A Novel Surface-Mounted Monoblock Dielectric Filter

Xi Wang, Ke-Li Wu, *Fellow, IEEE*, and Wen-Yan Yin, *Fellow, IEEE*

***Abstract*— A novel surface-mounted monoblock high Q dielectric filter is presented in this paper. The proposed filter is constructed on the basis of a surface-metalized dielectric monoblock and is surface mountable on a printed circuit board (PCB) by means of a reflow process. The monoblock dielectric filter can be easily manufactured by mold casting. Metal caps on the surface and through holes in dielectric body are introduced for tuning capability. The input/output coupling is realized by inserting a stepped probe into the dielectric cavity through a via structure on the PCB. A novel electric coupling method using microstrip line is presented for easy control of coupling coefficient by adjusting the length and width of the microstrip line and flexible routing of cross couplings. One prototype 8-2 surface-mounted monoblock dielectric filter operating at 1.9 GHz with 84 MHz bandwidth is designed, fabricated, and measured. The measured insertion loss at center frequency is 0.73 dB with 0.6 dB ripple and corresponding unloaded Q factor of around 1700, demonstrating that the proposed filter architecture is applicable to a radio front-end of advanced wireless communication systems.**

***Index Terms*— Dielectric filter, high Q, microstrip, monoblock, surface mount.**

I. Introduction

SMART active antenna arrays in lightRadio [1] that can improve multiple-input multiple-output (MIMO) gains and sophisticated beam-forming capability in a very small footprint have caught many eye balls in the wireless industry. In this architecture, complete RF transceivers are integrated into each antenna element, including filters, receivers, and power amplifiers. The filter requirements of miniaturizing in size and high integratability while maintaining a high Q factor and low cost become very crucial. Surface-mountable filters are highly favorite for such applications. One solution to meet the requirements has been proposed in [2] and [3] by using metalized plastic coaxial cavities on both sides of a printed circuit board (PCB). However, because the coupling is realized through striplines, a multilayer structure is needed. In addition, the inevitable misalignment in assembling this kind of filter will affect the resonant frequency significantly that may result in a poor performance. In [4], a millimeter-wave surface-mounted filter has been designed and realized using plastic injection molding and metal coating technology. In this design, to achieve desired (better than -15 dB) return loss, high precision in manufacturing process is necessary in the order of magnitude of ± 10 μm. With the similar concept, a transition structure between microstrip line and surface-mounted dielectric foam or plastic waveguide was presented in [5], and then been applied for waveguide filter integration. A time-delay filter was presented in [6] using cascaded surface-mount coaxial ceramic delay lines with quarter-wave length microstrip lines which are used as impedance inverters. A dual-mode [7] metallic cavity also has been proposed to be surface mounted on board. One important issue of the aforementioned surface-mounted filters is that their unloaded Q factor is not satisfactory, although the volume is large. In addition, the filter structure lacks tuning mechanism. Since precision in fabrication and assembly processes cannot be guaranteed, tuning is always required in real applications. Another issue is that the cross-couplings for introducing transmission zeros, especially an electric coupling, are hard to realize. Therefore, the coupling topology of such filters is limited.

In this paper, a novel surface-mounted monoblock dielectric filter is presented. The monoblock dielectric filter can be manufactured simply by mold casting with outer surface being metalized by silver. Tuning capability is introduced by metal caps soldered on the bottom surface of the resonators. The input/output (I/O) coupling is realized by inserting a stepped probe into a through hole on the dielectric resonator with its end soldered on microstrip. A novel cross-coupling method is introduced to realize electric coupling between nonadjacent resonators. This method presents two attractive features: 1) easy realization and control by adjusting the length and width of a microstrip line and 2) flexibility in routing of coupling path.

This paper is organized as follows. In Section II, the design concept is introduced. The configuration and characteristics of the proposed resonator are presented. The I/O coupling and interresonator coupling structure including magnetic and electric coupling are shown, in which the electric coupling through a microstrip line shows a great flexibility in realizing such kind of filters. In Section III, the manufacturing process of a surface-mounted 8-2 monoblock dielectric prototype filter is presented. The measured results show that the unloaded

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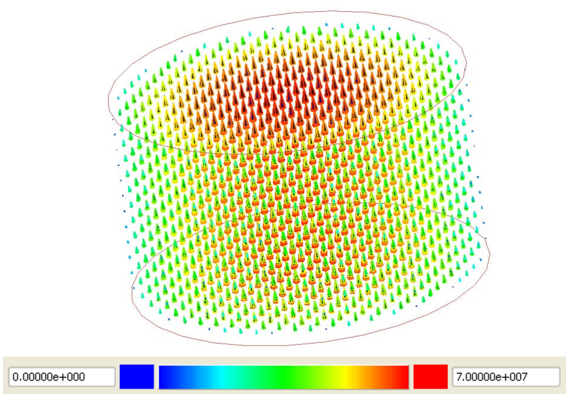

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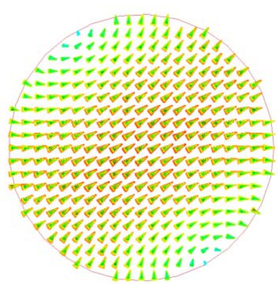

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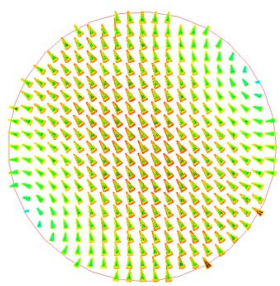


(c)

Fig. 1. Electric-field distribution of a metalized cylindrical dielectric resonator. (a) 3-D view of the TM_{01} mode. (b) and (c) Top view of the TE_{11} mode.

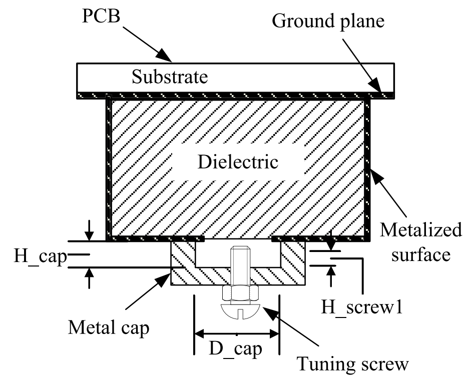
Q factor of the filter is around 1700, which is the highest among all the published surface-mountable filters in this frequency band.

II. Monoblock Dielectric Resonator

A. Configuration and Characteristics

Fig. 1 shows the electric-field distribution of the first three resonant modes of a metalized cylindrical monoblock dielectric resonator obtained using EMPro eigenmode simulator [8]. The dominant mode is TM_{01} mode, whereas the second and third modes are two degenerate TE_{11} modes. The cylindrical resonator is fabricated from a piece of monoblock dielectric with loss tangent of $2.5e-5$ and relative permittivity of 20.5. It is assumed that the conductivity of the metalized outer surface $\sigma = 1 \times 10^7$ S/m. The simulated Q factor of the TM_{01} mode is around 1800 at frequency of 1.96 GHz with diameter of 13 mm and height of 15 mm. The resonant frequency of the higher degenerate TE_{11} modes can be moved up by decreasing the height of the resonator with sacrifice of the Q factor of the dominate mode.

The configuration of the proposed resonator is shown in Fig. 2(a). The dielectric block is metalized on the outer surface and soldered on the ground plane of a PCB. It can be seen that, to introduce tuning capability, a round region on the bottom surface of the dielectric resonator has not been metalized [also shown in Fig. 8(b)]. Then metal cap with tuning screw is soldered on the surface using reflow soldering process. The resonant frequency for the dominant mode of a resonator without a blind tuning hole versus the length of the tuning screw is shown in Fig. 3(a), for which the corresponding dimensions are: $H\_cap = 4$ mm and $D\_cap = 7$ mm. It can be seen that before touching the surface of dielectric the screw



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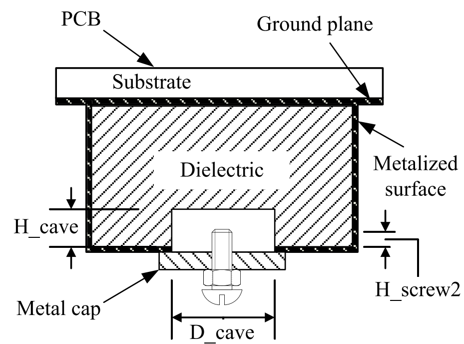

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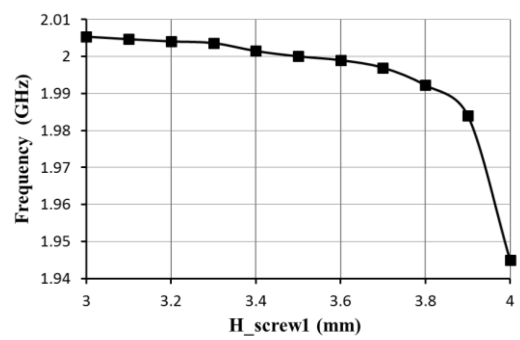
Fig. 2. Configuration of (a) resonator without a blind hole and (b) resonator with a blind hole.



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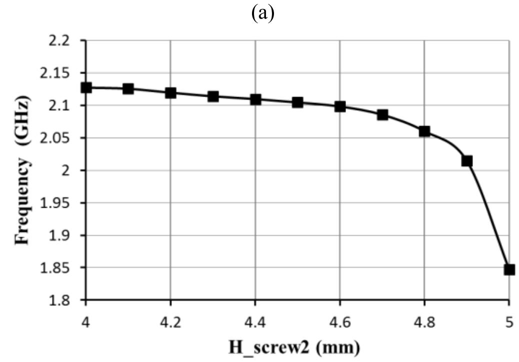

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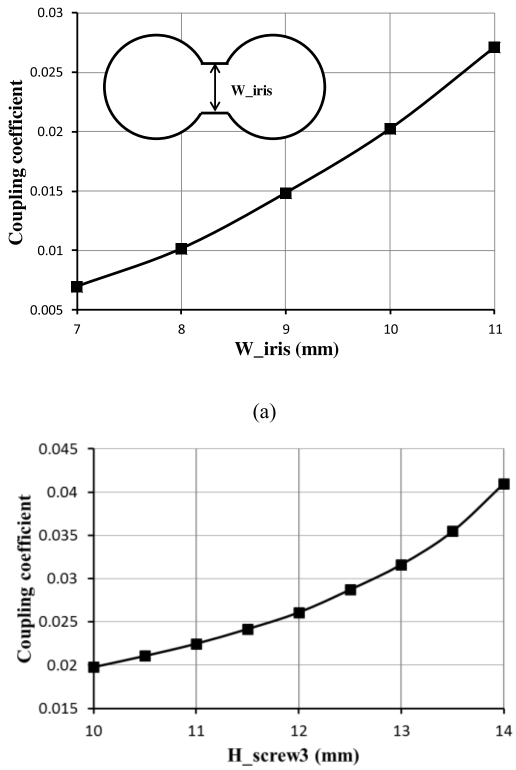
Fig. 3. Resonant frequency of the dominant mode of (a) resonator without a blind hole and (b) resonator with a blind hole.



(a)

(b)

Fig. 4. Coupling coefficient versus width of the coupling window (W_iris) and the length of tuning screw (H_screw3).

tuning range is about 1%. The tuning range can be significantly increased if a blind tuning hole is provided at the center of each resonator as shown in Fig. 2(b). About 7% tuning range can be seen in Fig. 3(b) with dimensions of H_cave = 5 mm, D_cave = 6 mm.

B. Interresonator Coupling

The coupling between two resonators can be controlled by changing the width of the iris in the same way as conventional waveguide filters. Fig. 4 shows the coupling coefficient versus the width of the iris and the length of the tuning screw. The diameter and height of the two identical resonators are 13 and 15 mm, respectively. The coupling coefficient is given by $(f_e^2 - f_m^2)/(f_e^2 + f_m^2)$ in which f_e and f_m are the even- and odd-mode of the coupled resonators calculated by EMPro eigenmode simulator [8]. It can be seen that the coupling coefficient increases while the width of the iris increases. It can be shown that the coupling is a magnetic type (i.e., $f_e > f_m$). Fig. 5 shows the configuration of magnetic coupling structure, in which a through hole is introduced in the middle of the iris for a tuning screw [also shown in Fig. 7(a)].

Electric coupling can be realized using a piece of microstrip line. The configuration of electric coupling structure is shown in Fig. 6. It can be seen that each metalized resonator has a cirque region that has not been metalized with a solder pad at the center [also shown in Fig. 8(c)]. Two metalized vias are then soldered on the solder pads of the two resonators with connection to the microstrip line. The coupling coefficient can

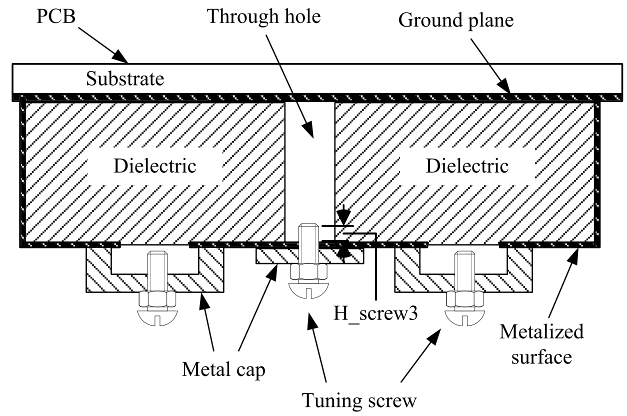


Fig. 5. Configuration of the magnetic coupling structure of the proposed filter.

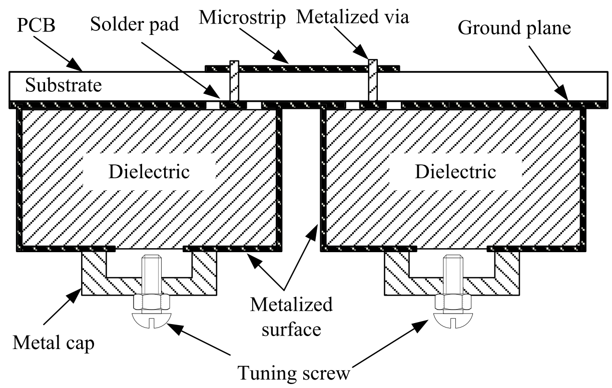


Fig. 6. Configuration of the electric coupling structure of the proposed filter.

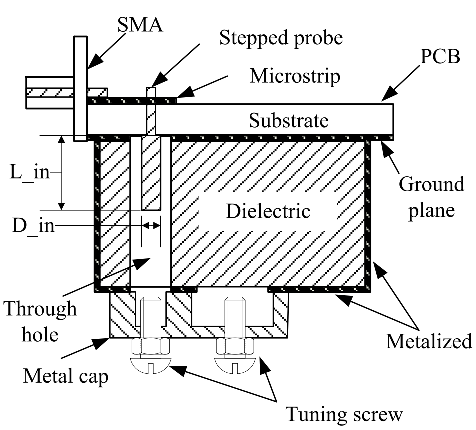


Fig. 7. Configuration of the I/O structure of the proposed filter.

be easily controlled by adjusting the length and width of the microstrip. One advantage of the proposed coupling method is that cross-coupling between nonadjacent resonators especially those that are far away from each other can be realized very easily. The unwanted couplings can be minimized since the main-line couplings are realized through the irises while the cross-couplings are through microstrip lines.

C. I/O Coupling

Fig. 7 shows the configuration of the I/O structure of the proposed filter. The SMA connector is soldered on the microstrip. A stepped metallic probe is soldered at the end of the microstrip through a via hole on the substrate, and then inserted into a through hole drilled on the dielectric to excite the dominate mode of the resonator. A tuning screw can also be inserted into the through hole of the dielectric for tuning the I/O coupling. In principle, the I/O coupling can be controlled by adjusting the length (L_in) and the diameter (D_in) of the inserted stepped probe. It should be mentioned that, to prevent the stepped probe from being short circuited to the ground plane of the PCB, a round shaped defect hole is provided on the ground plane of the PCB.

III. Filter Realization

For demonstration purpose, an eight-pole 8-2 monoblock filter surface mounted on the PCB has been designed, fabricated, and measured. The detailed structural information of the manufactured prototype is shown in Fig. 8. First, the bare monoblock dielectric is fabricated using water-jet machining with acceptable precision. For volume production, the filter dielectric body can be easily made by mold-casting process. The bare monoblock dielectric is shown in Fig. 8(a). It can be seen that seven through holes are manufactured for tuning screws and two for I/O stepped probes. The whole monoblock dielectric occupies 111 mm × 54 mm area with height of 15 mm. Second, the monoblock dielectric is surface metalized as shown in Fig. 8(b) and (c). It can be seen that eight round regions which have not been metalized on the top plane are for the frequency tuning with metallic caps soldered on the surface. On the bottom plane, there are two cirque parts with solder pads in the center for connecting to a cross coupling. At last, the monoblock dielectric is soldered on the ground plane of the PCB by means of a reflow soldering process, while metal caps for supporting tuning screws are soldered on the monoblock dielectric. The assembled filter can be seen in Fig. 8(d)–(f). The SMA connectors are soldered on the microstrip I/O structure whose end is connected to the stepped probe to excite the dominant mode in the dielectric resonator. The metal caps are soldered on the bottom surface of the dielectric block.

The fabricated monoblock dielectric filter operating at a center frequency of 1.9 GHz with bandwidth of 84 MHz is shown in Fig. 8. The nonzero elements of the normalized coupling matrix are $M_{01} = M_{89} = 1.02861$, $M_{12} = M_{78} = 0.85358$, $M_{23} = M_{67} = 0.60049$, $M_{34} = M_{56} = 0.55477$, $M_{45} = 0.60136$, and $M_{36} = -0.05524$.

Fig. 9 shows the measured results of the whole integrated filter. It can be seen that insertion loss of the filter varies from 0.73 to 1.3 dB in the whole operating band with corresponding unloaded Q factor of around 1700, which correlates well with the simulated unloaded Q factor. It also can be noticed that the rejection level is a bit higher than the synthesized performance owing to the parasitic coupling mainly caused by unwanted EM wave leakage between the I/O SMA connectors through the microstrip substrate. Such leakage can be suppressed using an appropriate design of the grounding structure in the substrate.

It should be mentioned that to further reduce the size and the weight, the height of the dielectric monoblock can be reduced

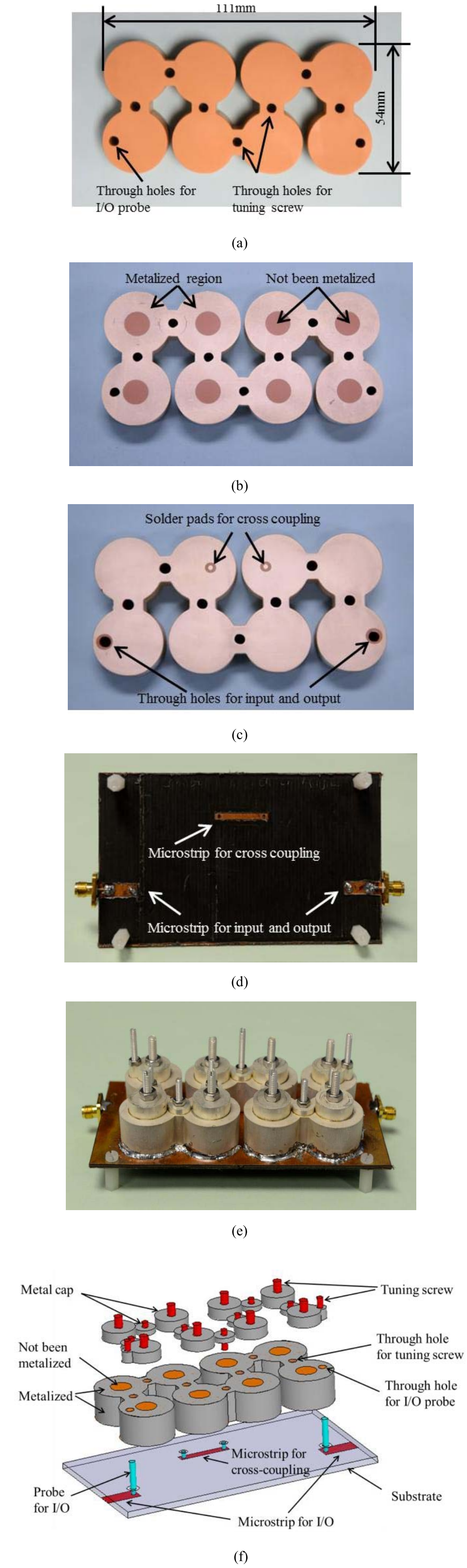
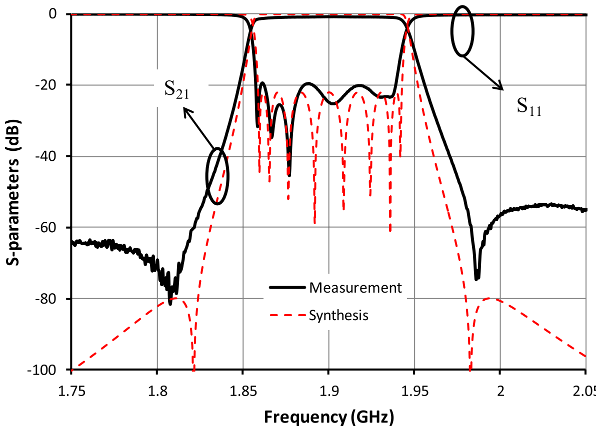


Fig. 8. Manufacturing process of the eight-pole monoblock filter. (a) Unmetalized bare monoblock dielectric. (b) Top view and (c) bottom view of the metalized monoblock dielectric. (d) Photograph of the back side of the PCB. (e) Photograph of the surface-mounted filter. (f) Assembly of the filter.

without influencing the operating frequency, because the dominant mode is TM_{01} mode. Practically, the resonance frequencies of the higher order modes (degenerate TE_{11} modes)



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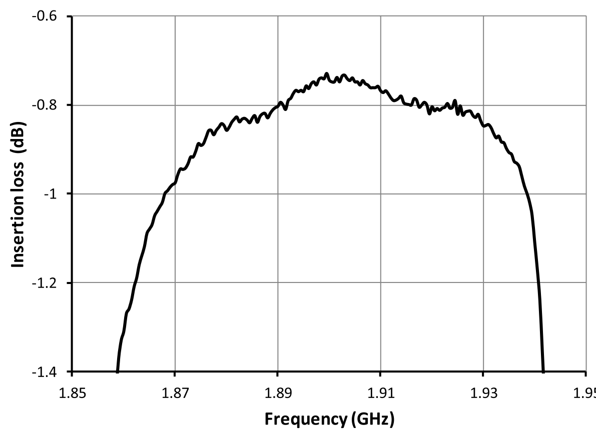

(b)

Fig. 9. (a) Synthesis and measured S-parameters of the fabricated filter. (b) Measured insertion loss.

will move up from the pass band when the height is reduced with sacrifice of the unloaded Q factor.

IV. Conclusion

In this paper, a novel monoblock TM_{01} mode surface-mountable dielectric filter is proposed, which is suitable for low-cost mass production while maintaining tuning capability. The details of designing the I/O coupling and interresonator coupling are discussed. A novel cross-coupling method is presented using microstrip on the PCB, which shows great flexibility and convenience in designing electric coupling. The prototype filter demonstrates that the proposed filter architecture is surface mountable, high-unloaded Q, compact in size, and suitable for mass production, all of which are the highly desirable features in future high-performance front-end systems.

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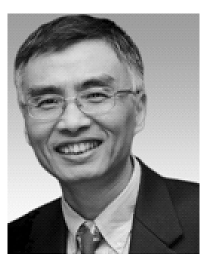

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