Multi-harmonic Suppression Band-Pass Filter for Communication System

Wenmei Zhang, Liping Han, Runbo Ma, and Junfa Mao

ABSTRACT—For the purpose of decreasing intermodulation distortion, a new multi-harmonic suppression band-pass filter based on a microstrip radial stub is studied. Compared with traditional resonator filters, the new filter can suppress the second, third, and even fourth harmonics directly. The dimension of the filter is about 0.3 $\lambda_{g0} \times 0.13\ \lambda_{g0}$ *(*λ_{g0} *is the guiding wavelength at the resonant frequency). Only one gap was introduced, so lower insertion loss can be obtained. Basic agreement between the measured and simulated results has been achieved.*

Keywords—Band-pass filter, microstrip radial stub, harmonic, slow-wave structure.

I. Introduction

In communication systems, harmonics cause intermodulation distortion. Traditional band-pass filters with half-wavelength resonators have inherently spurious passbands at harmonics; therefore, low-pass filters or band-stop filters must be used to suppress the harmonics. For band-pass filters with wide upper stopbands in [1]-[4], the harmonics fall into the stopband, and can be suppressed directly, whereas the filters shown in [1]-[4] are end-coupled slow-wave resonator filters [1]; slow-wave open-loop resonator filters [2], [3]; and stepped-impedance resonator (SIR) filters [4], respectively. The common characteristic of the filters in [1]-[4] is that more than one gap was used, resulting in larger insertion loss and a difficult design, especially in millimeter wavebands. Also, electromagnetic band-gap (EBG) structures were used to suppress the spurious passbands and harmonics [5]. However, the structures etched in the ground plane cause problems during the packaging and realization of MMICs. In [6], a new type of filter with one gap based on symmetrical microstrip EBG structures was presented.

In this paper, a new type of compact band-pass filter based on radial stubs is proposed. Because of its wide bandwidth and the low characteristic impedance of radial stubs, the new filter has a wider stopband. Unlike the filters proposed in [1]-[6], the proposed filter can suppress second, third, and fourth harmonics directly. Also, it is very compact due to the slow-wave characteristics. The filter measures about 0.3 λ_{g0}×0.13 λ_{g0}.

II. Theory and Design

Consider a loaded lossless transmission line as shown in Fig. 1, where $2Y$ and Y are the loaded admittance, and Z_{01}, β_1, and p are the characteristic impedance, the propagation constant, and the length of the unloaded lossless line, respectively. The electronic length of the unloaded line is $\theta = \beta_1 p$. The circuit response of Fig. 1 can be described by

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ -I_2 \end{bmatrix} \tag{1}$$

with

$$A = \cos\theta + jYZ_{01}\sin\theta\ , \tag{2a}$$

$$B = jZ_{01}\sin\theta\ , \tag{2b}$$

$$C = j\frac{1}{Z_{01}}\sin\theta + j2Y^2 Z_{01}\sin\theta + 3Y\cos\theta\ , \tag{2c}$$

$$D = \cos\theta + j2YZ_{01}\sin\theta\ , \tag{2d}$$

Manuscript received Feb. 7, 2007; revised Apr. 12, 2007.

This work was supported by the Natural Science Foundation of Shanxi province (2006011029), China.

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where A, B, C, and D are the network parameters of the transmission matrix. Because

$$A=\frac{V_1}{V_2}=\begin{cases}-1 & \text{for the fundamental resonance,}\\ 1 & \text{for the first spurious resonance,}\end{cases} \tag{3}$$

we have from (2a) that

$$\cos\theta_0+jYZ_{01}\sin\theta_0=-1\,, \tag{4a}$$

$$\cos\theta_1+jYZ_{01}\sin\theta_1=1\,, \tag{4b}$$

where the subscripts 0 and 1 indicate the parameters associated with the fundamental frequency and the first spurious resonance, respectively. Since we know Y, the ratio of the first spurious resonant frequency (f_1) and the fundamental frequency (f_0) can also be obtained.

Based on the circuit model of Fig. 1, a filter with radial stub is presented (shown in Fig. 2). It consists of two resonators coupling through a gap. Gap s mainly influences coupling between resonators, and has little effect on resonant frequency. According to [7], the simulation results for different r, p, and θ are obtained and shown in Figs. 3 to 5, respectively.

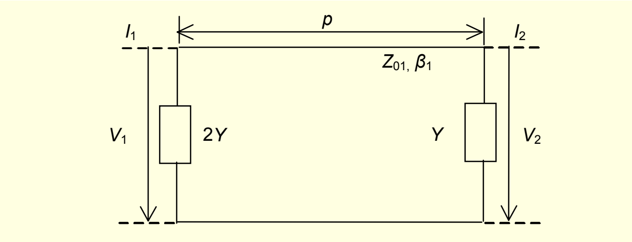

Fig. 1. Admittance loaded transmission line resonator.

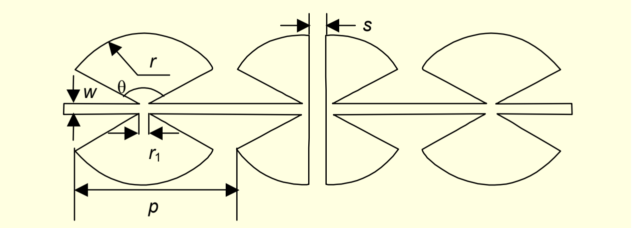

Fig. 2. Layout of the filter based on microstrip radial stub.

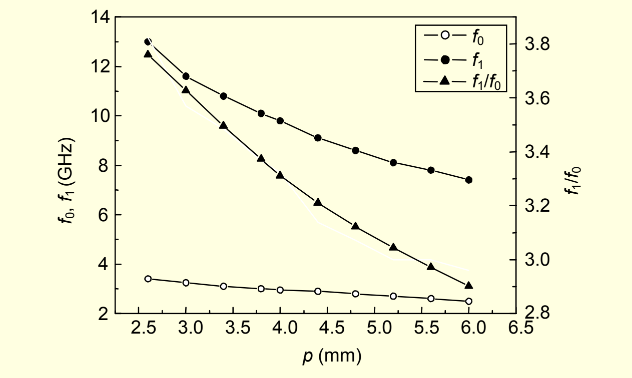

Fig. 3. Simulated results for different p (r=2.3 mm, θ=90°, s=0.15 mm, r_1=0.05 mm, w=0.146 mm, h=0.625 mm).

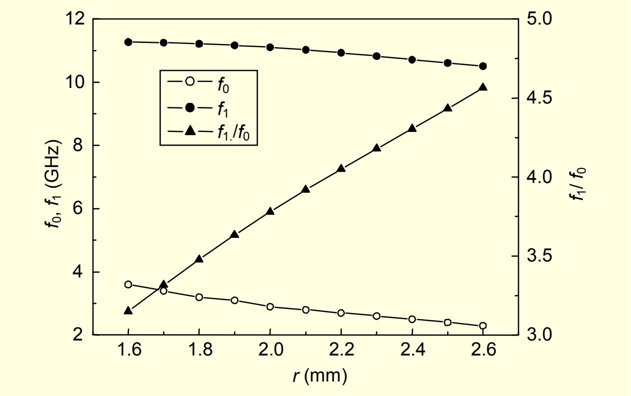

Fig. 4. Simulated results for different r (θ=90°, p=3.75 mm, s=0.15 mm, r_1=0.05 mm, w=0.146 mm, h=0.625 mm).

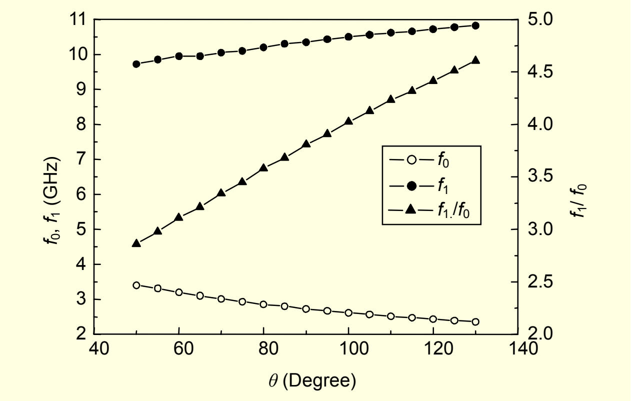

Fig. 5. Simulation results for different θ (r=2.3 mm, p=3.75 mm, s=0.15 mm, r_1=0.05 mm, w=0.146 mm, h=0.625 mm).

Figures 3 to 5 show that p, r, and θ have different influences on the filter. Larger r and θ result in a lower $1/(YZ_{01})$ ratio, and thus, larger f_1/f_0 [4]. However, larger p leads to a lower f_1/f_0 ratio due to f_1 decreasing. Also, by selecting r, p, and θ, the second, third, and fourth harmonics fall into the stopband, and can be suppressed.

Considering the open-circuit effect of the microstrip line and the structure of filter, p must meet

$$P-2r\cos((180-\theta)/2)\geq 2\times 0.44h, \tag{5}$$

where h is the thickness of the substrate.

Also, the multiple regression method is used to obtain the guiding wavelength λ_{g0}, λ_{g1} at f_0 and f_1. On the condition that the filter has the minimum length and insert loss (less than 0.5dB), the results are

$$\lambda_{g0}/2=4r+p+3/2r\theta+2r_1-0.5(w/h+h/w) \tag{6}$$

$$\lambda_{g1} = 2r + 1.5p - 0.2r\theta + 2r_1 \tag{7}$$

$$s < 0.05(r + h). \tag{8}$$

Also, h can be obtained according to the center frequency and substrate, and w must be designed reasonably, so that the input impedance loaded by the radial stub is 50 Ω.

In addition, for (6) to (8), the effect of the dielectric constant has been taken into account. Table 1 shows the results for different ε_r. The errors were obtained by comparing with results from Ensemble SV.

Table 1. The comparing results with Ensemble for different ε_r.

ε_r	f_0: GHz	f_1: GHz	λ_{g0}: mm	λ_{g1}: mm	Err. of (6)	Err. of (7)
12.9	3.1	13.25	34.8	7.86	-0.34%	-1.37%
9.8	3.8	14.1	32.3	7.92	7.54%	1.75%
8	3.9	17.06	34.5	7.9	0.68%	2.01%
6.	4.425	19.32	34.6	7.93	0.39%	1.62%
4.4	5.1	22.1	34.4	7.93	0.97%	1.62%

III. Simulation and Measurement

The dimensions of the realized filter are r=2.3 mm, θ=90°, p=3.75 mm, s=0.15 mm, r_1=0.05 mm, and w=0.146 mm. The substrate used is GaAs with a relative dielectric constant (ε_r) of 12.9 and a thickness (h) of 0.5 mm. The S-parameters of the fabricated filter are measured with N5230A and shown in Fig. 6. Basic agreement between the measured and simulated results has been achieved.

In Fig. 6, the resonant frequency of the realized filter is 2.9 GHz, the passband loss is 2.2 dB, and the 3-dB bandwidth is from 2.6 GHz to 3.2 GHz. Also, the stop-band rejection is better than -50 dB at the second, third, and fourth harmonics.

The size of the filter is 10.9 mm×4.8 mm, which is equal to 0.3 λ_{g0}×0.13 λ_{g0} (λ_{g0} at f_0 is 35.8 mm). It is very compact for a filter realized with microstrip line.

IV. Conclusion

A new type of resonator band-pass filter based on a microstrip radial stub was presented. The filter can suppress the second, third, and fourth harmonics directly. It is also much easier to fabricate and more compact. The dimension of the filter is reduced to about 0.3 λ_{g0}×0.13 λ_{g0}. When the filter is used in an oscillator or amplifier, the harmonics which fall into the stop-band can be suppressed directly.

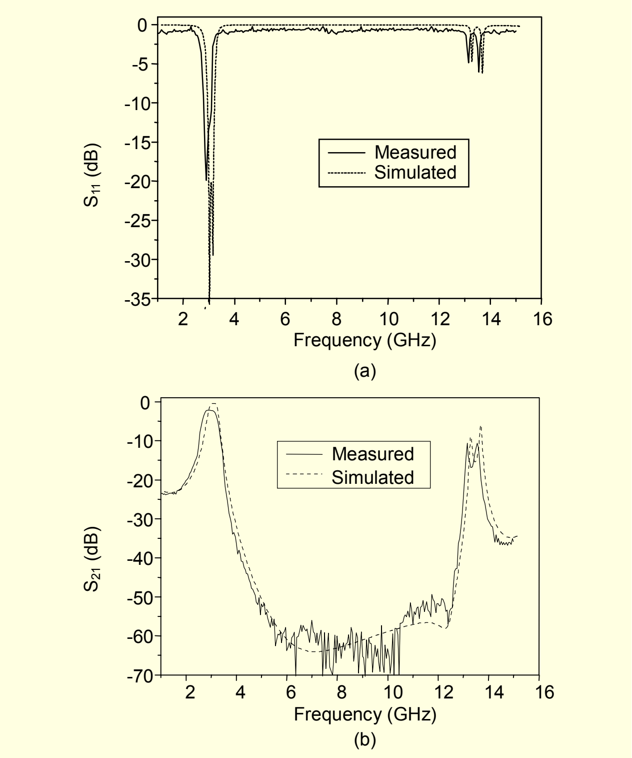

Fig. 6. Simulated and measured S_{11} (a) and S_{21} (b).

References

[1] J.S. Hong and M.J. Lancaster, "Theory and Experiment of Novel Microstrip Slow-Wave Open-Loop Resonator Filters," *IEEE Trans. on Microwave Theory and Tech.*, vol. 45, no. 12, Dec. 1997, pp. 2358-2365.

[2] J.S. Hong and M.J. Lancaster, "End-Coupled Microstrip Slow-Wave Resonator Filter," *Electron. Letters*, vol. 32, no. 16, Aug. 1996, pp. 1494-1496.

[3] 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.

[4] M. Makimoto and S. Yamashita, "*Microwave Resonators and Filters for Wireless Communications Theory and Design,*" Springer-Verlag, Berlin, Germany, 2001.

[5] S.T. Chew and T. Itoh, "PBG-Excited Split-Mode Resonator Bandpass Filter," *IEEE Microwave and Wireless Components Letters*, vol. 11, no. 9, Sep. 2001, pp. 364-366.

[6] W.M. Zhang, J.F. Mao, and X.W. Sun, "Compact Resonant Bandpass Filter Based on PBG Structure," *Electronics Letters*, vol. 39, no. 3, Apr. 2003, pp. 615-617.

[7] R. Sorrentino and L. Roselli, "A New Simple and Accurate Formula for Microstrip Radial Stub," *IEEE Microwave and Guided Wave Letters,* vol. 2, no. 12, Dec. 1992, pp. 480-482.