and surface micromachining technology, these barriers can be overcome by utilizing integrated circuits and MEMS [1].

In the proposed wireless microphone, the sound is first transferred to a voltage signal by a micromechanical capacitive pressure sensor and this voltage signal is then modulated to RF frequency through a vertically driven micromechanical oscillator. The whole system is introduced and the pressure sensor and the voltage-controlled oscillator are investigated in details. Since the micromechanical resonator replaces the traditional quartz resonator and related modulation circuits, the system is simpler than conventional system and the structure size and power consumption are greatly reduced. The micromachining fabrication process is also described in this paper.

Theory:

Fig. 1a shows a conventional system of a wireless microphone. The sound pressure is transduced to a voltage change by the capacitive pressure sensor, then modulated to inter-frequency, shifted to RF frequency and finally transmitted through an antenna. This structure is large and power consumption is high considering the normal microphone and oscillator used. Fig. 1b proposes a novel system of the wireless microphone by introducing MEMS based capacitive pressure sensor and a micromechanical oscillator. The micromechanical oscillator replaces the modulator, filter, mixer and oscillator in Fig. 1a and remains the same functionality. Since this oscillator is based on MEMS technology, it is very compact and its power consumption is very low, resulting in a high efficiency of the system. Fig. 2 shows the mechanical structure of the proposed microphone. Since the micromachining technique can be integrated with CMOS technique, all components can be built on single chip.



(a)

(b)

Fig.1 System of wireless microphones: (a) the conventional microphone, (b) the MEMS based microphone

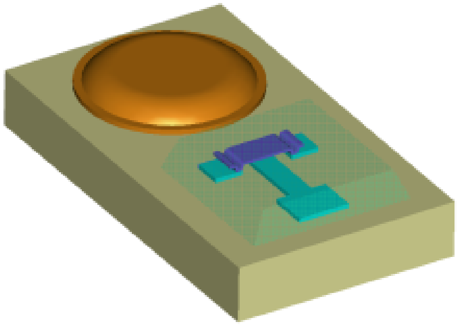


Fig. 2 The model of micromachined pressure sensor and oscillator.

Design:

I- Capacitive Pressure sensor

A capacitive pressure sensor [2] is designed to transfer the sound pressure to electrical current change. The membrane of the sensor has 1 mm diameter with 0.7 micron thickness and 2 micron distance between the electrodes.

Fig. 3 Capacitive Pressure Sensor

The capacitance of the sensor is then:

$$C = \frac{\varepsilon A}{d} = \frac{8.85*10^{-12} * \frac{\pi * .001^2}{4}}{2*10^{-6}} = 3.47\,pF \quad (1)$$

The pressure of the sound deforms the membrane. If the maximum deflection is h and the pressure P, we will have:

$$\frac{8}{3}\frac{E*t}{(1-v)R^2}h^3 + 4t\sigma_{res}h = PR^2 \qquad (2)$$

For conversation in 1 m distance from the microphone the pressure level (L_P) is around 50 db:

$$L_p = 20Log\frac{P_{rms}}{P_{ref}}db = 50db \qquad (3)$$

$$P_{ref} = 20\mu Pa \text{ then } P_{rms} = .006Pa \qquad (4)$$

Then the maximum deflection for this pressure will be 0.1 micron and the capacitance change because of the deflection:

$$\Delta C = \frac{\varepsilon A}{d^2}h = 0.2\,pF \qquad (5)$$

Now we can transfer the capacitance change to current change:

$$\frac{dQ}{dt} = C\frac{dV}{dt} + V\frac{dC}{dt} \qquad (6)$$

$$\frac{di}{dt} + \frac{1}{RC}i = \frac{(V_o - Ri)}{RC}\frac{dC}{dt} \qquad (7)$$

by assuming $\frac{1}{RC}i \gg \frac{di}{dt}$ and $V_o \gg Ri$ we will have:

$$i = V_o\frac{dC}{dt} \qquad (8)$$

The current change will be amplified and sent to the resonator to modulate the frequency.

II- Resonator

Fig. 4 gives an equivalent model of the vertically driven resonator [3].

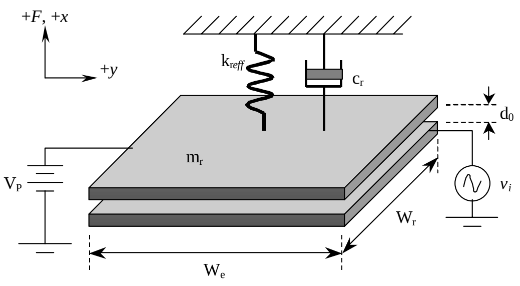


Fig.4 An analysis model of a vertically driven resonator.

The force is controlled by the bias voltage and the displacement of the plate. It can be calculated as below:

$$F = -\left.\frac{\partial W^{*}(V,x)}{\partial x}\right|_{V} = \frac{(V_P - v_i)^2}{2}\frac{\partial C}{\partial x} \qquad (9)$$

After ignoring the higher order term of x, the force is

$$F \approx -F_0\left(1-\frac{2}{d_0}x\right) \qquad (10)$$

where F_0 is denoted as

$$F_0 = \frac{1}{2}(V_P - v_i)^2\frac{C_0}{d_0} \approx \frac{1}{2}V_P^2\frac{C_0}{d_0} \qquad (11)$$

Thus, the mechanical system can be described in the following formula:

$$m_r\ddot{x} + k_{reff}\,x \approx -F_0\left(1-\frac{2}{d_0}x\right) \qquad (12)$$

Finally, the resonant frequency of this structure is

$$f = f_0\sqrt{1 - V_P^2\frac{eW_eL^3}{32Ed_0^3h^3}} \qquad (13)$$

It can be observed from equation (13) that the resonant frequency is controlled by the bias voltage Vp. Fig.5 shows the simulated frequency by equation (13) compared to the measured data good agreement can be observed. Therefore, after transferring the sound into voltage signal Vp(t), a frequency modulated signal can be obtained from this vertically driven resonator.

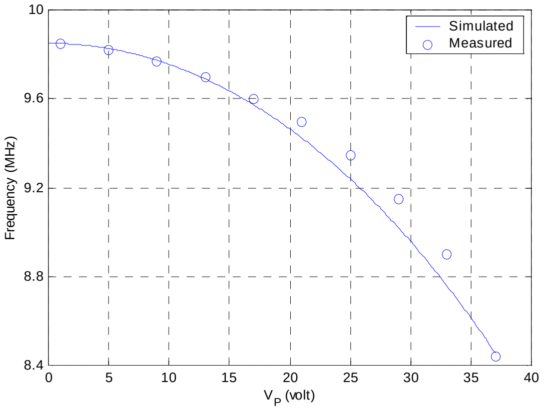


Fig.5 Comparison of the measured and simulated resonant frequency changes with control voltage.

Fabrication Considerations:

From the calculation of the membrane deflection, it is observed that to achieve an ultra-sensitive capacitive pressure sensor, a very large and thin diaphragm and a very small gap are needed. To this end, the dissolved wafer process will be used because of its simplicity [4, 5]. A silicon wafer is first dry etched to the desired height of the cavity and then selectively diffused with boron to define the radius of the pressure sensor. The depth of the boron diffusion determines the eventual thickness of the structural layer. The silicon wafer is then flipped over and anodically bonded to a glass wafer that has been inlaid with a Ti/Pt metal pattern that serves as the interconnect and provides the bond pads. The undoped Si is finally dissolved in ethylene diamine pyrocatechol (EDP), leaving the pressure sensor on the glass substrate. The key challenges in this sequence are the second lithography step and the anodic bonding, in both cases as a result of the high aspect ratio of the cavity sidewalls. To realize the FM modulation, a micromechanical clamped-clamped beam will be used to act as high frequency resonator. To date, the majority of micromechanical circuits for communication functions have been realized using this kind of micromechanical flexural-mode beam elements to get high frequency range and low series such as presented in [6]. This device consists of beam anchors (i.e. clamped) at the both ends, with an electrode underlying its central locations. Both the beam and electrode are constructed of constructive materials, such as metal, or doped silicon. The operation of this resonator beam microstructures in the ambient atmosphere results in low-quality factors of less than 100 due to air damping above and below the moving microstructure. Resonance quality factors from 100 to 10 000 are required for these devices for practical applications, hence, the hermetic sealing process has to be established. The processing procedure described in ref. [5] will be applied to make the wafer lever vacuum sealing of the resonator beam. This approach is promising to achiev high signal-to-noise ratio (with on-chip detection circuits) and high-quality factors of microelectromechanical resonators.

Conclusion:

In this paper, MEMS technique is applied to built a compact size, low power consumption wireless microphone. Two critical MEMS parts, a capacitive pressure sensor and a voltage controlled micromechanical oscillator, are discussed in details. A FM modulated signal is finally obtained.

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