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Journal of ELECTRICAL ENGINEERING, VOL. 66, NO. 2, 2015, 113–116

COMMUNICATIONS

DESIGN AND ANALYSIS OF AN ULTRA–WIDEBAND BAND–NOTCHED BAND–PASS FILTER

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In this paper it is intended to design an ultra-wideband band-pass filter, using new models of coupled transmission lines. In this paper, by providing a new model of resonators, the bandwidth of band-pass filters (which are one of the most crucial elements in communication systems) will be moderately increased, while their size and volume decreases. In addition to the increase in bandwidth in these filters, due to the increasing usage of new satellite communication systems, the frequency response of these filters will be developed to utilize notch in the pass band, and an ultra-wideband band-pass filter with notch will be designed and analyzed.

K e y w o r d s: multiple mode resonators, stepped impedance resonator, band-pass filter, notched ultra-wideband

1 INTRODUCTION

Band-pass filters are crucial elements in communication systems. With the rapid growth of wireless and mobile communications, the demand for new technologies face problems in the size, implementation and production cost of band-pass filters with low transmission losses for these systems. In order to overcome these problems and reach the desired objective, interest in studies to decrease the size and volume of these filters has increased.

In addition to the problems of size and volume, since the year 2002, the United States Federal Communication Commission (FCC) has assigned a very wide bandwidth for commercial purposes, and many wireless communication systems (including wireless local area networks (WLAN) and global mobile systems (WiMax)) use this determined bandwidth, which causes interference problems. Therefor the design of band-pass filters which can first: be used to cover a very large bandwidth, and second: have stop-band or notch in the bands of these networks, is of great importance. In order to design these types of filters, a great amount of academic studies has been dedicated to the design a new template for these filters [1–14].

Multiple-Mode Resonators (MMR) and Stepped-Impedance Resonators (SIR) are two of the most used resonators in the design of broadband band-pass filters. The new model proposed in this study is an improved model of these two resonators.

The main frequency and the frequencies created by the harmonics of the resonances of higher frequencies are used in the creation of stop-band in ultra-wide bandwidths. Equations (1) and (2) present these frequencies.

$$\theta_{01} = \tan^{-1}\sqrt{\frac{K_1K_2}{K_1+K_2+1}}\,, \tag{1}$$

$$\theta_{02} = \tan^{-1}\sqrt{\frac{K_1+K_1K_2+1}{K_2}}\,. \tag{2}$$

In these equations, θ_{01} and θ_{02} are the main frequency and second and higher frequency of a multiple-mode resonator and the parameters K_1 and K_2 are the impedance ratios of different parts of the resonator.

In the design of the proposed filter and with an accurate mathematical analysis, the relation of main and higher frequencies with K parameters were studied, and thus the location of stop band within ultra-wide bandwidth will be determined in order to be able to optionally adjust the stop-band.

2 RECENT BROADBAND PASS FILTERS

The two band pass filters which will be studied in this paper are from the most recent research made in the past few years. One of them has been designed using stepped-impedance resonators (SIR), and the other has been designed using multiple-Mode resonators (MMR). It must be noted that the greatest deficiency of these two filters is the lack of notch.

2.1 Three-Section MMR

One of the most important resonators which has gained the attention of designers of passive microwave elements, are MMR resonators, and many band pass filters

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DOI: 10.1515/jee-2015-0018, Print ISSN 1335-3632, On-line ISSN 1339-309X

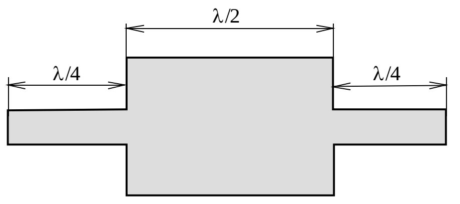

Fig. 1. The structure of a MMR

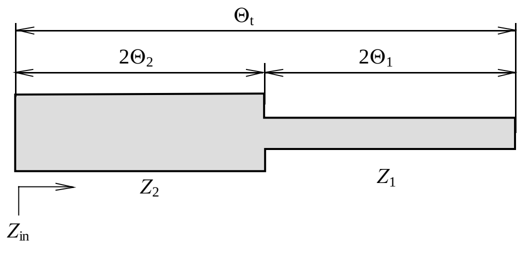

Fig. 2. Structure of the asymmetric two-section SIR used in reference in reference [2]

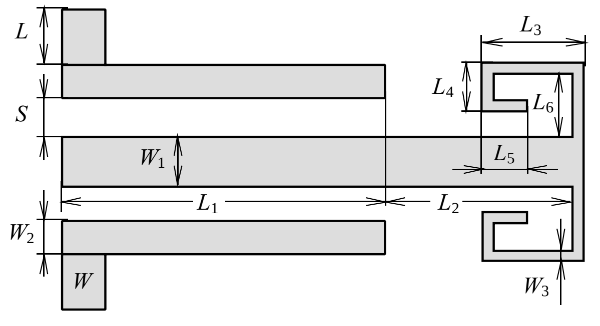

Fig. 3. Structure of the proposed broadband band-pass filter

have been designed based on these resonators [12, 15–18]. Figure 1 shows the structure of a MMR, which is the main resonator used in the design of such broadband filters.

2.2 Two-Section SIR Resonator

Another important resonator which has been studied by designers of passive microwave elements is the SIR resonator [2, 19, 20]. The broadband band pass filter designed in reference [2] is chosen. Figure 2 shows the structure of the asymmetric two-section SIR used in this reference.

3 DESIGN OF THE PROPOSED FILTER

In this section, in order to decrease the size and volume of these band-pass filters, first the structure of the proposed band-pass filter will be presented and then the frequency response will be simulated in the ADS software. Before simulation of the filter, its structure will be analyzed and the existence and location of transfer zeroes will be determined and presented. In the new structure it will be shown that theoretically, using transfer zeroes the frequency response of these filters can be improved, and thus improve the selectivity of these filters. The proposed resonator will be developed and another type of these resonators titled type II resonator will be developed to create stop-band or notch. Then, according to the proposed structure of these two resonators, a parallel structure will be proposed and presented. Finally, using the proposed type I and type II resonators, an Ultra-Wideband Band-Notched Band-Pass Filter will be proposed and presented.

3.1 Proposed type I resonator

As it is shown in Fig. 3, the structure of the proposed band-pass filter contains a two-section SIR in which the first section is similar to the first section of regular SIRs and the second section has two equal parallel branches. In this paper, first the proposed resonators will be analyzed for the design of a band-pass filter with large bandwidth. Figure 3 shows the structure of the type I resonator which uses the combination of two transmission lies with a length of $\lambda/4$ as feed lines. Generally the structure combined with these feed lines will provide a wideband band-pass filter. In Fig. 3, this band-pass filter is shown in the ADS software in terms of optimized parameters.

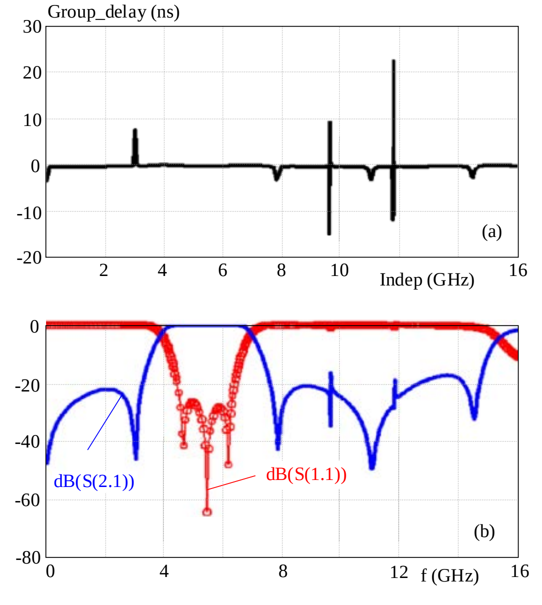

Fig. 4. Simulated frequency response of the proposed wideband in the ADS software in terms of (a) — return losses S_{11} and transmission losses S_{22} together, (b) — filter phase-delay

The optimized values of the proposed broadband band-pass filter are given in Table 1. As it is given in this table the proposed filter is divided into 6 transmission lines.

In this section in order to study the frequency response of this new band-pass filter, its structure was implemented in the ADS software, and its performance was simulated in terms of scattering parameters of transmission and return losses. It consists of 28 micro strip transmission lines.

After implementing the proposed band-pass filter, its structure was implemented on a substrate with a thickness of 0.787 mm and dielectric constant of 2.2 and its frequency response was simulated in the range of 0–16 GHz. For a better comparison both losses are shown together in the plots of Fig. 4a. As it is shown in Fig. 4a, the values of the S parameters have been provided, so the

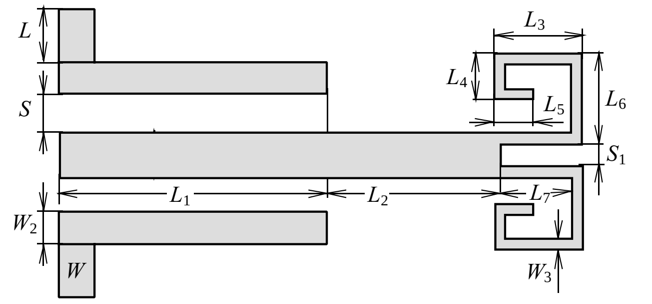

Fig. 5. Structure of the proposed type II resonator with coupling between the cochlear branches. $L_1 = 12$ mm, $L_2 = 3.4$ mm, $L_3 = 1.6$ mm, $L_4 = 0.5$ mm, $L_5 = 0.4$ mm, $L_6 = 1.4$ mm, $L_7 = 1.2$ mm, $W = 2.2$ mm, $W_1 = 0.3$, $W_2 = 0.28$ mm, $W_3 = 0.2$, $S = 0.1$ mm, $S_1 = 0.1$ mm

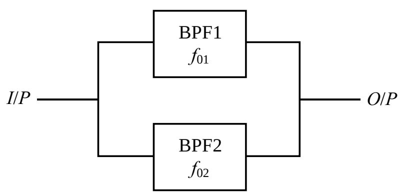

Fig. 6. Proposed structure for the design of a band-pass filter with an ultra-wide bandwidth

filter phase parameter must also be studied. Usually the phase parameter S_{21} is presented as phase delay. In this paper and in Fig. 4b this parameter is shown as group-delay.

3.2 Proposed type II resonator

In the previous section the type I proposed filter was presented and simulated. Using this type I filter it is only possible to design an ultra-wideband band-pass filter without any stop-band or notch in its pass-band. In this section the proposed type I resonator will be improved to include notch in the pass-band.

For the improvement of the type I resonator, a type of electric coupling is embedded between the cochlear branches of the SIR. The creation of this coupling in the type I resonator will create a notch in the ultra-wide pass-band. The resonator developed from the type I resonator is called the type II resonator. Figure 5 shows the structure of this with its values.

3.3 Proposed Structure of Parallel Resonators

As it can be observed from the frequency response of the proposed type I resonator given in Fig 4a, this resonator alone cannot create an ultra-wide bandwidth. The bandwidth of 3 dB simulation of this resonator ranges from 4.1 GHz to 6.4 GHz with a central resonance frequency of $f_0 = 5.25$ GHz and thus the relative bandwidth is calculated to be 43.8 %. Band-pass filters with a relative bandwidth lower than 50 % cannot be considered as ultra-wideband.

On the other hand based on the ultra-wideband bandwidth assigned by the FCC in 2002, an ultra-wideband bandwidth of 3.1 GHz and 10.6 GHz is required for these band-pass filters. In this paper, in order to increase the bandwidth of these filters and design a band-pass filter to cover the bandwidth regulated by the FCC, a new model was proposed and presented by setting these resonators parallel to each other. Figure 6 shows a schematic of the proposed structure of these resonators.

3.4 Ultra-Wideband Band-Notched Band-Pass

As shown in the previous section, if the two band-pass filters in the block-diagram of Fig. 6 (BPF1 and BPF2) are replaced with type I resonators, an ultra-wideband band-pass filter without any stop-band in its pass-band can be designed and simulated. Similarly, if one the wide-band band-pass filters of this structure is replaced with a proposed type II resonator, and the other is replaced with a type I resonator, then an ultra-wideband band-pass filter with notch-band in its pass-band can be designed.

Then the substrate of the filter was specified like the previous filter with a thickness of 0.787 mm and dielectric constant $\varepsilon_r = 2.56$ and finally its frequency response was simulated in terms of transmission and return losses. Figure 7 shows the return and transmission losses of the ultra-wideband band-pass notch filter.

As it can be observed from the frequency response given in Fig. 7, a frequency notch has been created in the pass band of the designed band-pass filter. For better comparison both losses are shown together. Their plots are shown in Fig. 8.

4 CONCLUSION

In this paper, before simulating the filter, its structure was analyzed and the existence of and location of transfer zeroes were determined and presented. In the new structure it was shown theoretically that using the transfer zeroes, the frequency response of these filters and thus their selectivity can be improved. Moreover, the proposed resonator was improved and another type of this resonator, named type II resonator, was developed to create stop-band or notch. Then according to the structure of these two proposed resonators, a parallel structure was proposed and presented. Finally using the type I and type II resonators Ultra-Wideband Band-Notched Band-Pass Filter was designed and proposed.

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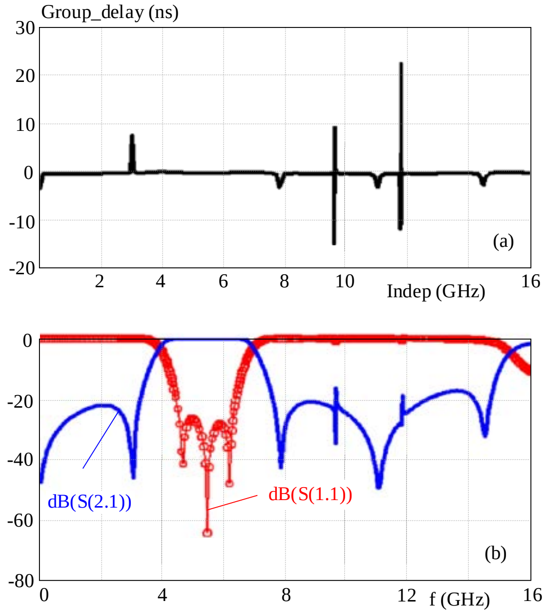

Fig. 7. Simulated frequency response of the proposed ultra-wideband band-pass filter in the workspace of ADS in terms of (a) — return losses (S_{11}), and (b) — transmission losses (S_{21})

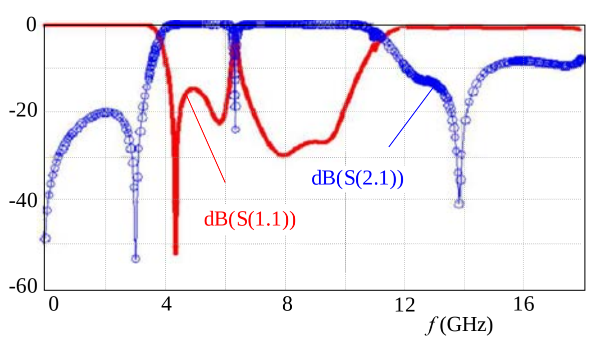

Fig. 8. Frequency response of the ultra-wideband band-pass filter with notch

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Received 23 April 2014

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