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Author(s)	Ma, Kaixue; Ma, Jianguo; Sun, Jianbo; Miao, Jianmin; Do, Manh Anh; Yeo, Kiat Seng
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A Miniaturized Silicon-Based Ground Ring Guarded Patch Resonator and Filter

Kaixue Ma, *Student Member, IEEE*, Jianguo Ma, *Senior Member, IEEE*, Jianbo Sun, Jianmin Miao, Manh Anh Do, and Kiat Seng Yeo

***Abstract*—A new miniaturized ground ring guided microstrip patch filter developed on the silicon wafer using micromachined technology is reported. The ground shunt can be used to lower the operating frequency up to one-third as compared to the traditional patch resonator. The size of the designed band pass filter operating in 5.17 GHz is only 8.7 mm × 2.9 mm.**

***Index Terms*—Ground ring, ground shunt, micromachined, miniaturized filter, patch resonator.**

I. Introduction

High performance filters with compact size are usually needed in modern RF/microwave communication systems. It is well known that filter performances and sizes are mainly determined by the characteristics of the resonators when the type of filter is determined. In the past, as a fundamental building block for filters, a resonator has been extensively studied [1]–[7]. Microstrip patch resonators [2], which have different shapes such as triangular, circular, etc,, are of interest for the design of microstrip filters to increase the power handling capability [2], [6]. Microstrip patch resonators also have lower conductor losses as compared with narrow microstrip resonators. The patch resonator filters tend to have stronger radiation loss, but the loss can be minimized by enclosing it in a metal housing [2]. However, the traditional patch resonator has a larger size, which is demonstrated as a disadvantage and limits its utilization for the high density integrated circuits.

Compared to the normal CPW, conductor-backed CPW (CBCPW) has extra advantages such as higher heat sinking ability, stronger mechanical strength, and lower characteristic impedance, etc. Therefore, it is attractive to be used in MMIC and packaging [8]. Generally speaking, transitions are needed between the CBCPW and microstrip structures. However, these transitions will increase the circuit size and loss, and possibly excite unexpected modes [9].

In this paper, a miniaturized ground ring guided patch resonator and filter, which is compatible with direct CBCPW feeding structures in I/O ports, is proposed and investigated. Under the same circuit dimensions, the operating frequency for the resonator/filter with the ground shunt is only $1/3$ of that for a traditional patch resonator/filter without the ground shunt.

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K. Ma, J.-G. Ma, M. A. Do, and K. S. Yeo are with Center for Integrated Circuits and Systems (CICS), Nanyang Technological University (NTU), Singapore 639798 (e-mail: pg05296107@ntu.edu.sg; EJGMa@ntu.edu.sg).

J. Sun and J. Miao are with the MEMS Center, Nanyang Technological University (NTU), Singapore 639798.

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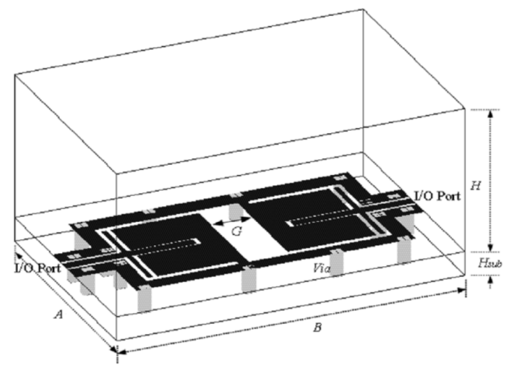

Fig. 1. Perspective view of ring guarded shunt patch filter ■ metal.

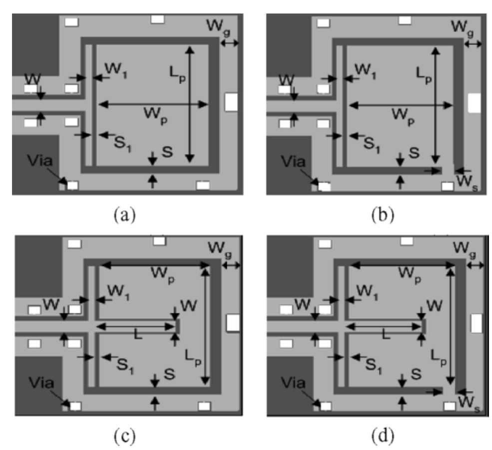

Fig. 2. Ground ring guarded patch resonators (a) rectangular (b) rectangular with shunt (c) "U" shape (d) "U" shape with shunt: Black = Substrate. Grey = metal.

The filter of proposed type as shown in Fig. 1 is realized on silicon wafer by using micromachining technology.

II. Guarded Patch Resonators

Ground ring guarded structures or guard-rings [10], which are formed by surrounding metal trace with a number of vias connected to the back ground metal, can be used to decrease the unexpected power leakage [11]. As shown in Fig. 2(a), the patch resonator, with width W_p and length L_p, is surrounded by the metal ground ring which is directly connected with lateral ground of the input CPCPW transmission line (center strip width W, slot width S_{in}). A section of vertical metal trace with width W_1 is connected to the end of the input CBCPW center strip. Then a "T" shape feed-in structure is formed. The ground ring can shift up the operating frequency of the patch resonator a

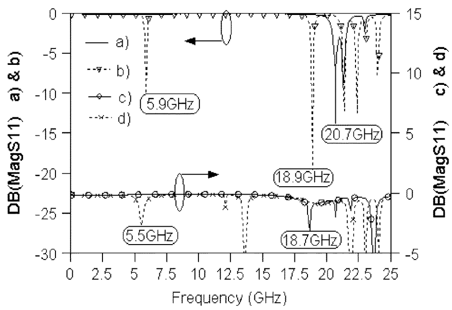

Fig. 3. Frequency response of the resonators in Fig. 2: W1 =50 μm, W_p =2 mm, L_p =2.28 mm, W_s =0.2 mm, S =0.15 mm, W_1 =0.1 mm, S_1 =0.1 mm, W_g =0.3 mm, L =1.8 mm, W =0.2 mm, $S_{\rm in}$ =0.12 mm.

little with increased via number, by changing the fringing field at the edge of the patch resonator. The resonant frequency for mnth mode could be obtained [12], [13]

$$f_{mn} = \frac{c}{2\pi\sqrt{\varepsilon_{\rm dyn}}}\sqrt{\left(\frac{m\pi}{L_{\rm eff}}\right)^2 + \left(\frac{n\pi}{W_{\rm eff}}\right)^2} \quad (1)$$

where $\varepsilon_{\rm dyn}$ is the dynamic permittivity of patch defined in [12] and c is the speed of the light in free space, $L_{\rm eff}$ and $W_{\rm eff}$ are effective width and length, respectively, [13].

The ground ring guarded patch resonator with ground shunt is shown in Fig. 2(b). Compared with the structure in Fig. 2(a), the only difference for Fig. 2(b) is that a ground shunt with width W_s is used to connect the patch to the ground ring. In Fig. 2(c) and (d), the patches are "U" shape patch with and without shunt respectively and each center strip of the CBCPW feed line is extend with length L. As a comparison, the frequency response characteristics of the structures shown in Fig. 2 are presented in Fig. 3. The fundamental mode frequencies of Fig. 2(a) are 20.7 GHz $({\rm m}=1, {\rm n}=0)$ and 21.3 GHz $({\rm m}=0, {\rm n}=1)$ using (1), while the fundamental mode frequencies of Fig. 2(b) are 5.9 GHz and 18.9 GHz. Obviously, for the same dimensions, the lowest resonant frequency of the ground ring guided resonator in Fig. 2(b) is only about 30% of the resonator without ground shunt. For the two "U" shape resonators in Fig. 2(c) and (d), the similar frequency ratio of the lowest operating frequencies, which are 5.5 GHz and 18.7 GHz, respectively, exists. Thus, for the same operating frequency, the ground shunt can contribute to a size reduction of more than three times as compared to the patch resonator without ground shunt.

III. Guarded Patch Filter

Four two-pole patch band pass filters are constructed by using the four types of resonators as shown in Fig. 2. Since we use the similar filter architecture, only the filter built by two resonators in Fig. 2(d) is demonstrated in Fig. 1. The I/O ports coupling is mainly determined by the line width W_1 and coupling gap S_1, while the extended feed line with length L and width W can further increase the coupling. The inter-stage coupling is mainly determined by the gap width G between two patch resonators as shown in Fig. 1. Since we mainly focus on the ground ring guided patch filter characteristics with/without ground shunt, the design procedure in [2] is adopted and not detailed here.

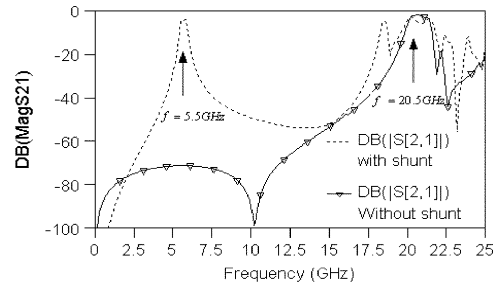

Fig. 4. Comparison between Fig. 2(a) and (b) type filters A =5 mm, B =7.9 mm, H =5 mm, S_1 =0.05 mm, G =1 mm, other parameters (see Fig. 3).

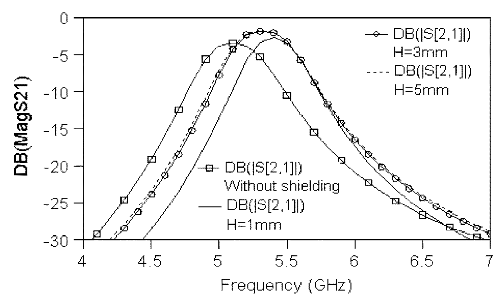

Fig. 5. Comparison of shielding effect on ring guarded shunt patch filter.

In Fig. 4, the frequency response characteristics of two pole filters with Fig. 2(a) and (b) type resonators are compared. The resonant frequencies of filters with and without ground shunt, as denoted by arrows, are 5.5 GHz and 20.5 GHz, respectively. The filter with shunt also has wider rejection band width and deep rolloff.

The filter in Fig. 1, with 11% relative bandwidth, is designed and the shielding effect of metal housing height H is compared as shown in Fig. 5. Without metal housing, the insertion loss is 3.4 dB which is much larger than that with metal housing 1.7 dB (when housing height H =3 mm). When H is below 3 mm (six time of the substrate height $H_{\rm sub}$ = 0.5 mm), the decreased height H can shift up the operating frequency. When H is larger than 3 mm, the increased height H almost has no effect on frequency response.

IV. Fabrication and Measurement

For fabrication of the patch filter, standard IC fabrication techniques along with deep reactive ion etching (DRIE) techniques were used for the realization of the conductor and the via. A 4-in high-resistivity silicon (4000 Ω·cm) wafer was used. Before processing, the wafer is polished on both sides to a thickness $H_{\rm sub}$ = 0.5 mm. After a cleaning process, the wafer is thermally oxidized to an oxide thickness of 0.8 μm. Next, the oxide and silicon were removed from the places where via holes have to contact top conductor layer and via holes were filled with metal [14]. Then the metallization layers (20 nm Cr, 8000 nm Cu) are defined using a lift-off process. This process yields very smooth surfaces of the Cu metallization and very steep edges of the metallization layer. After the back side was fully conducted with metal sputtering, the ground ring guided shunt patch filter is formed by this 3-D structure.

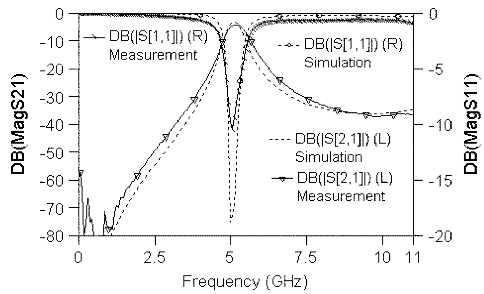

Fig. 6. Comparison of the theory and experiment results of the proposed filter.

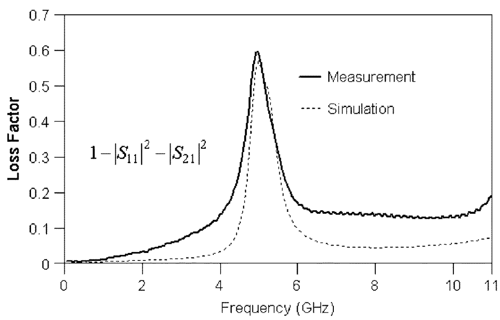

Fig. 7. Comparison of the theory and experiment loss factor of the filter.

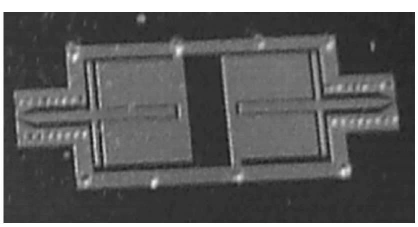

Fig. 8. Enlarged photo of the proposed filter in Fig. 1 Size: 8.7 mm × 2.9 mm.

Agilent 8510 C network analyzer, HP8516A S-parameter test set, HP83623A synthesized sweeper and 50A-GSG-100-VP microprobes from CASCADE MICROTECH were used for the measurements. Microwave calibration data was taken from the stored values in the analyzer, following the standard short-open-load-through measurements on a GGB CS-5 calibration substrate and the same cables as well as the probes. The measured results and the theory results of the filter type in Fig. 1 are compared in Figs. 6 and 7. As shown in Fig. 6, theory and experiment results are in good agreement. The simulated and measured loss factor $(1-|S_{11}|^2-|S_{21}|^2)$ of the filter are compared in Fig. 7. The filter losses are composed of substrate loss, metal loss as well as the radiation loss. Since the wafer is measured without metal housing, the radiation loss is about 1.7 dB in pass band as comparison of metal housing effects demonstrated in Fig. 8. That means if the filter is properly shielded with metal housing, the measured insertion loss of 4.2 dB can be reduced to about 2.5 dB.

V. Conclusion

In this paper, the ground ring guarded patch resonators and filters with/without ground shunt are investigated. A patch resonator with ground shunt can reduce the size of resonator without ground shunt up to one third under the same operating frequency. The ring guarded resonator with ground shunt can contribute to the similar size reduction for filter as demonstrated by simulation and experiment. Advantages of smaller size, lower power leakage and better compatibility with CBCPW I/O ports can make the circuits of the ground ring guarded patch resonator with ground shunt more suitable for MMIC's circuits than the traditional patch structures.

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