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ANALYSIS AND DESIGN OF MULTIPLE-BAND BANDSTOP FILTERS

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Abstract—A new transverserval coupling network is proposed to design of multiple-band bandstop filters. The resonators in the proposed transversal coupling network have a few of center frequencies and some of them have similar or the same resonating frequency to realize multiple-band bandstop suppression, which are applied to reject pulse signals or bandwidth signals in broadband technique applications. A triple-band bandstop filter is designed by adopting substrate integrated waveguide to demonstrate the feasibility of this proposed network.

1. INTRODUCTION

The increasing development of microwave and millimeter-wave communication systems has promoted the need for suppression of multiple unwanted signals for military broadband applications [1]. Bandstop and bandpass filters [2–4, 20, 21] play an important role in microwave and millimeter-wave systems, which are applied to discriminate the desired and unwanted signals.

Many bandstop filters are mainly designed for single-band rejection applications [5, 6]. Now, the research of dual- or multiple-band filters is a hot topic. There are some papers about bandpass filter applications [7–9] and few papers about bandstop filters cases [10, 11]. Dual-band bandstop filter is firstly presented in paper [10] used for the suppression of close-to-band intermodulation sidebands in high power systems. Multiple-band bandstop filters [11] for interference suppression for pulse signals in UWB systems are designed in paper by adopting microstrip structure. Recently, the transversal coupling network was proposed by Cameron [12] for synthesis of the "$N + 2$"

folded coupling matrix for bandpass filter applications at first shown in Fig. 1.

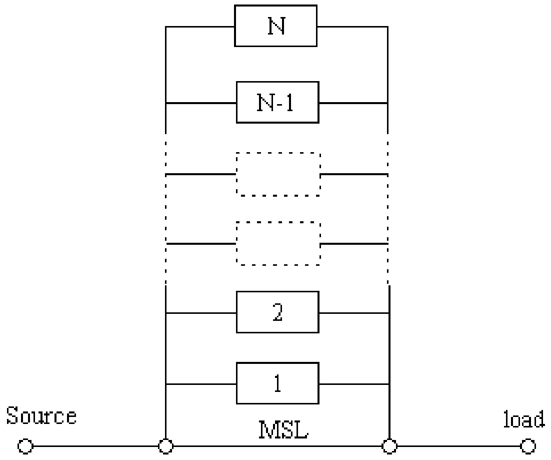


Figure 1. Conventional transversal coupling network. N-resonator structure.

Afterwards, Amari [13, 14] has extended the synthesis method of coupling matrix to the cross-coupled bandstop filters based on transversal coupling network at first. It has been shown that the cross-coupled bandstop filters with up to arbitrarily positioned reflection zeros at finite frequencies can be designed using "$N + 2$" transversal coupling network, which can provide sharp transition between passband and stopband. Afterwards, Cameron has proposed the synthesis methods for direct-coupled single- or dual-band bandstop filters for narrowband filter applications [15].

In this paper, we propose that the resonators in the transversal coupling network shown in Fig. 2 have a few of different resonating center frequencies and some of them have similar or the same resonating frequency to realize multiple-band bandstop suppression, which are applied to reject pulse signals or bandwidth signals in broadband technique applications. We can adopt the cross-coupled filter or conventional filter to suppress the bandwidth signals. The proposed structure explores the possibility of suppression of multiple signals for compact size and reduced costs in UWB applications. A triple-band bandstop filter is designed based on substrate integrated waveguide for meeting tight performance requirements and minimize costs. Measured results demonstrate the feasibility of the design approach.

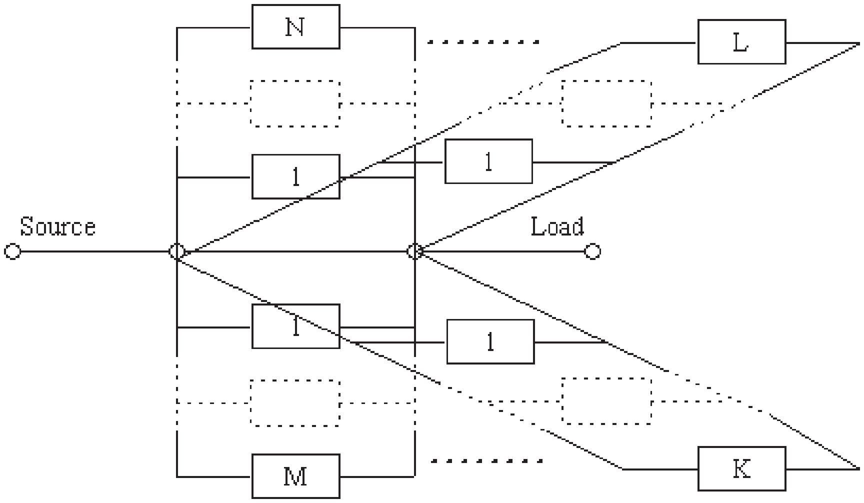


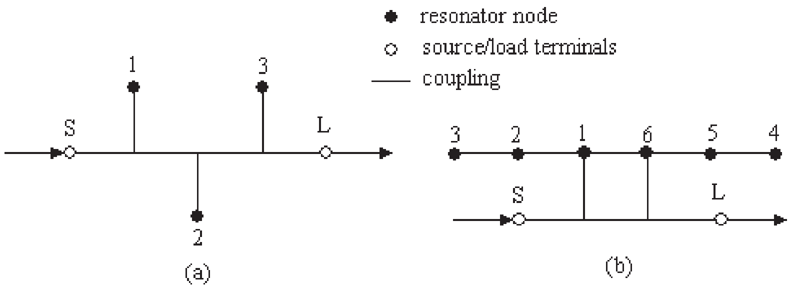
Figure 2. The proposed transversal coupling network. M, N, L, K mean the numbers of resonators which resonates at different center frequency.

2. BASIC THEORY

2.1. Coupling Schemes

The transversal coupling has some advantages compared with conventional coupling network. One of advantages is fully canonical filtering functions (i.e., Nth-degree characteristic with N finite-position transmissions zeros) can be synthesized. It is Amari that presented the minor modification of synthesis methods of the coupling matrix for bandstop filter based on the same coupling network. Cameron has successfully synthesized dual-band bandstop filter based on the transversal network only for narrow band filter, because the cross-coupled filters are mainly applied for narrow band filter. So, it is impossible to suppress the multiple signals at broadband range. The proposed transversal coupling network could include a few of cross-coupled filters or conventional filters which resonate at the different frequency to reject multiple different signals. In brief, the proposed transversal coupling network can be divided into a few of conventional transversal networks. The synthesis methods of the whole transversal coupling network have not been developed considering the interactive coupling. For one of them, the synthesis methods of coupling matrix have not changed. So, the proposed coupling network can suppress a few of pulse and bandwidth signals for broadband applications.

The proposed transversal network has some different coupling schemes. It could be consisted of a few of filters based on conventional filtering function (chebyshev, butterworth and so on) and another filters based on cross-coupled filtering function.



(a) 3-th conventional filter (b) 6-th cul-de-sac cross-coupled filter

Figure 3. Single-band bandstop filter coupling schemes.

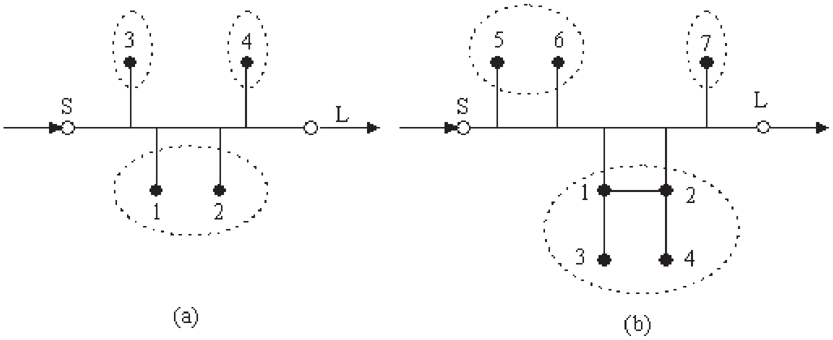


Figure 4. Multiple-band bandstop filter coupling schemes. Dashed curve means the resonators which resonates at the same center frequency. (a) Triple-band bandstop filter with one second-order cross-coupled filter and two first-order conventional filters. (b) Triple-band bandstop filter with one first-order conventional filter, one second-order and one fourth-order cul-de-sac cross-coupled filter.

For the coupling matrix of multiple-band bandstop filter, we can synthesize the different filter individually in advance. The interactive couplings are removed by simulation according to adjust the distance between different resonating frequency resonator. The methods to synthesis of the coupling matrix of cross-coupled filter are presented in paper [13, 15]. Note that the all-pole response of cross-coupled filter is not identical to the standard at the same frequency, but which also exhibits reflection zeros at infinite frequency (or at infinity for filters of odd orders [19]) [13].

2.2. Substrate Integrated Waveguide

It has been found that the rectangular waveguide resonators have wide range for microwave and millimeter-wave applications at high costs. The substrated integrated waveguide (SIW) resonator is firstly proposed probably by Piolote, Flanik and Zaki, which developed the idea of replacing the waveguide walls with a series of metallic holes via through the substrate to achieve the same effect of metallic walls [16, 17]. The SIW has more advantages, such as, high Q, low insertion, reduced size, low costs, and easily to be integrated with planar circuits. So, SIW are widely applied to all kinds of different filters design. As the initial dimensions of the simulation software, the size of the SIW cavity is determined by the corresponding resonance frequency from [18]

$$f_{101} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{\pi}{w_{eff}}\right)^2 + \left(\frac{\pi}{l_{eff}}\right)^2} \tag{1}$$

For the TE_{101} dominant mode, where w_{eff} and l_{eff} are the equivalent width and length of the SIW cavity, they are expressed by

$$w_{eff} = w - \frac{d^2}{0.95p}, \quad l_{eff} = l - \frac{d^2}{0.95p} \tag{2}$$

where w and l are real width and length of the SIW cavity. d and p are the diameter of the metallic vias and the distance between adjacent vias. c is the velocity of light in free space. μ_r and ε_r the relative permeability and relative permittivity of the substrate.

The coupling schemes are flexible and versatile for multiple-band bandstop filter design. For the SIW, the TM mode cannot be guided because of the extremely thin thickness of the substrate. Therefore, the TE mode is the sole propagating mode. This characteristic of SIW is very helpful to design multiple-band bandstop filter to eliminate the interactive coupling between different filters by simulation.

3. NUMERICAL EXAMPLE

In order to verify the feasibility of the proposed transversal coupling network, a triple-band bandstop filter is designed based on SIW technique. This filter is applied to suppress two pulse signal (10.45 GHz and 13.03 GHz) and one bandwidth signal (from 11.8 GHz to 12 GHz) for UWB applications. For the second-order cross-coupled filter, the synthesis method of coupling matrix was resented in paper [13]. The frequency response and coupling matrix of second-order cross-coupled filter are shown in Fig. 5 with −28 dB rejection level. It is obvious that the frequency response figure is different from that of standard chebyshev bandstop filter. Note that the direct input-output coupling MSL is equal 1, which can be formed form odd multiple of quarter of wavelength. The design method of bandstop filter realized by the coupling matrix is the same as the bandpass case. In the designing of the multiple-band SIW bandstop filter, an optimism procedure is needed for direct integration of individual filters into source-load coupling line to achieve good performance. In the process of simulation optimization, the radius of metallic hole is not changed. We can only change the distance of between the edges of two metallic holes.

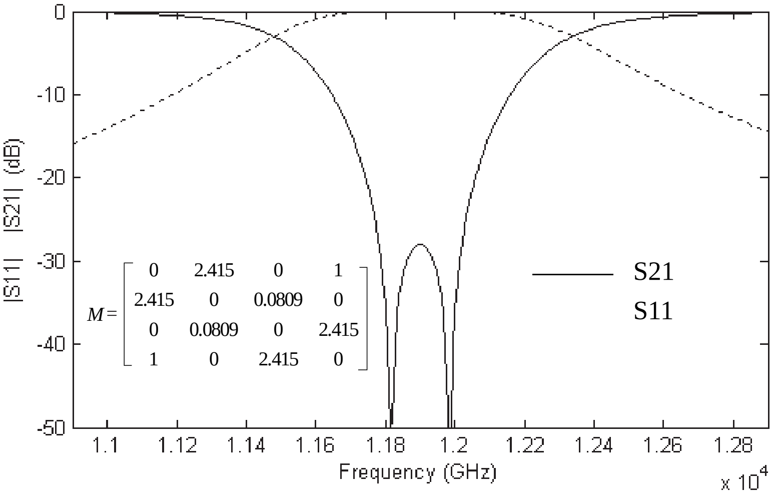


Figure 5. Frequency response of second-order cross-coupled filter and coupling matrix.

Fig. 6 depicts the configuration of the proposed multiple-band SIW bandstop filter with its physical parameters. The coupling scheme refers to Fig. 4(a). The diameter of metallic hole is 0.5 mm. The minima distance of between the edges of two metallic holes is 0.3 mm.

A triple-band bandstop filter is developed, and has been measured without any tuning. The structure was fabricated on Rogers RT/duriod 5880 substrate shown in Fig. 7. The substrate has relative permittivity constants is 2.2 mm with 0.254 mm thickness and a loss

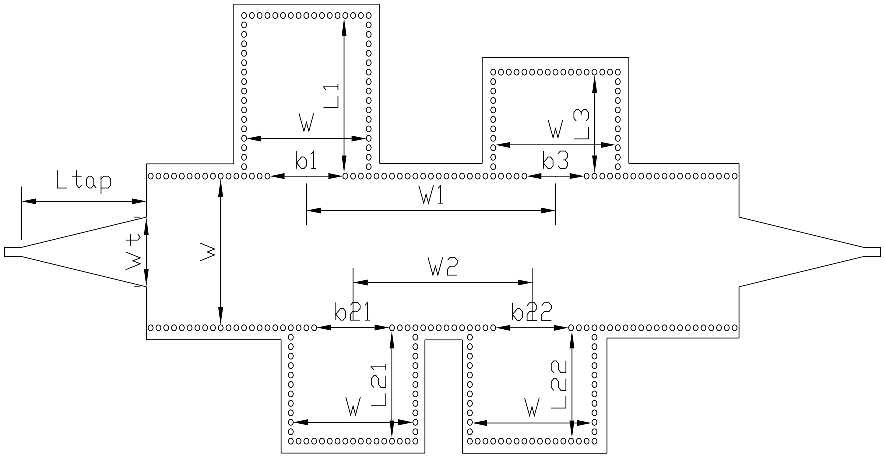


Figure 6. Configurations of the proposed triple-band SIW bandstop filter. Dimensions of SIW bandstop filter as following (Unit are all mm): $W = 12.3$, $L_{tap} = 12.8$, $W_t = 5.9$, $L_1 = 13.0$, $L_{21} = L_{22} = 9.0$, $L_3 = 8.2$, $B_1 = 7.4$, $b_{21} = b_{22} = 7.4$, $b_3 = 5.8$.

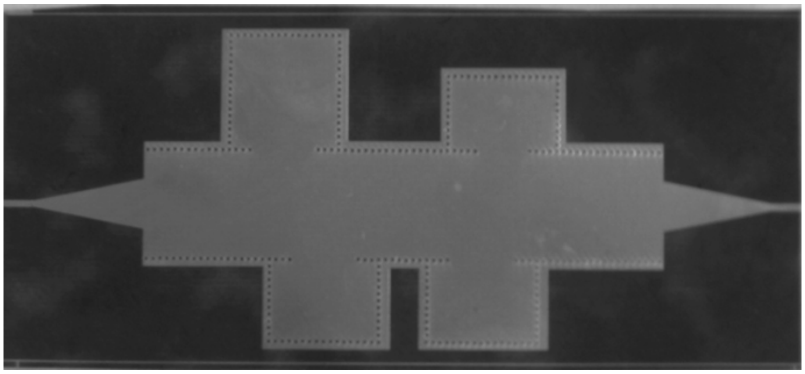


Figure 7. Photograph of triple-band SIW bandstop filter.

$\tan\delta$ of 0.0009. An SIW-microstrip tapered transition is designed with broadband response with return loss of less than −16 dB.

The comparison between simulation and measured results is given in Fig. 8. The measured results are good agreement with simulation results. The pulse signals at the 10.45 GHz and 13.03 GHz have less than −13 dB suppressions. The bandwidth signal from 11.8 GHz to 12 GHz has less than −19 db suppressions and are almost around

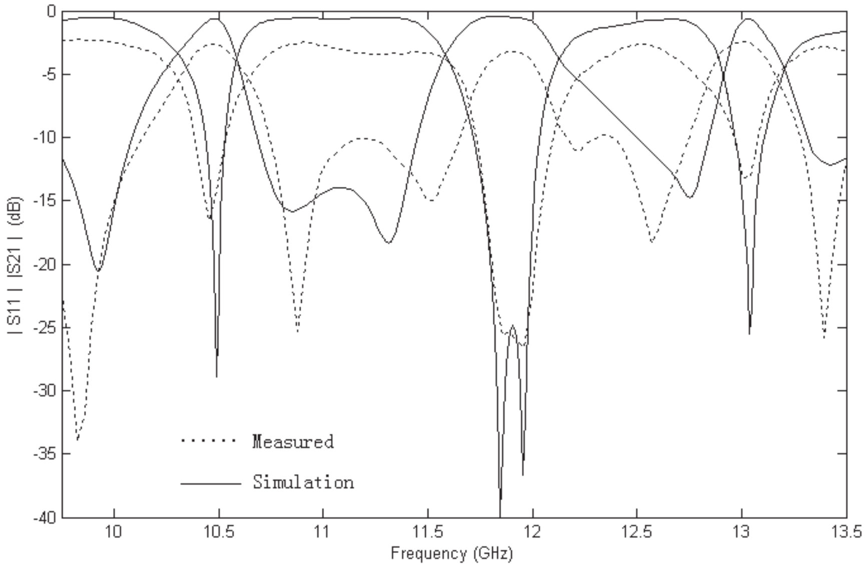


Figure 8. Simulation and measured results of triple-band SIW bandstop filter.

−25 dB suppressions. The return loss is less than −10 dB. The insertion loss is around −2.8 dB. The loss of SMA and SIW-microstrip transitions are also included.

4. CONCLUSION

Analysis and design of multiple-band bandstop filters are presented based on the proposed transversal coupling network in this paper. This bandstop filter has some coupling schemes, which include a few of different cross-coupled filters or conventional filters to realize the multiple-band rejection. A triple-band SIW bandstop filter is fabricated and measured to show the validity of the proposed network.

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