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Design and Modeling of Nonlinear Coupled Mems Resonator using Electrostatic Actuation for L-Band Mobile Satellite Communication

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Abstract : This research presents a Micro Electro-Mechanical System (MEMS) resonator structure a creative style and miniature sizing to meet the requirements of performance.There are essentially grown an interconnection of mass, spring and actuators to perform the desired functions. The goals of inter-digitated comb finger structures are demonstrated to be effective for electrostatically exciting the resonance of microstructures and characteristics of static displacement.The aim of this paper focused on exploiting nonlinear behavior arises from coupled effects of the flexural beam structure on a mechanical system and coupling to improve the performance of MEMS resonators using sensing applications. The key research presents output are resonant frequencies of the laterally-driven structures range 1.6 GHz, quality factors range 32 in air and capacitance displacement of 4.425 fF. For developing the comb drive resonator structure driving voltages are applied to inter-digitated comb fingers and this voltage produces an electrostatic force between movable finger and fixed fingers. Since the overlapping comb fingers are used to generate capacitive coupling for the actuation mechanism on lateral and transversal movements. The device using two sets of non inter-digitated comb drives, one for tuning and one for actuation, that allow the effective linear and nonlinear stiffness to be electrostatically tuned. This work mainly focuses on the design and testing of tunable parametrically excited MEMS resonators to demonstrate a novel nonlinear tuning scheme developed for communication systems.The modeling, analysis and design of these MEMS resonators are presented.The electrostatic actuation on a comb drives MEMS resonator has be suitable for L band use of mobile satellite communication system applications. The geometries are two dimensional structures based on the coupled nonlinear electrostatic comb drive MEMS resonator is designed and analyzed for using COMSOL Multiphysics 4.4 software. The measured data are compared with the analytical and simulation results.

Keywords : Coupled MEMS resonator, Nonlinear characteristics, Electrostatic actuation, Capacitance sensing and mobile satellite communication.

1. Introduction

Micro electromechanical systems (MEMS) are miniaturized devices can be developed with the advancement of the MEMS technology. The coupled comb-drive MEMS resonator is one of the most principle designs based on electrostatic actuation [1,2]. In recent years, coupled MEMS resonator is growingly as parts of sensor and actuator systems have been used in various application fields such as gyroscopes, wireless communications, filters [3,4,5].The proposed device can be used for mobile satellite communications with operates for the resonant frequencies in GHz range and high quality factors. Depending on the methods of electrostatic actuation and design, the specific MEMS resonator devices are recognized properties to produce nonlinear responses at a large amplitude excitation force in the hard-spring effect or soft-spring effect [6,7]. Hence the device is an amplitude-resonance frequency responses curve tends to bend toward higher or lower frequencies of the nonlinear responses is exhibited. These actuation mechanisms are known as two inter-digitated comb fingers in the laterally driven comb-drive resonator. This behavior can determine for nonlinear effects on the parametric resonance in mass sensor with the comb drive actuator [1,7]. The study presented in this paper offers a design and modeling of the specific MEMS resonators in the nonlinear coupled system. However the electrostatic comb-fingers structures have been capacitance, tunable and adjustable are key elements in the design process to control or detect the resonant frequency of the structure. Therefore the MEMS resonator is vibrating various modes an excited electrostatic force is developed for coupled MEMS resonator in MEMS terminology. The devices of coupled nonlinear response can exhibit at a higher vibration amplitude and the particular hard spring effect in electrostatically excited comb-drive resonator[8]. The paper is organized as follows: First in section 2, the design process of a coupled MEMS resonator is depicted and its nonlinear resonance properties are described. Next the characteristics of the theoretical model are studied and the results from the simulation results in section 3. Finally the simulations of the lateral movement of the operation as considerable of comb drive and spring suspension are presented.

2. Design of a Coupled MEMS Resonator

2.1. Structure of a Coupled MEMS Resonator

Figure.1 shows the illustrates a coupled MEMS comb drive resonator that can be used prototype design of Multiphysics model. The laterally driven comb drive device consists of two inter-digitated comb fingers on fixed and movable is connected to perforated mass which is suspended by flexural folded beam. This flexural folded beam pairs are attached to the trusses. The device is designed for x-y direction to produce on stable oscillation. The proposed method is development of resonator device, when a voltage is applied between the fixed combs and the movable combs and it generates an electric field E [9]. Therefore the coupled MEMS resonator structure moves on in the x-direction of the actuation forces as the suspended folded beams in that direction. Generally the current motion which is propositional to change in the capacitance between the movable and fixed comb fingers at the excitation voltages is measured and also the resonator generates the maximum total displacement at the resonant frequency. These features mentioned for reduce axial stress, restrict out of plane movement and the device minimize unstable end unwanted vibrations in the other axes [10]. However the important dimensions and features of the devices are follows as table 1.

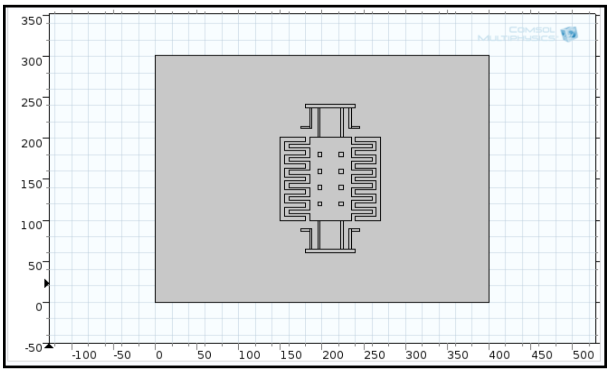


Figure.1 Coupled MEMS Resonators in 2D view

Important dimensions of the coupled MEMS resonator show in the figure.1.

Table.1. Important parameters of the device

Part description	**Designed values**
Structure thickness T_{th}	1μm
No.of movable fingers (one side)	6
Mass length x width	100 μm x 50 μm
Gap (g)	3 μm

Comb finger length x width	25 µm x 5 µm
Overlapping length, (s)	20 µm
Inner beam length x width	35 µm x 3 µm
Outer beam length x width	25 µm x 3 µm
Truss length x width	60 µm x 5 µm
Anchor size width×length	10 µm ×5 µm

2.2. Electrostatic Forces

The static capacitance between the movable comb and fixed comb fingers are either side changes of the devices shown in the figure 1. The change in capacitance can be expressed as:

$$C(x) = \frac{2N\varepsilon_0(s+x)T_{th}}{g} \qquad (1)$$

Where, N is the total number of movable comb fingers, x is the displacement in x direction, s is the overlap comb finger, T_{th} is the thickness of the structure and g is the gap between the fixed and movable comb fingers on the one side.

2.3. Modeling of the Coupled MEMS Resonator

The modeling is a laterally driven comb-drive resonator an one degree of freedom can be represented as,

$$mx^2 + cx^1 + kx = F_e \qquad (2)$$

Where, x is the displacement along the x-axis, m is the total mass including the fingers, c is the damping co-efficient. Here it is assumed that as F_e changes direction and due to the change in polarity of V. Therefore the storing force F_k and the damping force F_d also change their directions to oppose F_e.

2.3.1. Nonlinear system

Nonlinear system of MEMS resonator is a large deformation in the flexural folded beam pair with identical lengths can be harden of the beams as known observed[11,12,13]. When the force is applied to the beams, the energy potential is stored in the form of elastic deformation energy in the entire beam span which solution in the linear elastic restoring force that is governed by Hooke's law and additional reaction forces due to axial loading. As a result the folded beams harden when they are driven by large force and this can lead to the nonlinear restoring force. These device creates a ratio between the inner beams and outer beams L_{ib} = 35um and L_{ob} = 25um, $K_{ob}/K_{ib}=L^3_{ib}/L^3_{ob}$ = 1.4. Here it can be seen that the inner beam exhibits linear behavior over a large displacement range and has a smaller spring constant. Beyond this range, the inner beam shows nonlinearity. The outer beam also exhibits substantial non-linearity when driven by a large force as it causes large deformation and it hardens more than the inner beam. Note that this simulation indicates the hard-spring effect in both the beams. Here the difference between the inner beam stiffness and outer beam stiffness is taken to compare the mismatch between the two beams as if they were uncoupled. Note that this simulation is based on static displacement and does not accurately predict the dynamic behavior.

2.4.1. Parameter values

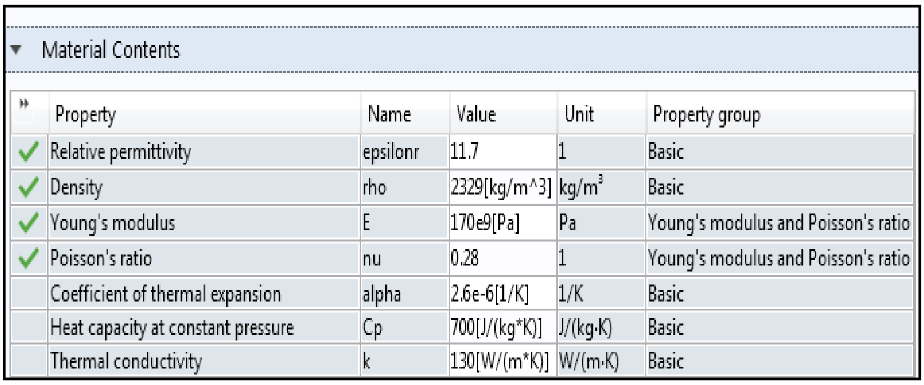
The mass can be derived from is $M = A\rho h = 55.9 \times 10^{-12} kg,$ where A the total area is obtained from the structure layout, h is the structural thickness and ρ is the density of Silicon in $2.33 \times 10^3 kg/m^3$. The spring values calculated from folded beams and the spring approximated constant $K = 5.9 \times 10^3\ N/m$. The resonance frequencies vales is 1.6 GHz obtained from $f_r = \frac{1}{2\pi}[K/M]$, Other important parameters on quality factor, estimating the damping effect of the system is one of the most important steps in the analysis and design process of the MEMS resonators. The Q factor as a function of air damping is expressed as $Q = \frac{k}{f_r C_{Total}}$ Where C_{Total} is the total damping coefficient (Nsm^{-1}), k is spring constant and f_r is resonance frequency. The effects of air damping are approximated by two mechanism slide film and squeeze film damping. That Quality factor range is 32 laterally driven on MEMS resonator.

3. Simulation Results

3.1 Design of MEMS Resonator 2D Model

The coupled MEMS resonator is designed by a structural mechanism and there are two material properties are used in the device shows the table 2 & 3. The silicon material is applied to the structure surround by air medium.

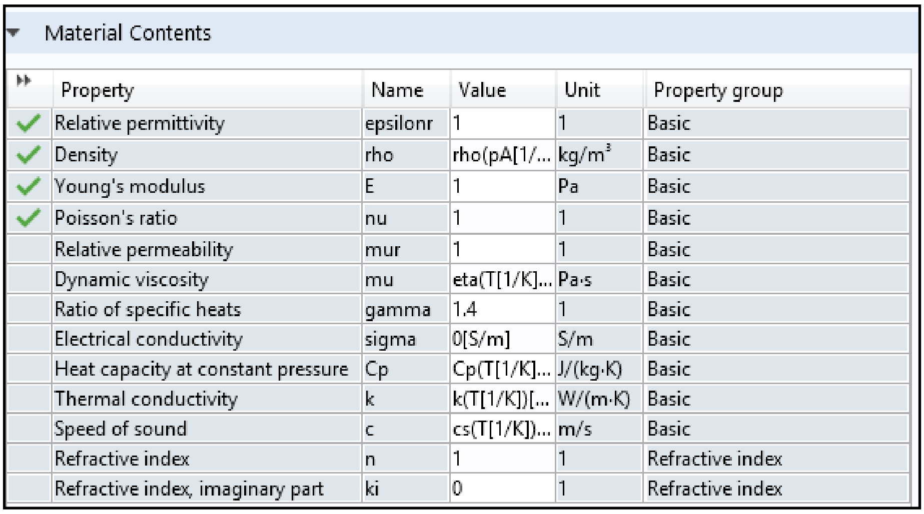
Table.2 Silicon material property



Material Contents

	Property	Name	Value	Unit	Property group
✓	Relative permittivity	epsilonr	11.7	1	Basic
✓	Density	rho	2329[kg/m^3]	kg/m^3	Basic
✓	Young's modulus	E	170e9[Pa]	Pa	Young's modulus and Poisson's ratio
✓	Poisson's ratio	nu	0.28	1	Young's modulus and Poisson's ratio
	Coefficient of thermal expansion	alpha	2.6e-6[1/K]	1/K	Basic
	Heat capacity at constant pressure	Cp	700[J/(kg*K)]	J/(kg·K)	Basic
	Thermal conductivity	k	130[W/(m*K)]	W/(m·K)	Basic

Table.3 Air material property



Material Contents

	Property	Name	Value	Unit	Property group
✓	Relative permittivity	epsilonr	1	1	Basic
✓	Density	rho	rho(pA[1/...	kg/m^3	Basic
✓	Young's modulus	E	1	Pa	Basic
✓	Poisson's ratio	nu	1	1	Basic
	Relative permeability	mur	1	1	Basic
	Dynamic viscosity	mu	eta(T[1/K]...	Pa·s	Basic
	Ratio of specific heats	gamma	1.4	1	Basic
	Electrical conductivity	sigma	0[S/m]	S/m	Basic
	Heat capacity at constant pressure	Cp	Cp(T[1/K]...	J/(kg·K)	Basic
	Thermal conductivity	k	k(T[1/K])[...	W/(m·K)	Basic
	Speed of sound	c	cs(T[1/K])...	m/s	Basic
	Refractive index	n	1	1	Refractive index
	Refractive index, imaginary part	ki	0	1	Refractive index

Free triangular meshing is done for the geometry to compute the finite element analysis. The mesh is presented in general physics of the triangular specification show in figure 3.2.

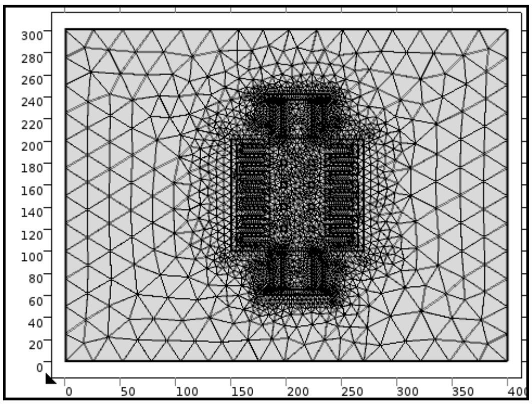


Figure 3.2 Triangular Mesh

3.2 Electrostatic Actuation

The 2D structure is actuated the electric potential distribution on 2V and 5V shows in figure 3.3 and 3.4. First this paper focuses an electrostatic force production in laterally driven on y direction. Next, the nonlinearity in MEMS resonator is presented in hard spring flexural folded beam. The beam displacement is total displacement a 1V and 4V shows in figure 3.5 and 3.6 in the presented.

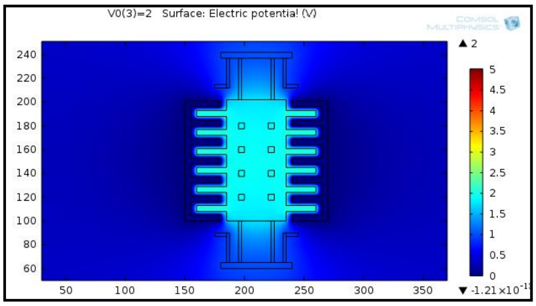


Figure 3.3 Electric potential 2V

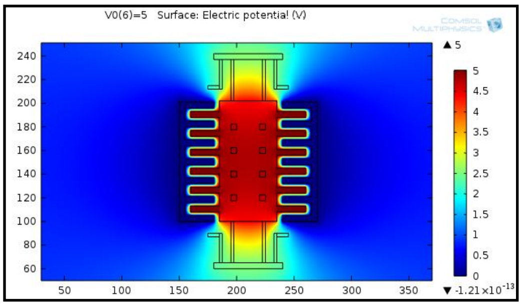


Figure 3.4 Electric potential 5 V

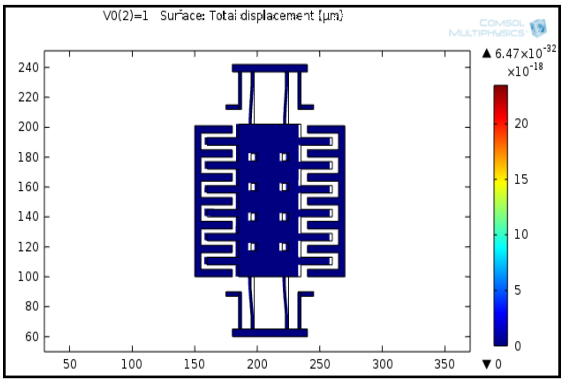


Figure 3.5 Total displacement of 1V

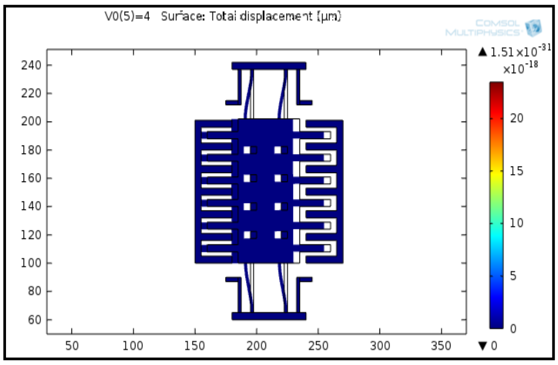


Figure 3.6 Total displacements 4 V

3.3. Nonlinear Characteristics

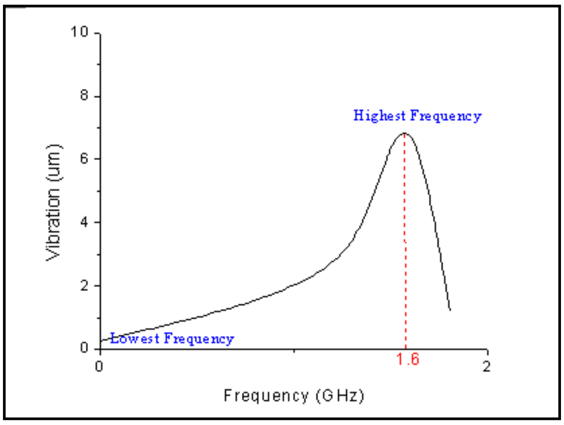


Figure 3.7 Resonance Frequencies

The result is shown in figure 3.7 resonance frequency and if nonlinearity characteristics. These characteristics are driven on large forces applied to structure can present the electrostatic force in capacitance sensing for energy. The figure .3.7 analyze for hysteresis characteristics is any two points during the highest and lowest of the frequency. Since the shift in resonance frequency that the coupled MEMS resonator is exhibits spring-hardening effect. However in vacuum at 170GPa, this effect is more pronounced while varying dc bias from 0V to 5V. The characteristics focus on specific value of the frequency during upsweep, the resonator cannot maintain the high amplitude as it becomes an unstable and begins to vibrate at lower amplitude in order to sustain the oscillations.

3.4. Capacitance Measurements

The figure 3.8 shows that linear displacement of the comb fingers. The flexural folded beam is displaced to the y-direction and it depends on voltages and its static displacement. Here electrostatic force is produced on two overlapping comb fingers as well capacitance sensing can be done using this resonator device.

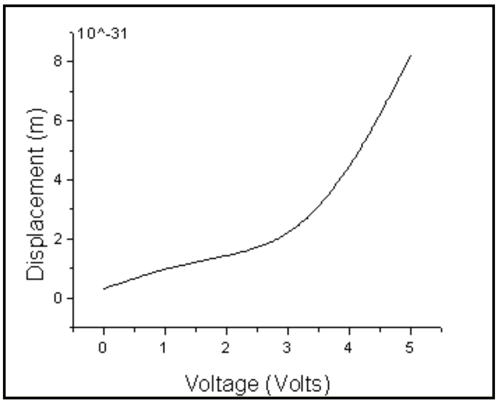


Figure 3.8 Displacement vs voltages

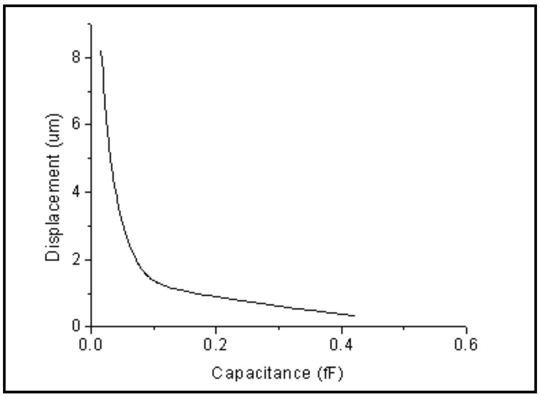


Figure 3.9 Capacitance vs Displacement

The applied voltage is increasing corresponding displacement is also increased. Capacitance sensing electrostatic comb drive resonator is reported [14]. These capacitance sensing is only lateral direction produces large electrostatic force and transverse direction produces in small electrostatic force dependent on the electric potential. Here some energy is stored by the coupled MEMS resonator. However the capacitance increasing while distance between the movable and fixed comb finger (two parallel plates) gap is very small and this coupled MEMS resonator is for small micro-scale. The graphical representation shows in figure 3.9 capacitance vs displacement. In this work capacitance sensing in the lateral direction of the comb fingers for the capacitance values are correlated to the maximum deflection of the mass in y direction.

3.5. Discussions

This paper presents the coupled MEMS resonator is mainly work based on the principle of electrostatic actuation. These electrostatic actuations are driven on laterally mode and transverse mode in the electrostatic forces. The coupled MEMS resonator is between the movable and fixed comb fingers produce an electrostatic force and some energy stored. Various parameter values are measured like resonator frequency, quality factor, displacement and capacitance. Hence the graphical representation also described. The application of this coupled nonlinear comb-drive MEMS resonator is used as tunable MEMS resonator based on the resonator frequencies and capacitance. This tunable MEMS resonator is used in mobile satellite communication. The satellite connectivity to mobile users can be providing by international maritime satellite. This kind of MEMS resonators is very much useful in transreceiver circuit of mobile phones and L-band satellite communication.

4. Conclusion

This research work is mainly designed for modeling and characterizing the nonlinear coupled MEMS resonator. This paper focuses on nonlinear coupled MEMS resonator for electrostatic actuation. In this study laterally driven an electrostatic force comb drive, is designed for capacitance sensing and nonlinear MEMS resonator can exhibited for the hard spring response. Hence the analytical calculation and simulation analysis are described. However the working principle and dimensional parameters of the coupled MEMS resonator are determined and simulated by COMSOL Multiphysics 4.4. The solution of quality factor is very well, capacitance sensing range 4.425fF and the resonance frequency is 1.6 GHz is use for mobile satellite communication application.

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