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Design and realization of a miniaturized low loss iris bandpass filter on substrate integrated waveguide configuration in 2.4GHZ band

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Abstract: In this paper, a fourth order bandpass Chebyshev filter based on Iris discontinuities and using SIW technology is designed. The structure of the filter consists of SIW cavity resonators that are connected to each other with Iris discontinuities, which operate as impedance inverters. This filter is implemented on a substrate of RO4003C with a central frequency of 2.45GHz and a fractional bandwidth of %4.08 and is designed to be used in Wireless Local Area Networks (WLAN) or Bluetooth. The main idea is to reduce the size of the filter with a factor of two without any distortion in the frequency response. Simulations are done using full-wave HFSS simulator.

Keywords: Substrate Integrated Waveguide, Wireless Local Area Networks (WLAN), Iris Discontinuity, Bandpass Filter, Impedance Invertor

1. Introduction

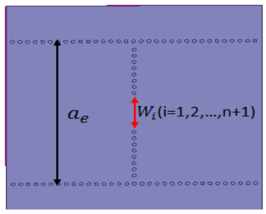
Designing filters in millimeter-wave and microwave systems with high quality factor and appropriate performance has always been a challenging subject. WLAN compatible with the IEEE 802.11 b/g standard work on a carrier frequency of 2.4 GHz. These frequency bands cover radio frequency heating processes, Bluetooth, wireless digital phones, and medical diathermic machines [1]. Many bandpass filter structures in the unlicensed band of 2.4-2.5 GHz have been suggested so far. In [2], an appropriate method is proposed to minimize the bandpass filter dimensions based on the artificial quasi-TEM transmission lines using multiple platform technology. These transmission lines are separated by meshed planes so as to reduce the coupling effect of the layers, and thus, to improve the performance of the system. A microstrip bandpass filter with parallel coupling has been discussed in [3] in the same frequency band. A bandpass filter with serial structure using.

multilayer technology “Low Temperature Co-fired Ceramic” has been suggested in [4].This filter has a grounded capacitor connected to two LC resonators, which are parallel to the filter, and results in two Transmission zeroes in the frequency response. Bandpass filters based on acoustic wave surface technology with high selectivity and low loss are used widely in communication systems. Bandwidth constraint and the necessity of using redundant matching elements are the main disadvantages of acoustic wave filters[5].On the other hand, LTCC technology can be exploited to integrate some more bandpass filters in a substrate [2,4,6],but due to the low quality factor in LTCC technology, these filters are not suitable from sensitivity and selectivity viewpoints. Combining these two technologies, one can gain advantage from both of them in the sense of selectivity, amount of loss, and filter’s dimension. The design procedure of an acoustic wave surface filter based on LTCC technology which is to be used in WLAN and Bluetooth is proposed in [7]. Microwave filters using waveguide technology are used in aerospace systems mostly due to low loss and high power transmission capability [8, 9]. But since these structures are too bulky, they cannot be used for mass production. Moreover, assembly is a way time-consuming and costly process which sets barriers for using such structures [10, 11]. With the appearance of integrated waveguide substrate, many circuits have been designed and implemented based on this structure [11, 12]. Most components of the flat waveguide have been realized using SIW technology, since the integrated waveguide substrate structure have the same propagation characteristics as the rectangular waveguide. This solution can significantly decrease the size and weight of the components compared to the rectangular waveguide. Furthermore, the loss of SIW components is less than those of microstrip components and the radiation and packaging problems are also resolved. The SIW components make a good compromise with rectangular waveguide and microstrip line structure [11]. In this paper, a fourth-order bandpass filter with Chebyshev frequency response and symmetric metallic walls, known as Iris filter is designed and simulated. This filter is implemented on the integrated waveguide substrate structure with unlicensed 2.4-2.5 GHz frequency band for WLAN, which is also compatible with IEEE 802.11 b/g standard. It contains TE_{101} half-wave waveguide resonators that are separated from each other by the Iris discontinuity. Using impedance invertors (k) and a circuit structure for the distance between the wall, the physical dimensions of the structure are extracted [13]. In the second section, an appropriate approach for designing an Iris bandpass filter along with its simulation results are discussed. The third section is dealt with reducing the filter's dimensions by a factor of two without any distortion in the frequency response. The paper is concluded in section four.

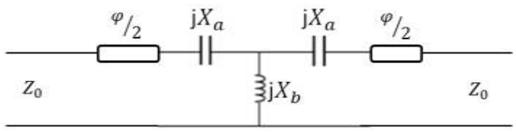
2. Filter Design Process

The SIW structure is realized by two lines of metallic vias that are periodically embedded inside the insulator substrate [11]. Because of these metallic layers that surround SIW, only TE_{n0} modes are propagated in this structure [14]. The most important parameters are the distance between adjacent vias and their diameter. For specific values of $^{p}/_{\lambda c_c}$ and $^{d}/_{\lambda c_c}$,the integrated waveguide substrate structure has the same behavior as the rectangular waveguide and its radiation loss can be approximately ignored[15].Applying usual discontinuities in the waveguide structure, one can realize the waveguide filters. But due to the constraints in the fabrication process, the only ways to make a reactive element in the SIW are to create totally empty and metal lined cavities or to pattern its upper and lower metallic planes. Hence, it is not possible to create capacitor discontinuities in the one-layer SIW structure [16].

Figure (1-a) shows one of such realizable discontinuities in the SIW structure, which the filter is known as an Iris filter. Iris discontinuities create a symmetric induction window with width $W_i(i = 1,2,\dots,n)$ and the cavity resonators that have a length of $L_i(i = 1,2,\dots,n+1)$ are embedded between these discontinuities. The coupling between cavity resonators are controlled by the width distance of the Iris discontinuities [17].



(a)



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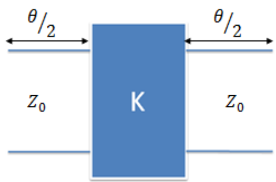


(c)

Figure (1). *(a) Iris discontinuity in SIW structure, (b) T network equivalent circuit of Iris discontinuity in the SIW structure, (c) Iris discontinuity equivalent circuit using impedance inverter in the SIW structure*

According to figure (1-c), these induction posts that connect SIW transmission lines to each other, act as impedance inverters [9]. Hence, the design process of SIW filter with Iris discontinuity reduces to finding the inverter characteristic impedance and the width distance between the symmetric metallic walls[13].The impedance inverter normalized characteristic impedance for a bandpass filter with Chebyshev frequency response can be calculated as the following [17].

$$\Delta = \frac{\lambda_{g1} - \lambda_{g2}}{\lambda_{g0}}$$

$$\frac{K_{0,1}}{Z0} = \sqrt{\frac{\pi}{2}\frac{\Delta}{g_0 g_1 \Omega}}$$

$$\frac{K_{j,j+1}}{Z0}\Big|_{j=1\ to\ n-1} = \frac{\pi\Delta}{2\Omega}\frac{1}{\sqrt{g_i g_{i+1}}} \qquad (1)$$

$$\frac{K_{n,n+1}}{Z0} = \sqrt{\frac{\pi}{2}\frac{\Delta}{g_n g_{n+1}\Omega}}$$

$$\lambda_{g0} = \frac{\lambda_{g1} + \lambda_{g2}}{2}$$

In (1), g_i's are the values for the lowpass filter components. with Chebyshev response , Δ is the relative bandwidth of the guided wavelength , Ω is the normalized lowpass frequency, Z_0 is the characteristic impedance of the transmission line, λ_{g1} and λ_{g2} are the guided wavelengths in the upper and lower edges of the bandpass filter, respectively [17]. Determining the characteristic impedance values of the impedance inverters, one can calculate the physical length of the cavity resonators as below [17]:

$$\frac{X_{j,j+1}}{Z_0} = \frac{\frac{K_{j,j+1}}{Z_0}}{1-(\frac{K_{j,j+1}}{Z_0})^2}$$

$$\theta_i = \pi - \frac{1}{2}\left[tan^{-1}\left(\frac{2X_{j-1,j}}{Z_0}\right) + tan^{-1}\left(\frac{2X_{j,j+1}}{Z_0}\right)\right] \; Li = \frac{\theta_i \lambda g0}{2\pi} \quad (2)$$

Figure (2-b) shows the T equivalent circuit of this discontinuity. The values of its elements depend on frequency, dimensions, and Iris discontinuity position. The T equivalent circuit parameters are derived from the following equations [18]:

$$\varphi = -tan^{-1}(2X_p + X_s) - tan^{-1}(X_s)$$

$$jX_s = \frac{1-S_{12}-S_{11}}{1-S_{11}+S_{12}} \quad (3)$$

$$jX_p = \frac{2S_{12}}{(1-S_{11})^2 - S_{12}S_{12}}$$

In equation (3), $X_s = \frac{X_b}{Z_0}$, $X_s = \frac{X_b}{Z_0}$, and $S_{ij}\big|_{i,j=1,2}$ are the corresponding scattering parameters in each Iris discontinuity.

After determining the physical parameters of the Iris waveguide filter by equations (1) to (3), the equivalent SIW parameters are calculated as [19]:

$$L_{SIW} = L + \frac{d^2}{0.95p}$$

$$a_{SIW} = a_e + \frac{d^2}{0.95p} \quad (4)$$

Note that to obtain a filter with suitable frequency response, optimum design of the transmission converter from microstrip to SIW becomes particularly important. One of the most common converters used between SIW structure and microstrip is tapered converter which is shown in figure (2). This converter converts the dominant propagation mode of microstrip line to dominant propagation mode of SIW [20].

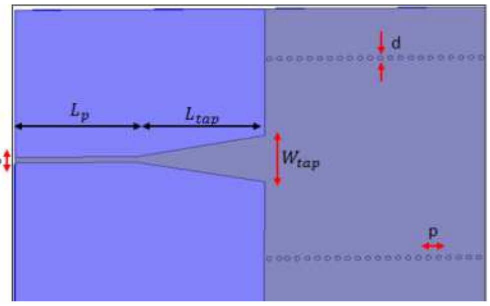


Figure (2). *microstrip to SIW converter*

We design a fourth-order SIW bandpass filter with Chebyshev frequency response and a ripple of 0.03 dB. The substrate is RO4003C with 0.508 mm thickness, the loss tangent is 0.0027, and the dielectric constant is chosen to be 3.38. The cutoff frequency of the dominant mode is 1.8 GHz in this design. Moreover, in order to minimize the radiation loss of the SIW structure, we set d=0.5mm and p =1mm. Figure (3) shows the structure of a fourth order SIW Iris bandpass filter. The optimum parameters for this filter calculated in 2.4 GHz frequency and %4.08 fractional bandwidth are given in Table (1).

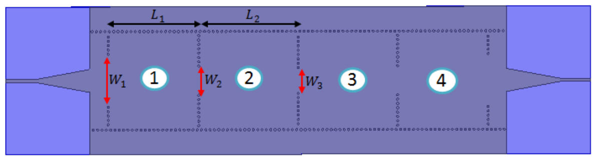


Figure (3). *The structure of an SIW fourth-order Iris bandpass filter realized by direct coupling*

Table (1). *physical dimensions of the designed SIW bandpass filter (unit: mm)*

p	1	L_{tap}	25.45
d	0.5	L_1	40.8009
a_{SIW}	44.4919	L_2	45.1924
W_p	.2531	W_1	24.1518
L_p	13.3476	W_2	13.1308
W_{tap}	10.64	W_3	11.6328

The frequency response of the designed filter is obtained by HFSS as illustrated in Figure (4).

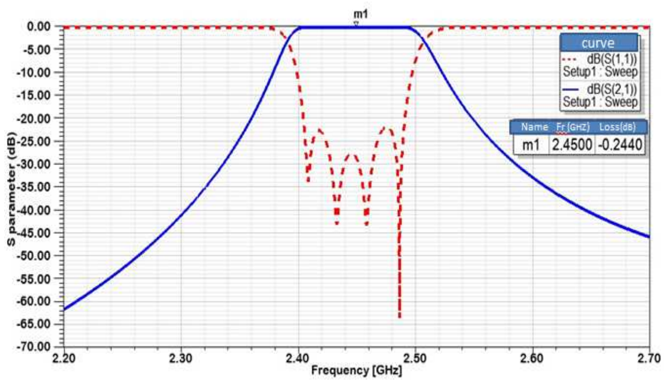
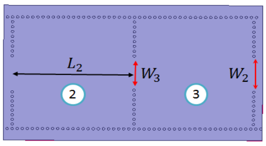


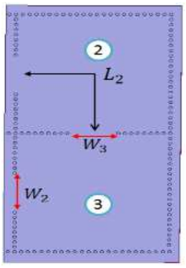
Figure (4). *The frequency response of an SIW fourth-order Iris bandpass filter realized by direct coupling*

3. Filter Dimension Reduction

Since the designed filter in Figure (3) has a symmetric structure, using a simple procedure at the discontinuity point W_3 that is placed in the center of the structure, it is possible to fold the filter. But in order to prevent the degradation in the frequency response of the filter, it is required to regulate the discontinuity point W_3 such that the guided wave between the two discontinuities W_2 and W_3 travel the same length L_2 . Figures (5-a) and (5-b) show the procedure of designing the folded filter. Finally, the frequency response of the folded SIW filter is shown in Figure (6).



(a)



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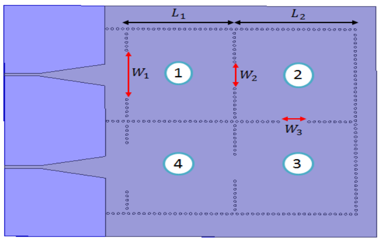

(c)

Figure (5). *(a) Direct coupling between cavity resonators 2, 3, (b) Cross coupling between cavity resonator 2, 3, (c) Folded fourth-order SIW Iris bandpass filter*

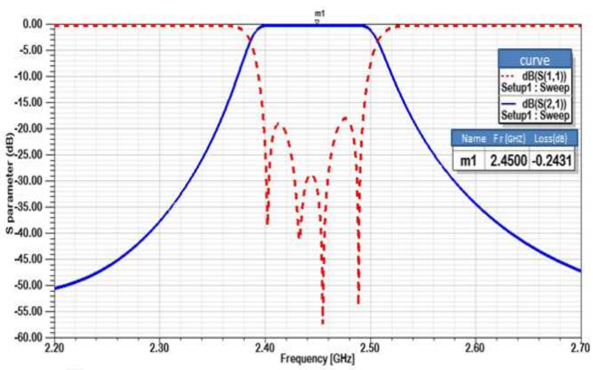

Figure (6). *The frequency response of the folded fourth-order SIW Iris bandpass filter*

Similarly, the cavity resonator 1, 4 can be folded to form a T structure, which is illustrated in Figure (7). The frequency response of the T structure filter is shown in Figure (8).

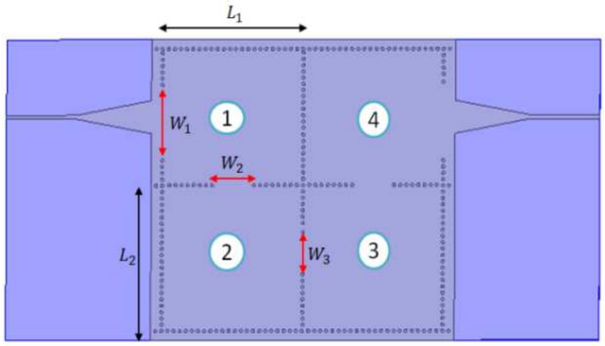

Figure (7). *Fourth-order SIW Iris bandpass T-structured filter*

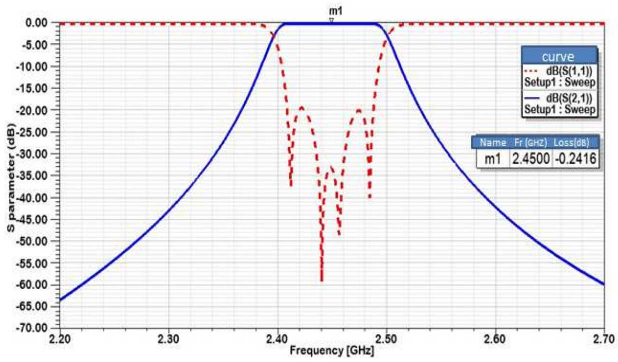

Figure (8). *The frequency response of the fourth order SIW bandpass T-structured filter*

4. Discussion and Conclusion

In this paper, an appropriate approach for designing an Iris bandpass filter using the concepts of impedance inverters and TE_{101} half-wave resonators has been proposed. This filter is implemented on the integrated waveguide substrate structure with unlicensed 2.4-2.5 GHz frequency band for WLAN, which is also compatible with IEEE 802.11 b/g standard.

The dimensions of the filter are reduced in our design. High selectivity, low loss, proper performance, lumped dimensions, low cost fabrication, and the ability to be integrated with other planar circuits are the main advantages of the proposed filter.

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