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Design of SIW Bandpass Filter with 6 dB Offset

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***bstract—* This paper presents a novel design of SIW bandpass ilter based on even- and odd-mode predistortion technique. This echnique allows for the realization of lossy filter responses quivalent to lossless filter responses, although at an increased nsertion and return loss. Hence, the filter can be designed with ow Q_u resonators, which will significantly contribute to the eduction of its physical size and weight. An experimental third-egree filter with Chebyshev characteristic demonstrated good easured results, which were in-line with the simulated results.**

Keywords- Bandpass filters; predistorted filters; SIW filters; ossy filters.

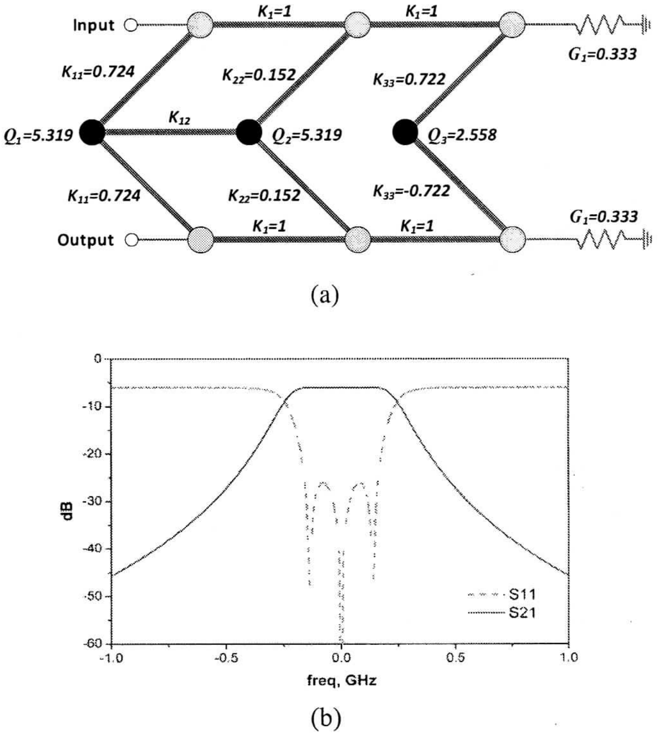
I. INTRODUCTION

Since the explosion of wireless communication systems, emand for further size and cost-reduction in microwave filter as increased. However, in general, the design of high-erformance with highly selective filters requires high Q_u esonators, which contribute to significant physical size or xpensive technologies. For instance, a dual mode waveguide ilter [1] is bulky when used for satellite communication in pace stations. Whilst dielectric resonator filters can offer high nloaded Q factors in reasonable physical size [2, 3], but they re expensive if low loss dielectric is required. Moreover, the uperconducting filters offer very small physical size compared o dielectric resonator, but at the price of requiring the cooling ystems [4].

Therefore, in order to overcome the aforementioned roblems, it is preferable to design microwave filters in such a ay to use low Q_u resonators and make them behave like high Q_u resonators. This can be achieved with passive loss ompensation techniques with the aim of minimizing unloaded Q factor of the resonators, and consequently decreasing the size nd expense of the filters.

There are several techniques of compensating losses such s reported in [5]-[9]. In this paper, a new class of SIW andpass filter based upon a synthesis technique introduced in 10] is presented. It is shown in [10] that a symmetrical etwork can be formed directly from predistorted even- and dd-mode subnetworks, therefore eliminating the need for a ybrid 90^0 coupler. The advantages of this technique are the ealizations of lossy filter responses are equivalent to an ideal ossless filters that are offset by a constant amount and would ot require external devices.

The technique of predistorted even- and odd-mode has been well explained in [10],[11]. Fig.1 (a) shows a 3rd-order Chebyshev lowpass prototype in the form of simplified network. Its response is shown in Fig.1(b). The lowpass prototype contains two high- Q_u factor resonators (Q_u = 5.39) and one low-Q_u factor resonator (Q_u = 2.558). The dark circles represent 1 Farad capacitors with a given loss factor. Admittance inverters are represented by connecting lines and shaded circles represent nodes.



(a)

(b)

Fig. 1. Ideal 3rd-order Chebyshev lowpass prototype (a) simplified circuit, and (b) ideal response with 6dB offset [10],[11].

II. PRACTICAL SIW FILTER DESIGN

In this section, a systematic filter development using the lowpass prototype (Fig. 1(a)) as a starting point will be demonstrated. For realization purposes, the lowpass prototype is transformed to a bandpass filter using standard transformation. The theory behind the transformation is well

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explained in [12]. The focus here will be with the resonators as can be seen in Fig. 2 the transformation to bandpass filter from owpass prototype.

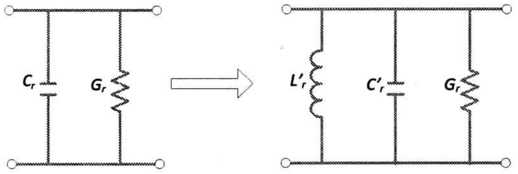

Fig. 2. Bandpass transformation of a capacitor with dissipative element.

Design example: Center frequency, f_o at 6.5 GHz with 125 MHz fractional bandwidth. The following equations for the bandpass transformation of a capacitor of the lowpass prototype (Fig. 2) are applied to obtain element values for element capacitors and inductors [12]:

$$C_r' = \frac{\alpha' C_r}{\omega_0} \tag{1}$$

$$L_r' = \frac{1}{\alpha' C_r \omega_0} \tag{2}$$

where α' is the bandwidth scaling factor,

$$\alpha' = \frac{\omega_0}{\omega_2 - \omega_1} \tag{3}$$

After scaling to 50 Ω the new element values for bandpass esonators are 2.5465x10^{-11} F and 2.3544x10^{-11} H respectively. The resistive element for the first and second resonator is 265.95 Ω and 127.90 Ω for the third resonator, respectively. The unloaded Q factor for this circuit is calculated using:

$$Q_u = \frac{\omega C}{G} \tag{4}$$

where

$$\omega = \frac{1}{\sqrt{LC}} \tag{5}$$

The bandpass filter now contains two high- Q_u resonators $Q_u = 267.23$) and one low- Q_u resonator ($Q_u = 133.02$). Thus, he average Q_u factor is 238.26 and the filter is suitable to be ealized in Substrate Integrated Waveguide (SIW) resonators 13]-[15]. The response of the 3rd-order Chebyshev bandpass filter is shown in Fig. 3 with passband insertion loss and return loss value of 6 dB and 26 dB respectively.

Further modifications on the circuit are needed for practical physical realization. For instance, the resistive loads on the ends of both main-lines are scaled to 50 Ω. Therefore, additional transmission lines are introduced in order to allow 50 Ω terminations for each main-line. Furthermore, the admittance inverters main-lines are replaced with 3λ/4 microstrip lines in order to accommodate the separation between the SIW cavities. The final circuit is shown in Fig. 4.

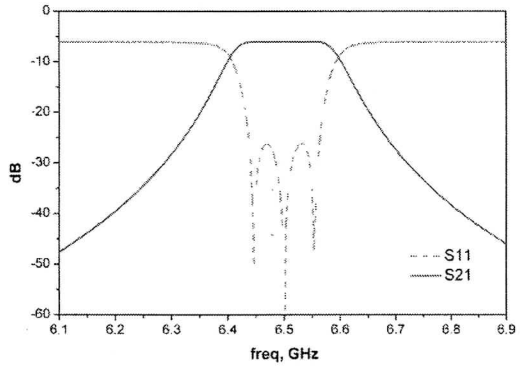

Fig. 3. Ideal response of 3rd-order bandpass filter with Chebyshev characteristic.

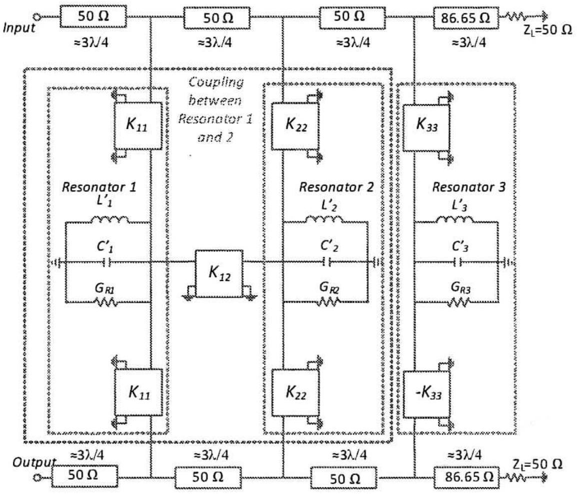

Fig. 4. Final circuit of bandpass filter.

The dimensions of rectangular waveguide for TE_{10} mode operation with cut-off frequency of 4.301 GHz can be found using:

$$l = \frac{\lambda_g}{2} = \frac{\lambda_0}{2\left[1-\left(\frac{\omega_c}{\omega}\right)^2\right]^{\frac{1}{2}}} = \frac{\lambda_0}{2\left[1-\left(\frac{\lambda_0}{2a}\right)^2\right]^{\frac{1}{2}}} \tag{6}$$

The resonant frequency is determined using;

$$f_0 = \frac{c}{\lambda_0} = \frac{c(a^2+l^2)^{\frac{1}{2}}}{2al} \tag{7}$$

where l and a are the length and width of the rectangular waveguide.

The transformation to rectangular SIW is done simply by diving the length, l, and width, a, of the rectangular waveguide with $\sqrt{\varepsilon_r}$. The equivalent dimensions of the SIW cavity together via holes can be determined using a set of design rules explained in [16] and [17]. In this case, a diameter and distance of 0.8 mm and 1.6 mm is calculated, respectively. All these dimensions can be further tuned and optimized during the simulation in order to obtain the desired responses.

The transition method from a rectangular SIW cavity to microstrip line is realized through coupling slot. In this case, the responses for each SIW resonator must be reasonably matched with the ideal responses exhibited from the ideal circuits. The coupling between first and second resonator is realized based on iris. They are connected through microstrip line in order to have a 3λ/4 separation between the SIW resonator cavities. All the three SIW resonators can now be merged with microstrip main-line as bandpass filter; a combination of SIW and microstrip technology as shown in Fig. 5.

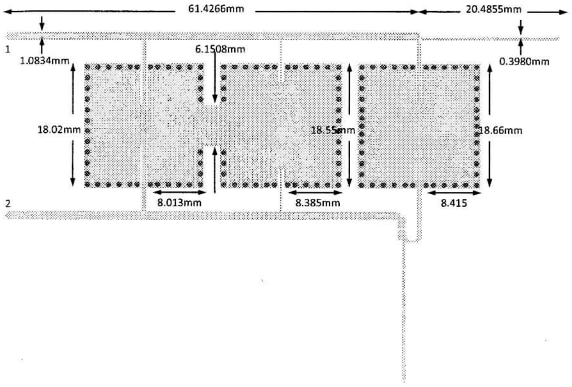

Fig. 5. Layout of SIW bandpass filter.

III. EXPERIMENTAL RESULTS

To verify the theory and simulation, the design is nanufactured using a standard PCB process. The device is onstructed using a 0.508 mm thick, Roger RO4350, dielectric ubstrate with permittivity constant ε_r = 3.48. The copper hickness of copper is 35 μm and loss tangent is 0.0037.

The manufactured SIW bandpass filter, with overall length nd width dimension of 81.94 mm x 61.40 mm, is shown in ig. 6. The comparison between measured and simulated esults is shown in Fig. 7. The measured results show the nsertion loss (S_{21}) is approximately -7.09 dB and return loss S_{11}) is better than -19 dB are obtained in the passband. Iowever, there is a frequency shift of 68 MHz (≈ 1.046 %) rom the desired centre frequency, which is due to the ariations of permittivity in the substrate, i.e. 3.48 ± 0.05 and he inconsistencies of dielectric thickness, i.e. 0.508 ± .0381μm, and also manufacturing tolerance. The small mounts of losses in the passband are due to the losses of ransition from microstrip to SIW, copper loss through onductivity, radiation loss through the surface of the SIW avity, and losses through SMA connectors.

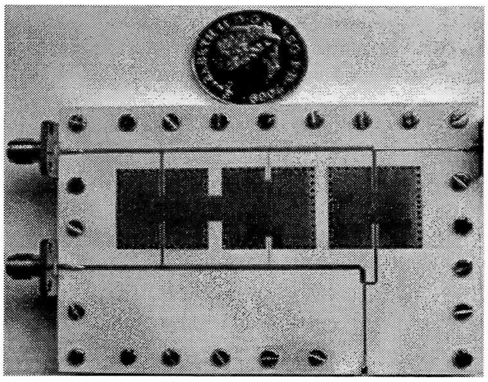

Fig. 6. Photograph of predistorted SIW bandpass filter.

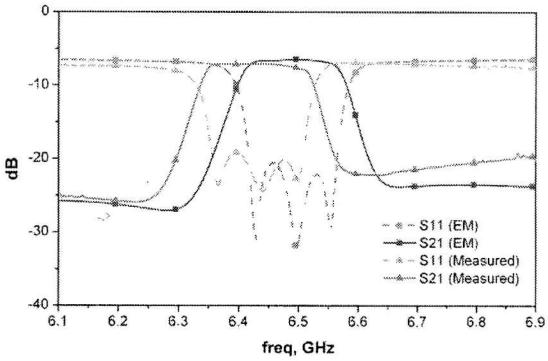

Fig. 7. SIW bandpass filter simulated and measured results.

IV. CONCLUSION

A new design of SIW bandpass filter based o predistortion technique has been successfully designed manufactured and measured. The resulting lossy filter exhibi ideal lossless responses with an offset of approximately 6 dB The filter is suitable for microwave systems where th increased insertion loss can be tolerated and size and weigh reduction is very important such as in a satellite IMUX.

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