this design has the capacity of polarization and pattern reconfiguration, and its size is more compact.

ACKNOWLEDGMENT

This work was supported in part by Tsinghua Chuanxin Research Fund and NEC mobile terminal division

REFERENCES

1. J. Hämäläinen, R. Wichman, J.-P. Nuutinen, J. Ylitalo, and T. Jämsä, Analysis and measurements for indoor polarization MIMO in 5.25 GHz band, Vehicular Technol Conf IEEE1 (2005), 252-256.
2. N.K. Das, T. Inoue, T. Taniguchi, and Y. Karasawa, An experiment on MIMO system having three orthogonal polarization diversity armes in multipath-rich environment, Vehicular Technol Conf IEEE 2 (2004), 1528-1532.
3. V. Erceg, H. Sampath, and S. Catreux-Erceg, Results and modeling dual-polarization versus single-polarization MIMO channel measurement, IEEE Trans Wireless Commun 5 (2006), 28-33.
4. M. Shafi, M. Zhang, A.L. Moustakas, P.J. Smith, A.F. Molisch, F. Tufvesson, and S.H. Simon, Polarized MIMO channels in 3-D: Models, measurements and mutual information, IEEE J Selected Areas Commun 24 (2006), 514-526.
5. Y.B.A. Cetiner, E. Akay, E. Sengul, and E. Ayanoglu, A MIMO system equipped with multifunctional reconfigurable antennas, Antennas Propag Soc Int Symp IEEE (2006), 157-160.
6. B.A. Cetiner, E. Akay, E. Sengul, and E. Ayanoglu, A MIMO system with multifunctional reconfigurable antennas, IEEE Antennas Wireless Propag Lett 5 (2006), 463-466.
7. H. Scott and V.F. Fusco, Polarization agile circular wire loop antenna, IEEE Antennas Wireless Propag Lett 1 (2002), 64-66.
8. Y.J. Sung, T.U. Jang, and Y.-S. Kim, A reconfigurable microstrip antenna for switchable polarization, IEEE Microwave Wireless Compon Lett 14 (2004), 534-536.
9. F. Yang and Y. Rahmat-Samii, A reconfigurable patch antenna using switchable slots for circular polarization diversity, IEEE Microwave Wireless Compon Lett 12 (2002), 96-98.
10. M.K. Fries, M. Gräni, and R. Vahldieck, A reconfigurable slot antenna with switchable polarization, IEEE Microwave Wireless Compon Lett 13 (2003), 490-492.
11. M. Boti, L. Dussopt, and J.-M. Laheurte, Circularly polarised antenna with switchable polarisation sense, Electron Lett 36 (2000), 1518-1519.
12. W.H. Chen, Z.H. Feng, M.Y. Fan, and Y. Furuya, Dual-band reconfigurable antenna for wireless communications, Microwave Opt Technol Lett 40 (2004), 503-505.
13. W.H. Chen and Z.H. Feng, Planar reconfigurable pattern antenna by reactive load switching, Microwave Opt Technol Lett 47 (2005), 506-507.
14. T.-I. Lee, S. Kim, and Y.E. Wang, Compact polarisation and spatial multiplexing antenna for MIMO applications, Electron Lett 42 (2006), 839-840.

DUAL-BANDGAP CHARACTERISTICS OF SPURLINE FILTERS AND ITS CIRCUIT MODELING

Haiwen Liu,[1,2] Lingling Sun,[1] and Zhiguo Shi[3]
[1] Microelectronic CAD Center, Hangzhou Dianzi University, Hangzhou 310018, China; Corresponding author: liuhaiwen@gmail.com
[2] High-frequency Tech. Group, Kiel University, Kiel 24143, Germany
[3] Department of Information and Electronic Engineering, Zhejiang University, Hangzhou 310027, China

Received 11 April 2007

ABSTRACT: *A novel asymmetrical spurline filter is introduced in this article. Its dual-bandgap characteristics are reported for the first time and can be adjusted by changing the difference between the two spurlines' lengths. Moreover, a simple circuit model is set up for the new filter by using two LCR-resonators. The proposed spurline filter and its circuit model are discussed and verified by a good agreement between simulations and measurements.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 2805–2807, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22862

Key words: *spurline; dual-bandgap; circuit modeling; filter; resonator*

1. INTRODUCTION

Spurline is commonly based on microstrip transmission lines with band-stop (notch) characteristics. It is very convenient for dense integrated circuits because of their inherently compact design and ease of integration [1]. Generally, spurline is a simple defected

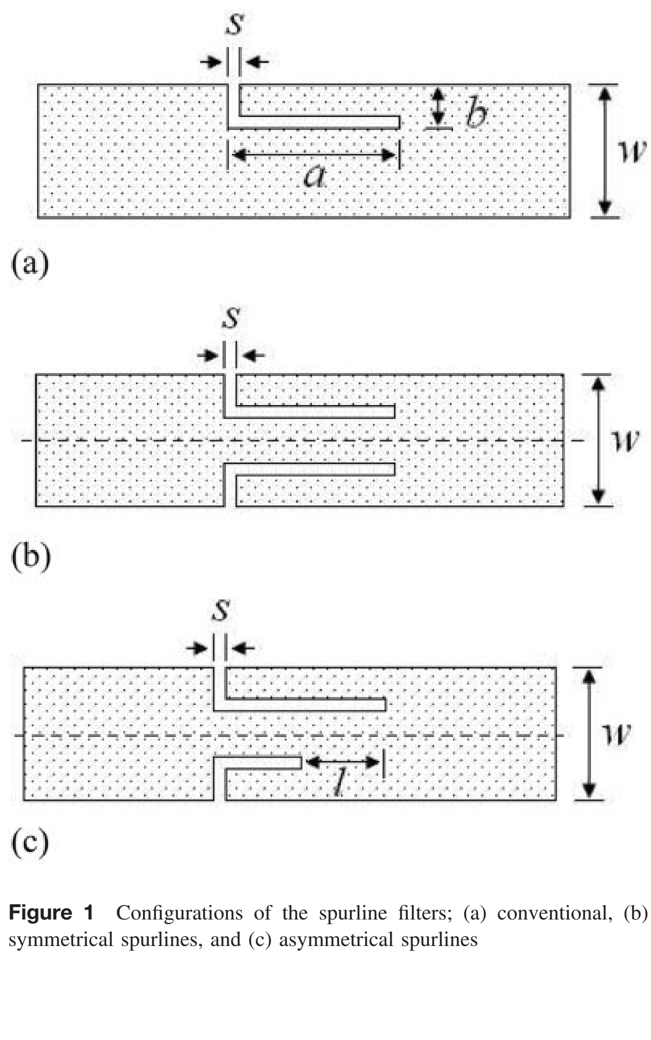
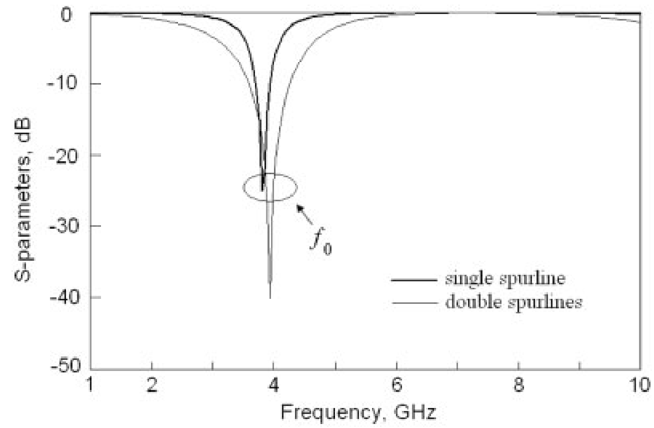
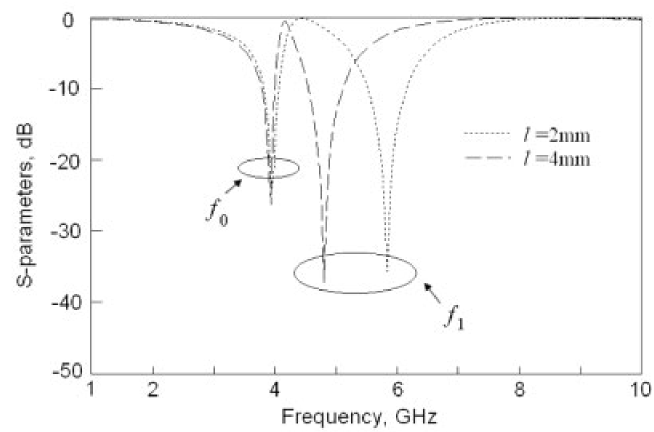


Figure 1 Configurations of the spurline filters; (a) conventional, (b) symmetrical spurlines, and (c) asymmetrical spurlines



(a)



(b)

Figure 2 Simulated insertion loss of the spurline filters. (a) Single-bandgap characteristics of spurline filters in Figures 1(a) and 1(c); (b) dual-bandgap characteristics of spurline filters in Figure 1(c) with different l

structure, which is realized by etching one L-shape slot on top microstrip line. Without any stubs and etched processing on backside ground plane, it can provide excellent bandgap characteristics and can be applied in antenna and filter designs [2, 3]. Spurline filters usually exhibit moderate to narrow-band rejection, at about 10% around the central frequency. For example, Tu and Chang [4] reported that a spurline filter connected with open stubs was used to bandstop filter design, and Griol et al. [5] adopted spurline filter as input/output ports to reduce high-order harmonics for multistage coupled ring bandpass filter. In addition, the spurline structure was applied to excite degenerate modes for dual-mode triangular-patch bandpass filter in our previous research [6]. However, the reported spurline filters only provide single bandgap. On the other hand, very limited research on its equivalent circuit has been studied.

In this article, we propose a new asymmetrical spurline filter, its dual-bandgap characteristics are reported for the first time. Moreover, a simple circuit model is set up for the new filter by using two LCR-resonators. The proposed spurline filter and its circuit model are analyzed and simulated. Finally, simulations and measurements are given.

2. BANDGAP CHARACTERISTICS OF SPURLINE FILTERS

Schematic view of a conventional spurline filter is shown in Figure 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 capacitive effect, while the narrow microstrip line exhibits inductive effect. Thus, the effective permittivity of dielectric substrate increases as the effective inductance and capacitance of the microstrip line are improved by the spurline structure. Furthermore, two new double-spurline filters are proposed in Figure 1. One is composed of symmetrical spurlines, shown in Figure 1(b), while the other consists of asymmetrical spurlines. The difference between the spurlines' lengths is described by l, shown in Figure 1(c).

To study these spurline filters' transmission characteristics, they are simulated by electromagnetic (EM) simulator, Ansoft Ensemble 8.0. The dimensions of the spurline structures in Figure 1 are as follows: $s = 0.2$ mm, $a = 12$ mm, and $b = 0.4$ mm. The substrate on a Rogers TMM10 substrate with a relative dielectric constant of 3.38 and thickness of 0.508 mm is used for simulations and measurements. The spurline is etched on a 50-Ω microstrip line with a width of $w = 1.17$ mm. Their insertion loss characteristics are described in Figure 2.

The simulations in Figure 2 are summarized in Table 1. It is concluded that

1. The conventional spurline filter and the symmetrical spurline filter exhibit single-bandgap characteristics, whereas the asymmetrical spurline filter provides obvious dual-bandgap characteristics.
2. In Figure 2(a), the fundamental resonant frequencies (f_0) of the conventional spurline filter and the symmetrical spurline filter are 3.80 and 3.94 GHz, respectively, while their -10 dB bandgap widths (BW_{10dB}) at f_0 are 0.25 and 0.65 GHz, respectively. After adopting symmetrical double-spurline, f_0 and BW_{10dB} at f_0 are improved by 3.7% and 1.6 times, respectively.
3. In Figure 2(b), the parameter l has little effect on controlling f_0 while it can change the first higher-order resonant frequency (f_1) greatly. For $l = 2$ mm and $l = 4$ mm, f_1 are 4.80 and 5.84 GHz, respectively. The dual-bandgap characteristics show that the different l means different etched areas on the microstrip lines which lead to different inductive and capacitive effects, so that a new resonant frequency (f_1) is produced. In Figure 1(c), the shortened slot length ($a - l$) reduces the capacitive effects that produce another higher resonant frequency, f_1.

TABLE 1 Comparative Study of Bandgap Charateristics of the Spurline Filters

	Conventional	Symmetrical Spurlines	Asymmetrical Spurlines	
			$l = 2$ mm	$l = 4$ mm
f_0 (GHz)	3.80	3.94	3.94	3.94
f_1 (GHz)	—	—	4.80	5.84
BW_{10dB} at f_0 (GHz)	0.25	0.65	0.22	0.23
BW_{10dB} at f_1 (GHz)	—	—	0.55	0.64

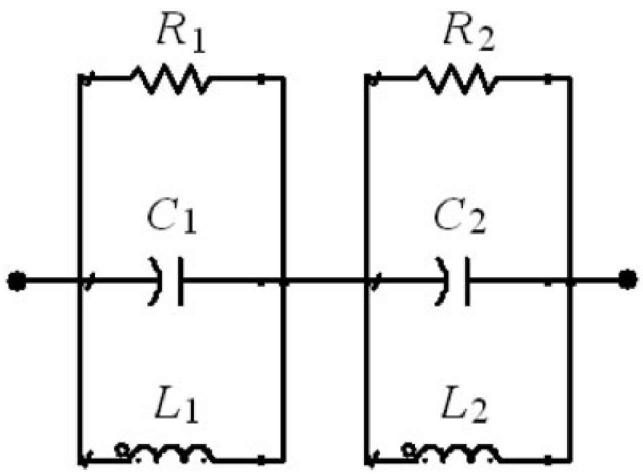


Figure 3 Equivalent circuit of the proposed filter with asymmetrical spurlines

3. CIRCUIT MODELING AND MEASUREMENTS

A simple circuit model with two resonators for the asymmetrical spurline filter is proposed in Figure 3. Dual-bandgap characteristics are molded by L_1C_1 and L_2C_2. The radiation effect and transmission loss are considered by including the resistors, R_1 and R_2. Based on the transmission line theory and the spectral domain approach [7], the circuit parameters can be extracted using the following equations.

$$R_i = 2Z_0(1/|S_{21,i}| - 1)|_{f=f_i} \tag{1}$$

$$C_i = \frac{\sqrt{0.5(R_i + 2Z_0)^2 - 4Z_0^2}}{2.83\pi Z_0 R_i \Delta f_i} \tag{2}$$

$$L_i = \frac{1}{4(\pi f_0)^2 C_i} \quad i = 1,2 \tag{3}$$

where Z_0 is the characteristic impedance of the transmission line, f_i is the resonant frequency, $S_{21,i}$ is the insertion loss, and Δf_i is the -3 dB bandwidth of $S_{21,i}$ at f_i.

To verify the dual-bandgap characteristics of the asymmetrical spurline filter and the proposed circuit model, an asymmetrical spurline filter is designed, fabricated, and measured. Its layout is given in Figure 4, and the dimensions are as follows: $s = 0.2$ mm, $a = 12$ mm, $b = 0.4$ mm, and $l = 4.8$ mm. Simulated insertion loss performances of this filter are presented in Figure 5, and compared with measured results. Results show that there are two bandgaps centered at 3.94 and 6.25 GHz, respectively. The circuit was measured by the network analyzer-Agilent 8720ES.

Based on the EM simulations in Figure 5 and Eqs. (1)–(3), the extracted circuit parameters, L_1, C_1, R_1, L_2, C_2, and R_2 are 0.6997 nH, 2.3324 pF, 1.713 kΩ, 0.7449 nH, 0.8717 pF, and 5.967 kΩ, respectively. The circuit simulation is realized by Agilent ADS. From 1 to 10 GHz, a good agreement between the EM simulations, circuit simulations, and measurements can be observed, which verifies the validity of the circuit modeling.

Figure 4 Layout of the proposed spurline filter

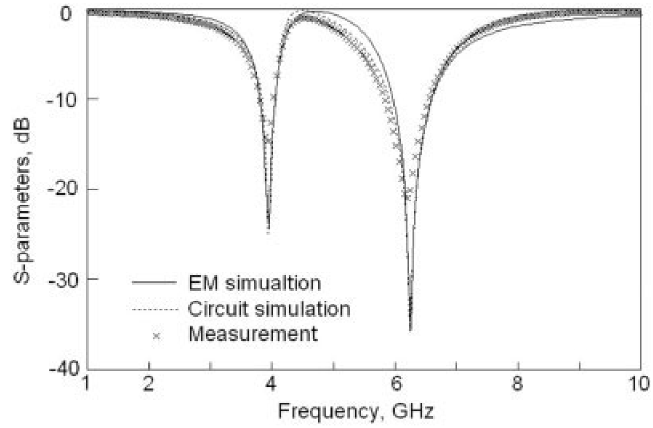


Figure 5 Comparison of simulated and measured results for proposed filter shown in Figure 4

4. CONCLUSIONS

A novel spurline filter is introduced in this article. The filter consists of asymmetrical spurlines. Its dual-bandgap characteristics are discussed and can be adjusted by changing the difference between the two spurlines' lengths. In addition, a simple circuit model is set up for the new filter and verified by measurements. The proposed circuit model of the spurline will help in developing microwave circuit computer-aided design techniques. Without any stubs or etched processing in the ground plane, the compact spurline filter can be widely used to higher harmonics suppression for microstrip circuit applications. It is expected that potential applications will be extended widely to many microwave materials with monolithic microwave integrated circuit, low temperature cofired ceramic, and micro-electromechanical system technologies.

ACKNOWLEDGMENTS

This work was supported by Alexander von Humboldt Research Fellowship, Germany.

REFERENCES

1. C. Nguyen and K. Chang, On the analysis and design spurline bandstop filters, IEEE Trans Micowave Theory Tech 33 (1985), 1416–1421.
2. S. Hong and K. Chang, Single-feed triple-frequency rectangular microstrip patch antenna with pairs of spur-lines, Electron Lett 42 (2006), 673–674.
3. Y.Z. Wang and M.L. Her, Compact microstrip bandstop filters using stepped-impedance resonator (SIR) and spur-line sections, IEE Proc Micowave Antenn Propag 153 (2006), 435–440.
4. W.H. Tu and K. Chang, Compact microstrip bandstop filter using open stub and spurline, IEEE Microwave Wireless Compon Lett 15 (2005), 268–270.
5. A. Griol, J. Marti, and L. Sempere, Microstrip multistage coupled ring bandpass filters using spur-line filters for harmonic suppression, Electron Lett 37 (2001), 572–573.
6. H.W. Liu, Z.Q. Cheng, and L.L. Sun, Dual-mode triangular-patch bandpass filter using spur-lines, Electron Lett 42 (2006), 762–763.
7. D.M. Pozar, Microwave engineering, 2nd ed., Wiley, NY, 1998.