# Miniaturized Bandstop Filter Using Meander Spurline and Capacitively Loaded Stubs

Haiwen Liu, Reinhard H. Knoechel, and Klaus F. Schuenemann

**A miniaturized bandstop filter (BSF) is introduced in this paper. The filter consists of one meander spurline and a pair of capacitively loaded stubs. The meander spurline with low resonant frequency and improved slow-wave factor exhibits excellent resonant bandgap characteristics which can be modeled by a longitudinally coupled resonator. The design of the proposed microstrip BSF is presented, and its performance is measured. Measurements show that there is a stopband from 2.3 to 5.6 GHz with $S_{21}$ less than –20 dB. The total length of this BSF equals 23 mm.**

**Keywords: Bandstop filter, meander spurline, slow-wave, bandgap, circuit modeling.**

## I. Introduction

Microstrip filters play an important role in rejecting higher harmonics and spurious response for microwave, millimeter-wave, and THz applications [1], [2]. The conventional method to implement bandstop filters (BSFs) involves the use of shunt stubs or stepped-impedance microstrip lines with large circuit size. Recently, some periodic materials such as photonic bandgap (PBG), electromagnetic bandgap (EBG), and defected ground structure (DGS) [3], [4], have been shown to exhibit good bandstop characteristics and are popularly applied in BSF designs. However, their stopband bandwidth and sharp cutoff frequency response are enhanced by four or more cells, which leads to larger size and more transmission loss in the stopband. Moreover, PBG, EBG, and DGS require an etching process on the backside ground plane and additional position calibration which improve time-consumption and help overcome some difficulties in machining [5].

A spurline is a simple defected structure which is realized by etching one slot on a microstrip line. It provides excellent bandgap characteristics and can be applied in antenna and filter designs [6], [7]. However, very limited research on its equivalent circuit has been reported. Based on our previous work [8], [9], a compact meander spurline with low resonant frequency and improved slow-wave factor is proposed and analyzed in this paper. Then, an equivalent circuit model of a spurline on a microstrip structure is derived based on circuit analysis theory and is verified by electromagnetic (EM) simulations. In addition, the design and fabrication of a miniaturized microstrip BSF using a spurline structure and capacitively loaded stubs are presented along with measured test results. Measurements verify the validity of this method.

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Manuscript received Mar. 17, 2007; revised May 10, 2007.

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## II. Characteristics and Modeling of Meander Spurlines

A schematic view of a conventional spurline is shown in Fig. 1(a). The configuration of the spurline is described by slot width *s*, slot length *a*, and slot height *b*. In general, the slot gap provides a capacitive effect while the narrow line exhibits an inductive effect. Thus, the effective permittivity of the dielectric substrate increases as the effective inductance and capacitance of microstrip line are improved by spurlines. A novel spurline using a meander structure is shown in Fig. 1(b). A cross-section view including three layers is presented in Fig. 2. The top layer is the microstrip with a spurline, the middle layer is the substrate, and the bottom layer is the ground plane. Two physical parameters, *c* and *d*, indicate periodicities of the meander spurline. Actually, the total slot length and interdigital capacitive effect of the meander spurline show great improvement compared to those of the conventional spurline; thus, the effective inductance and capacitance of microstrip line are improved.

To study spurline transmission characteristics, we simulated them using an EM simulator (Ansoft Ensemble 8.0). The dimensions of the spurline structure were the following: $s = 0.1$ mm, $a=7.9$ mm, $b=0.8$ m, $c=0.7$ m, and $d=0.6$ mm. The substrate on a Rogers TMM10 substrate with a relative dielectric constant of 3.38 and thickness of 0.508 mm was used for simulations and measurements. The spurlines were etched on a 50 Ω microstrip line which was 1.17 mm wide. A comparison of transmission characteristics between the conventional spurline and the proposed meander spurline is described in Fig. 3. There is an obvious bandgap at the resonant frequency of 5.66 GHz for the conventional spurline and another bandgap at 4.01 GHz for the proposed meander spurline. Note that the resonant frequency is reduced by 27.6% after adopting a meander spurline. Moreover, the meander spurline provides higher insertion loss and narrower bandwidth.

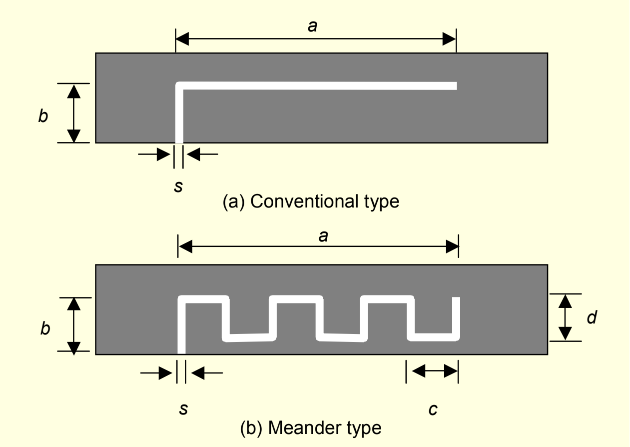

Fig. 1. Layout of the spurlines.

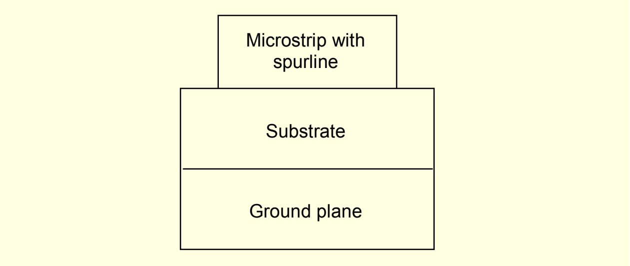

Fig. 2. Cross-section of the proposed spurline.

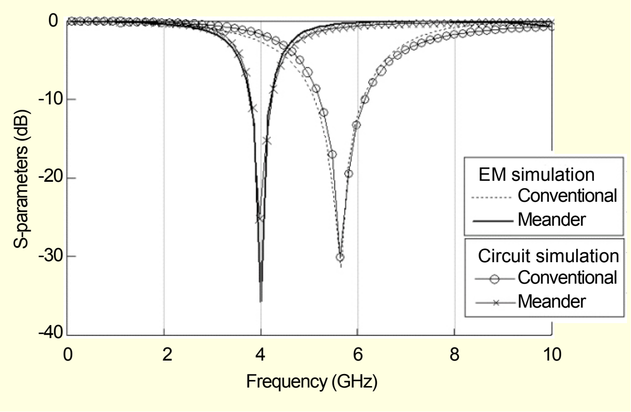

Fig. 3. Simulated insertion loss of the spurlines.

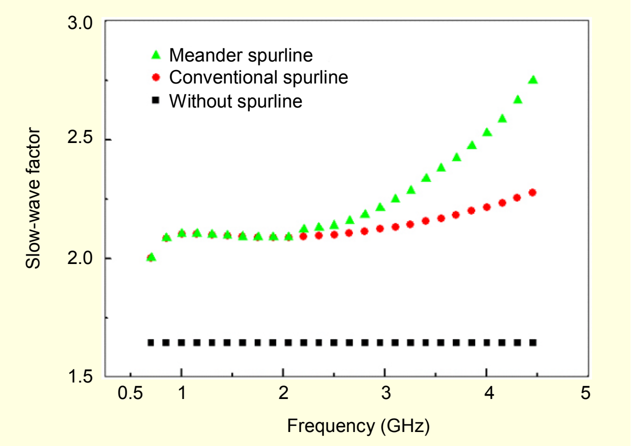

Fig. 4. Slow-wave factors of the spurlines.

Figure 4 presents a comparison of the slow-wave factors of a 50 Ω microstrip line, a conventional spurline, and a meander spurline [9]. Clearly, spurlines help improve the slow-wave factors. The slow-wave factors at 4.5 GHz are 1.65, 2.27, and 2.75 for microstrips without a spurline, with the conventional spurline, and with the meander spurline, respectively. The slow-wave factors are improved by 37.6% and by 66.7%, respectively, due to the use of spurlines. This demonstrates that the proposed meander spurline can provide a lower resonant frequency and an improved slow-wave factor which makes size-reduction possible.

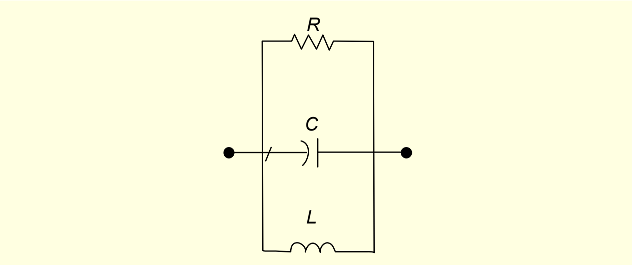

Fig. 5. Equivalent circuit model for spurline.

A simple circuit model with one LCR-network resonator for a spurline is shown in Fig. 5. The resonant characteristics are modeled by one LC-resonator, and the radiation effect and loss are considered by including resistor, $R$. Based on the transmission line theory and the spectral domain approach, the circuit parameters can be extracted using the following equations:

$$R = 2Z_0(1/|S_{21}|-1)\Big|_{f=f_0}, \tag{1}$$

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

$$L = \frac{1}{4(\pi f_0)^2 C}, \tag{3}$$

where $Z_0$ is the 50 Ω characteristic impedance of the transmission line, $f_0$ is the resonant frequency, $S_{21}$ is the insertion loss, and $\Delta f$ is the -3 dB bandwidth of $S_{21}$.

Based on the EM simulations in Fig. 3, the extracted circuit parameters are the following. For the conventional spurline, $L$=1.3282 nH, $C$=0.5953 pF, and $R$=3.6397 kΩ. For the meander spurline, $L$=1.2049 nH, $C$=1.3097 pF, and $R$=6.0395 kΩ. Circuit simulations using a circuit simulator (Agilent ADS) are presented in Fig. 3, where they are compared to EM simulations. Excellent agreement between the circuit simulations and the EM simulations was achieved as shown in Fig. 3.

## III. Bandstop Filter Design

A new BSF was designed by employing one meander spurline on a 50 Ω microstrip line with a pair of capacitively loaded stubs. Figure 6 shows the layout of the designed BSF. The geometry of the stubs is determined by $l_1$, $l_2$, and $l_3$ , while the distance between two stubs is $l_5$. In Fig. 6, $l_4$ indicates the distance between the left stub and the spurline. The 50 Ω microstrip line has a line width of $w$. The structure of the capacitively loaded stub is optimized by using Agilent ADS. The physical parameters $l_1$, $l_2$, $l_3$, $l_4$, $l_5$, and $w$ of this BSP are chosen to be 7 mm, 8 mm, 2 mm, 2.4 mm, 13 mm, and 1.17 mm, respectively. The dimensions of the meander spurline are $s = 0.2$ mm, $a = 7.9$ mm, $b = 0.8$ m, $c = 0.7$ m, and $d = 0.6$ mm. The filter characteristics were simulated by EM simulator and circuit simulator. The simulation results shown in Fig. 7 demonstrate that the filter has a stopband from 2.28 to 5.48 GHz with $S_{21}$ less than –20 dB. From 0.1 GHz to 10 GHz, a good agreement between the EM simulations and the circuit simulations can be observed.

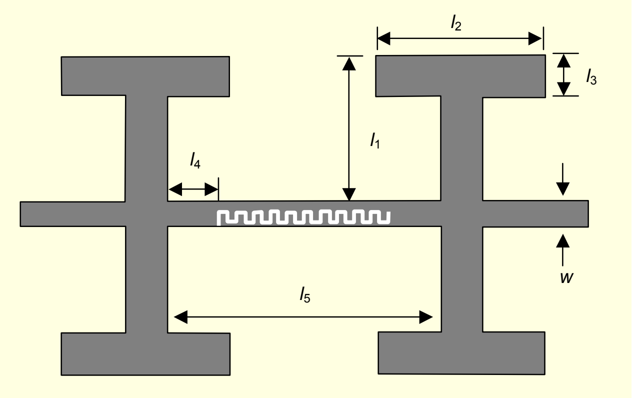

Fig. 6. Layout of the proposed BSF.

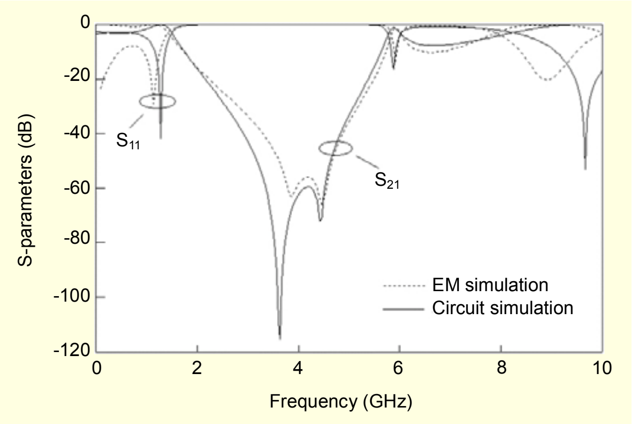

Fig. 7. Simulated frequency characteristics of the proposed BSF.

## IV. Experimental Results

The proposed BSF was fabricated and measured. A photograph of it is shown in Fig. 8. The experimental results plotted in Fig. 9 show that the filter has a stopband from 2.3 to 5.6 GHz with $S_{21}$ less than -20 dB. The maximum insertion loss within the passband is 1.0 dB. Furthermore, there are two transmission zeros on the stopband. They are -54 dB and -63 dB at the frequencies of 4.3 GHz and 4.6 GHz, respectively. The deep bandstop characteristics are excellent in practical engineering applications. In addition, the total length of this BPF is 23 mm, which equals about $0.18\lambda_g$ ($\lambda_g$ is the guided

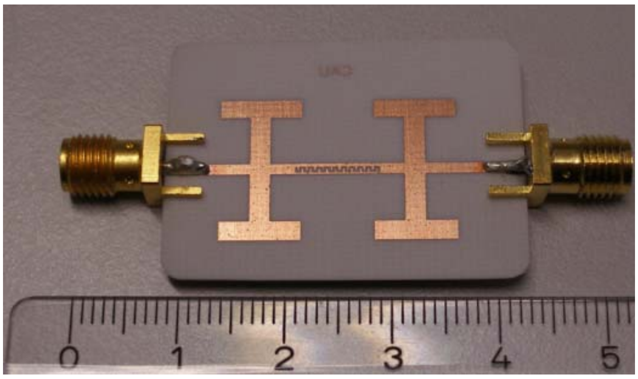

Fig. 8. Photograph of the proposed BSF.

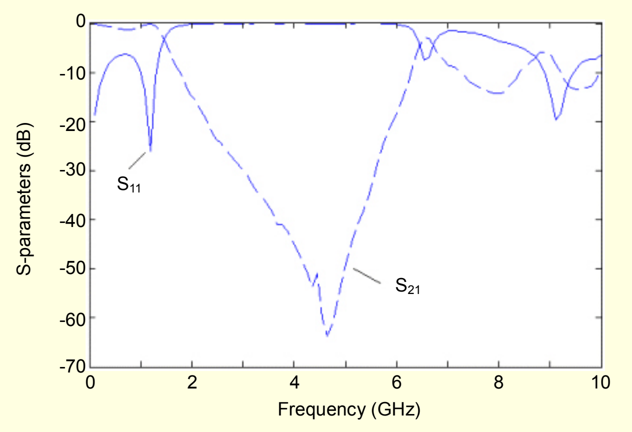

Fig. 9. Measured results of the proposed BSF.

wavelength at a -3 dB cutoff frequency of 1.42 GHz). Without any periodic structures, the circuit size can be reduced dramatically. Also, the printed circuit processing with a defected spurline structure on the microstrip line is easy to implement. Measurements were performed with a vector network analyzer (HP8722D) over the frequency range from 0.1 to 40 GHz.

## V. Conclusion

The implementation and performance measurement of a simple miniaturized BSF using a meander spurline and capacitively loaded stubs was presented in this paper. The resonant bandstop characteristics of this meander spurline were interpreted by an LCR-resonator. Results showed good agreement between EM simulations and circuit simulations based on the extracted parameters. Also, the proposed BSF was measured, and results show that excellent bandstop characteristics are obtained. The proposed spurline circuit model will be useful in the development of microstrip circuit computer-aided design (CAD) techniques. The new BSF can be widely used to suppress harmonics in microwave integrated circuit and THz applications.

## Acknowledgment

We gratefully acknowledge the Alexander von Humboldt Research Fellowship (Germany) for supporting this work.

## References

[1] P. Akkaraekthalin and J. Jantree, “Microstrip Slow-Wave Open-Loop Resonator Filters with Reduced Size and Improved Stopband Characteristics,” *ETRI Journal*, vol. 28, no. 5, Oct. 2006, pp. 607-614.

[2] D.S. Jun, H.Y. Lee, D.Y. Kim, S.S. Lee, and E.S. Nam, “A Narrow Bandwidth Microstrip Band-Pass Filter with Symmetrical Frequency Characteristics,” *ETRI Journal*, vol. 27, no. 5, Oct. 2005, pp. 643-646.

[3] S.Y. Huang and Y.H. Lee, “A Tapered Small-Size EBG Microstrip Bandstop Filter Design with Triple EBG Structures,” *Microw. and Optical Tech. Lett.*, vol. 46, no. 2, July 2005, pp. 154-158.

[4] J.S. Lim, Y.T. Lee, C.S. Kim, D. Ahn, and S. Nam, “A Vertically Periodic Defected Ground Structure and Its Application in Reducing the Size of Microwave Circuits,” *IEEE Microw. Wireless Compon. Lett.*, vol. 12, no. 12, Dec. 2002, pp. 479-481.

[5] D.W. Kim, “Small-Sized High-Power PIN Diode Switch with Defected Ground Structure for Wireless Broadband Internet,” *ETRI Journal*, vol. 28, no. 1, Feb. 2006, pp. 84-86.

[6] F.C. Nguyen and K. Chang, “On the Analysis and Design of Spurline Bandstop Filters,” *IEEE Trans. Microw. Theory Tech.*, vol. 33, no. 12, Dec. 1985, pp. 1416-1421.

[7] W.H. Tu and K. Chang, “Compact Microstrip Bandstop Filter Using Open Stub and Spurline,” *IEEE Microw. Wireless Compon. Lett.*, vol. 15, no. 4, Apr. 2005, pp. 268-270.

[8] H.W. Liu, C.Z. Qun, and L.L. Sun, “Dual-Mode Triangular-Patch Bandpass Filter Using Spur-Lines,” *Electronics Lett.*, vol. 42, no. 13, Jun. 2006, pp. 762-763.

[9] H.W. Liu, Z.F. Li, and X.W. Sun, “Compact Defected Ground Structure in Microstrip Technology,” *Electronics Lett.*, vol. 41, no. 3, Feb. 2005, pp. 132-134.

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