Design of selectable-band patch filter for WiMax applications using MEMS varactor

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Abstract. A selectable-band triangular patch filter for WiMax application using MEMS varactors is proposed. The MEMS varactor was designed based on the envisioned fabrication process and the required capacitances to be incorporated to the filter using a flip-chip process and a final MEMS release after incorporation. The filter was simulated by an EM-simulator using the extracted equivalent electrical circuit model for the MEMS varactor. The widths of the 2.5 GHz and 3.5 GHz passbands are 8.35 % and 4.84 %, respectively. The insertion loss within both bandwidths is better than 2.6 dB and the return loss is better than 10 dB.

1. Introduction

Currently, different wireless communication standards such as GSM, WCDMA, WLAN and WiMAX are using more than one operating band to handle more efficiently the information in wireless communication systems. As a consequence, RF/microwave selectable-band circuits are essential for further developments in wireless systems.

The use of MEMS as tuning elements is interesting for their higher performance in terms of loss and nonlinearity when compared to traditional tuning elements such as PIN or varactors diodes, and provides a simple integration with planar resonators, offering a compact size and a wide tuning range On the other hand, planar patch resonators are very attractive for applications in satellite and mobile communication systems where low insertion loss and high power handling are required [1], besides its simple low cost fabrication [2]-[3].

In this paper, MEMS varactors are integrated to a patch filter through a flip-chip process in order to change the filter center frequency. The selected frequencies are the ones assigned to WiMAX frequency bands. The design of a selectable-band patch filter at 2.5 GHz and 3.5 GHz is proposed with a detailed description of the envisaged MEMS varactors fabrication process.

2. Tunable Filter Design

The design of the patch filter in this work is based on the analysis of the dual-mode triangular patch filter with inverted "T" slots of reference [4]. This topology was chosen due to its flexibility shown by the possibility of controlling independently the frequency of each fundamental degenerate mode.

The tunability concept illustrated in [5] was applied to the triangular patch filter in order to obtain a multi-band reconfigurable filterIn [5], two face-to-face varactors diodes were used across each of the four slots of a circular patch filter to change its center frequency and bandwidth. The face-to-face configuration was required to correctly bias the varactors.

Here, in order to simplify the polarization scheme and simply the topology of the MEMS varactor, the triangular patch was divided in four smaller patches. Each of the smaller patches is connected to its neighbor by a varactor. Thus, the varactor can be biased by applying a dc voltage between any two of the smaller patches. The layout of this patch filter is shown in Fig. 1.

The patch resonator is formed by an equilateral triangle with base of 10.8 mm. All the gaps and slots in the layout are 200-μm wide. The small vertical and horizontal slots in Fig. 1 are 1.55-mm and 3.1-mm long, respectively, and they are used to reduce the frequency of the resonant modes, yielding greater miniaturization. The feed lines were designed to have a characteristic impedance of 50 Ω, considering a commercial substrate (Rogers 3010 with ε_r=10.2 and thickness of 25 mils). The varactors C1, C2, C3 and C4 were placed strategically where their influence on the resonant modes are the strongest. The input capacitors (C_{in}=1 pF) are used to achieve a stronger coupling between the feed lines and the resonator.

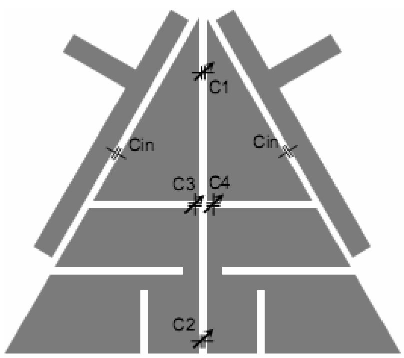

Fig. 1. Layout of the selectable multiband triangular patch filter.

The patch filter of Fig. 1 was simulated with a 3D-planar electromagnetic simulator (Momentum - Agilent) considering the dielectric and conductor losses of the substrate. The influence of ideal varactors on the filter response was simulated with a circuit simulator (ADS - Agilent Technologies) using simple capacitances. The capacitances were varied in order to obtain passbands with center frequencies assigned to WiMax applications *i.e.* 2.3 GHz, 2.5 GHz, 3.5 GHz and 5.8 GHz. Fig. 2 shows the filter frequency responses with different bands and Table 1 lists the insertion and return losses, the 3 dB bandwidth and the capacitances (C1, C2, C3 and C4) required to obtain the related central frequency, Fc. The results demonstrated great center frequency tuning flexibility.

Table 1. Multi-band filter responses and capacitances

Fc (GHz)	Insertion Loss (dB)	Return Loss (dB)	3 dB Bandwidth (%)	C1 (pF)	C2 (pF)	C3 (pF)	C4 (pF)
2.3	1.8	10.4	5.2	7.1	7.1	100	0.85
2.5	1.4	10.6	7.2	7.1	7.1	100	0.3
3.5	2.2	10.2	3.45	2.75	2.75	2.7	0.3
5.8	1.8	15.7	3.8	1.8	1.8	0.2	0.3
3.5/5.8	2.0/1.8	24.5/15.8	4.6/3.8	1.8	1.8	4.5	0.3

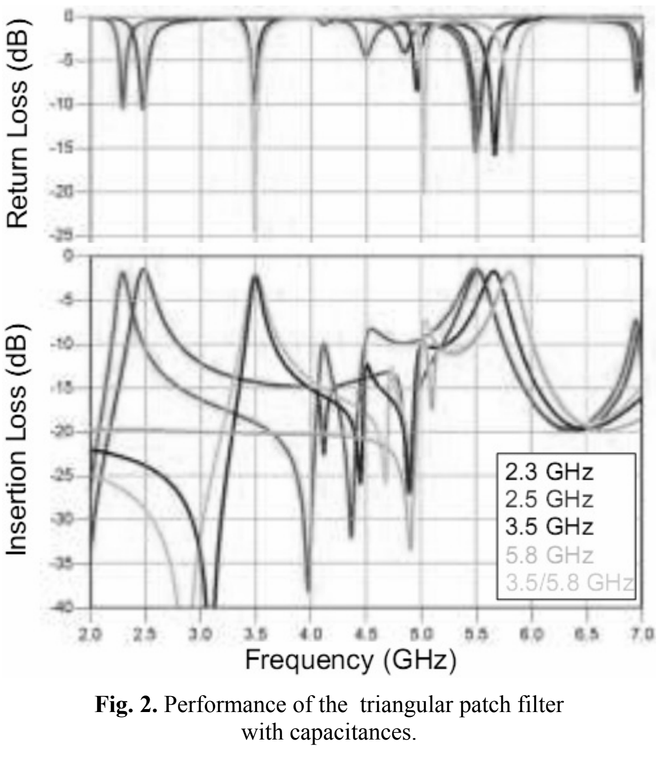

Fig. 2. Performance of the triangular patch filter with capacitances.

The filter frequency responses shown in Fig. 2 are not the only possible ones, since it is possible to arrive at similar results with different combinations of capacitances. For example, the value of C3 could be reduced down to 53 pF with only a small increase in the insertion loss (IL) at the 2.3 GHz and 2.5 GHz passbands. Considering this change, all the capacitances can be obtained with commercial varactors. However, the series resistances of these devices range from 0.8 Ω up to 3.15 Ω [6], which completely degrades the filter response, highly increasing its IL. In fact, resistances greater than 0.1 Ω result in IL greater than 3 dB for most of the passbands of this filter. For this reason, MEMS varactors were developed to tune the filter.

3. MEMS Varactor Design and Modeling

Considering the capacitances ranges required to obtain all the passbands illustrated in Fig. 2, MEMS varactors with up to four positions would be necessary. To simplify the MEMS design and the filter complexity, only two passbands were selected as a proof-of-concept: 2.5 GHz and 3.5 GHz. Simulations showed that it is possible to switch between these two passbands using only MEMS with up to two positions. In this case, C1 is not required, C2 and C4 have the same capacitances of 70 pF (DOWN position) and 2.45 pF (UP position), while maintaining C3 and Cin constant at 3.9 pF and 1 pF, respectively.

The MEMS varactors were designed to be fabricated using the process described in Fig. 3. The main idea is to fabricate the patch filter using conventional printed circuit board technology on commercial RF substrates and to incorporate the MEMS with a flip-chip process.

The MEMS is to be fabricated using conventional microelectronic processes on low-cost glass substrate. In the envisioned fabrication process (Fig. 3), a sacrificial film, such as SiO_2, is deposited over the substrate to allow the structure to be released from the substrate after it integration to the patch filter. A seed layer of titanium, used for adherence, followed by a layer of copper, is deposited over the sacrificial layer (Fig. 3a).

Then, the geometry of the MEMS structure, with 500 μm by 500 μm parallel plates, is defined with conventional photolithography. The photoresist is used as mask to electroplate a thicker copper film (1μm) that will be the structural material of the MEMS varactor. After that, an insulator (Si_3N_4–85 nm) and another sacrificial layer

(SiO_2 –1 μm) are deposited and patterned (Fig. 3b). Once again, a seed layer of Ti/Cu is deposited and the geometry of the copper supports is defined on a photoresist. A thick copper film (10 μm) is then electroplated to form the supports that will be attached to the patch filter (Fig. 3c). These supports are bonded using solder spheres to the patch filter and a final release step (Fig. 3d) removes the sacrificial films, freeing the MEMS varactor and eliminating the glass substrate.

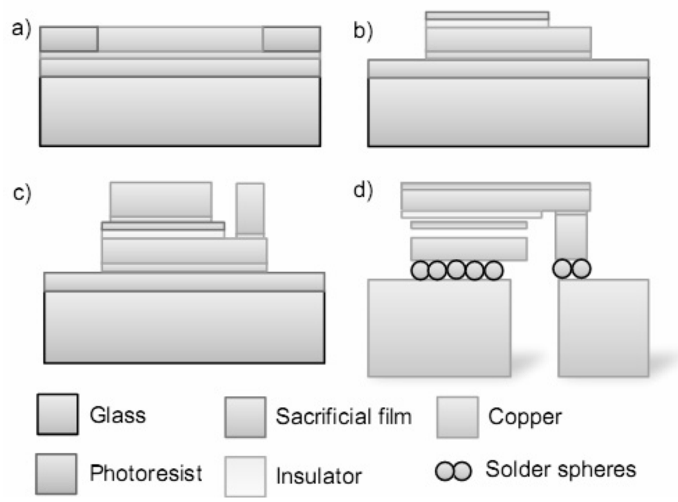

Fig. 3. Fabrication process flow for the MEMS varactor.

Based on the fabrication process described above, the MEMS varactor, shown in Fig. 4, was simulated using a full-wave 3D electromagnetic simulator (HFFS – Ansoft).

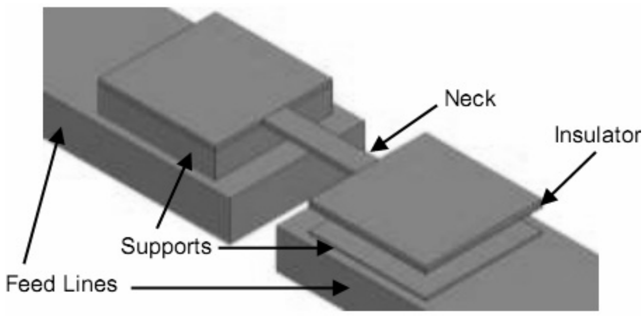

Fig. 4. Topology of the MEMS varactor in the UP position.

Considering the dimensions of the neck (400 μm × 100 μm), a low pull-in voltage is estimated of approximately 8 V, based on [7]. The capacitance in the DOWN position is expected to be 70 pF and in the UP position, 2.45 pF.

By comparing the HFSS simulated results with an equivalent RLC circuit, it was possible to extract values for the equivalent capacitance, resistance and inductance of the MEMS varactor, shown in Fig. 5.

Fig. 5. RLC equivalent circuit for the UP position (2.45 pF) and the DOWN position (70 pF).

Fig. 6 shows that the HFSS simulation results of the MEMS structure and the equivalent electrical circuit model results agree considerable well.

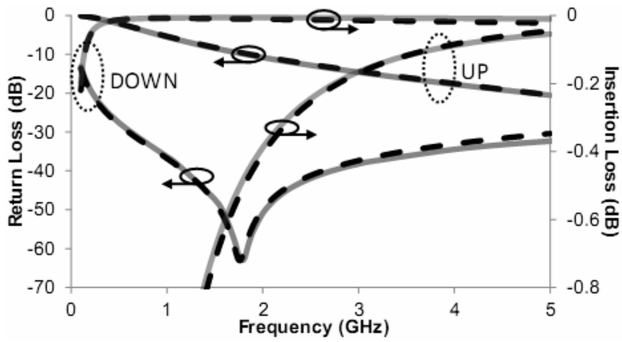

Fig. 6. Comparison between the results of the HFFS model (solid line) and the equivalent RLC circuit (dashed line) for the MEMS varactor in the UP and DOWN positions.

The equivalent RLC circuit was incorportated into the patch filter model (Fig. 1). The capacitances at the UP and DOWN positions and the filter layout had to be adjusted to account for the parasitic inductance of the MEMS model. The small vertical and horizontal slots were increased to 1.75 mm and 3.4 mm long, respectively. The UP and DOWN capacitance were changed to 2.65 pF and 65 pF, respecively, and C3 was changed to 3.8 pF. Fig. 7 shows the performace of the triangular patch filter with the MEMS varactors. In theses simulations, the substrate losses were considered.

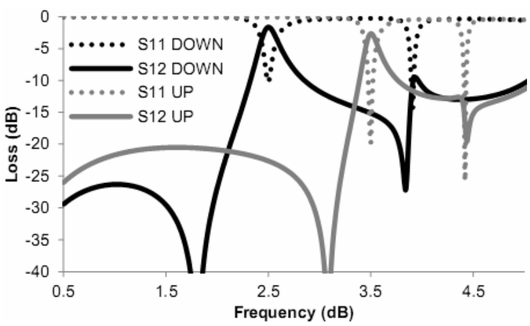

Fig. 7. Simulated performance of the selectable band patch filter with MEMS varactor.

In the selectable band patch filter, the bandwidths of the 2.5 GHz and 3.5 GHz passbands are 8.35 % and 4.84 %, respectively. The insertion loss within the passbands is better than 2.6 dB and the return loss is better than 10 dB.

4. Conclusion

A selectable-band filter was designed for integration with MEMS varactors through a flip-chip process. Two-position MEMS varactors were designed with 65 pF and 2.65 pF capacitances and modeled based on the proposed low-cost fabrication process. The simulated filter response demonstrates that the filter can be switched rom 2.5 GHz to 3.5 GHz using a low bias voltage of approximately 8 V, maintaining adequate performance.

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