Novel Miniaturized Triplexer Using Substrate Integrated Technology

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***Abstract* — In this paper a novel multilayer triplexer is presented where a Substrate Integrated Waveguide (SIW) filter is integrated with Substrate Integrated Coaxial (SICx) filters in the same space for system miniaturization. It will be shown that low cross-coupling levels are achieved. The SIW and one SICx filters are designed using Composite Rigth Left Hand (CRLH) cells, while the other SICx filter is designed using hairpin resonators. Simulated and experimental results are shown with good agreement.**

***Index Terms* — Substrate Integrated Waveguide, coaxial filters, multiplexers, triplexers, CRLH cell.**

I. Introduction

With the constant need for increased capacity in modern communication systems, multiple channel configurations are becoming the norm in many applications [1]. For these types of multi-band and multi-service systems multiplexers are key elements as they select different channels into one single channel for transmit operations, or the reciprocal for receive operations. Several types of multiplexers have been suggested in the literature [2]; however, the manifold configuration offers the smallest size with very low insertion losses [3].

For ultra light communication systems, Substrate Integrated (SI) technology provides filters with higher Q factor when compared to other planar technologies (such as microstrip or coplanar) with high integrability [4]. The term Substrate Integrated circuit is commonly used for Substrate Integrated Coaxial Structures (SICx) [5,6], Substrate Integrated Waveguides (SIW) and Non-radiating Dielectric Waveguides (NRDW) [4].

SIW based multiplexers have been previously suggested with ultra compact size. In [7] a diplexing network is presented for C-band. Nevertheless, conventional integration methods are based on contiguous SIW filters for each frequency, hence their size is relatively large when several channels are needed.

In this paper, a novel SI triplexer approach is presented where SICx and SIW structures are integrated in the same space thus resulting in extremely compact circuits. The triplexer is achieved with a manifold arrangement.

The triplexer frequencies are 2.2GHz, 3GHz and 3.7 GHz. The first dual-mode SIW filter centered at 2.2GHz is the host filter and it is realized as a CRLH Half Mode transmission line [8]. The second filter centered at 3GHz consists of hairpin resonators and the third filter at 3.7GHz consists of two coupled CRLH zeroth order resonators. Both filters at 3GHz and 3.7GHz are hosted inside the SIW cavity providing a shielded structure which acts as a Substrate Integrated Coaxial line. This triplexer configuration provides high miniaturization as the same SIW space is used for the three different filters.

In this paper experimental and simulation results are presented with good agreement throughout the band.

II. SIW host filter based on CRLH cell

The host filter is based on the SIW concept and it is formed by two metallic layers at the bottom and top planes of the substrate where metallic via arrays interconnect both layers. As it is well known, SIW propagation offers similar characteristics of a conventional rectangular waveguide [9]. Moreover, for the dominant TE_{10} mode, the symmetric plane along the Poynting vector direction is equivalent to a magnetic wall, thus cutting the SIW to half with a magnetic wall will not disrupt the field distribution [10].

The design starts by implementing a half mode SIW with an interdigital capacitor at the surface to form a CRLH line [8]. To calculate the width of the half mode SIW, equation (1) is used, where a ε_r =2.2 substrate of height h=1mm is employed at a cutoff frequency f_c=2.2GHz.

$$f_C = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m\cdot\pi}{2L}\right)^2+\left(\frac{n\cdot\pi}{h}\right)^2} \qquad (1)$$

where c is the speed of light, and m and n are the mode indexes.

For a center frequency of 2.2GHz the final dimensions are L=28mm, and d= 19.6mm.(Fig 1.).

In order to implement a dual mode operation [11], an interdigital capacitor is inserted with 14 fingers as shown in Fig 1(a). The spacing between fingers and finger width are 0.5mm. The length of the fingers (Lf) is calculated depending on the filter characteristics. In our case a Chebyshev two pole bandpass filter is designed with a fractional bandwidth *FBW*=6% and a ripple 0.06dB. Following [12] the g value coefficients become, $g_{0=}\ g_3=1$ and $g_{2=}\ g_3=0.5$ by taking equal input and output impedances. For these values, the required external quality factor Q_{ext} and coupling coefficients can be obtained from (2) as Q_{ext} =7.2 and k=0.14.

$$Q_{ext} = \frac{g_0 g_1}{FBW},\quad k = \frac{FBW}{\sqrt{g_1 g_2}} \tag{2}$$

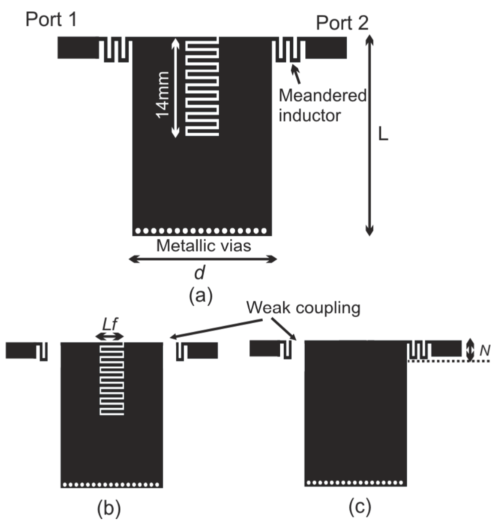

Fig. 1. (a) Layout of SIW filter based on CRLH cell, (b) circuit used to calculate k; (c) structure used to calculate Q_{ext}.

To extract the k coupling coefficient, the circuit is weakly coupled at both ports by leaving a gap between the input meandered inductor and the SIW as shown in Fig 1(b). Then the whole structure is simulated for different values of *Lf* and equation (3). is used to calculate the coupling coefficient [13].

$$k = \frac{f_2^{\,2} - f_1^{\,2}}{f_2^{\,2} + f_1^{\,2}} \tag{3}$$

where f_1 and f_2 correspond to the simulated resonant frequencies.

Fig 2 shows the different coupling coefficients (k) versus the finger length (*Lf*). The final required value is *Lf*=4.4mm.

Moreover, to calculate the external Q (Q_{ext}) the interdigital capacitor is removed and the structure is fed by the meandered inductor on one port while the other port is left weakly coupled (Fig 1(c)). The width of the inductor is 0.5mm. This circuit is then simulated for different values of N and by using (3) Q_{ext} is calculated [13].

$$Q_{ext} = \frac{f_0}{FBW_{3dB}} \tag{4}$$

where f_0 is the center frequency and FBW_{3dB} is the 3dB bandwidth.

From Fig 2 the required N (in Fig.1) is calculated as N=2.4mm. The final circuit is shown in Fig.1.

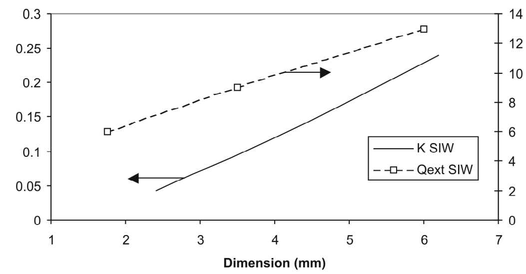

Fig. 2. Q_{ext} and k values for SIW filter

III. Cross coupling analysis

In this paper, a novel structure is investigated where coaxial filters are hosted inside an SIW structure. In order to examine the cross-coupling level of this structure, a simulation is carried out [14] where an SIW line using the parameters of the previous section hosts an SICx transmission line as shown in Fig.3 . By changing the distance S, the cross-coupling level *S14* and *S13* can be recorded. The coupling level is plotted in Fig 4. As expected, for large values of S the cross coupling level is small. When S is greater than 18mm the cross coupling level is smaller than -20dB for *S14* and *S*13.

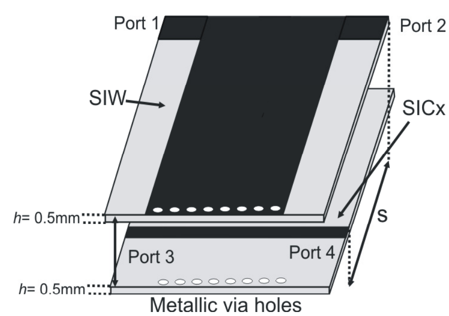

Fig. 3. Cross coupling of SIW line and SICx

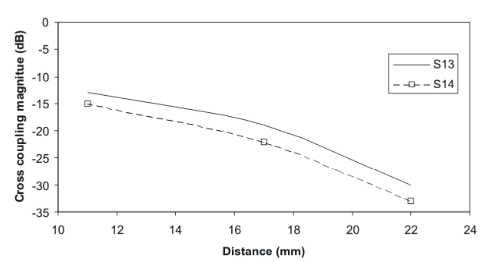

Fig. 4. Cross coupling level (*S13* and *S14*) of structure in Fig3

IV. SUBSTRATE INTEGRATED COAXIAL FILTERS

Both coaxial filters are designed in substrate integrated coaxial (SICx) technology with two substrates of ε_r=2.2 and height h=0.5mm.

The first coaxial filter is centered at 3GHz and has a fractional bandwidth FBW=7%. It is designed following the procedure described in section II with g_0=g_3=1 and g_1=g_2=0.8 for a 0.1dB ripple, which give Q_{ext} =11.9 and k=0.09 calculated from (2). Fig 5 shows the structures used to extract Q_{ext} and k respectively. Fig 5 (a) depicts the hairpin resonator with one port weakly coupled and a tapping line connecting the other port. Simulations are carried out by changing the value of the tapping distance a. The values obtained from (4) are plotted in Fig 6.

For the external coupling, Fig 5(b) is used where both ports are weakly coupled and the gap G is varied in a simulator. Then equation (3) is employed and the results are shown in Fig 6. The final dimensions are G=0.025mm and a=5mm.

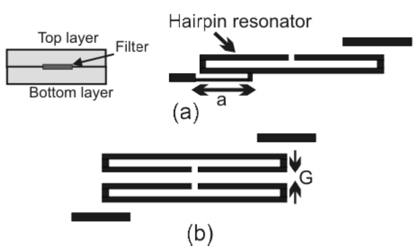

Fig. 5 (a) Hairpin resonator used to calculate Q_{ext}, (b) structure used to calculate k.

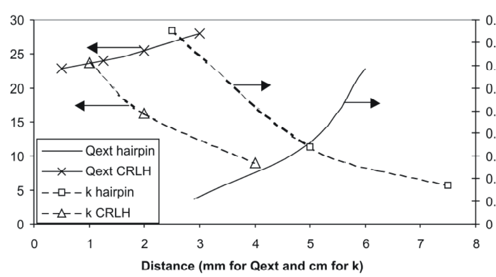

Fig. 6. Q_{ext} and k values of SICx hairpin and CRLH filters

The second SICx filter was designed using two zeroth order CRLH resonators at a center frequency of 3.7GHz with FBW=4%. The CRLH cell is shown in Fig 7. The width of the interdigital fingers and the inter-finger gap are 0.25mm. The width of the right hand inductor LR is 0.25mm and of the left hand inductor LL is 0.2mm.

The required g values are g_0=g_3=1 and g_1=g_2=0.8, which give Q_{ext} = 20 and k=0.05 calculated from (2). Fig 7(a) shows the simulated circuit used to calculate the k value, where by varying the gap P and by using (3) the k values are obtained and plotted in Fig 6. To extract Q_{ext}, the structure in Fig 7(b) is used, where the tapping position b is changed and with the aid of (4) Q_{ext} is computed. The extracted Q_{ext} values are plotted in Fig 6. The final dimensions are calculated as P=0.2mm and b=0.5mm.

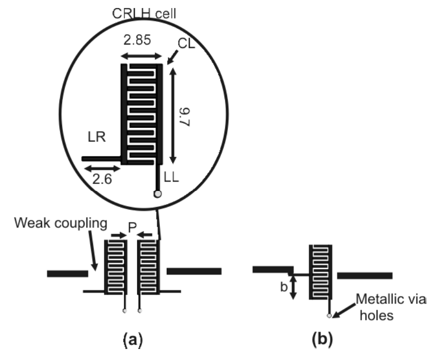

Fig. 7. (a) CRLH zeroth order resonator used to calculate k and (b) structure used to calculate Q_{ext}. Dimensions are in millimeters

V. MANIFOLD TRIPLEXER

The filters at 3 and 3.7GHz are placed inside the SIW filter in a two layer configuration as shown in Fig 8. The SIW via holes are used to ground the CRLH filter.

The outputs of each filter are connected in a manifold configuration with microstrip lines. An optimizer is used [14] to obtain the required impedances of branches 1, 2 and 3.

The filter is finally fabricated on two RT Duroid substrates with ε_r=2.2 of h=0.5mm each. The top and bottom layers are assembled together as shown in Fig 9. To connect the output of the SIW filter to the microstrip feed line a bonding ribbon is used.

The final simulated and experimental results are shown in Fig 10 and 11. The maximum insertion loss for the experimental response is obtained for the 3.7GHz band as 2.7dB. For the 3GHz band it is about 1.8dB while it is 0.8dB for the 2.2GHz band. Since this latter is made of SIW cavity, insertion losses are expected to be very low. The return losses at the 2.2GHz and 3.7GHz bands are better than –18dB, whereas for the 3GHz the highest lobe is at –12dB. However, simulated and measured responses show good agreement.

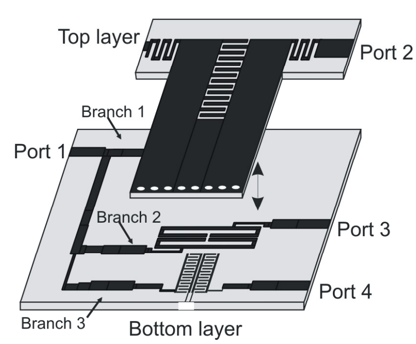

Fig. 8. Multilayer triplexer circuit

VI. Conclusion

A novel manifold triplexer using a multi-layer structure has been successfully demonstrated at 2.2, 3 and 3.7GHz. This circuit offers miniaturization capabilities as SIW and SICx technologies are integrated in the same space. Simulated and experimental results show good agreement.

Acknowledgement

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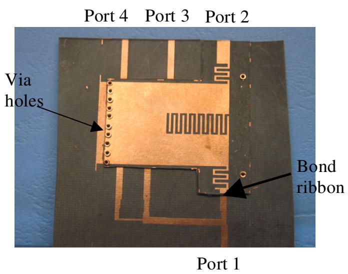

Fig. 9 Fabricated triplexer

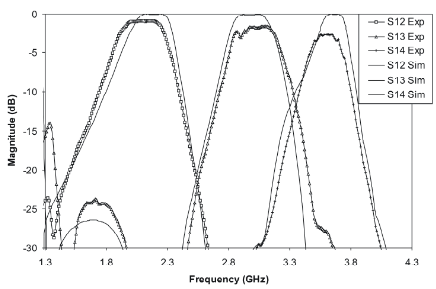

Fig. 10 Simulated and experimental insertion losses of triplexer

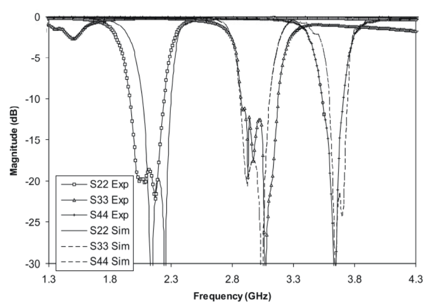

Fig. 11. Simulated and experimental return losses of triplexer.

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