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Miniaturization of bandstop filter using double spurlines and double stubs

***Abstract**. This paper presents a new type of compact bandstop filter. The proposed filter topology consists of double spurlines and double open stubs. Double spurlines are introduced to a conventional open stub filter for filter circuit size miniaturization and bandstop region improvement. It is clearly shown that the rejection region of the proposed filter is wider and deeper compared to the conventional open stub filter without any cascading circuits or periodic structures. The proposed filter is designed with Finite-Difference Time-Domain Method (FDTD). To validate the proposed topology, a compact filter prototype with bandstop centered at 3.5 GHz is fabricated and transmission coefficient measurements are conducted. Measurements show that there is a rejection region from 1.68 to 5.17 GHz with S_{21} less than -3 dB. The total length of the prototype equals to 49.2 mm.*

***Streszczenie.** W artykule przedstawiono kompaktowy filtr pasmowo-zaporowy, zawierający podwójne struktury mikropaskowe i podwójne pętle otwarte. Przy projektowaniu wykorzystano metodę różnic skończonych w dziedzinie czasu (ang. Finite-Difference Time-Domain Method). (**Wykorzystanie podwójnej struktury mikropaskowej i podwójnej pętli do miniaturyzacji filtru pasmowo-zaporowego**)*

Keywords: Finite-Difference Time-Domain (FDTD), bandstop filter, conventional stub filter, double spurlines.
Słowa kluczowe: Metoda Różnic Skończonych w Dziedzinie Czasu (FDTD), filtr pasmowo-zaporowy, filtr pętlowy, podwójne struktury mikropaskowe.

Introduction

With rapid development in modern communication technology, there has been a growing interest in microwave devices for communication applications. The microstrip filter is an example of a microwave device which is widely used in modern communication systems. In the research community, microstrip filters of various responses are highly employed, e.g., lowpass, highpass, bandpass and bandstop filters. In addition, microstrip ring resonator with harmonic suppression using compact and double spurlines has been published [1].

Firstly, Modern communication systems often require low cost and compact size devices. Research trends in modern communication systems, therefore, tend to implement low cost, compact size, and simple fabrication for modern communication devices.

Bandstop filters are important devices in rejecting higher harmonics and spurious response for microwave, millimeter wave, and Terahertz applications [2-4]. The conventional technique to implement bandstop filters involves the use of stepped impedance microstrip lines and open stubs that increase the circuit size [5].

Basically, an open stub filter is a conventional filter, which is highly used [5]. By cascading more open stubs of an open stub filter, a wider rejection bandwidth and a deeper rejection can be obtained at the expense of increasing the insertion loss in the passband and the overall circuit size. The conventional open stub filter is depicted in Fig. 1. [5].

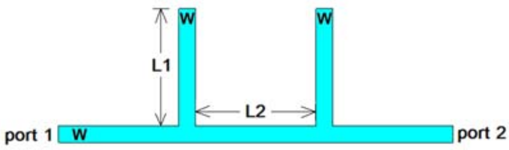

Fig.1. Layout of a conventional open stub bandstop filter

Recently, some structures such as defected ground structures (DGS) [6], and photonic band gap (PBG) [7-8] have been studied and published. However, the problems of DGS and PBG are that they allow for a remarkable backside radiation, which disturbs the radiation characteristics of the RF front-end module such as microstrip antennas. In addition, these techniques require the fabrication of additional structures at the ground plane and increase the design complexity. Also, the proper alignment between the structures on microstrip line and the structures on ground plane is required. Consequently, it increases the fabrication cost.

Among microstrip filter designs, spurline is a simple defected microstrip structure and is the smallest structure compared to other filter designs [9]. It is realized by etching an L-shaped slot on a microstrip line. It can provide moderate rejection bandwidth with its compact size. Its structure is presented in Fig. 2 [10].

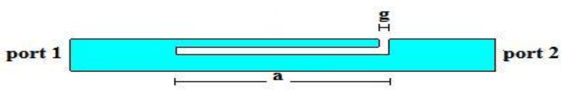

Fig.2. Layout of a conventional spurline bandstop filter

In this paper, a simple wider rejection bandwidth and deeper rejection microstrip bandstop filter with compact circuit size is proposed. With the use of two spurlines of proper length inserted between double open stubs, it is clearly found that the wider rejection bandwidth and deeper rejection of the proposed filter can be effectively achieved. Details of the proposed design are described. The simulations and experiments are conducted. Then, the simulated and experimental results are presented and discussed.

Numerical electromagnetic method for analysis

In the numerical electromagnetic method for analysis, the Finite-Difference Time-Domain method (FDTD) is conducted to simulate the designs. FDTD is a simple electromagnetic simulation tool to analyze our designs associated with Maxwell's equations. The details on FDTD theory are available in [11]. To conduct the FDTD simulations, transmitted electric fields are sampled for the same polarization as the incident fields. The samples that are in time domain then are used to determine the transmission coefficients (S_{21}) with Fourier transformation as in the following equation.

(1) $$S_{21} = \frac{FT(E_t)}{FT(E_i)}$$

where FT stands for the Fourier transformation, E_i = incident electric fields in time domain, and E_t = transmitted electric fields in time domain.

The transmission coefficient is a parameter that describes the transmission power response for each frequency obtained from the filters. Consequently, it is very important to extract the parameter for filter performance assessments.

Modeling of single spurline, double spurlines, and conventional open stub filter

A schematic view of a conventional spurline is presented in Fig. 2. The configuration of the spurline is described by slot length (a), and slot width (g). Normally, the slot gap exhibits a capacitive effect while the narrow microstrip line provides an inductive effect [8]. The desired rejected wavelength can be calculated using the follow equation.

(2) $$a = \frac{\lambda_g}{4}$$

where a = the length of the spurline, and λ_g = the desired rejected wavelength in the substrate.

Equation (2) can be derived into the frequency domain as follows:

(3) $$f_{stop} = \frac{c}{4a\sqrt{\varepsilon_{eff}}}$$

where a = the length of the spurline, ε_{eff} = effective permittivity of the substrate, c = 3x10^8 m/s, and f_{stop} = the desired rejected frequency.

To obtain the wider rejection bandwidth without increasing the overall circuit size, the effects of double spurlines on transmission coefficients are investigated to compare with those of the single spurline.

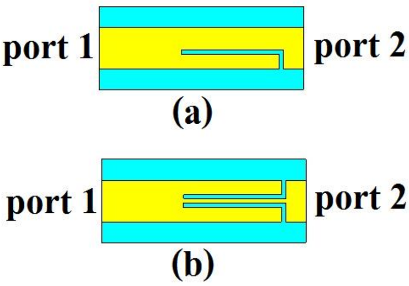

Fig.3. Configurations of spurline filters (a) single spurline (b) double spurlines

The effects of double spurlines on transmission coefficients (S_{21}) are studied using the FDTD simulations. In Fig. 3, the microstrip feed lines are simply simulated with PEC (Perfect Electric Conductor). For both types of spurlines, the AD260A substrate is simulated with the substrate permittivity ε_r = 2.60. The ground plane is at the bottom layer. The length of the microstrip line is 30 mm. The width of the microstrip line is 2.1 mm. The substrate thickness is 0.76 mm. The dimensions of the spurlines are a= 15 mm, and g = 0.4 mm. The simulated results shown in Fig. 4 demonstrate that the rejected frequency for both types of spurlines is about 3.6 GHz. The rejected frequency obtained from simulated results is verified by a good agreement with the calculation from equation (3). The stopband region at -3 dB level of the double spurlines increases to about 3.3 times wider than that of single spurline.

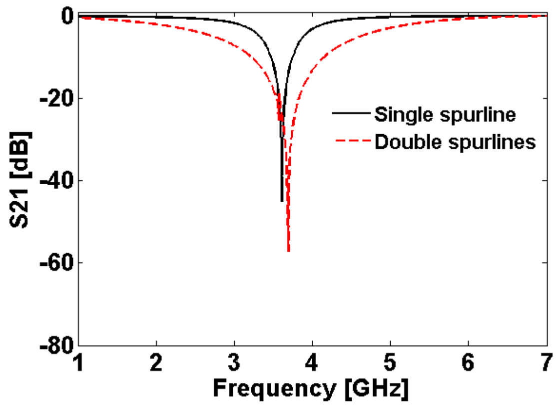

Fig.4. Comparison of simulated transmission coefficients (S_{21}) for single spurline filter and double spurline filter

From the simulated results in Fig. 4, the rejection bandwidth of double spurlines is very wide compared to that of single spurline. Also the rejection level of double spurlines is very deep compared to that of single spurline. With the compact circuit size of double spurlines, it is very suitable to apply double spurlines as a compact bandstop filter.

Both types of spurlines can be modeled as one parallel LCR resonator. The resonant frequencies are modeled by one LC resonator, and the radiation effect and transmission loss are considered as a resistor (R). Based on the transmission line theory and the spectral domain approach [5, 121], the circuit elements can be extracted using the follow equations.

(4) $$R = 2Z_0\left(\frac{1}{|S_{21}|} - 1\right)$$

(5) $$C = \frac{\sqrt{0.5(R+2Z_0)^2 - 4Z_0^2}}{2.83\pi Z_0 R\Delta f}$$

(6) $$L = \frac{1}{4(\pi f_0)^2 C}$$

where Z_0 is the $50\ \Omega$ characteristic impedance of the microstrip line, f_0 is the resonant frequency, S_{21} is the transmission coefficient at f_0, and Δf is the -3 dB bandwidth of S_{21}

From the simulated results in Fig. 4, the extracted circuit elements are the following. For the single spurline, L= 0.977 nH, C= 1.9995 pF, and R = 17.76 $k\Omega$. For the double spurlines, L= 3.095 nH, C= 0.601 pF, and R = 71.33 $k\Omega$.

The simulated results of the double spurlines in Fig. 3(b) are compared to the simulated results of the conventional open stub filter in Fig. 1. The open stub filter is simulated with the dimensions: L1= 14.5 mm L2 =15 mm, and W = 2.1 mm on a substrate thickness of 0.76 mm with a relative permittivity of 2.60. The transmission coefficient comparison of both types of filters is presented in Fig. 5.

It can be clearly found that the transmission coefficients of the double spurlines are very comparable to those of conventional open stub filter as in Fig. 5. In addition, the dimensions of double spurlines can be tuned to obtain the transmission coefficient close to the conventional open stub filter's transmission coefficient.

With the integration of double spurlines and double open stubs, the proposed filter can be obtained with the compact circuit size. Details of the proposed filter design and the experimental results will be presented and discussed in the following sections.

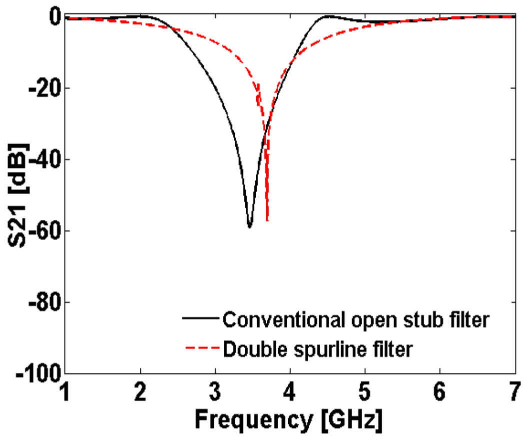

Fig.5. Comparison of simulated transmission coefficients (S_{21}) for double spurline filter and conventional open stub filter

The proposed filter design

Based on the transmission responses of the double spurlines and the conventional open stub filter in Fig. 5, the newly proposed filter is introduced by inserting the double spurlines between two open stubs.

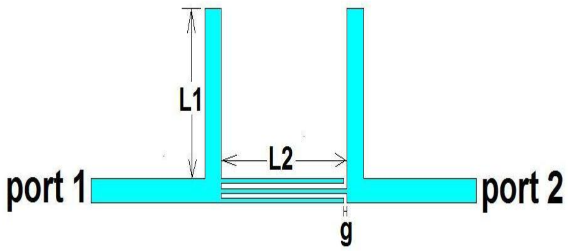

Fig.6. Layout of the proposed bandstop filter

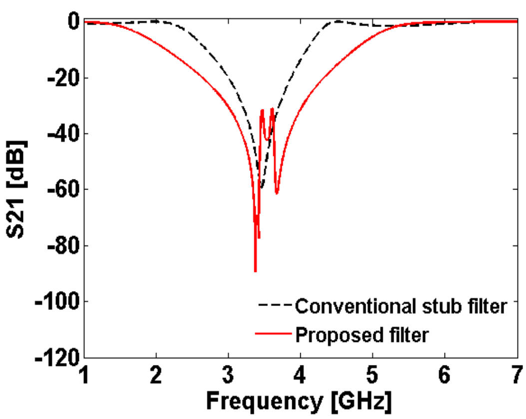

Fig.7. Comparison of simulated transmission coefficients (S_{21}) for the conventional open stub filter and the proposed filter

Fig. 6 shows the layout of the proposed bandstop filter. The geometry of the stubs is determined by L1, while the distance between two open stubs is L2. In Fig. 6, g indicates the slot width of the double spurlines, and L2 is the slot length of the spurlines. The 50 Ω microstrip line has a line width of W. The parameters L1, L2, W, and g of the proposed bandstop filter are chosen to be 14.5 mm, 15 mm, 2.1 mm, and 0.4 mm, respectively. The substrate thickness is 0.76 mm with a relative of permittivity of 2.60. The calculation from equation (3) gives us the center frequency of 3.5 GHz. The filter characteristics were simulated by FDTD simulations. The simulated results shown in Fig. 7 demonstrate that the proposed filter has a rejection band from 1.66 to 5.18 GHz with S_{21} less than -3 dB, while the conventional open stub filter has a rejection band from 2.4 to 4.3 GHz. The proposed filter offers a wider bandwidth, about 1.9 times that of the conventional filter, without increasing the circuit size or adding any periodic structures. In addition, the rejection level of the proposed filter is deeper than that of the conventional open stub filter.

Experimental results

To validate the FDTD simulated results, the proposed filter is fabricated for transmission coefficient measurements. The proposed filter is fabricated with all dimensions from the previous section. A photograph of the filter is presented in Fig. 8. It is obviously found in Fig. 8 that the overall circuit size is very compact.

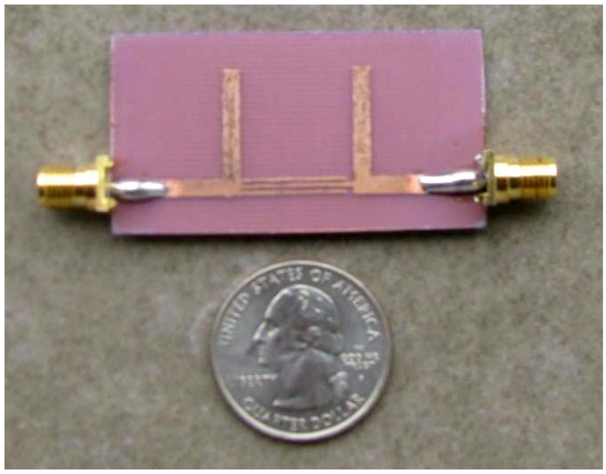

Fig.8. The photograph of the proposed bandstop filter

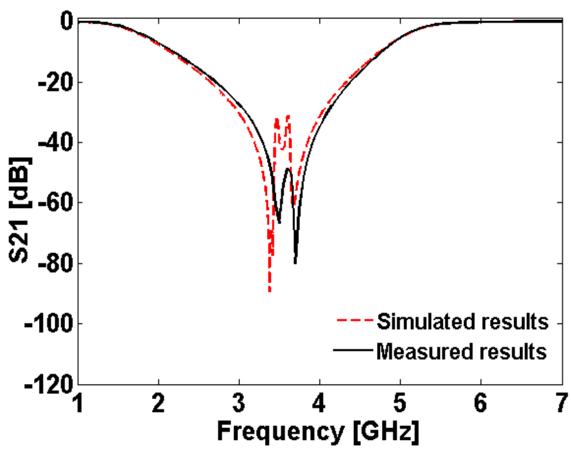

Fig.9. Comparison of simulated and measured transmission coefficients (S_{21}) for the proposed filter

An Agilent HP-E5071B vector network analyzer with 50 Ω airlines is used to measure the transmission coefficients of the proposed filter. Fig. 9 shows the transmitted power obtained from simulations and measurements. The simulated results for the proposed filter are in good agreement with measured results.

The experimental results plotted in Fig. 9 show that the proposed filter has a rejection band from 1.68 to 5.17 GHz with S_{21} less than -3 dB. The deep bandstop characteristics are perfect for practical communication engineering applications.

The total length of the proposed filter is 49.2 mm, which equals to about $0.39\lambda_g$ (λ_g is the guided wavelength at the -3 dB lower cutoff frequency of 1.68 GHz). It can be found that the overall circuit size can be reduced without any cascading circuits or periodic structures.

Conclusion

A new and miniaturized bandstop filter has been proposed in this paper. The proposed filter's circuit size is reduced using double spurlines and conventional open stubs. The bandstop characteristics of double spurline filter are studied and its LCR circuit elements are extracted. The spurlines are inserted between two open stubs for the purpose of bandstop region improvement and circuit size miniaturization. In order to demonstrate its potential, a bandstop filter prototype has been simulated and implemented for comparison. The transmission coefficients are measured using Agilent HP-E5071B vector network analyzer. The measured results are in good agreement with the FDTD simulated results. It has been obviously shown that the proposed bandstop filter provides wider bandstop and deeper rejection with compact circuit size compared to the conventional open stub filter. The proposed technique for compact bandstop filter design will be useful in harmonic suppression for microwave integrated circuits, microstrip ring resonators, microstrip diplexers, and Terahertz applications.

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