高介電係數陶瓷基板之雙模態帶通濾波器的研製
The Fabrication of Dual-Mode Bandpass Filter By Using High Permittivity Ceramic Substrate

戴國圓
Kok-Wan Tay
吳鳳科技大學 電機工程系
Department of Electrical Engineering, Wu-Feng University

摘要

本論文提出在高介電常數的 $Nd(Mg_{0.5}Ti_{0.5})O_3$ 陶瓷基板製備了雙模態共振器的帶通濾波器。所設計的雙模態帶通濾波器，其中心頻率在 2.45GHz 及頻寬預設在 10%，並製作在 FR4(Flame Retardant4)及摻雜 10 mol% B_2O_3 的 $Nd(Mg_{0.5}Ti_{0.5})O_3$ (NMTB)陶瓷基板上。實驗結果顯示，NMTB 陶瓷基板上的帶通濾波器，其中心頻率是在 2.62 GHz， - 3dB 頻寬約為 9.1 %。測量帶通濾波器的反射損失和插入損失分別是-20.28dB 及-1.985dB。一對傳輸零點的帶斥頻段為 2.1 和 3.1GHz 分別壓縮抑制在-37 和-36 dB。相對於 FR4 做比較，本論文使用 NMTB 基板研製雙模態帶通濾波器，不僅可減少 76.86% 的電路整體面積，還可獲取較高的濾波器選擇比。

關鍵詞：高介電係數，雙模態帶通濾波器，陶瓷基板。

ABSTRACT

A compact bandpass filter using dual-mode resonators was fabricated on high permittivity of $Nd(Mg_{0.5}Ti_{0.5})O_3$ ceramics substrates is presented. The designed of a dual-mode bandpass filter at a center frequency of 2.45GHz and 10% bandwidth were fabricated on both FR4 and $Nd(Mg_{0.5}Ti_{0.5})O_3$ doped 10 mol% B_2O_3 (NMTB) ceramic substrates. The experimental result of NMTB ceramic substrates shown that center frequency of the fabricated bandpass filter is at 2.62 GHz and the -3dB bandwidth is about 9.1%. The measured return loss and insertion loss of the filter is -20.28 and -1.985dB, respectively. A pair of transmission zeros at 2.1 and 3.1GHz with –37 and –36 dB rejection, respectively. In comparison with FR4, the bandpass filter using NMTB substrate not only has 76.86% reduction of its circuit size, but also obtained excellent filter selectivity are presented in this article.

Key Words: high permittivity, dual-mode bandpass filters, ceramics substrate

I. INTRODUCTION

The microwave filters with compact size and high permittivity are essential component for many RF communication systems, which is usually used in both receivers and transmitters. Planar filters using microstrip method are usually applied in RF filters because they can be fabricated by using printed circuit technology at low cost and small size. Since microstrip resonators are the basic components of a planar-filter design, it is necessary to select the proper resonator types to be used in a filter design. A compact size is essentially required in many microwave filter applications, such as cellular telephones, ceramic material with a high quality factor (Q x f) value (>10,000) and a high permittivity provides a means to create small resonator structure, such as coaxial structure, which can be coupled to form combline bandpass filter [1]. However, further miniaturization becomes more difficult for this filter. Planar filters using high-permittivity ceramic substrate, such as parallel-coupled filter [2], interdigital filter [3], combline filter [4], and hairpin filter [5], provide good miniaturization ability. Generally speaking, a conventional half-wavelength open-line microstrip resonator is too large to be used in modern communication systems such as personal communication systems at 900 and 1800 MHz, and wireless location area networks at 2.4 and 5.3 GHz [2].

Microstrip bandpass filters using dual-mode resonators have been receiving a great deal of attention because the number of resonators required for a given filter may be reduced by half, resulting in a compact filter configuration [6,7]. Dual-mode filters have two main advantages: first, size reduction, since a single resonator will support dual degenerate modes corresponding to a two-pole section in the filter construction; secondly, they manifest the implementation of sophisticated filter responses, which includes the elliptical or quasi-elliptical responses for improving the skirt characteristics [8-10]. These intrinsic characteristics of dual-mode filters are more excellent than those of traditional microstrip half-wavelength resonator bandpass filters in microwave applications. This paper describes the design, fabrication and measured frequency responses of the dual-mode bandpass filters base on different high permittivity ceramics substrate of FR4 and $Nd(Mg_{0.5}Ti_{0.5})O_3$ doped 10 mol% B_2O_3 (NMTB). The results among of these filters regarding performance and compact size are investigated.

II. DESIGN AND IMPLEMENTATION OF THE DUAL-MODE BANDPASS FILTER

1. Design of the Dual-Mode Bandpass Filter

Dual-mode filters consist of two degenerate modes, which have the approach resonant frequencies to each other. Passband characteristic can be formed by adding a perturbation for mode-coupling. However, it is recognized that the higher order resonant modes for two degenerate modes might also result in spurious responses by adding a perturbation. To suppress the spurious response, the input/output coupling structure is designed to stagger higher order resonant frequencies. Since higher order modes are disturbed, they cannot build up to cause spurious responses.

The advantage of using high permittivity ceramic substrates and dual-mode resonators are to miniaturize the sizes of microstrip bandpass filters. The symmetrical resonators configuration and a perturbation are necessary. The orthogonal I/O is designed to cause two out-of-phase transmission paths for generating a pair of transmission zeros near the passband. Therefore, changing the length of transmission paths can decide the position of transmission zero. These zeros are useful in the rejection of strong interference in the stopband of the filter.

Figure 1 demonstrates layout of the microstrip dual-mode bandpass filter. Input and output ports are spatially separated orthogonally and a perturbation is introduces within the resonator. There are two propagation paths between the input and output ports, the dual-mode filter features two transmission zeros near the resonant frequency, obtaining excellent filter selectivity. If there was no perturbation, for odd-mode excitation the output port would be coupled to a position of the zero electric field along the resonator leading to a short circuit. Therefore, no energy is extracted from the resonator which provides a stopband. In this configuration, the lengths of path-1 and path-2 are 90° and 270°, respectively, corresponding to a transmission zero due to cross coupling effect.

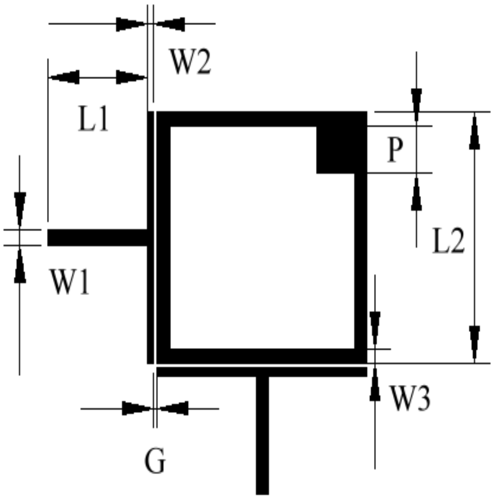

Fig. 1 Layout of the microstrip dual-mode bandpass filter.

The short transmission line provides a signal path-1 for conventional dual-mode filter, while the perturbation introduces a main cross-coupling path-2 which the signal would cancel the one traveling along path-1 at certain frequencies. The signals from these two paths have nearly 180° out-of-phase at two frequencies such that they would cancel out each other at these two frequencies. Therefore, the whole filter characteristic has two transmission zeros. The transmission zero exists at a frequency where the eigen-impedances of the even and odd modes are equal to cancel the currents each other at output port. Thus, from even-mode and odd-mode analysis the transmission zero frequencies can be calculated as following [11]:

$$Y_{U21} = -Y_{L21} \tag{1}$$

$$Y_{even} = -jY_o\left(\frac{y_p\tan\theta_2 - 1}{y_p(1-\tan\theta_1\tan\theta_2)+\tan\theta_1+\tan\theta_2} - \frac{1}{y_g}\right)^{-1} \tag{2}$$

$$Y_{odd} = -jY_o\left(\frac{1}{(\cot\theta_1+\cot\theta_2)} - \frac{1}{y_g}\right)^{-1} \tag{3}$$

Where Y_o is the terminated admittance, Y_{even} and Y_{odd} are the input admittances of the half-circuit corresponding to the even and odd modes about the symmetric line, respectively, y_g and y_p are the equivalent admittances of the coupling gap and perturbation, respectively.

The designed of dual-mode bandpass filter was fabricated on FR4 and NMTB-based ceramics substrate with same thickness of 0.8 mm, both substrates of dielectric constant ε_r and $\tan\delta$ was 4.4, 0.015, 26.2, and 0.00001631, respectively. The center frequency of designed bandpass filter is f_0 = 2.45GHz and 10% bandwidth. Frequency responses of dual-mode bandpass filter are simulated by using Ansoft HFSS software. After careful adjustment in simulation, the dimension parameters of the dual-mode bandpass filters with different high permittivity ceramic substrates are presented in Table 1.

Table 1 Dimensions of dual-mode bandpass filters with different ceramic substrates

Sizes (mm)	W1	W2	W3	L1	L2	P	G
FR4 Substrate	1.18	0.59	1.18	17.27	18	3	0.12
NMTB Substrate	0.45	0.50	1.0	7.89	8.40	1.4	0.10

2. Implementation of the Dual-Mode Bandpass Filter

Specimen powders were prepared by a conventional solid-state method. High-purity oxide powders (>99.9%): Nd_2O_3, MgO and TiO_2 were used as raw materials. The powders were weighed according to the composition $Nd(Mg_{0.5}Ti_{0.5})O_3$, and were ground in distilled water for 12h in a balling mill with agate balls. Prepared powders were dried and calcined at 1100℃ for 2h in air. The calcined powers were mixed as desired composition $Nd(Mg_{0.5}Ti_{0.5})O_3$ with 10 mol% Bi_2O_3 of low temperature sintering promoter and re-milled for 12h. These fine powders were mixed with the organic binder (PVA) and pressed at $25kg/cm^3$ into pellets with dimensions of 30 mm diameter and 0.8 mm thickness as the NMTB ceramic substrate. These pellets were sintered at temperatures of 1325℃ for 6 h in air. The heating and cooling rates were both set at 5℃ /min. The NMTB ceramic substrate can obtain the dielectric constant $\varepsilon_r = 26.2$, and $\tan\delta = 0.00001631$. Silver paste was then printed on NMTB-based ceramics substrate and was fired at 80℃ for 5 min. The backside with copperplate and SMA connectors were soldered to fabricated dual-mode bandpass filters. The microwave properties of the specimens were measured by an Anritsu 37347C Vector Network Analyzer. Figure 2 shows photograph of the filter prototypes for FR4 and NMTB ceramics substrate. The size of the dual-mode bandpass filter using FR4 is 18.71 x 18.71 mm^2, while that using NMTB ceramics substrate is 9 x 9 mm^2, which is 76.86% reduction of its circuit size.

Fig. 2 Photograph of the filter prototypes: (a) FR4, and (b) NMTB ceramic substrates.

III. SIMULATED AND MEASURED RESULTS

The dual-mode bandpass filters are designed on FR4 substrate with dielectric constant (ε_r) of 4.4, loss tangent ($\tan\delta$) of 0.015, and thickness of 0.8mm. The simulated and measured frequency responses of the dual-mode bandpass filter are shown in Figure 3(a) and Figure 4(a). The measurements present a bandpass center frequency of 2.59 GHz and a -3dB bandwidth of 10.6%, compared with simulated values of 2.44 GHz and 18.4%, respectively. The measured minimum passband insertion loss (S_{21}) is -0.75dB, compared with a simulated value of -1.864 dB and the measured maximum passband return loss (S_{11}) is -32.2 dB, compared with a simulated value of -34.18 dB. Moreover, it is found that two transmission zeros of measured value are occur at 2.0GHz and 3.2 GHz, compared with simulated values of 2.02 GHz and 3.19 GHz.

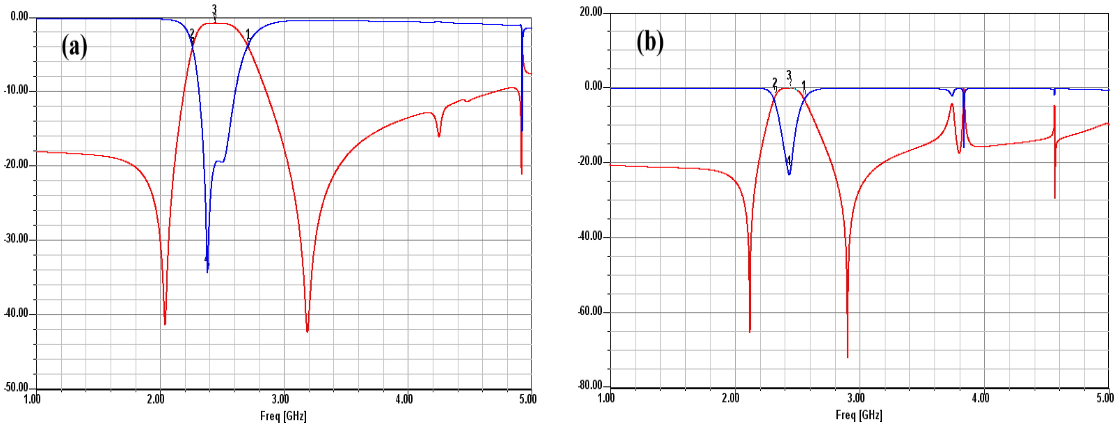

Fig. 3 Simulated frequency responses for (a) FR4, and (b) NMTB ceramic substrates.

The dual-mode bandpass filters are designed on NMTB substrate with high dielectric constant (ε_r) of 26.2, loss tangent ($\tan\delta$) of 0.00001631, and thickness of 0.8mm. The simulated and measured frequency responses of the dual-mode bandpass filter are shown in Figure 3(b) and Figure 4(b). The measurements present a bandpass center frequency of 2.62 GHz and a -3 dB bandwidth of 9.1%, compared with simulated values of 2.44 GHz and 9.4%, respectively. The measured minimum passband insertion loss is -0.02 dB, compared with a simulated value of -1.985 dB and the measured maximum passband return loss is -20.28 dB, compared with a simulated value of -22.91 dB. The two transmission zeros close to the passband are found at 2.1 and 3.1GHz with –37 and –36 dB, compared with simulated values of 2.15 and 2.9 GHz with –65 and –72 dB, respectively. The slight difference between the measured and simulated results might be due to the variation of the dielectric constant of fabricated NMTB ceramic substrates, surface roughness, silver paste conductor thickness, and the SMA of electric contact. This fabrication error could be controlled by the improvement of fabrication technology.

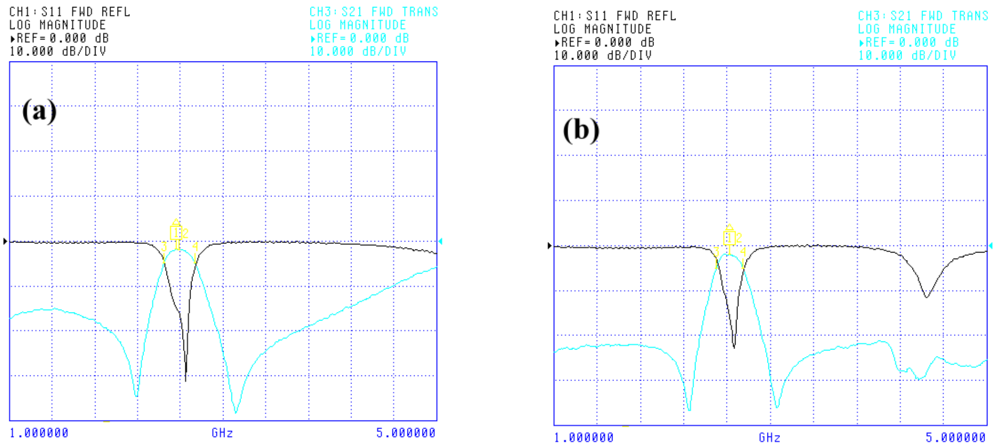

Fig. 4 Measured frequency responses for (a) FR4, and (b) NMTB ceramic substrates

IV. CONCLUSION

The designed of a dual-mode bandpass filter at a center frequency of 2.45GHz and 10% bandwidth were fabricated on both FR4 and $Nd(Mg_{0.5}Ti_{0.5})O_3$ doped 10 mol% B_2O_3 (NMTB) ceramic substrates have been investigated. The experimental result of NMTB ceramic substrates shown that center frequency of bandpass filter is at 2.62 GHz and the -3dB bandwidth is about 9.1%. The measured return loss, insertion loss, and a pair of transmission zeros of the filters is -20.28 dB, -1.985dB, 2.1GHz and 3.1GHz, respectively. The center frequency is slightly shifted from 2.45 to 2.62GHz is due to the variation of the dielectric constant of fabricated NMTB ceramic substrates, surface roughness, silver paste conductor thickness, and the SMA of electric contact. This fabrication error could be controlled by the improvement of fabrication technique. In comparison with FR4, the dual-mode structure of bandpass filter using NMTB substrate not only has 76.86% reduction of its circuit size, but also improved the selectivity, stopband rejection, and tunable transmission zeros. Therefore, the microstrip dual-mode bandpass filter could be widely applied in modern communication system.

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