Makara Journal of Technology

Volume 18 | Number 2 Article 2

8-2-2014

Adjustable Resonance Frequency of RF-MEMS Capacitor by Using Comb- Drive Actuators: A Design Approaches

Agus Santoso Tamsir
Head of MinaEMS-RG (Micro-Nano Electro-Mechanical System-Research Group), Department of Electrical Engineering, Universitas Indonesia, Depok 16424, Indonesia, tamsir@vlsi.eng.ukm

Sandy Tannu Wijaya
Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia

Dato' Burhanuddin Yeop Majlis
Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Recommended Citation
Tamsir, Agus Santoso; Wijaya, Sandy Tannu; and Majlis, Dato' Burhanuddin Yeop (2014) "Adjustable Resonance Frequency of RF-MEMS Capacitor by Using Comb- Drive Actuators: A Design Approaches," *Makara Journal of Technology*: Vol. 18 : No. 2 , Article 2.
DOI: 10.7454/mst.v18i2.2942
Available at: https://scholarhub.ui.ac.id/mjt/vol18/iss2/2

Makara J. Technol. 18/2 (2014), 59-62
doi: 10.7454/mst.v18i2.2942

Adjustable Resonance Frequency of RF-MEMS Capacitor by Using Comb-Drive Actuators: A Design Approaches

Agus Santoso Tamsir[1*], Sandy Tannu Wijaya[2], and Dato' Burhanuddin Yeop Majlis[3]

1. Head of MinaEMS-RG (Micro-Nano Electro-Mechanical System-Research Group), Department of Electrical Engineering, Universitas Indonesia, Depok 16424, Indonesia
2. Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia
3. Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

[*]*e-mail: tamsir@vlsi.eng.ukm.my; agus.santoso@ui.ac.id*

Abstract

The needs of smaller size RF varactor is a must today, and MEMS comes to be the potential one. In this paper we proposed an adjustable resonance RF-MEMS varactor by using comb-drive actuators placing in each side of the square movable plate. In our preliminary simulation, we found that the device can work properly but some constraints comes such as the dominancies of harmonic resonance frequencies that influences into the nominal capacitances. Therefore for the next step of development we have to find out the window of the structural dimension for a certain spans and a certain operating frequencies.

Abstrak

Frekuensi Resonansi yang dapat Disesuaikan dari Kapasitor RF-MEMS dengan Menggunakan Aktuator *Comb-Drive*: Pendekatan Rancangan. Kebutuhan RF varactor berukuran lebih kecil merupakan keharusan sekarang ini, dan MEMS menjadi yang berpotensial. Dalam makalah ini kami mengusulkan RF-MEMS *varactor* resonansi yang dapat disesuaikan dengan menggunakan aktuator *comb-drive* yang diletakkan pada masing-masing sisi pelat segi empat yang dapat bergerak. Dalam simulasi awal yang kami lakukan, kami menemukan bahwa peralatan ini dapat bekerja dengan baik tetapi terdapat beberapa kendala seperti dominansi frekuensi resonansi harmonis yang mempengaruhi ke dalam kapasitansi nominal. Oleh karena itu, untuk langkah perkembangan berikutnya kami harus mengetahui jendela dimensi struktural untuk rentang tertentu dan frekuensi pengoperasian tertentu.

Keywords: capacitor, comb-drive actuators, resonance frequencies, RF-MEMS varactor

1. Introduction

An RF-MEMS variable capacitor (varactor) has replaced a conventional one due to very small size, high-quality of large tunability range, and low tuning voltage spans. Some researchers already developed the RF-MEMS varactor such as the parallel-plate capacitor, Young, et al. [1] in which the top plate was suspended by cantilever beam with a nominal capacitance of 2 pF and a *Q* of 62 at 1 GHz and tunning range of 16% over 5.5 V, later on a nominal capacitance of 4 pF with a *Q* of 9.6 at 1 GHz and tunning range of 25% by using polysilicon surface-micromachining process has been proposed by Dec et al. [2], the movable-dielectric varactor, Yoon et al. [3] for eliminating the trade-off between *Q* and actuation voltage with nominal capacitance of 1.14 pF which characterized between 0.6 and 6 GHz exhibited a *Q* of 218 at 1 GHz and tuning range of 40% for more than 10 V, a digitally controlled parallel-plate varactor which varies both the interplate distance and the capacitor area with typical performance of 1 pF for an interplate distance of 2 μm and a *Q* of 140 at 745 MHz and a tuning range of 400% for a voltage span of 35 V. In terms of suspending approaches, we observed the four suspending type of upper plate such as oblique suspender MEMS varactor, Nabovati et al. [4] and MEMS varactor using thermal actuator [5].

From the suspending approaches above, for a wider frequency range, we propose a horizontal square plates varactor with upper movable plate and adjusted the spring

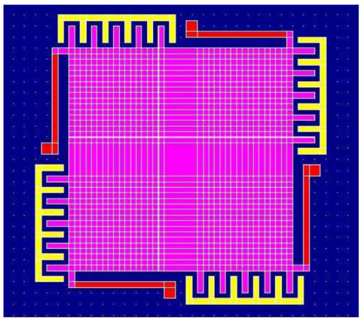

Figure 1. The Top-view of Upper Square Plate of the Adjustable Resonance Frequency Varactor by Using Comb-drive Actuator at Each Sides

constant by using comb-drive actuator at the four sides of the square plate as shown in Figure 1. For the preliminary study we just observed the nominal and changing capacitance, the changing of resonance frequency due to electrostatic softening forces by changing the voltage applied to the comb-drive actuator and the pull-in voltage of the system. The design observation has been done for 25 x 25 µm and 50 x 50 µm, 100 x 100 µm, 150 x 150 µm, and 200 x 200 µm.

2. Methods

For the design observation purposes, we do two approaches such as simulation by using Intellisuite (in collaboration with IMEN-UKM) and some analytical approaches for calculating the fix spring constant and the pull-in voltages [6-7]. For the fix spring constant we use crab-leg beam as define below

$$k_z = 48S_{ea}S_{eb}\left(S_{gb}L_a + S_{ea}L_b\right)\left(S_{eb}L_a + S_{ga}L_b\right)/ \quad S_{eb}^2 S_{gb} L_a^5 + 4S_{ea}S_{eb}^2 L_a^4 L_b + S_{eb}S_{ga}S_{gb}L_a^4 L_b + 4S_{ea}S_{eb}S_{ga}L_a^3 L_b^2 + 4S_{ea}S_{eb}S_{gb}L_a^2 L_b^3 \tag{1}$$

where $S_{ea} = EI_{x,a}$, $S_{eb} = EI_{x,b}$, $S_{ga} \equiv GJ_a$, and $S_{gb} \equiv GJ_b$.E is Young's modulus of material used for the varactor, $I_{x,a}$ and I_{xb} are the moment of inertia of the beam, G is the Torsion's modulus, and J_a and J_b are the torsion constants.

For the pull-in voltage, we use an approach as follows

$$V_p = \frac{2d}{3}\sqrt{\frac{2kd}{3sA}} = 0.544d\sqrt{\frac{k}{C_0}} \tag{2}$$

Where k is the spring constant of the crab-leg flexure, d is the distance between the upper movable square plate and the lower fixed plate, A is the area of the square plate, and ε is the dielectric of the medium between the two plates.

3. Results and Discussion

By defining the structural dimension of the devices as depicted in Table 1, we could get the analytical result for the electrostatic force as shown in Figure 2.

By calculating the crab-leg flexure of as defined by the structural dimension stated in Table 1, we found the fix spring constant of the flexures as described in Figure 3.

Based on the structural dimension of the devices, we found by analytical approaches, the pull-in voltage of the devices as shown in Table 2.

Table 1. The Structural Dimension of the Adjustable Resonance Frequency of RF-MEMS Varactor

Dimension of Plates (µm)	Plates Thickness (µm)	*Comb-drive* Length (µm)	*Comb-drive* Width (µm)	Plates Distance (µm)	Thigh Length (µm)	Thigh Width (µm)	Shin Length (µm)	Shin Width (µm)
200x200	1	25	5	20	30	5	70	5
150x150	0.75	18.75	3.75	15	22.5	3.75	52.5	3.75
100x100	0.5	12.5	2.5	10	15	2.5	35	2.5
50x50	0.25	6.25	1.25	5	7.5	1.25	17.5	1.25
25x25	0.125	3.125	0.675	2.5	4.05	0.675	9.45	0.675

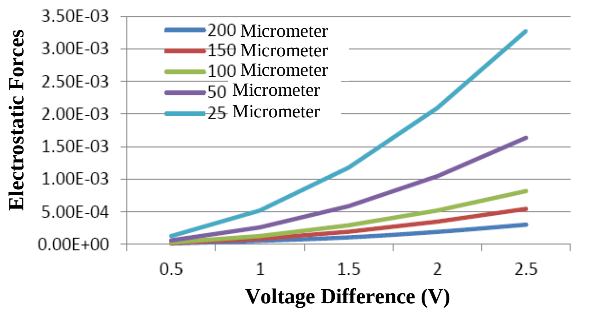

Figure 2. Plot of Analytical Approach Electrostatic Forces as a Function of DC Voltage Applied to the Comb-drive Actuator

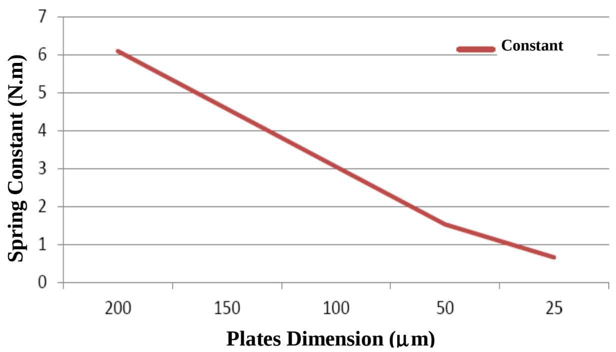

Figure 3. The Plot of the Spring Constant of the Flexures as Defined by Table 1 as a Function of the Size of the Plates

From simulation, we found the influences of the variations of the voltage applied into the comb-drive actuators to the resonance frequencies as plotted in Figure 4.

Due to inconsistent variation of the structural dimensions we have defined in Table 1, we found in Figure 4 uncertainty changing of the resonance frequencies as a function of the voltage applying into the comb-drive actuators. Anyway, we still could conclude that the combination of structural dimension we defined at 100 x 100 μm gives a better changing of the resonance frequencies. Anyway, in general, by our hypothetical point of view we are sure that the change of the voltage applied into the comb-drive actuator with a constant defined of structural dimension will give change into the resonance frequency of such device based on simple equations of resonance frequency, $\omega = \sqrt{(k_{fl} + k_e)/m}$. The k_{fl} is similar with equation (1), the k_e as defined Figure 3, and the *m* is the mass of the movable square plate (depends on the structural dimension).

By changing the voltage applied into the comb-drive actuator, we have simulated the nominal capacitances of the devices as shown in Figure 5. The rapid changing of the nominal capacitance for 200 x 200 µm and 100 x 100 µm we predicted due to the dominance of the harmonic resonance frequency of the device, meanwhile at the other structure, the changing quite small. By our hypothetical point of view, the greater the spring constant will give the movement of the movable plate shorter and gives the nominal capacitance value lower. But, the problem we have to consider is the trade-off between the mass, spring constant, and the damping ration will changing the dominancy of the resonance frequency into the harmonic one.

Table 2. The Analytical Approaches of the Pull-in Voltage of the Devices

Ukuran Pelat (µm)	Beda Tegangan (V)				
	0.5	1	1.5	2	2.5
200x200	201.8534251	201.8561553	201.8596	201.8653	201.8725
150x150	151.3907024	151.3950473	151.4023	151.4124	151.4255
100x100	100.9283419	100.9348589	100.9457	100.9609	100.9805
50x50	50.46742946	50.48046149	50.50217	50.53256	50.57159
25x25	23.37192241	23.40004942	23.44685	23.51222	23.596

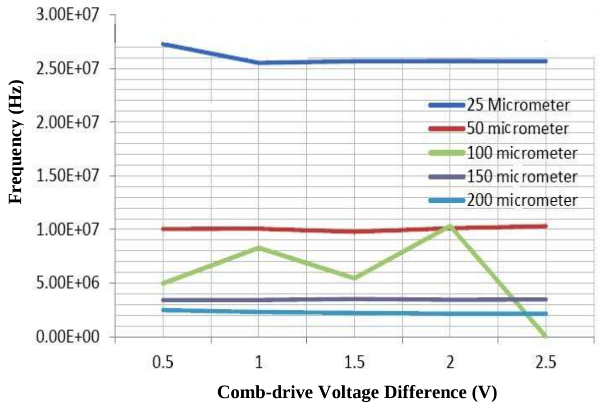

Figure 4. The Changing of Resonance Frequencies as a Function of Voltage Variation Applied into the Comb-drive Actuators

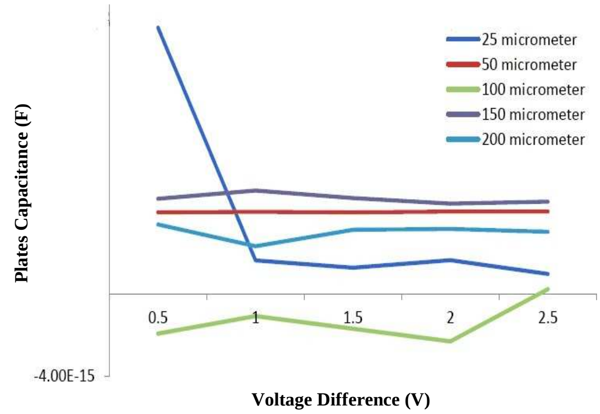

Figure 5. Plot of Nominal Capacitance Changing Due to Voltage Applied into Comb-drive Actuators

4. Conclusions

The works still in the preliminary stage, but we still can conclude that the influence of voltage applying into the comb-drive actuator gives changing in the value of resonance frequencies and nominal capacitance of the devices. The adjustment of the resonance frequency and nominal capacitance are quite crucial or must be defined very carefully due to the possibility of the dominance of the harmonic resonance frequencies. The dominance of the harmonic resonance frequencies will make device undeterministic.

References

[1] D.J. Young, B.E. Boser, A Micro-machined Variable Capacitor for Monolithic Low-Noise VCOs, Proceedings of International Conference on Solid-State Sensor and Actuator, IEEE, Washington, DC, 1996, p.86.

[2] A. Dec, K. Suyama, IEEE Transactions on Microwave Theory Technol. 46/2 (1998) 2587.

[3] J.-B. Yoon, C.T.-C. Nguyen, IEEE Technical Digest. International Electron Devices Meeting, San Fransisco, CA, USA, 2000, 489.

[4] H. Nabovati, K. Mafinejad, H. Keshmiri, A. Nabovati, J. Scientia Iranica, 13/1 (2006) 60.

[5] J. Mireles Jr., H. Ochoa, V. Hinostroza, J. Computación y Sistemas 10/1 (2006) 1.
[6] A. Selvakumar, Ph.D Dissertation, University Michigan, Ann Arbor, Michigan, 1997.
[7] G.K. Fedder, Ph.D Dissertation, Engineering-Electrical Engineering and Computer Sciences, University of California, 1994.