Design and Simulation of a MicroElectroMechanical Resonator Oscillator

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ABSTRACT

In this paper a design of 458 kHz oscillator is simulated and prepared for implementation by properly adjusting the physical dimensions of the micromechanical resonator. The Dimensions of the resonator is tuned to achieve higher resonance frequencies. Electrical model and governing equations of interdigitated finger structure are studied. Based on results of these studies a micromechanical oscillator is designed to attain abovementioned frequency. The study is carried out both analytically and on the equivalent circuit.

Keywords: Oscillator, Microelectromechanical sytems (MEMS), Resonator.

1 INTRODUCTION

MicroElectroMechanical (MEM) vibrating structures such as linear drive resonators can be used as driving components in signal processing applications. The choice of these components is assisted by the fact that these MEM devices display high quality factor values when operated under vacuum. The design of a highly stable oscillator is an example utilizing the linear drive resonators and working samples are demonstrated at 16.5 kHz [1]. For this oscillator to be used in portable communication devices, the operating frequency will have to be increased to at least 455 kHz which is the threshold of IF.

As it has high Q (over 80.000 [3]) laterally driven microresonators can be a good miniaturized replacement of a crystal and surface acoustic wave (SAW) resonator based oscillators used in telecommunication applications. The electrical model of the microresonator is given and used as a frequency selective network in the oscillator design. The circuit is simulated at two different frequencies namely 62 kHz and 458 kHz. To derive oscillation frequency of this circuit first the gain of the system is derived and operating frequency is found. To see the consistency simulation results are validated with the theoretical values. Finally electrical noise analysis of the oscillator is done.

2 INTERDIGITATED MICROMECHANICAL RESONATOR

In this study a micromechanical resonator is employed as a transducing element. One criteria for oscillator design is high Q and since lateral drive micromechanical resonators show promising results for high Q, this structure is used as a transducing element as shown in Figure 1 in this work. Resonance frequency for this interdigitated-comb structure is given below for the purpose of designing optimum resonator dimensions [2].

$$f_r = \frac{1}{2\pi}\left(\frac{2\times E\times h\times\left(\dfrac{W}{L}\right)^3}{M_P+0.3714\times M}\right)^{1/2} \tag{1}$$

The resonance frequency of this micromechanical resonator is determined largely by W/L ratio of the folded beams. Therefore, by decreasing the length L of the beam and by keeping the other parameters in Equation 1 constant, the resonance frequency is tuned to the desired value.

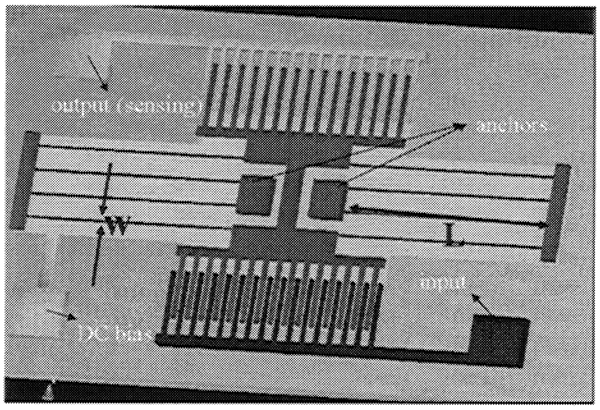

Figure 1: General view of a comb-transduced micromechanical resonator.

Figure 1 shows important dimensions in the resonator structure. In this structure AC signal is applied to the input drive electrode and the response is detected capacitevely at the output drive electrode. A DC voltage is applied to the resonator and its underlying ground plane to bias and excite the device [1]

Parameter		Value
E	Young's modulus:	150 GPa
μ	Absolute viscosity of air	17.46×10^{-6} Ns/m^2
H	Structure thickness	2 μm
W	Beam width	2 μm
L	Beam length	25μm
M	Mass (beam + truss)	1.791110^{-12} Kg
M_P	Shuttle mass	$3.4333\text{x } 10^{-11}$ Kg
k_{sys}	System spring constant	303.543 N/m
Q	Quality factor	1250.22
f_r	Resonance frequency	459.017 kHz

Table 1: Critical dimensions of 458 kHz microresonator used in the design of oscillator.

The variables as presented in Table 1 above, define critical parameters along with their values used in this study. The resonance frequency can be obtained by using combining information of Table 1 and Equation 1.

2.1 Electrical Model

It has been showed that the small-signal electrical equivalent of laterally driven comb-like microresonator can be represented as a series RLC circuit. Figure 2 shows circuit view of this model. In this model C1 represents the electrode-to-resonator capacitance when the resonator is motionless. Series RLC circuit represents circuit behavior when the resonator vibrates [1]. Therefore parallel capacitors can be ignored when constructing the simulation circuit.

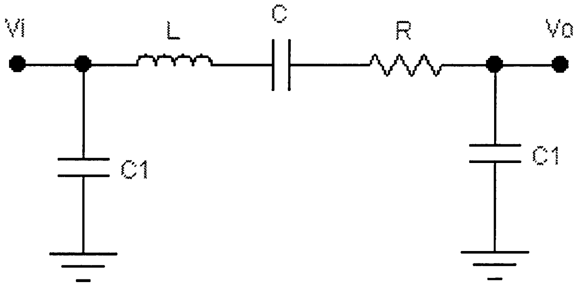

Figure 3: Electrical equivalent circuit of two-port micro electromechanical resonator.

Circuit component values are derived in [1] and given below.

$$R=\frac{\sqrt{m\times k_{sys}}}{Q\times\eta_n^2} \tag{3}$$

$$L=\frac{m}{\eta_n^2} \tag{4}$$

$$C=\frac{\eta_n^2}{k_{sys}} \tag{5}$$

Where $\eta_n = V_P\partial C/\partial x$, k_{sys} system spring constant and m is the effective mass.

Oscillator	R (MΩ)	L (kH)	C (fF)	$C1$ (fF)
at 458 kHz	4.6	20.222	0.0059	6.3
at 62 kHz	2.5	11.419	0.55	10.6

Table 2: Component values for two different frequencies.

The corresponding numbers used for the design of 458 kHz and 62 kHz oscillator respectively are tabulated above. The devices are assumed to operate under vacuum and hence have considerably small series resistance (R) values.

3 OSCILLATOR DESIGN

The basic structure of a sinusoidal oscillator consists of an amplifier and a frequency selective network connected in a positive-feedback loop. This can be illustrated in a block diagram as shown below [4].

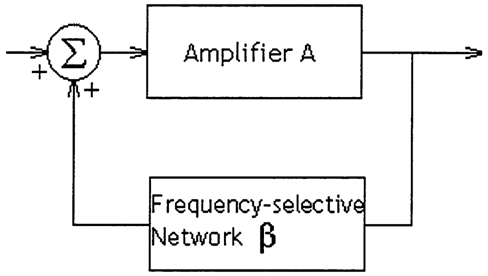

Figure 4: The basic structure of a sinusoidal oscillator.

For this block diagram the gain with feedback is given by Equation 6:

$$A_f(jw)=\frac{A(jw)}{1-A(jw)\beta(jw)} \tag{6}$$

The condition for the feedback loop of Figure 5 to provide sinusoidal oscillation of frequency w_0 is that [4]

$$L(jw_0)=A(jw_0)\beta(jw_0)=1 \tag{7}$$

It is important to mention that the frequency of oscillation is determined solely by the phase characteristic of the feedback loop. The loop oscillates at the frequency for which the phase is zero. Using micro resonator as a frequency selective network in the positive feedback loop we can construct the oscillator. Figure 5 shows us system level schematic of this work [5].

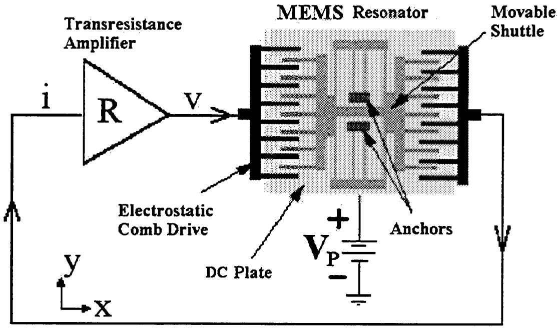

Figure 5: System level circuit schematic of the oscillator.

Therefore replacing the micro resonator with its electrical equivalent gives us following circuit.

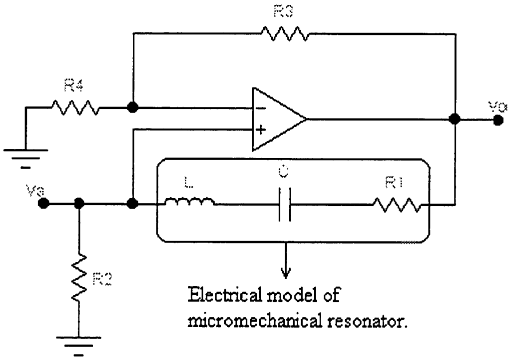

Figure 6: The circuit schematic of an oscillator used in the simulations.

The circuit of Figure 6 consists of an op amp connected in the noninverting configuration, with a closed-loop gain of $(1+R_2/R_1)$. In the positive feedback path electrical model of resonator is connected. Open loop gain of overall system can be easily obtained by multiplying the transfer function $V_a(jw)/V_o(jw)$ of the feedback network by the amplifier gain $(1+R_3/R_4)$.

$$L(jw)=\left[1+\frac{R_3}{R_4}\right]\frac{R_2}{(R_1+R_2)+jwL+\frac{1}{jwC}} \tag{8}$$

The frequency at which phase is zero will be the oscillation frequency. Therefore oscillation frequency of the above circuit will be:

$$w_0=\frac{1}{\sqrt{LC}} \tag{9}$$

4 SIMULATION RESULTS

4.1 Transient Analyses

The oscillator circuit is simulated for two different component values. The simulated values are taken from Table 2. Simulation results are verified with the theoretical values found by using Equation 9.

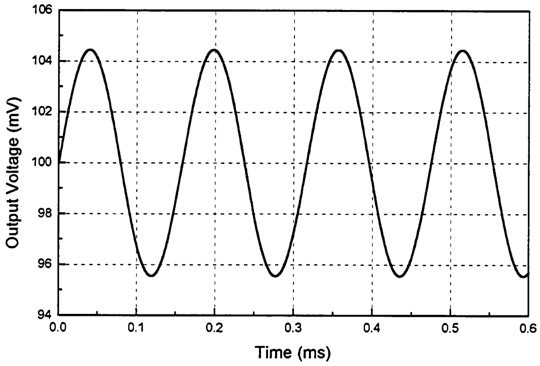

Figure 7: Simulation output at 62 kHz.

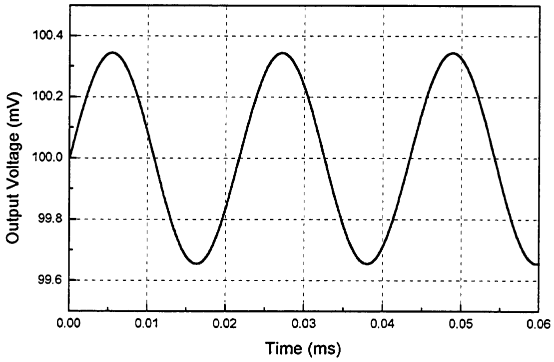

Figure 8: Simulation output at 458 kHz.

In order to obtain sustained oscillations the choice of the R_3 and R_4 is important. To ensure that the oscillation will start, R_3 should be chosen slightly greater than unity. The amplitude of oscillation can be determined and stabilized by using nonlinear control network. This can be realized by employing simple diode limiter circuits connected in the positive feedback loop.

Oscillator	Theoretical (kHz)	Simulated (kHz)
at 62 kHz	63.507	62.614
at 458 kHz	460.767	458.812

Table 3: Confirmation of the simulated values with the theoretical counterpart.

Table 3 summarizes the theoretical and simulation values obtained after the design. The values agree closely with each other and hence provide proof of Equation 9.

4.2 Noise Analyses

Noise is an important issue in oscillator. Especially the noise coming from electronics circuit must be minimized in order to obtain stable oscillation and low phase noise in this device. The circuit is simulated in terms of noise due to the variety of components connected in the circuit. This noise analysis is done using SPICE. In this analyses noise has variety of components these includes thermal, shot and flicker noise. The resulting graphic for the case of 458kHz is shown in Figure 9.

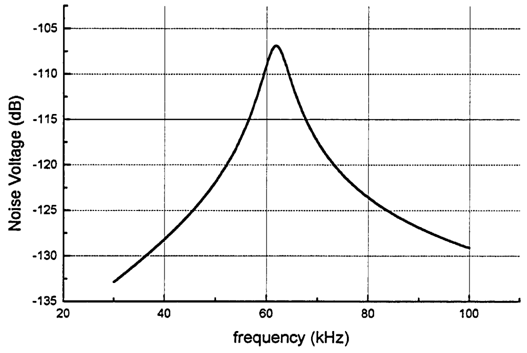

Figure 9: Noise spectral density. Note that noise increases around the operation frequency of oscillation.

We can see from Figure 9 that the noise voltage increases to maximum at the operating frequency which then contributes to the phase noise and degrades the overall performance of the oscillator.

5 CONCLUSION

A working oscillator oscillating at 458 kHz has shown to operate at the simulation level. The device dimensions are corrected and optimized to serve the proper frequency range. Noise analysis at circuit level is carried out and has shown to cause drastic device performance degradation. The future work will focus on design and implementation of fully monolithic microresonator oscillator with oscillating frequency in the IF band. The device miniaturization issues at higher frequency for instance increasing noise, damping and instability will be taken into account.

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