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가변 직렬 인덕터를 이용한 무선랜 응용 MEMS 가변 대역 통과 필터

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A Micromachined Tunable Bandpass Filter Using Tunable Series Inductors For WLAN Applications

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Abstract - In this paper, a novel tunable bandpass filter using tunable series inductors and MEMS switches for wireless LAN applications was proposed. The proposed tunable filter was fabricated using a micromachining technology and performances of the fabricated filter were estimated. The filter consists of spiral inductors, MIM capacitors and direct-contact type MEMS switches, and its frequency tunability is achieved by changing the inductance that is induced by ON/OFF actuations of the MEMS switches. The actuation voltage of the MEMS switches was 58 V, and the measured center frequencies were 2.55 GHz and 5.1 GHz, respectively. The passband insertion loss and 3-dB bandwidth were 4.2 dB and 22.5 % at 2.55 GHz, and 5.2 dB and 23.5 % at 5.1 GHz, respectively.

1. INTRODUCTION

Tunable filters are the basic components of transceivers and multi-band communication systems. Developments of micromachining technology have made it possible to transfer conventional electrical tuning elements, such as active resonators and varactor diodes, to a micromachined tuning device with superior advantages - lower insertion loss, negligible power consumption, and higher linearity [1].

With increased demands for MEMS tunable filter, many micromachined tuning elements have been developed. Generally, a number of researchers have mainly studied variable MEMS capacitors as the tuning element [1-4]. However, variable MEMS capacitors have a small capacitance change and they cannot provide a wide tuning range in simple configurations. Also, they show the nonuniform capacitance change ratio according to fabrication process and some fabrication conditions.

The tunable inductors can be successfully implemented on the tunable filter topology. In this case, the frequency tunability is controlled by discrete change of the inductance with switch ON/OFF configurations. Because the frequency tunability is determined by the uniplanar metal pattern and the switch actuations, stable frequency tuning ratio and large frequency tuning range can be obtained [5-6]. This digital type tuning method is available for obtaining a discrete change of the center frequency for WLAN applications, which have two center frequencies of 2.4 GHz and 5.1 GHz.

In this paper, tunable filter using tunable inductors for WLAN applications was fabricated with micromachining technology and its electrical responses were measured.

2. DESIGN

Figure 1 shows the layout of the designed two-pole tunable filter. The proposed filter consists of spiral inductors, MIM capacitors, and MEMS switches, and LC-based elements are used as the resonators. All the components of the filter were designed with commercially available electromagnetic simulator, IE3D and ADS. Total size of the designed filter is 3.53 mm × 1.21 mm. The width of the signal line and the distance between the signal line and the ground plane are 20 μm and 40 μm, respectively. In our study, only tunable inductors have a role of tuning the center frequency and the coupling capacitors are chosen to give the correct bandwidth. The tunable inductors are realized by the MEMS switch actuations. Figure 2 shows the concept of the tunable inductor used in this paper. In case of switch OFF state, the applied RF signal flows along the spiral inductors. On the other hand, the signal passes through the straight signal line in the switch ON state. As the application of DC bias, two MEMS switches are simultaneously actuated. The DC bias is applied through a resistive line to isolate the DC and RF signals.

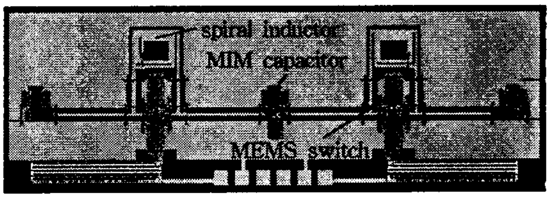

Figure 1. *Layout of the designed tunable filter.*

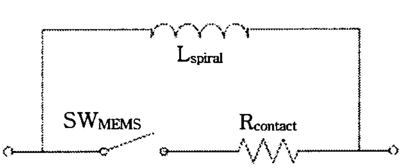

Figure 2. *The equivalent circuit of the tunable inductor, L_{spiral} is inductance of the spiral inductor, $R_{contact}$ is contact resistance in the switch ON state.*

Figure 3. shows the schematic view of the implemented direct-contact MEMS switch. This switch has already been reported [7], and in this work, it is successfully used to tune the center frequency of the filter. All the components of the

switch are formed on the CPW. The total length and the width of the switch membrane are 552 μm and 100 μm, respectively. The contact material is suspended on the separated signal line. The contact bar and the actuation pad are connected through silicon nitride for electrical isolation between the two parts. The support beam is employed to make it possible to improve the contact force and to decrease the structural deformation. The RF switching operations are achieved by electrostatic force generated as the application of the DC bias between the actuation pad and the bottom electrode.

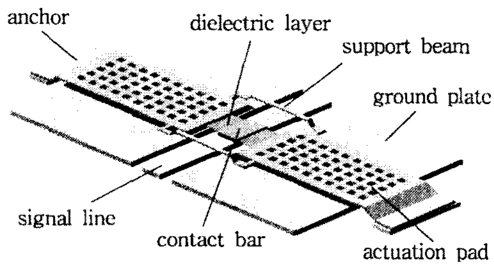

Figure 3. *Schematic view of the designed MEMS switch*

3. FABRICATION

All the components of the filter are fabricated on the 520 μm-thick quartz substrate through a batch process. A CPW, used as the transmission line, is formed by electroplating of gold. The bottom electrode and the DC bias pad are connected by a NiCr resistive line to isolate the DC and RF signals. The electroplated nickel is served as the structural material for the actuation pad of the switch. Figure 4 shows the fabrication process. At first, 800 Å-thick NiCr resistive line is formed on the quartz substrate by lift-off process. On the NiCr resistive line, 3 μm-thick CPW is electroplated.

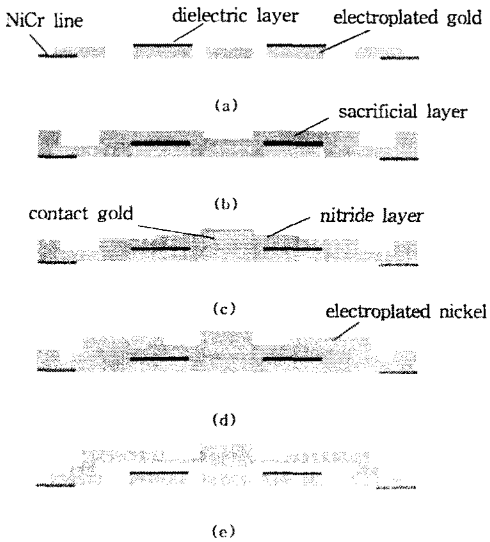

Figure 4. *Fabrication process, (a) CPW line and dielectric layer patterning, (b) sacrificial layer and contact region patterning, (c) contact metal electroplating and dielectric membrane forming, (d) Ni actuation pad electroplating, and (e) structure release with oxygen plasma*

0.3 μm-thick silicon nitride(Si_3N_4) layer is deposited and patterned for electrical isolation between the actuation pad and the bottom electrode. Photoresist is used as sacrificial layer material. The deposited sacrificial layer is patterned and cured to the temperature of 210 °C. The thickness of the cured sacrificial is 1.5 μm. Next, contact bar is defined by anisotropic reactive ion etching. From this process, the gap between the contact bar and the signal line is determined to be 1 μm. The electroplated gold is used as contact material. Next, a 0.3 μm-thick silicon nitride is deposited and patterned to connect with the contact bar and the actuation pad. The actuation pad is fabricated by electroplating of nickel with 2 μm-thickness. Finally, the sacrificial layer is removed by oxygen plasma process.

Figure 5 shows the fabricated results. Figure 5 (a), (b), and (c) are SEM photographs of the fabricated MEMS switch, spiral inductor, and MIM capacitor, respectively.

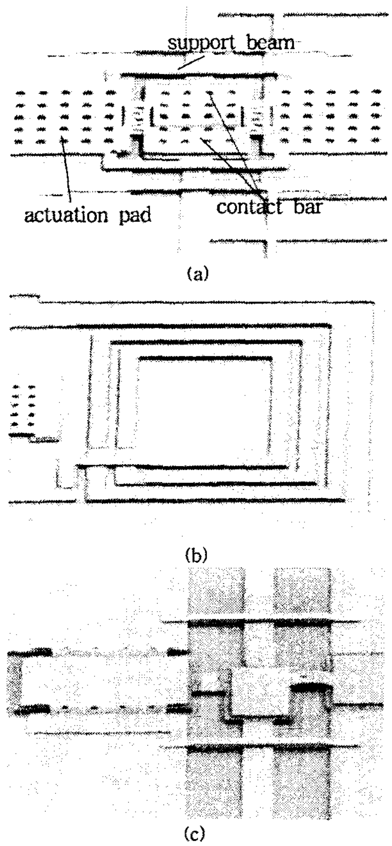

Figure 5. *Fabrication results, (a) MEMS switch, (b) spiral inductor, and (c) MIM capacitor*

3. MEASUREMENT

Measured pull-in voltage and actuation voltage of the fabricated switch were 40 V and 58 V, respectively. Figure 6 shows the measured RF responses of the switch. Measurement of the fabricated switch was performed using an HP 8510 network analyzer with the frequencies range from 0 GHz to 60 GHz. The fabricated switch shows the insertion loss of 0.1 dB and the isolation of 26.3 dB at 2 GHz.

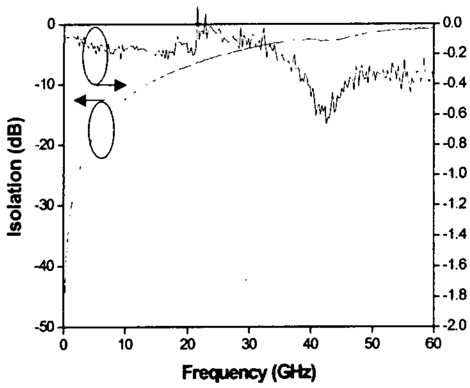

Figure 6. *Measured RF performances of the fabricated switch.*

RF performances of the fabricated filter were also measured using the HP 8510 network analyzer with the frequencies range from 0 GHz to 10 GHz. Figure 7 shows the measured RF responses of the fabricated filter. The measured center frequencies were 2.55 GHz with 3-dB bandwidth of 22.5 %, and 5.1 GHz with 3-dB bandwidth of 23.5 %, respectively. In the low and high frequency band, the total insertion losses were 4.2 dB and 5.2 dB, respectively. The frequency tuning ratio was 50 %, and this result is available for digital mode of operation. The insertion loss of this fabricated filter heavily depends on the conductor loss in the switch OFF state, and the contact resistance in the switch ON state. Therefore, it is expected that the filter performances will be improved through optimization of the design for the conductor line and the switch.

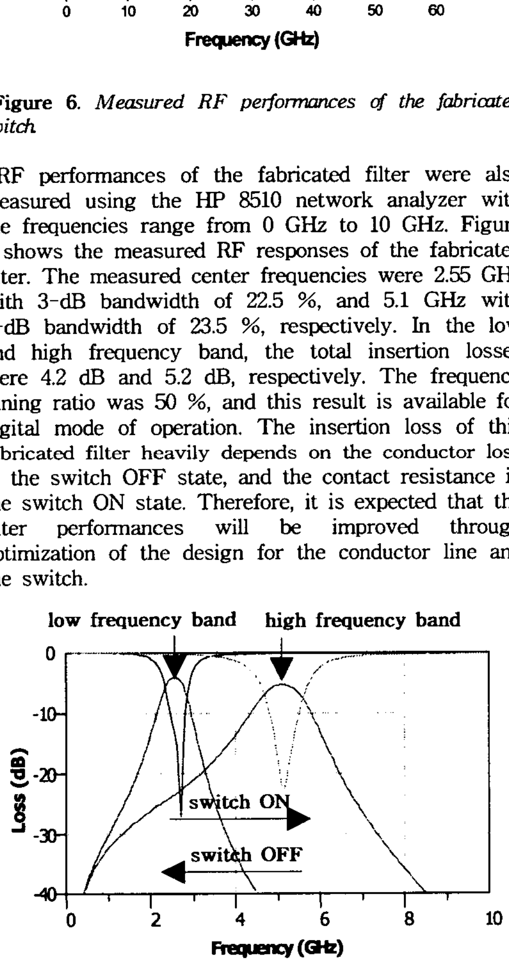

Figure 7. *Measured RF performances of the fabricated filter.*

3. CONCLUSION

A novel micromachined tunable filter for wireless LAN applications has been designed and fabricated using MEMS technology. The RF responses of the fabricated filter were measured. The direct-contact MEMS switch was successfully implemented for changing the inductance, and the digital frequency tunability using only inductance change with direct-contact switch could be obtained for center frequencies of 2.55 GHz and 5.1 GHz. The actuation voltage of the MEMS switch was 58 V, and the measured center frequencies of the filter were 2.55 GHz with 3-dB bandwidth of 22.5 %, and 5.1 GHz with 3-dB bandwidth of 23.5 %. The passband insertion losses were 4.2 dB at 2.55 GHz, and 5.2 dB at 5.1 GHz. From these results, the tunable filter using only inductance change gives feasibility to be applied for obtaining the stability of the frequency tuning.

ACKNOWLEDGEMENT

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