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Design and Investigation of RF MEMS Switch

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Abstract – **In the last 5-10 years, the high frequency (RF) applications of MicroElectroMechanical Systems (MEMS) devices have reached significant progress, because of their low price, technology, matched with the ordinary microelectronic technologies, good RF parameters and yield.**

The process of research, investigation and design of RF MEMS switch are presented. The results from this process, in connection with the design of ordinary RF coplanar transmission line, interrupted RF coplanar transmission line and their combination with a contacting metal electrode are shown.

Keywords – **Radio Frequency (RF), RF MEMS, RF MEMS Switch, PolyMUMPs, SOFTMEMS, CADENCE**

I. INTRODUCTION

The high frequency (RF) applications of different microelectronic devices include also the using of RF MicroElectroMechanical System (RF MEMS) devices.

Some of the representatives of this group are RF MEMS devices, such as:

- 3D Inductors,
- Capacitors with variable capacitances,
- RF switches,
- Antennas,
- Tuned filters,
- Transmission lines,
- Phase shifters.

Depending on their applications and design, these devices could be used up to different frequencies, [1], [2], [3], [4].

Some of the main areas of application of RF devices are:

- Mobile communications (GSM, Bluetooth),
- Wireless Local Area Networks (WLAN),
- Satellite communications (Mobile Satellite Services – MSS, Navigation Systems – GPS, Direct TV Broadcasting – DBS, Satellite telephones, Weather Satellite Services etc.),
- Automotive electronics (NOD – System for distinguishing and identification of nearby standing objects, Shock preventing detector, Radar illumination detector, Vehicle identification, Speed control System etc.)
- Military and defense systems (Electronic Warfare – EW, Surveillance and detection Systems etc.).

Depending on the applications, RF MEMS could work at frequencies, up to 2 GHz for Mobile communications and higher than 30-40 GHz for Satellite communications.

Some of the main advantages of RF MEMS devices are in connection with their technology, compatibility with the ordinary microelectronic technologies, very high precision of structures, batch process, giving the possibility of law prices and short production process, small dimensions of the devices with law consumption. The main advantage is the possibility for device integration, using the microelectronic production process, giving the possibility of creating so called “smart” sensors, combining the sensing and actuating part of the system with signal processing.

There are several different types RF MEMS devices, some of them are still on the stage of design and investigation. The most of them are based on the principle of micromechanical actuation for changing of some of the important parameters, such as resistance, inductance, capacitance and the characteristic impedance, ensuring the design of more sophisticated systems, such as transmission lines, filters, phase shifters, antennas etc.

II. RF MEMS SWITCH

RF MEMS switches should have very low resistance, lower than 1 Ohm in ON-position and very high resistance in OFF-position. This is very important at very high frequencies (RF), in order not to deteriorate the impedance of the transmission lines, which usually has the value of 50 Ohm. RF MEMS switches should have very low power consumption, in order not to introduce some parasitic disturbances in the transmitted signal.

The main ways of actuation of the switch could be thermal, electrostatic, magnetostatic or piezoelectric and their main characteristics are shown in Table 1. The thermal and magnetostatic switches, besides their higher current and power consumption, they are too slow. The time of reaction is in the range between 300 and 10,000 μs. The piezoelectric switch has good electrical parameters, but in technological sense, it is not very convenient and cheap.

Table 1

Actuation mechanism	Voltage [V]	Current [mA]	Power [mW]	Dimensions	Switching time [μs]	Switching force [μN]
electrostatic	10 - 80	≈ 0	≈ 0	small	1 - 200	50 - 1000
thermal	3 - 5	5 - 10	0-200	big	300-10000	500-4000
magnetostatic	3 - 5	20 - 150	0-100	medium	300 - 1000	50 - 200
piezoelectric	3 - 20	≈ 0	≈ 0	medium	50-500	50 - 200

In the case of electrostatic actuation, the principle of the simple attraction between two electrodes, charged with opposite polarity, is used. The first of these electrodes is a tightly fixed to the substrate. The second, the movable, contacting electrode is made as a low resistivity metal structure, suspended on two or several springs, in position over the contact structure, so called OFF-position.

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The aim of this paper is to design a RF MEMS switch with electrostatic actuation, using coplanar transmission 50 Ohm line and metal contact electrode with the following parameters:

- Frequency of the transmitted signal – 1-50 GHz,
- Switching frequency – 30 kHz,
- Capacitance of the switch
  in OFF position – 40-80 fF,
- Isolation - -45 dB,
- Inserted losses – 0,2-0,5 Ohm,
- Actuating voltage – 2-5 V.

III. DESIGN OF RF COPLANAR LINE

The design process should be divided in several steps. [1], [2], [3], [4].

Firstly, a coplanar transmission line, with 50 Ohm characteristic impedance, should be designed. The construction of coplanar lines is built on one plane of the substrate and consists of one main transmission line, surrounded by large metal grounded areas, situated everywhere around the line (Fig. 1). This kind of transmission lines has less loss by RF interferences and electromagnetic radiation in comparison with the microstrip lines. The dimensions of the coplanar transmission line, with 50 Ohm characteristic impedance are designed by using WEB Calculator [5]. Assuming as a base the substrate material – silicon wafer, with thickness higher than 380 μm, dielectric constant 11.8 and width of the line – 20 μm, we can find the width of the spaces between the line and ground planes – 11.8 μm. The length is not limited; the characteristic impedance of 50 Ohm doesn't depend on the length.

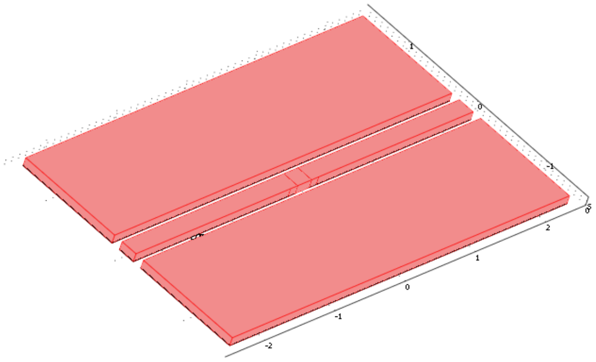

Figure 1. 50 Ohm coplanar transmission line.

The next step is to make the interruption in the line. This will be the place, where the switching will occur. The length of this gap will be 20 μm (Fig. 2).

The third step is to design the contact metal element, which should be suspended on metal springs and after electrostatic attraction will contact the interrupted parts of the line (Fig. 3). For this reason, the spring constants should be calculated. Having in mind the dimensions of this electrode, the applied voltage and the parameters of the spring, the behavior of this element could be analyzed, using of the model, created by SOLIDWORKS.

The next step is to calculate the capacitance of this structure in upper (OFF) position, using the simple formulas for this case. The obtained result is 68 fF, which is in the limits, given as one of the starting parameters.

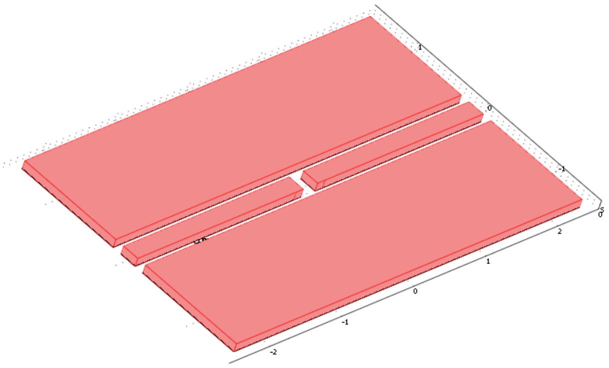

Figure 2. 50 Ohm coplanar transmission line with 20 μm interruption gap.

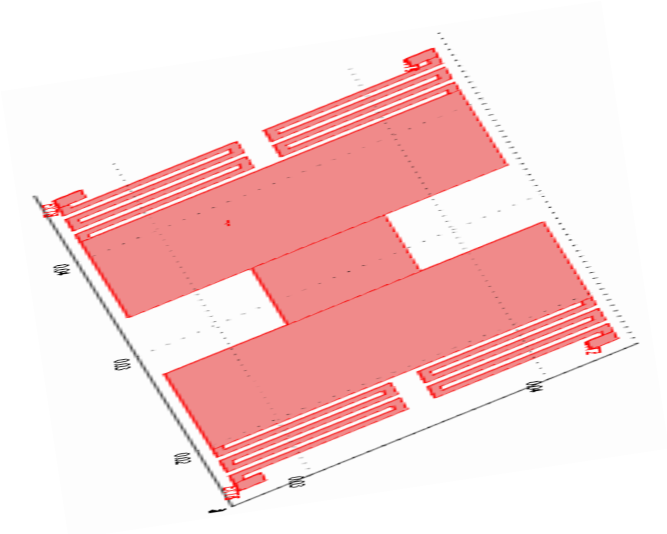

Figure 3. Contact metal element, which is suspended on metal springs and contacts the interrupted parts of the line.

IV. ELECTROMAGNETIC SIMULATION OF THE STRUCTURE

The electromagnetic simulations of this structure are done by using the software EM3DS, ver.9.1.2. The microwave scattering S-parameters are calculated and the S-matrix is found. These parameters are giving information for important characteristics of the system. There, S_{11} is the input port voltage reflection coefficient, S_{12} is the reverse voltage gain, S_{21} is the forward voltage gain and S_{22} is the output port voltage reflection coefficient. In this way, the losses and the isolation are calculated in a large frequency range, between 0 and 60 GHz. The results give information for the returned losses, by S_{11} and insertion losses (attenuation), by S_{21}.

The frequency distribution of S_{11} and S_{21} for the cases of 50 Ohm coplanar transmission line are shown in Fig. 4, for 50 Ohm coplanar transmission line, with interruption of 20 μm – in Fig. 5, and the whole structure (50 Ohm interrupted coplanar transmission line with the contact element) in Fig. 6.

From the results, shown in Fig. 4, it is clear that for frequencies $f < 50$ GHz, the line has $S_{11} < -23$ dB and very low coefficient S_{21}. This means that the transmission line has excellent parameters for high frequencies. From Fig. 5 is clear that, for this frequency range, S_{11} is around zero and $S_{21}= -43$ db at 30 GHz. This means that the line is interrupted for the signal and there is high isolation of the gap. From Fig. 6 is clear that, for the switch, the inserted losses are very low ($S_{21} < -0.2$ dB) and the reflected losses are low ($S_{11} < 45$ dB) even at 30 GHz. The reflected signal will be around 1-2%.

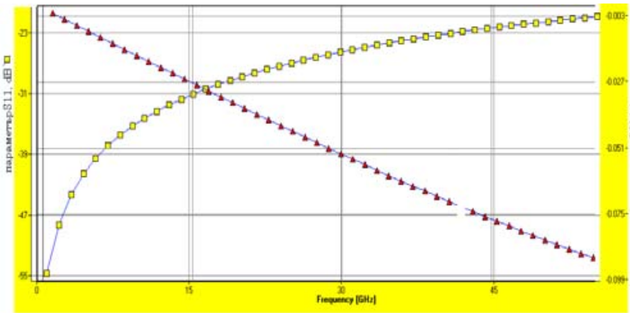

Figure 4. S_{11} and S_{21} parameters for 50 Ohm coplanar transmission line in the frequency range of 0-60 GHz.

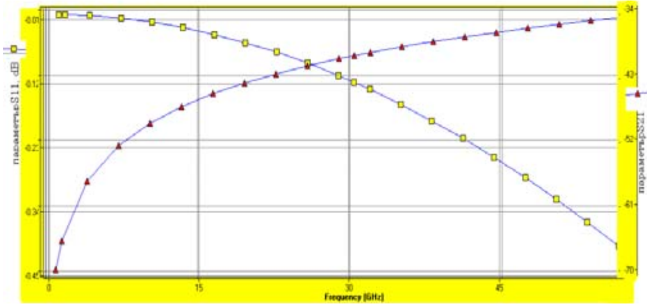

Figure 5. S_{11} and S_{21} parameters for 50 Ohm coplanar transmission line with 20 μm interruption gap, in the frequency range of 0-60 GHz.

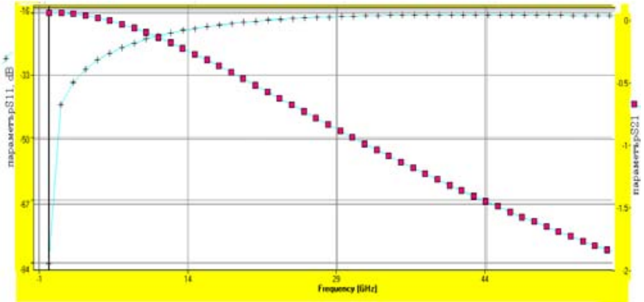

Figure 6. S_{11} and S_{21} parameters for the whole structure of RF MEMS switch (50 Ohm interrupted coplanar transmission line with the contact element), in the frequency range of 0-60 GHz.

In Fig. 7, the current distribution over the structure, in ON-position, at 1 GHZ, is shown. The lower figure is for the transmission line, and the upper picture is for the whole structure with the metal contact electrode. It is clear that the current has higher density for the edges of the line and at the periphery of the metal contact. The reason for this current distribution is in the skin effects. In Fig. 8, the similar pictures, but for frequency of 60 GHz are shown.

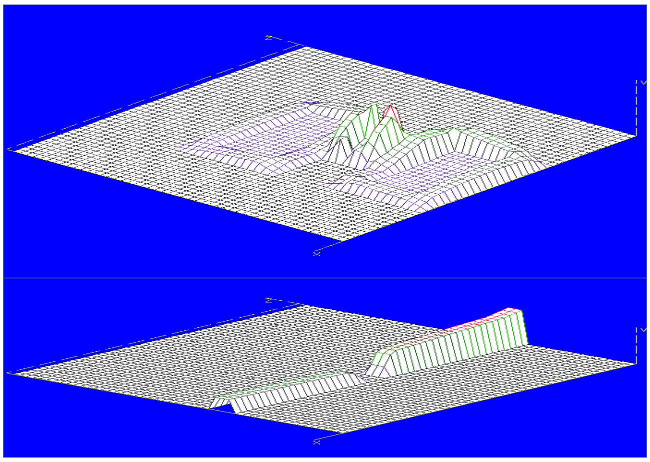

Figure 7. Current distribution over the structure, in ON-position, at 1 GHZ.

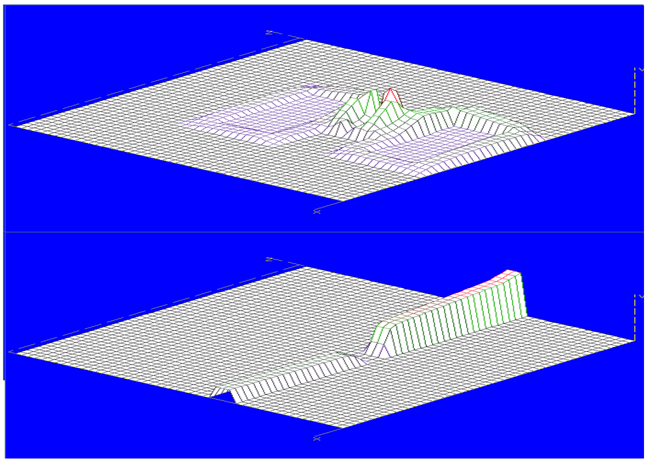

Figure 8. Current distribution over the structure, in ON-position, at 60 GHZ.

V. TECHNOLOGY AND LAYOUT DESIGN OF THE STRUCTURE

The production cycle, as well as the process of design of the structure, is in correspondence with the design rules and prescriptions of the technology sequence PolyMUMPs [6], [7]. This is a technology procedure, included in one multiproject cycle, which ensures the production of MEMS structures, using three polisilicon layers, as structural films, two oxide layers as sacrificial films, one metal and one Si_3N_4 layers. This combination gives the possibility for creation of bulk or surface micromachining structures. It is specialized for production of MEMS structures. By using the software product SOFTMEMS, integrated in CADENCE, the structure has been designed.

In Fig. 9, the assembly drawing of the structure of the MEMS switch is shown. Here, it could be seen the 50 Ohm coplanar transmission line, with 20 μm interruption area, the lower electrode, creating the electrostatic field for attraction of the anchor, and the upper electrode, switching ON and OFF the transmission line.

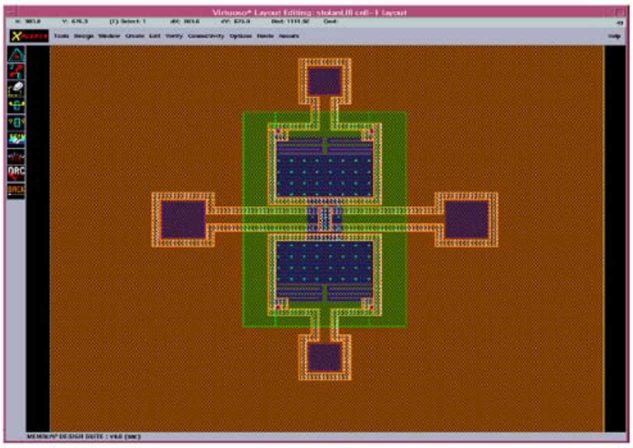

Figure 9. Assembly drawing of the RF MEMS switch.

In Fig. 10, the configuration of the first polisilicon layer, which defines the areas of the transmission line and the lower electrode.

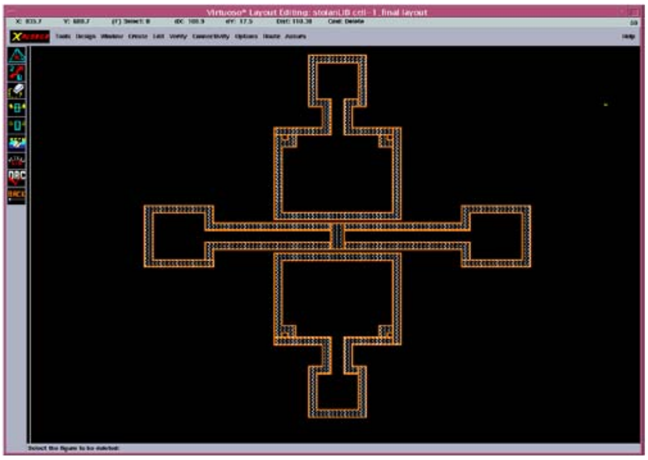

Figure 10. The configuration of the first polisilicon layer, whith the areas of the transmission line and the lower electrode.

In Fig. 11, the configuration of the upper metal electrode is shown. Here, the 4 suspending springs could be seen.

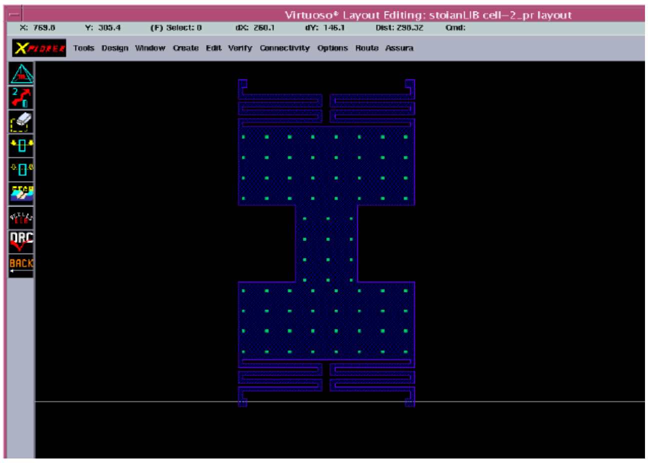

Figure 11. The configuration of the upper metal electrode with the 4 suspending springs.

VI. CONCLUSION

RF MEMS switch, with electrostatic actuation has been designed. For this reason, a 50 Ohm coplanar transmission line, with 20 µm interruption area is designed.

The combination of the transmission line and metal switching electrode has been modeled by using of SOLIDWORKS and investigated and analyzed by EM3DS, ver.9.1.2. The S-parameters of the structure, in large frequency range between 0 and 60 GHz, are obtained and shown.

The technology sequence, based on PolyMUMPs process, has been defined. The configuration of the structure has been created by using the software product SOFTMEMS, integrated in CADENCE.

The parameters of designed RF switch fulfill all requirements, included in the starting parameters of the structure, shown above.

VII. ACKNOWLEDGEMENTS

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