A TM_{01} Mode Monoblock Dielectric Filter

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***Abstract*—A novel $\mathbf{TM_{01}}$ monoblock dielectric filter is presented in this paper. The proposed filter is made from a single piece of ceramic with silver-plated external surfaces and a metallic lid for hosting tuning screws. The dominant $\mathbf{TM_{01}}$ mode is supported by a centered dielectric rod with one end short-circuited. Not requiring a metallic housing and dielectric resonator mounting fixture, the filter maximizes the space utilization, achieves an optimal Q factor for a given volume, and provides a high mechanical and thermal stability. One prototype filter operating at 2.6 GHz with 50-MHz bandwidth is designed, fabricated, and measured. To demonstrate its superiorities in terms of Q factor and thermal stability, a metal coaxial filter of the same size working at the same frequency and bandwidth is fabricated and measured as well. The measured unloaded Q factor of the monoblock dielectric filter and the metal coaxial filter are about 3000 and 1800, respectively. Furthermore, the frequency drift due to temperature change for the proposed monoblock dielectric filter is -2.7 ppm/°C while that of its coaxial counterpart is -14.2 ppm/°C. More detailed design considerations for such monoblock filters are also given.**

***Index Terms*—Dielectric filter, high Q, monoblock, temperature stability.**

I. Introduction

DIELECTRIC filters have been widely used in modern communication systems since they can achieve relatively higher Q factor, smaller size, and also better temperature stability as compared to all metal resonator filters of the same size. Various modes have been utilized in dielectric filter design. The most preferred mode is $\mathrm{TE}_{01\delta}$ [1]–[5] mode since it achieves excellent quality factor if the metallic cavity is sufficiently large. One concern for this mode is that its spurious modes are close to the dominate mode. $\mathrm{TM}_{01\delta}$ mode [6] also represents a high-Q factor, but its spurious mode issue is even worse since it is usually a higher order mode. TM_{01} mode [7], on the other hand, exhibits a much better spurious performance, but its Q factor is relatively low and its dielectric resonator requires to be short circuited at the two ends. A quasi-TM_{01} mode can be supported by a dielectric rod with one [8] or two [9] ends open circuited in a metallic cavity. Also, a number of dual-mode dielectric filter configurations [10]–[12] have been proposed to better utilize the space while maintaining a good Q factor. Normally, these kinds of dielectric filters are made of a dielectric puck or a rod (resonator) situated in a metallic housing with a necessary mounting fixture. A reliable and low-loss mounting mechanism of dielectric resonators in metallic cavities is very important to withstand the thermal stress and mechanical vibration shock with minimal loss. Additionally, the metallic cavity usually introduces additional weight and wastes certain amount of the filter volume taken by the metallic walls, which is especially significant when the cavity is small.

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Monoblock dielectric filters were developed firstly based on a combline type of TEM mode filter [13]–[16]. In these filters, the outer surface of the dielectric is metallized, and blind holes of about a quarter-wavelength deep are formed by molding and platting processes. In [17], a TE_{10} mode dielectric waveguide filter was proposed based on the concept of a monoblock dielectric rectangular resonator that is metallized on the outer surface. A filter using this concept is constructed by cascading multiple such resonators side by side. Such a filter is an attempt toward a monoblock dielectric filter. A major problem for such a filter is that it lacks a tuning mechanism. In [18], a dielectric filter, whose dielectric resonators are made of a single piece of a high dielectric constant ceramic slab, was reported, in which multiple dielectric resonators are interconnected on the same piece of ceramic slab and are cut using a water-jet process. Such a filter configuration is good for mass production and only requires a simple mounting structure. However, the filter still needs a separate metallic housing.

In this paper, a novel TM_{01} monoblock dielectric filter is presented. In such a filter, both dielectric resonators and the housing are made of a single piece of ceramic block with the outer surface metallized by silver platting. A metal lid is provided to host tuning screws for a wide tuning range. In this filter configuration, there is no need for any supporting structure for dielectric resonators. The measured results show that an excellent Q factor and temperature stability can be achieved with a compact size and lightweight structure. The proposed filter configuration is very suitable for mass production using clay casting and firing manufacturing process with little mechanical machining. Generally speaking, the proposed new concept of making a filter can provide an optimal Q factor for a given filter volume.

This paper is organized as follows. In Section II, the detailed filter configurations and basic characteristics of the proposed resonator are presented. In Section III, the I/O and inter-resonator coupling structures including magnetic and electrical couplings are discussed. The manufacturing process of a 4–2 monoblock dielectric prototype filter is then given. To show the superiority of the proposed dielectric filter, comparison between the monoblock dielectric filter and a conventional metal coaxial

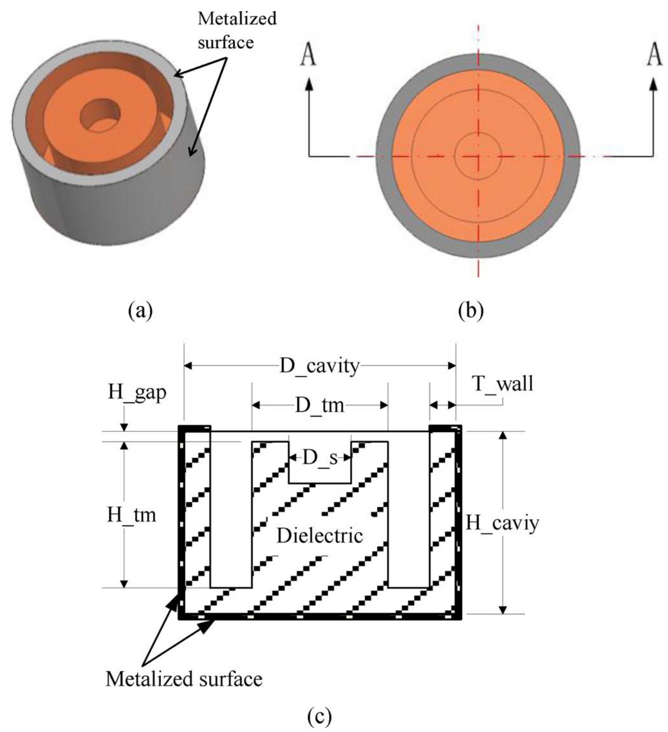

Fig. 1. Proposed monoblock dielectric resonator (metal lid is removed for illustration). (a) 3-D view, (b) top view, and (c) cross section view of the A–A plane.

filter of the same size is carried out experimentally for both the Q factor and temperature stability. The measured results show the significant advantage of the proposed dielectric filter configuration. Considering its unique features, such as its optimal Q factor for a given filter volume, light weight, simple to assemble, and suitable for mass production, it is believed that the proposed filter configuration will find a wide applications for advanced communication systems.

II. TM_{01} Mode Monoblock Dielectric Resonator

A. Filter Configuration

Fig. 1 shows the configuration of the novel TM mode monoblock dielectric resonator. The resonator is made of a single monoblock dielectric with a loss tangent of 2.5×10^{-5} and relative permittivity of 20.5 that is metallized on the outer surface of the ceramic block. The metallic lid will be soldered on the top surface of the dielectric base. It can be seen in Fig. 1(c) that the inner rod of the dielectric resonator is short circuited on the bottom surface while open circuited on the top surface. Dimensional parameter $\mathrm{H\_gap}$ denotes the distance between the metallic lid and the inner rod of the dielectric resonator. The dominate mode of this resonator is TM_{01} mode. One obvious advantage of the resonator is that since the mid rod is open circuited on the top plane and short circuited on the bottom plane, the TM_{01} mode resonator can be realized without any fixture or applied glue that may introduce extra loss and instability as compared to a traditional TM mode dielectric resonator in a metallic cavity. Additionally, space utilization is significantly improved since the volume of metallic walls is removed, which consequently improves the Q factor. The cave on the mid rod is provisioned for a tuning screw.

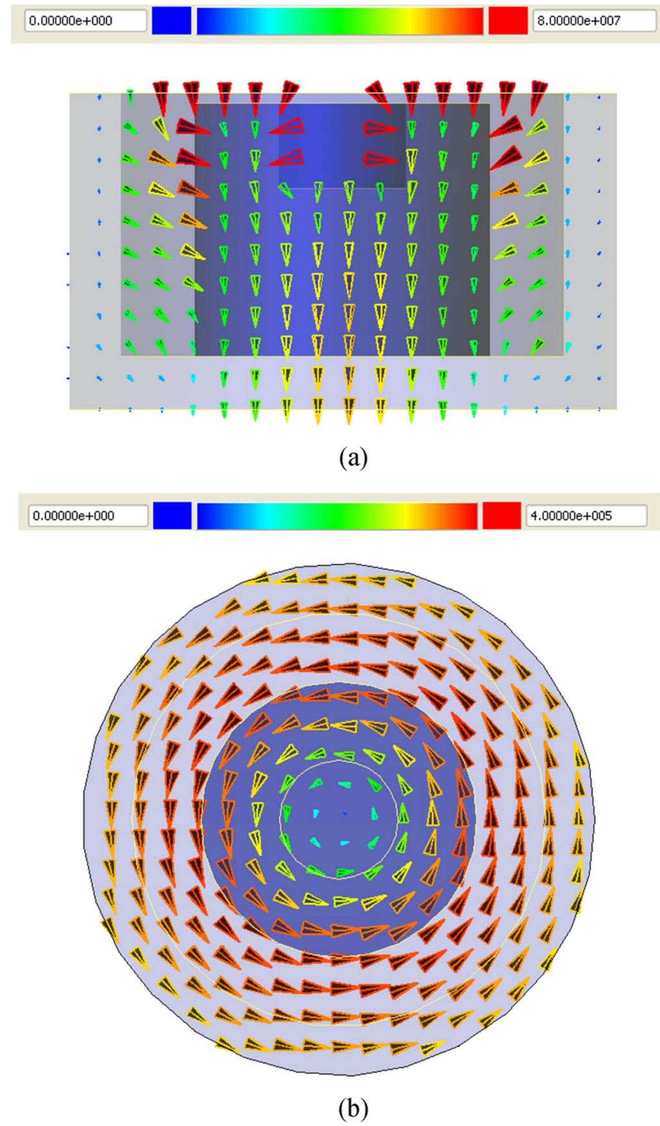

Fig. 2. (a) Electric-field distribution of TM_{01} mode in vertical cross-section plane cut through the center axis. (b) Magnetic-field distribution of TM_{01} mode in horizontal cross-section plane cut at the middle of the height.

B. Characteristics of Resonator

Cross-section view of electric-field distributions of the first resonate mode of the proposed resonator is shown in Fig. 2 and the mode chart versus dimensions of $\mathrm{H\_gap}$ and $\mathrm{D\_tm}$ for the first four modes are given in Fig. 3. Figs. 2 and 3 are obtained by an EMPro eigenmode simulator [19]. It is seen from electromagnetic (EM) simulation that the dominate mode is the TM_{01} mode, and the HE_{11} and HE_{12} modes are two sets of degenerate modes. The dimensions in the simulation are: $\mathrm{D\_cavity} = 26$ mm, $\mathrm{H\_cavity} = 15$ mm, $\mathrm{D\_tm} = 14$ mm, $\mathrm{D\_s} = 6$ mm, $\mathrm{T\_wall} = 2.5$ mm, while a tuning screw with a diameter of 3 mm is inserted into the cavity with insertion depth of 4 mm. The simulated Q factor of the TM_{01} mode is around 3200 at a frequency of 2.6 GHz. In the EM simulation, the parameters related to the materials are: relative permittivity and loss tangent

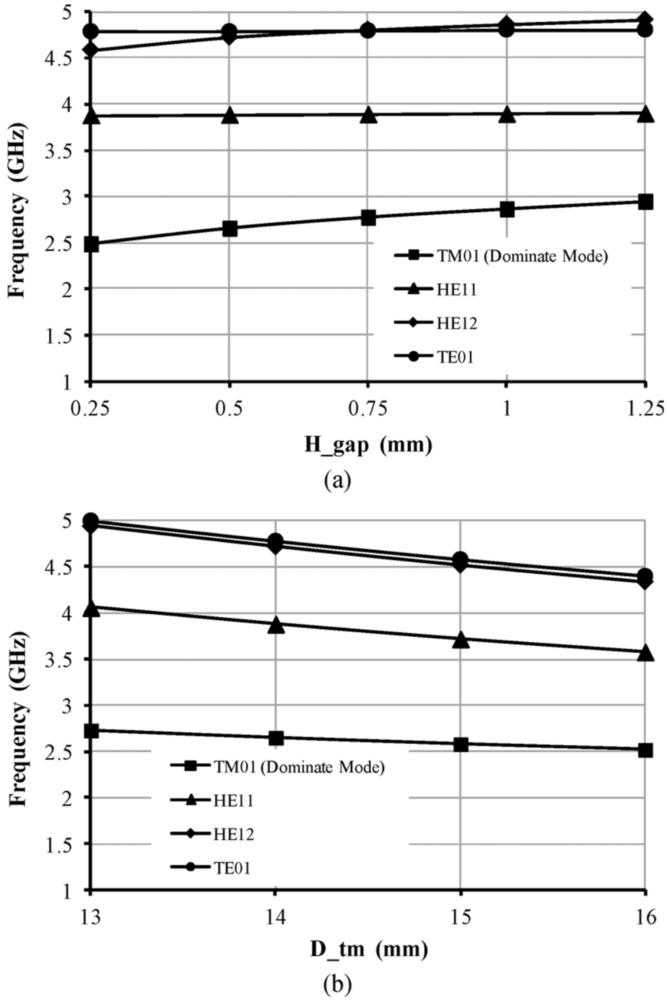

Fig. 3. Mode chart of the first four modes versus: (a) $\mathrm{H\_gap}$ and (b) $\mathrm{D\_tm}$.

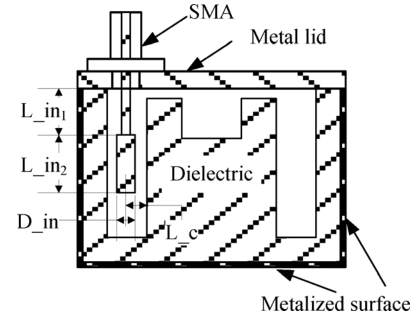

Fig. 4. Cross-section view of the I/O coupling structure.

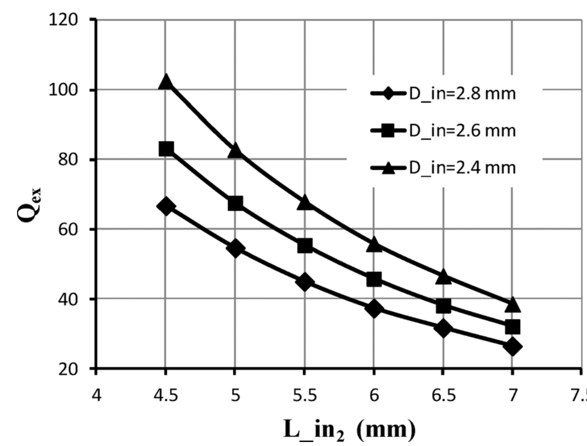

Fig. 5. Q_{ex} versus length of the I/O probe ($\mathrm{L\_in}_2$) with different diameters.

of the dielectric are 20.5 and 2.5×10^{-5}, respectively; the conductivity $\sigma = 2\times 10^7$ S/m. From Fig. 3(a), it can be seen that the gap dimension will affect the resonance frequency of the dominate mode to a certain extent. However, the first spurious mode is not sensitive to the gap dimension when the gap is small. In order to have a good spurious performance, the gap should be kept to a small value. It is shown in Fig. 3(b) that while the diameter of the inner dielectric rod increases, resonate frequency of the first six modes decreases simultaneously (while $\mathrm{H\_gap}$ is chosen to be 0.5 mm).

III. Design of a 4–2 Monoblock Filter

A. I/O Coupling

The I/O coupling is achieved by mounting an SMA connector vertically from the top metal lid with a top-loaded probe, as is shown in Fig. 4. The diameter ($\mathrm{D\_in}$), length ($\mathrm{L\_in}_2$) of the metal rod, and the distance ($\mathrm{L\_c}$) between the metal rod and dielectric rod can be adjusted to achieve the designated I/O coupling. It is seen from Fig. 5 that the external quality factor Q_{ex} decreases while the diameter and length of the probe increase. The I/O configuration is suitable for surface-mount applications.

B. Inter-Resonator Coupling

The inter-resonator coupling is realized by opening a window between two adjacent resonators, which is shown in Fig. 6. This window can be filled with either air or dielectric. If it is filled by air, the spurious mode caused by the iris will not be excited. If it is filled by dielectric, spurious modes might be excited and are very close to the dominate mode of the resonator. In this design, the air filled window is utilized to avoid the spurious modes. Fig. 7 shows the calculated coupling coefficient as function of the width of the air window with different heights. 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 resonance frequencies of odd and even modes, respectively, of the coupled resonators calculated by the EMPro eigenmode simulator [19]. For simplicity, the height of the iris is set to be the same as that of the resonator.

The window coupling mainly provides magnetic coupling. In order to realize electrical coupling, a U-shaped metal probe with a low dielectric constant supporter is introduced, as shown in Fig. 8. The coupling coefficient can be controlled by adjusting the length ($\mathrm{L\_cc}$) and the height ($\mathrm{H\_cc}$) of the probe, as shown in Fig. 9.

C. Filter Realization

A four-pole 4–2 monoblock dielectric filter is fabricated for verification. Fig. 10 shows the manufacturing process of the filter. First, mould casting or other mechanical machining is used to create the initial monoblock clay with designed geometry; the clay is then sintered to get the monoblock dielectric that is shown in Fig. 10(a) and (b). Second, the outer surface

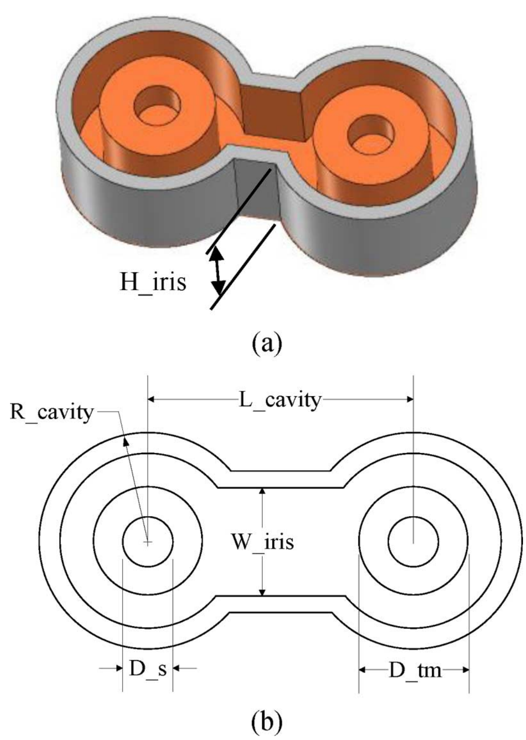

Fig. 6. Coupling between two resonators (metal lid is removed for illustration). (a) 3-D view. (b) Top view.

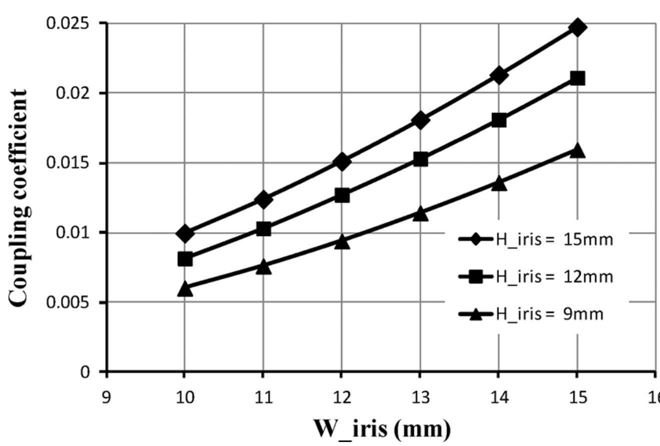

Fig. 7. Coupling coefficient versus width of coupling window (W_iris) with different height (H_iris).

of the monoblock dielectric is metallized. The surface includes the bottom surface, side surface, and the cirque part of the top surface, as illustrated in Fig. 10(c). It can be noticed that since the mid rod of each resonator is opened on the top surface, they are not metallized. At last, the metallic lid is soldered on the top surface of the monoblock dielectric using a reflow process; as shown in Fig. 10(d) and (e), SMA connectors and tuning screws are then assembled.

The center frequency and equal ripple bandwidth of the fabricated filter are 2.6 GHz and 50 MHz, respectively. The real estate taken by the filter is 54 mm $\times$ 54 mm $\times$ 17.5 mm, including the metal lid whose thickness is 2.5 mm. Each resonator occupies 26 mm $\times$ 15 mm space. The diameter of the mid rod in

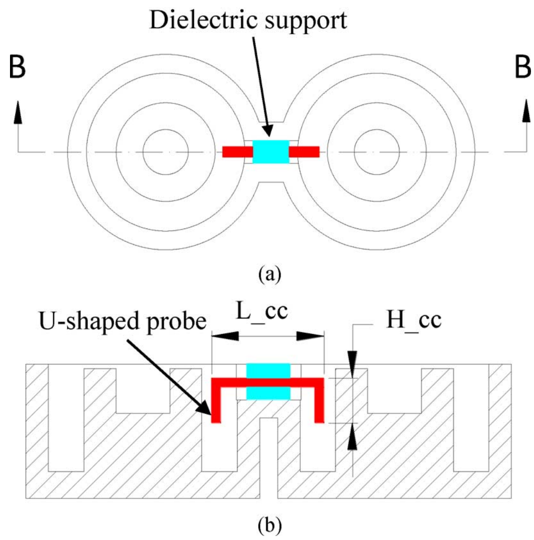

Fig. 8. Electrical coupling between two resonators (metal lid is removed for illustration). (a) Top view. (b) B–B cross-section view.

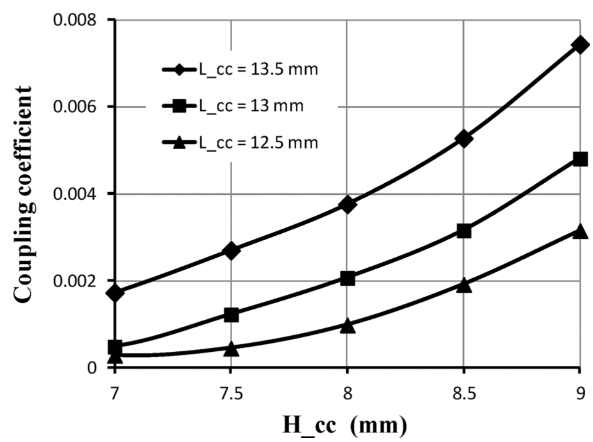

Fig. 9. Coupling coefficient versus height of the probe (H_cc) with different length (L_cc).

each resonator is 13.1 mm in resonators 1 and 4, and 13.4 mm in resonators 2 and 3. The diameter of the cave on each mid rod is 6 mm with a height of 4 mm. The cross coupling between resonators 1 and 4 is for realizing the two transmission zeros. The nonzero elements of the normalized coupling matrix are $\mathrm{M}_{01} = \mathrm{M}_{45} = 1.06836$, $\mathrm{M}_{12} = \mathrm{M}_{34} = 0.91175$, $\mathrm{M}_{23} = 0.7985$, and $\mathrm{M}_{14} = -0.19494$.

The simulated and measured results of the 4–2 filter are shown in Fig. 11. Due to some parasitic coupling between the input/output probe and nonadjacent resonators, the rejection level at the lower frequency band and higher frequency band are not equal. The measured result shows that the insertion loss of the fabricated filter is around 0.3–0.4 dB, the corresponding Q factor of the filter is around 3000. The measured wideband response is given in Fig. 12, showing that the first spurious mode appears at 3.8 GHz.

D. Comparison With a Metal Coaxial Filter

For comparison purposes, a conventional metal coaxial 4–2 filter is designed, fabricated, and measured. The filter has the

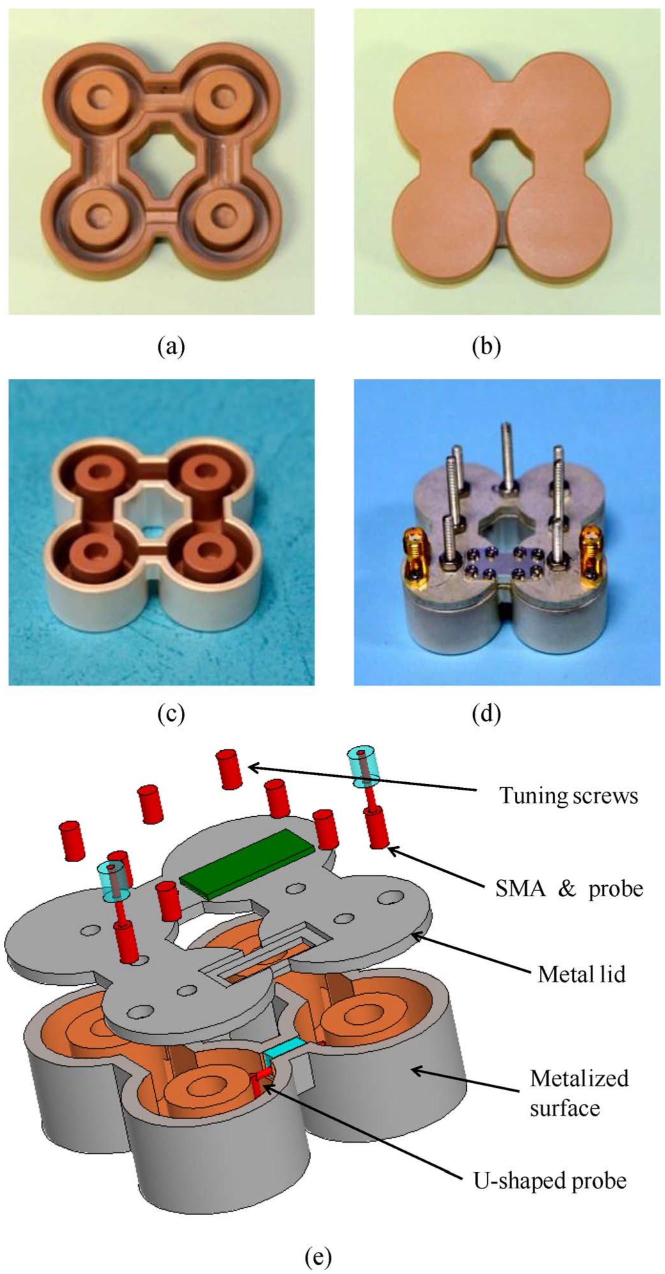

Fig. 10. Fabricated filter. (a) Top view of the dielectric monoblock. (b) Bottom view of the dielectric monoblock. (c) Metallized dielectric monoblock. (d) Assembled filter with metal lid soldered on the top plane. (e) Assembly of the monoblock filter.

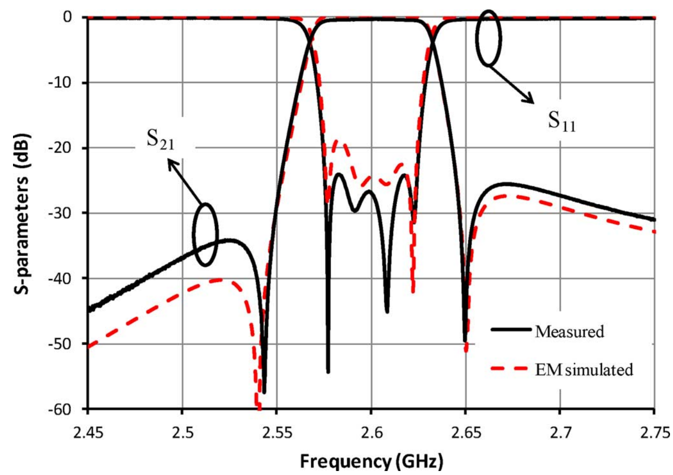

Fig. 11. Measured and simulated S-parameters of the monoblock prototype filter.

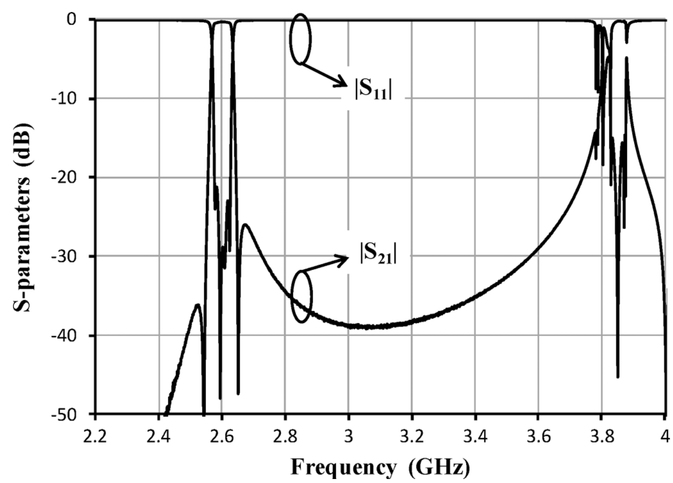

Fig. 12. Measured wideband performance of the monoblock filter.

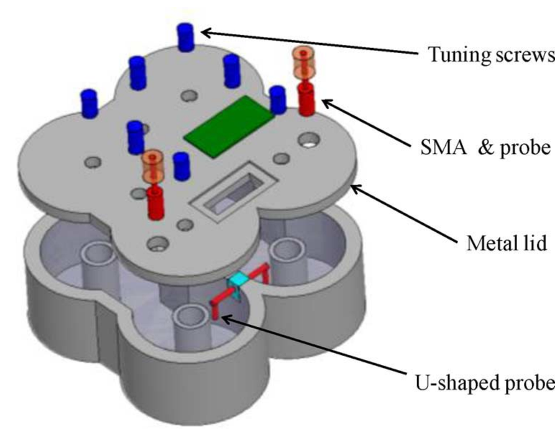

Fig. 13. Assembly of the metal coaxial filter.

same size as that of the monoblock dielectric filter. Fig. 13 shows the assembly of the coaxial filter, which has the same input/output and cross coupling structures as those of the monoblock dielectric counterpart. The measured results of the coaxial and the monoblock dielectric filters are shown in Fig. 14. It is expected that the insertion loss of the coaxial filter of 0.7–0.8 dB with corresponding Q factor of around 1800 is significantly worse than those of the monoblock dielectric filter. However, the measured first spurious mode of the coaxial filer appears at 7.45 GHz.

To investigate the temperature stability of the proposed filter configuration, temperature tests are conducted. The measured filter performance at 20 °C and 60 °C for the monoblock dielectric and the metal coaxial filters are presented in Fig. 15. It should be mentioned that neither the monoblock filter, nor the coaxial one is built with temperature compensation. The coaxial filter is made of aluminum and silver plated on both inner and

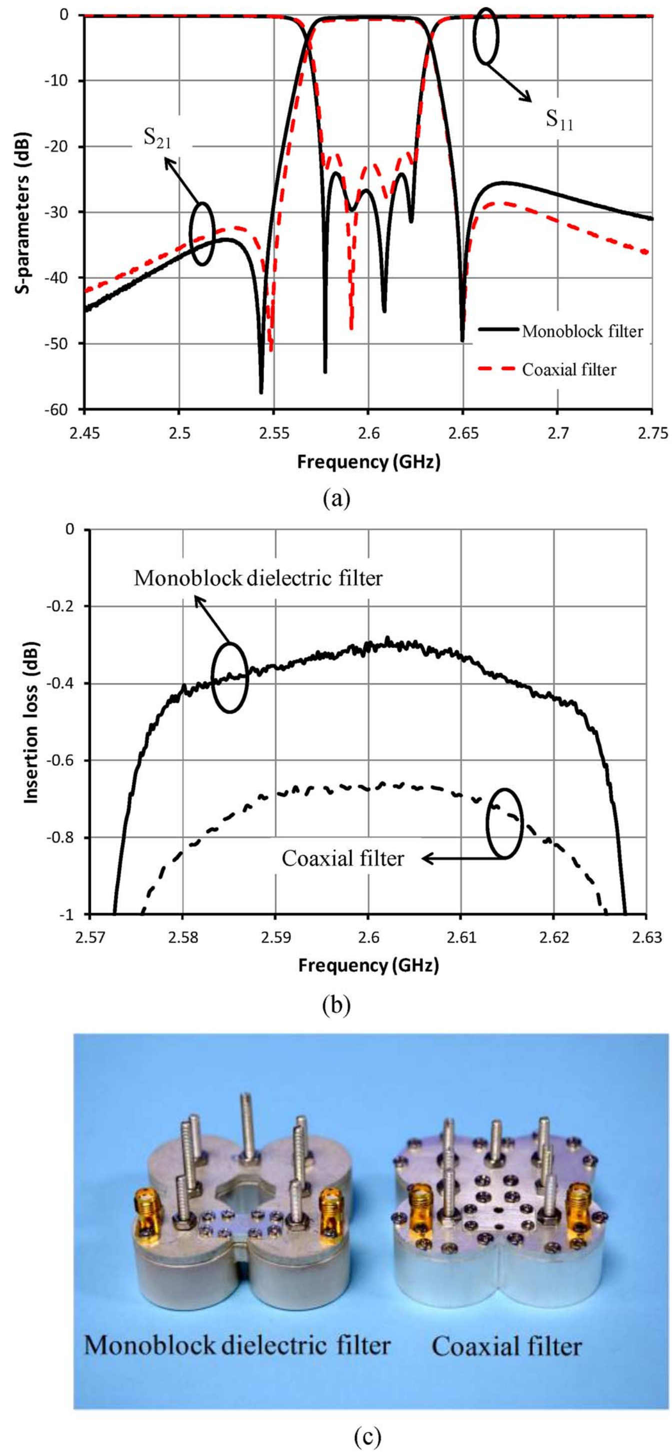

Fig. 14. Comparison between the monoblock filter and the coaxial filter. (a) Measured S-parameters. (b) Measured insertion loss. (c) Photograph of the prototype filters.

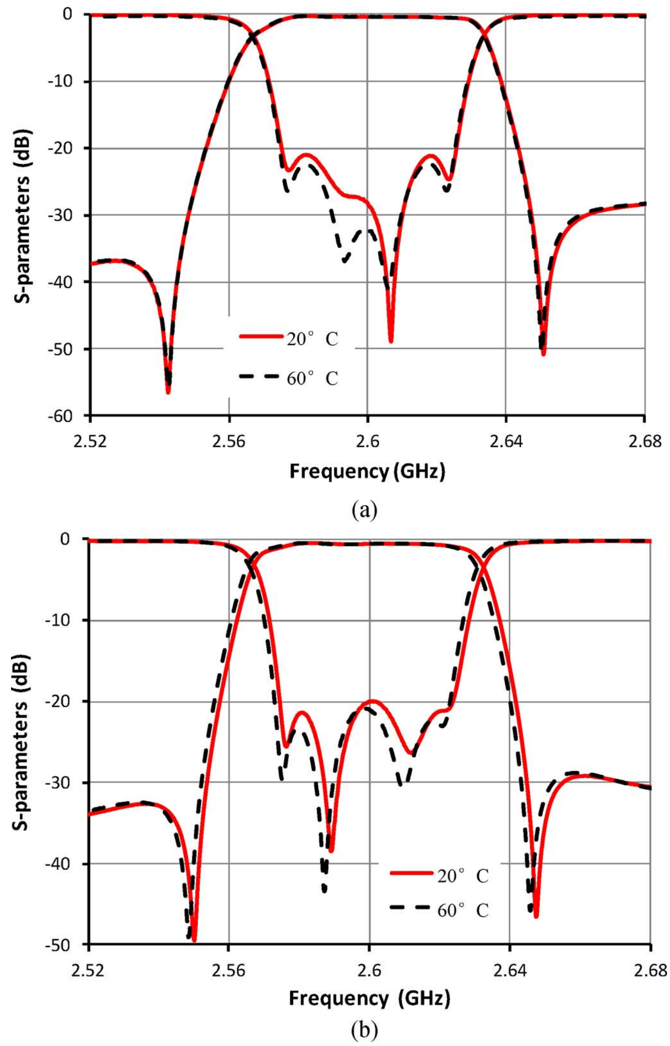

Fig. 15. Measured S-parameters of the: (a) monoblock dielectric filter and (b) coaxial filter, in different temperatures.

outer surfaces. The metallic lid of the monoblock dielectric filter is manufactured with the same aluminum material, as well as the same type of tuning screws. The frequency shift by temperature change of the monoblock dielectric filter can be calculated to be -7.1 kHz/$^\circ$C, while the coaxial filter is -37 kHz/$^\circ$C. The corresponding temperature coefficient of frequency variation is -2.7 ppm/$^\circ$C for monoblock dieletric filter and -14.2 ppm/$^\circ$C for coaxial filter. The temperature coefficient of frequency variation is calculated by $\tau_f = (1/f_0 \cdot \Delta f/\Delta T)$, where f_0 is the center frequency, and Δf is the total frequency variation corresponding to the temperature shift ΔT.

IV. Conclusion

In this paper, a novel monoblock TM_{01} dielectric filter has been proposed. This kind of filter is made of a single piece of dielectric with a silver-plated outer surface and a metallic lid. No metallic housing is required. The dominant TM_{01} mode is supported by a centered dielectric rod that is short circuited at one end by the metallized dielectric surface. The major advantages of such filter include: 1) relatively high Q; 2) easy for mass production; 3) high thermal and mechanic reliability; and 4) low cost. A prototype monoblock filter has been fabricated and tested with a center frequency of 2.6 GHz and bandwidth of 50 MHz. Its superiorities over a conventional metal coaxial filter with the same external size has been demonstrated both in Q factor and temperature stability. Since the filter is light in weight and compact in size, it is highly suitable for the applications in which surface mountable filters are required.

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