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Novel half-mode substrate integrated waveguide bandpass filters using semi-hexagonal resonators

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In this paper, a novel bandpass filter is presented, designed, and implemented by using a triple mode semi-hexagonal Half-Mode Substrate Integrated Waveguide (HMSIW) cavity, which has the advantages of compact size, low insertion loss, and high selectivity in upper and lower passband. To realize a triple mode filter, the first resonant mode is shifted to near the next two modes using a via hole perturbation. Two microstrip open stubs connected to open edge of HMSIW resonator are introduced to generate two transmission zeros in the lower passband. The position of transmission zeros could be controlled by adjusting the coupling gap between the microstrip open stub resonators. By etching an E-shape slot on the top plate of HMSIW resonator, two other transmission zeros are produced in the upper passband. A wide-band planar six-pole bandpass filter, which has the advantages of wide bandwidth and small size, is also proposed and fabricated by cascading two triple mode resonators. Measured results indicate that 29% and 47% fractional bandwidth, as well as approximately 1 dB and 1.1 dB insertion loss, are achieved for the proposed filters. Measured results of all those filters agree well with the simulated results.

1. Introduction

Recently, planar microwave filters owning to their wide applications have been developed as the key components of modern communication circuits such as wireless and RF/microwave circuits. Multimode resonators have been widely utilized in the filter design process due to their capabilities in reducing the number of resonating elements, inherent size reduction, and improving performance in filter response's selectivity. Triple mode filter is one kind of the multimode filters, having three resonances in one resonator. One of the resonances is considered as a central frequency and the other two modes are located in close to edges of the passband. Several types of triple mode filters based on different structures such as cylindrical and rectangular waveguide technology [1,2], microstrip structures [3,4], and planar structures with multi-layer resonators [5] have been proposed in the literature. Cavity waveguides, as well as multi-layer resonators, are bulky and complicated to fabricate and integrate with planar structures. Although planar structures could be integrated with planar circuits, they have higher conductor loss and lower power capability. Substrate integrated waveguides (SIW) structure is considered as appropriate replacement for implementing microwave and millimeter components due to having the advantages of conventional metallic waveguides including, high quality factor, low insertion loss, low cost, easy fabrication process, ease of integration with planar structure [6–8]. Recently, HMSIW as a new structure has been proposed in which the size and the dominant mode are half of SIW [9–11]. The principal idea in HMSIW is that the symmetric plane of SIW along the propagation direction is equivalent to a magnetic wall. Hence, HMSIW is obtained through bisecting SIW on the magnetic wall while the half field distribution is kept unchanged. Many filters based on SIW techniques with various resonators such as split ring resonators (SRR) [12], stepped-impedance resonator (SIR) [13], compact microstrip resonator cell (CMRC) [14] and defected ground structure (DGS) [15], have been reported. These filters have appropriate performances, however, they are characterized with narrow bandwidth and most of their resonators operate in one mode. In [16], a triple mode filter has been designed by placing an additional via at the center of a circular SIW cavity resonator in which its fractional bandwidth (FBW) is 15% in the central frequency of 33.5 GHz. In [17], a wideband filter has been proposed by placing u-shape slots on the top metallic plate of SIW which has the high selectivity in the upper side of the passband and its FBW is equivalent to 42% in the central frequency of 8.5 GHz. Furthermore, a triple mode filter has been introduced utilizing isosceles right triangular resonator based on quarter mode substrate integrated waveguide (QMSIW) with an

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FBW 38% in the central frequency of 5.2 GHz [18]. In this paper, a triple mode filter with compact size and high selectivity in passband has been proposed using a HMSIW hexagonal cavity. The first mode resonant frequency has been increased through placing a metalized via-hole in the center of cavity and it is approached the other two resonant modes while they remain unchanged.

By etching an E-shaped slot on the top plate of HMSIW, two transmission zeros are produced in the upper side of the passband, increasing the filter selectively in high frequencies. Moreover, to improve the filter selectivity, two microstrip open stub resonators connected to open edge of HMSIW resonator are used to create two transmission zeros in the lower side of the passband. Finally, after extensive parametric investigations and numerical optimizations, a wide-band planar six pole bandpass filter is designed and fabricated by using two HMSIW hexagonal cavities. Then, by etching two U-shape slots on the top plate of the cavities, one transmission zero is created in upper side of the passband to obtain an improved frequency selectivity performance.

2. Triple mode HMSIW filter using one resonator

(A) *HMSIW resonator*

An HMSIW is obtained by cutting the SIW hexagonal cavity along any long diagonals of the hexagon. The open boundary of HMSIW cavity is approximately considered as a magnetic wall, and the array of metallic via-holes approximates the boundary to the electric wall. SIW and HMSIW hexagonal cavities are indicated in Fig. 1. As has been shown, HMSIW cavity is half the size of SIW cavity. These cavities have been simulated on a Rogers RO4003 substrate with thickness of 0.8 mm, a relative dielectric constant of 3.38 and loss tangent 0.0027. Via diameter (d) and distance between both adjacent vias (p) are 0.5 mm and 1 mm, respectively.

Fig. 2 shows the resonant frequencies of SIW and HMSIW resonators. Transmission coefficients of SIW and HMSIW resonators are specified with solid blue curve and dash red curve, respectively. The first five resonant modes of these resonators have been named as f_1 to f_5, respectively. The resonant frequencies of HMSIW resonator excited in 6.5, 10.5, 13.3, 15.2, and 16.5 GHz have been slightly shifted in comparison with the corresponding SIW resonator modes because of the fringing field of the equivalent magnetic wall. Fig. 3 shows the electric field distributions of SIW and HMSIW resonators. As shown in Fig. 3b, the electric fields of the excited modes in SIW resonator are symmetrical at the center plane which is equivalent to a magnetic wall and the electric field distribution of HMSIW resonant modes is half of the corresponding modes in SIW cavity.

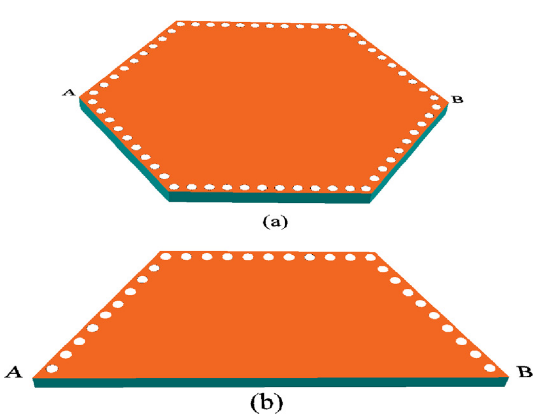

Fig. 1. Configuration of the cavity resonators: (a) Hexagonal SIW cavity resonator, (b) HMSIW hexagonal cavity resonator.

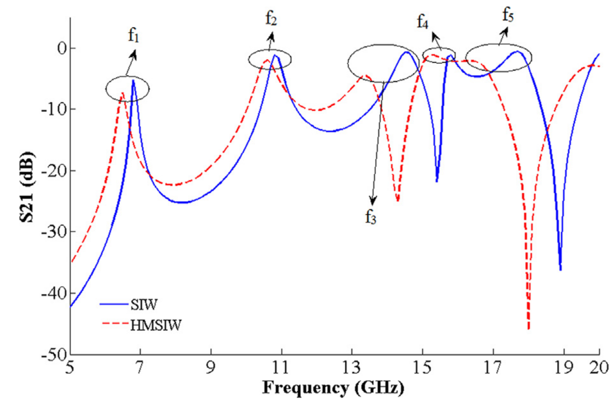

Fig. 2. Transmission coefficients of the hexagonal SIW and HMSIW resonators against frequency simulated in HFSS.

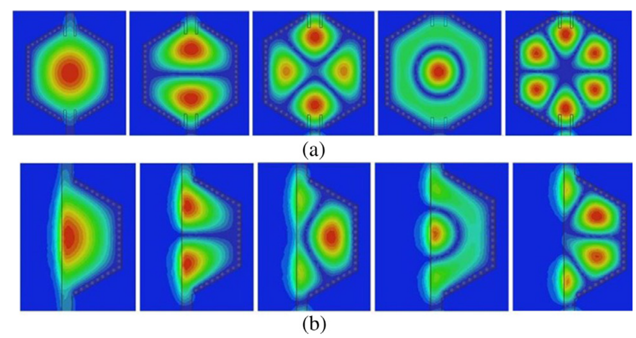

Fig. 3. Electric field distribution of the first five resonant modes in the cavity resonators: (a) Hexagonal SIW cavity resonator, (b) HMSIW cavity resonator.

(B) *Triple mode HMSIW filter designing*

Considering the electric field distributions of HMSIW resonant modes shown in Fig. 3(b), it can be seen that in the center of the symmetry axis of the HMSIW cavity the electric fields for the first and fourth modes is maximum and for the rest is approximately equal to zero.

A metalized via-hole placed in the center and at the distance (D) of the lower edge or magnetic-wall, as shown in Fig. 4(a), is proposed to shift both the f_1 and f_4 towards the high frequencies, whereas the other resonant modes remain constant and a triple mode HMSIW filter is created. After adding via-hole, the electric field distribution of HMSIW resonator in resonance frequencies has been depicted in Fig. 4(b). By Changing the distance of the via-hole from the edge of open boundary of HMSIW cavity, the position of resonant frequencies of a resonator is changed. Fig. 5 shows the simulated frequency response of the filter, using full-wave simulation software Ansoft HFSS for different values of D. The first resonant mode becomes close to the second mode and the fourth resonance frequency is transmitted and located after the fifth mode, and as it was expected due to the weak electric fields of the other resonant modes in the via-hole position, these resonance frequencies have been almost unchanged. As shown in Fig. 5, the filter has a poor upper stopband rejection because of resonance frequencies of higher order modes. In order to increase the filter selectivity in upper passband frequencies, an E-shape slot has been etched on the top metallic plate of the resonator. This E-shape slot creates two transmission zeros in the stopband which improves filter selectivity and extends upper stopband.

The positions of the transmission zeros could be controlled by changing h_1 and h_2. As depicted in Fig. 6, E-shape slot is actually