Miniaturized Quasi-elliptic Bandpass Filter Using the Novel Coplanar Double Stepped Impedance Resonators without Bond-wire Bridges

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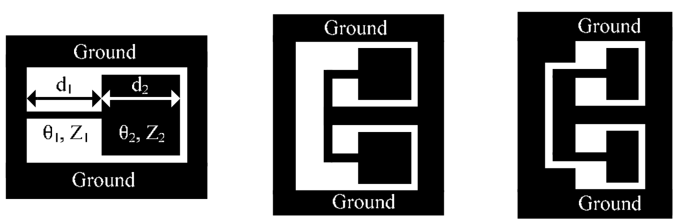
1. Introduction

Coplanar waveguide (CPW) has been an important building block for monolithic microwave integrated circuits (MMIC's) due to several attractive features in comparison to microstrip line. The predominant advantage of CPW structures is that the resonator frequency is less dependent upon the thickness of the substrate and therefore they offer the possibility of filters with less or no post fabrication tuning. Moreover, these CPW structures eliminate via holes in the substrate and make it easier to insert both series and parallel components with high circuit density. In most of conventional coplanar circuit designs, bond-wire bridges are used to keep two ground planes at the same potential, thereby eliminating slot line mode because the bond-wire bridges exhibit a short circuit for slot line mode [1]. However, the parasitic reactance of the bond-wire bridges may have significant impact on the filter performance, which is often undesirable in both the design and fabrication procedures, and then introduces extra loss. In this paper, new coplanar types of resonators in which bond-wire connections are not necessary are suggested. Fig. 1 shows a typical coplanar stepped impedance resonator (SIR) and two types of novel miniaturized coplanar double SIRs (NMC DSIRs).



(a) (b) (c)

Fig. 1. Layout of the coplanar SIR: (a) Conventional coplanar SIR and (b) NMC DSIR (type I) (c) NMC DSIR (type II)

As presented in Fig. 1, compact configurations are proposed to reach a compromise between size and performance. It is possible to add extra-grounded stubs between resonators to replace the bond-wire bridges. These stubs connect two ground planes and help the potential on both sides be at the same level and, therefore, remove the need of bond wires. The couplings between the resonators are weak, which is able to design the narrower BPFs. Moreover, the proposed coplanar quasi-elliptic filter is so attractive because they exhibit ripples in both passband and stopband. It is easy to improve both frequency selectivity and passband insertion loss [2]. This property is of much interest in narrow BPFs where the passband insertion loss is strongly related to the number of resonators. The quasi-elliptic and elliptic filters, depending on the phase of cross-coupled signals, may also flatten the group delay. In this paper, design and experiment of the novel miniaturized quasi-elliptic coplanar bandpass filter (NMQEC BPF) using two types of NMC DSIRs are presented.

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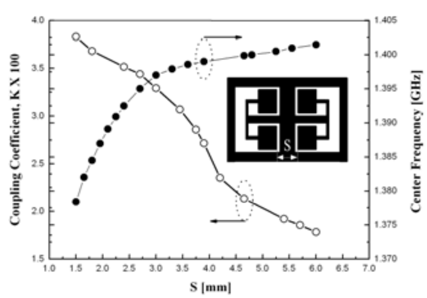
2. Coupling and Filter Design

Two types of the NMC DSIRs shown in Fig. 1(b) and (c) are achieved by connecting the transmission line between the middle of a DSIR and ground planes. The NMC DSIR (type I) of Fig. 1(b) has a dimension of 13.735 mm ×15.45mm while that of Fig. 1(c) (type II) is 11.60 mm × 12.45 mm at the center frequency of the proposed filter. Compared with the conventional coplanar resonator shown in Fig. 1(a) [3, 4], the BPF using the NMC DSIRs is not only more compact, but also has much narrow bandwidth. General theory of NMC DSIRs shown in Fig. 1(b) and (c) is similar to one of the conventional coplanar SIR, such as ABCD matrix of the resonator, relationship between the impedance ratio and resonant frequencies, and the condition for the effective dielectric constant and the phase constant of the two transmission lines [5, 6].

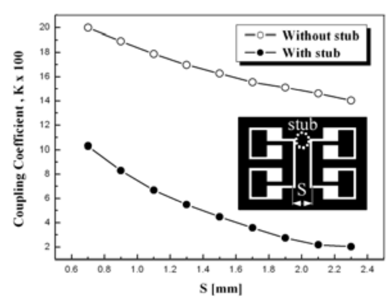
A. Coupling coefficients

Fig. 2(a) depicts the electric coupling structure, consisting of mainly inductive stub connected to ground planes between adjacent resonators and coupling coefficients against resonator distance *S*. In order to realize the desired values for the coupling coefficients, it may be extracted using the pole-splitting method [7] in conjunction with full-wave simulations. However, note that when the distance between input and output resonators is increased, the resonant frequency is a little shifted to the upper frequency. To get a desired coupling coefficient at the expected center frequency, the required length of the resonators is getting larger and the width of the stub is smaller.

Fig. 2(b) explains the magnetic coupling structure and coupling coefficients against resonator distance *S* with or without an inductive stub between resonators. The added stub also reduces the size of the circuit in two ways compared to the conventional structure without it. First, capacitance exists between the stub and open end of the resonator, which helps decrease the resonant frequency. Second, the stub weakens the coupling between these resonators considerably, as shown in Fig. 2(b). The resonators will be much closer for the same coupling coefficient. Such as the case of electric coupling, in order to get the desired value for the magnetic coupling coefficient, it is carefully considered to the shift of the resonant frequency.



(a)



(b)

Fig. 2. Coupling coefficients (K) versus distance (S): (a) Electric coupling structure and (b) Magnetic coupling structure

B. External Coupling

As shown in Fig. 3(a), the external coupling can be controlled by the value of the interdigital capacitor inserted between an input or output CPW feed line and the slot line resonator. By changing the gap size and/or finger length of the interdigital capacitor, a wide range of external coupling values can be realized. The external Q associated with external coupling is, therefore, a function of the overall capacitance of the interdigital capacitor. However, note that when the finger length of the capacitor is increased, the resonant frequency of the structure shifts to the lower frequency. To alleviate the frequency shift, the size of the resonator must be trimmed to maintain the previous resonant frequency of the structure. These changes of the resonant frequency aid to slightly alleviate the frequency lifted up due to the electric coupling. However, in order to design the QEC BPF, it needs more time and tuning.

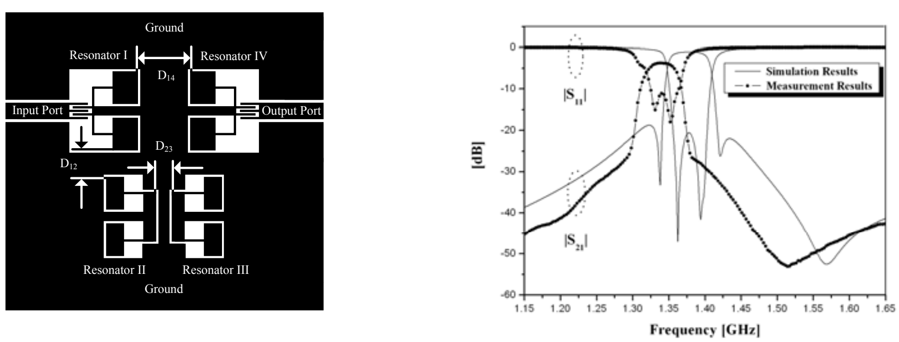
C. Filter Design and Experiment

The filter specifications are the center frequency of 1.38 GHz, the fractional bandwidth of 4.2 % (58 MHz), and the stopband rejection of 20 dB at ± 38.5 MHz. This rejection is achieved in the design by replacing a transmission zeros at 41.67 MHz from the center frequency. The filter can be synthesized using a method described in [8], from which the lumped-element values of a lowpass prototype is determined as $g_0 = 1.0$, $g_1 = 0.921$, $g_2 = 1.280$, $J_1 = -0.1520$, $J_2 = 1.0509$. The design parameters of the BPF (namely, the elements of coupling matrix and input/output single-loaded external Q_e) can then be calculated as follows.

$$M_{12} = M_{34} = \frac{FBW}{\sqrt{g_1 g_2}} = 0.03868 \qquad M_{23} = \frac{FBW \cdot J_2}{g_2} = 0.03448$$

$$M_{14} = \frac{FBW \cdot J_1}{g_1} = -0.006931 \qquad Q_{ei} = Q_{eo} = \frac{g_0 g_1}{FBW} = 21.928$$

The positive coupling coefficients, $M_{12} = M_{34}$ and M_{23} are realized by the mixed and magnetic couplings, respectively, while the negative coupling coefficients M_{14} is realized by the electric coupling. However, the simulated coupling coefficients have some discrepancies in the filter design, due to an alteration of the resonator's center frequency affected by the changes in stub width connected to both ground planes. The actual coupling coefficients are $M_{14} = -0.008686$, $M_{12} = M_{34} = 0.04028$, $M_{23} = 0.02640$. In this paper, the feed using the interdigital capacitor is used for the loaded external quality factor, though the other means of feed such as the meander lines can be adopted. The minimum linewidth of the filter is 0.25 mm. The layout and measurement results of the proposed filter are shown in Fig. 3.



(a) (b)

Fig. 3. Layout and measurement results of the NMQEC BPF using two types of NMC DSIRs; The distances between resonators: $D_{14} = 10.0$ mm, $D_{12} = 4.30$ mm, and $D_{23} = 1.90$ mm.

The circuit dimensions are obtained from simulation for the optimum condition and minimum circuit size. The filter is fabricated on a substrate with a relative dielectric constant of 3.5 and a thickness of 1.524 mm. In Fig. 3(a), the size of the central circuit, without the ground planes and the 50 Ω feed lines, is 36.15 mm × 34.3 mm. The first and fourth resonators have a dimension of 13.325 mm × 15.05 mm while the second and third resonators have a dimension of 11.57 mm × 15.45 mm. The fabricated filters are measured with an HP 8510C vector network analyzer. In Fig. 3(b), measured insertion loss is about 3.78 dB at the center frequency of 1.34 GHz, which is mainly resulted from the conductor loss while the simulated insertion loss is 1.09 dB. The measured return loss is about 11.4 dB while the simulated return loss is 20.89 dB. The difference between the simulation and measurement results is considered due to process error. The measured rejection is achieved in the design by replacing a pair of attenuation poles at ± 39 MHz from the center frequency, respectively. Although the measured center frequency is a little shifted down about 2.89 % in the frequency response and there are some discrepancies in return loss, the measurement results for the novel miniaturized coplanar quasi-elliptic filter are well agreed with the simulation data.

3. Conclusion

A new technique for the design of narrow-band NMQEC BPF using two types of NMC DSIRs has been described. The topology has compact lateral dimensions, requires no extrinsic ground plane equalization, e.g., air-bridge, and is relatively free of discontinuity effects. Novel external and internal coupling structures have been proposed and the techniques applied in this filter design make the size of the filters more compact and the couplings more controllable. The transmission zeros at both sides of the passband of the proposed filter are generated by the resonators' arrangement. It is shown that the size of the filter can be greatly reduced by connecting the transmission line between the middle of a double SIR and ground planes. The effect of the frequency-dependent cross-coupling on the NMQEC BPF has been also investigated. The agreement between the simulated and measured responses of this filter has shown to be excellent.

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