DIPLEXER DESIGN USING PRE-SYNTHESIZED WAVEGUIDE FILTERS WITH STRONGLY DISPERSIVE INVERTERS

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Abstract: An approximate synthesis technique for strongly dispersive inverters is introduced. The technique allows the prescription of transmission zeros at finite frequencies on either side of the filter passband - symmetrically or asymmetrically - as required for diplexer applications. Several direct-coupled resonator filters with additional attenuation poles and a related diplexer design at 18.5 GHz are presented. The computerized design procedure is based on CIET (coupled-integral-equations technique) and MMT (mode-matching technique) modules. Excellent agreement between measurements and theoretical predictions is achieved.

I. INTRODUCTION

Direct-coupled resonator filters are commonly used in front-end diplexer applications,. Accurate synthesis and design techniques for this type of filters have been known for many decades, e.g., [1] - [4].

While design techniques to generate elliptic or pseudo-elliptic responses are also widely known, e.g. [5], [6], such filter are used only in L- or S- band diplexers with stringent frequency specifications. In Ku- to Ka-band diplexers, due to increased manufacturing accuracies, cost and more relaxed channel separation, the use of direct-coupled resonator filters has prevailed.

However, recent diplexer specifications with closer frequency spacing between Rx and Tx channels and asymmetric responses inspired the generation of additional attenuation poles at finite frequencies in direct-coupled resonator filters. But only a few attempts have been made to create such poles in direct-coupled waveguide filters. The most common mechanism used consist in overmoding the resonators, thereby generating poles only in the upper stopband. In waveguide filters, this approach results in all coupling sections being irises, e.g. [7]-[9].

A different technique comprises the use of inverter sections which simultaneously provide a transmission zero and the correct inverter value for the filter design. The basic principle of operation has been verified in [10] and [11].

This paper presents a design procedure for pre-synthesized, strongly dispersive inverters with application in waveguide filters and diplexers. Excellent agreement between measured and computed filter responses in the 15 and 38 Gigahertz range is demonstrated. A branching-type diplexer design operates at 18.5 GHz.

II. FILTER DESIGN

The filter design follows standard synthesis procedures to calculate impedance inverters which can be realized as low dispersive irises (Fig. 1a) or strongly dispersive stubs or T-junctions (Fig. 1b, c). If transmission zeros are not needed, then the model of the (possibly asymmetric) inverter is a shunt reactance X_p with two series reactances X_{s1}, X_{s2} and associated phases ϕ_1 and ϕ_2. Using coupled-integral-equations techniques (CIET) or mode-matching techniques (MMT), the scattering parameters of the inverter are related to the model by the following expressions:

$$jX_{s1} = \frac{[1+S_{11}][1-S_{22}]+S_{21}^2-2S_{21}}{[1-S_{11}][1-S_{22}]-S_{21}^2} \tag{1}$$

$$jX_{s2} = \frac{[1-S_{11}][1+S_{22}]+S_{21}^2-2S_{21}}{[1-S_{11}][1-S_{22}]-S_{21}^2} \tag{2}$$

$$jX_p = \frac{2S_{21}}{[1-S_{11}][1-S_{22}]-S_{21}^2} \tag{3}$$

$$\begin{bmatrix}\phi_1\\ \phi_2\end{bmatrix} = -\arctan\left\{\frac{X_{s1}+X_{s2}+2X_p}{1-X_{s1}X_{s2}-X_p(X_{s1}+X_{s2})}\right\} \mp\arctan\left\{\frac{X_{s1}-X_{s2}}{1+X_{s1}X_{s2}+X_p(X_{s1}+X_{s2})}\right\} \tag{4}$$

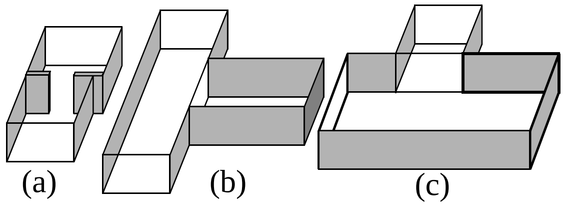

Fig. 1 *Examples of waveguide circuits used as impedance inverters: asymmetric iris (a), stub (b) and shorted T-junction (c).*

A search algorithm varies the dimensions of the circuit until the prototype inverter values K are obtained.

$$K = \sqrt{\left|\frac{1+\Gamma\exp(-j\phi_1)}{1-\Gamma\exp(-j\phi_1)}\right|} \qquad (5)$$

$$\Gamma = \frac{(jX_{s1}+jX_p-1)(jX_{s1}+jX_p+1)+X_p^2}{(jX_{s1}+jX_p+1)(jX_{s1}+jX_p+1)+X_p^2} \qquad (6)$$

In order to prescribe one or two transmission zeros at frequencies ω_{z1} and ω_{z2} to an inverter, we are solving the following equations

$$K_{Prototype} = K_{dispersive}(\omega_0, \text{dimensions}) \ . \qquad (7)$$

$$S_{21}(\omega{=}\omega_{z1}) = 0 \quad , \quad S_{21}(\omega{=}\omega_{z2}) = 0 \qquad (8)$$

simultaneously by minimizing the cost function

$$F_{cost} = [K_{Prototype} - K_{dispersive}(\omega_0, \text{dimensions})]^2 + |S_{21}(\omega{=}\omega_{z1})|^2 + |S_{21}(\omega{=}\omega_{z2})|^2 \qquad (9)$$

In a special case, where a highly dispersive element is added to a filter without acting as inverter simultaneously, the cost function is modified as

$$F_{cost} = \sum_i [1 - |S_{21}(\omega_i)|]^2 + |S_{21}(\omega{=}\omega_{z1})|^2 + |S_{21}(\omega{=}\omega_{z2})|^2 \quad (10)$$

where ω_i are the passband frequency samples. The typical inband return loss achieved by such an approximate synthesis is in the order of 10 dB (c.f. Fig. 6) - as compared to several trial-and-error approaches which usually fall only in the 2 - 4 dB return-loss range. A final optimization, e.g. [12], of the entire filter structure is required to fine tune the return loss while maintaining the transmission zeros.

Two prototype structures involving strongly dispersive inverters have been manufactured. Fig. 2 shows the photograph of a four-pole Ku-band filter with four finite transmission zeros. Computed and measured performances are depicted in Fig. In this design, only the shorted T-junction at the lower right of the circuit (Fig. 2) is used as an inverter which generates the transmission zero (attenuation pole) at 14.175 GHz. The remaining three zeros are generated by the additional H-plane stub which does not act as an inverter. The measured insertion loss is between 0.2 and 0.3 dB within a 20dB return loss bandwidth.

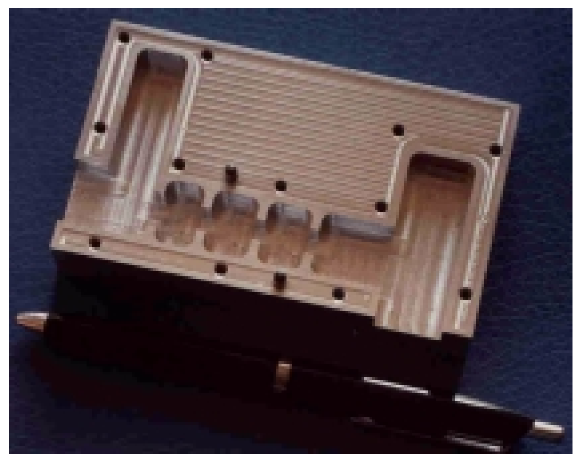

Fig. 2 *Ku-band prototype of waveguide filter with dispersive inverters.*

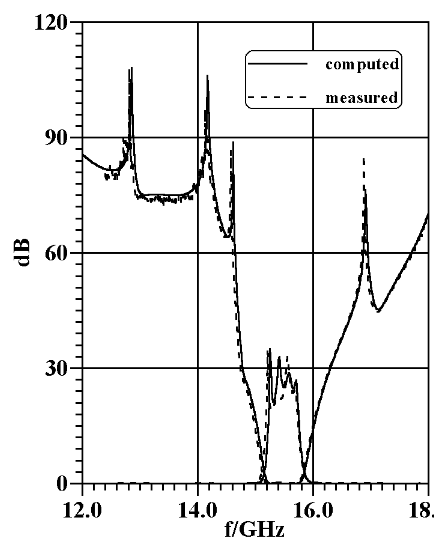

Fig. 3 *Measured and computed performance of Ku-band prototype filter (c.f. Fig. 2).*

The second example is a three-pole Q-band (WR22) filter with nearly maximally flat performance. Emphasis was placed on symmetric skirts with sharp cutoffs. Fig. 4 shows the principle layout and Fig. 5 the computed and measured results. In this design, both shorted T-junctions act as inverters. Since the shorted sections are longer than a wavelength, they produce a number of transmission zeros but only one each in the frequency range shown. The measured insertion is between 1.1 and 1.5 dB over the 20 dB return-loss bandwidth of 230 MHz.

Note that for both prototypes, excellent agreement between measurements and the CIET/MMT analysis techniques is demonstrated.

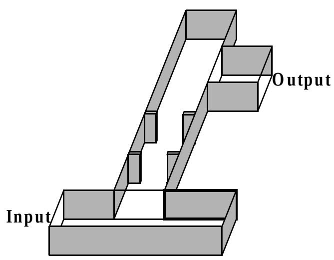

Fig. 4 *Principle layout of 38.5 GHz filter.*

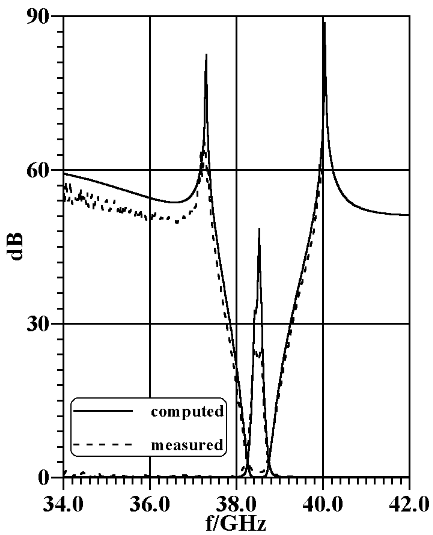

Fig. 5 *Measured and computed response of Q-band prototype filter (c.f. Fig. 4)*

III. DIPLEXER DESIGN

Using the procedure outlined in the previous section, a diplexer was designed according to the following specifications: 17.9GHz - 18.3GHz and 18.7-19.1GHz passbands with 24dB return loss, 60dB isolation. The minimum manufacturable thickness was set to 0.75mm (appr. 0.03”). As an additional requirement, Rx and Tx port locations were to be right beside each other.

Fig. 6 shows the computed performances of the pre-synthesized and fine-optimized five-pole channel filters with one attenuation pole each. Note that the pre-synthesized design is ideally suited as initial data for fine optimization. In this specific case, the optimization even varied the entire waveguide width for the benefit of a better return loss. However, the attenuation poles were kept at the same frequencies.

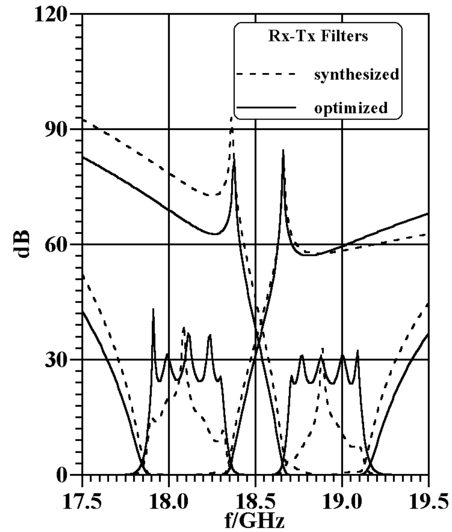

Fig. 6 *Responses of synthesized (dashed lines) and optimized (solid lines) diplexer channel filters.*

The principle layout of the branching-type diplexer is shown in Fig. 7. In order to facilitate a small spacing between the two filters, irises and stubs are pointing toward opposite sides. A combined CIET-MMT code, which is has been verified in [13], is used as analysis tool in the final diplexer fine-optimization. The resulting response is depicted in Fig. 8. In addition to the attenuation poles provided by the two stubs, the diplexer exibits the typical peaks at the cross-over frequencies of the respective other channel ([4], [13]). However, the attenuation poles are responsible for achieving the specified isolation of 60 dB. A similar diplexer design based on five-pole iris filters without strongly dispersive inverters (not shown here) achieves only 54 and 36 dB isolation at the respective inband frequencies and would require six- and seven-order filters to match the isolation performance of the design in Fig. 8.

IV. CONCLUSIONS

Pre-synthesized waveguide filters with strongly dispersive inverters offer an attractive solution in diplexers whose specifications would otherwise require higher-order filters. Several design examples presented here demonstrate that this is a viable option in Ku- to Ka-band diplexer applications.

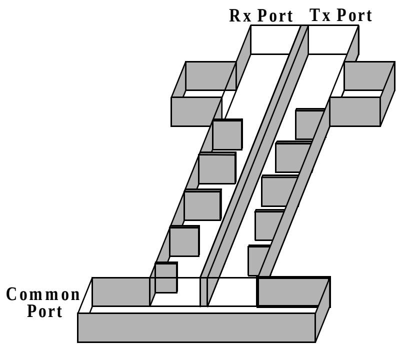

Fig. 7 *Principle layout of 18.5 GHz diplexer.*

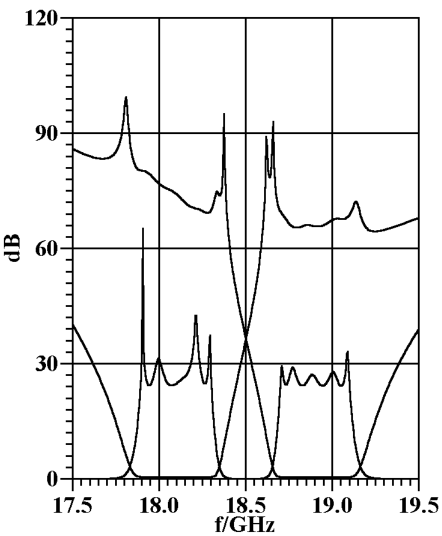

Fig. 8 *Performance of 18.5 GHz diplexer*

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