

# A Low Noise Microwave Filter with Minimum Distortion

Cheng Yuan Hung, Min Hang Weng, Siang Wen Lan, Wei Yu Chen, Hung Wei Wu, Chun Yueh Huang

**Abstract**—In this paper, a low noise microwave bandpass filter (BPF) is presented. This filter is fabricated by modifying the conventional cross-coupled structure. The spurious response is improved by using the end open coupled lines, and the influence of the noise is minimized. Impedance matrix of the open end coupled circuit clarifies the characteristic of the suppression of the spurious response. The rejection of spurious suppression region of the proposed filter is greater than 20 dB from 3-13 GHz. The measured results of the fabricated filter confirm the concepts of the proposed design and exhibits high performance.

**Keywords**—Low noise, signal transmission, bandpass filter, end open coupled line, communication system.

## I. INTRODUCTION

IN microwave communication systems, the quality of the communication is taken seriously, and undistorted information is necessary for signal transmission [1]. If the signals out of the passband are not filtered completely, these signals will interference the whole communication systems. Mostly, resonators excite the spurious response of the frequency multiplications, and the spurious response will influence the microwave communication systems. In order to decrease the signal distortion, suppressions of the spurious responses attract highly attentions for eliminating undesired noises.

For designing a narrow-band bandpass filter, cross-coupled is a good structure with a high performance [2]. Cross-coupled structure exhibits a low insertion loss response, and demonstrates a rapid attenuation rate out of the passband. However, cross-coupled structure excites spurious response at the frequency multiplications, and these frequency multiplications are regarded as noises and interference the microwave communication systems. The most common way for spurious suppression is cascading a low-pass filter (LPF). A simple way to design a microwave LPF is using

stepped-impedance microstrip line according to the LC ladder-type of the equivalent circuit [3]. However, the extra LPF occupies some area in the filter design, and enlarges the whole sizes. In [4], Itoh et al. proposed defected ground structure (DGS) to suppress the spurious response, and DGS disturbed the shield current distribution in the ground plane. However, DGS increases the degree of complication of the filter design, because it should etch the pattern and holes on the ground plane [5]. In [6], Chang et al. proposed a photonic bandgap (PBG) structure to suppress the spurious response. However, the center frequency of the PBG structure can not be determined accurately, and PBG structure increases the complexity of the design process.

In this paper, a low noise microwave filter is proposed to minimize the distortion of the microwave communication systems. This filter is constructed by modifying the conventional cross-coupled structure, and it is regarded as end open coupled filter (EOCF). The fundamental frequency of this filter is operated at 2.75 GHz according to the electric length of the resonators. As shown in Fig. 1, the parallel end open coupled lines are used to suppress the spurious responses and decrease the signal distortion. According to the analysis of the image impedance of the end open coupled lines, the positions of the attenuation poles can be controlled by tuning the electric length of the coupled lines. This filter exhibits high performance, and rejection of the suppression region of the spurious response is greater than 20 dB from 3 to 13 GHz. The insertion loss is 2 dB at the fundamental frequency, and the fractional bandwidth (FBW) is 5.9%.

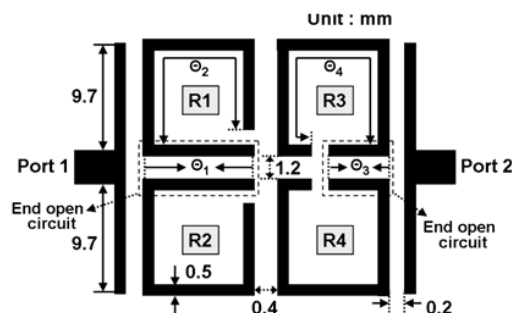


Fig. 1 Practical layout of the designed EOCF designed on a 0.787-mm-thick substrate with a dielectric constant of 2.2

This work was supported by the National Science Council of Taiwan under grant NSC 100-2221-E-272 -003 and NSC 100-2628-E-168 -001 -MY2.

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## II. DESIGN OF A LOW NOISE BPF

## A. Analysis of End Open Coupled Line

Fig. 1 depicts the schematic of the proposed end open coupled filter (EOCF). The EOCF mainly consists of four half-guided-wavelength  $\lambda_g/2$  resonators with an impedance line around  $115 \Omega$  and two parallel coupling input/output (I/O) ports at the two sides. Unlike the conventional design of I/O ports which are only attached to the resonators (R1/R2) or the resonators (R3/R4), the proposed I/O ports has coupling lines to transmit energy into the resonators. In this paper, a RT/Duroid 5880 substrate with a relative dielectric constant of 2.2, a loss tangent of 0.0009 and a thickness of 0.787 mm, is used for the simulation and the practical fabrication.

The following discusses the analysis of the end open coupled line to obtain the desired suppression frequency. The parallel end open coupled line section with voltage and current definitions is shown in Fig. 2. We will derive the end open circuit matrix for this two-port network by considering the superposition of even and odd mode excitations [7]. The  $V_1$  and  $V_2$  are expressed as:

$$V_1 = \frac{-j}{2} (Z_{0e} I_1 + Z_{0e} I_2 + Z_{0o} I_1 - Z_{0o} I_2) \cot \Theta_1 \quad (1)$$

$$V_2 = \frac{-j}{2} (Z_{0e} I_1 + Z_{0e} I_2 + Z_{0o} I_1 - Z_{0o} I_2) \cot \Theta_1 \quad (2)$$

where  $\Theta_1$  is electrical length of the end open coupled line and  $Z_{0e}$  and  $Z_{0o}$  are the even and odd mode characteristic impedances, respectively. This result yields the top row of the end open circuit impedance matrix  $[z]$  that describes the coupled section. The matrix elements are expressed as:

$$Z_{11} = Z_{22} = \frac{-j}{2} (Z_{0e} + Z_{0o}) \cot \Theta_1 \quad (3)$$

$$Z_{12} = Z_{21} = \frac{-j}{2} (Z_{0e} - Z_{0o}) \cot \Theta_1 \quad (4)$$

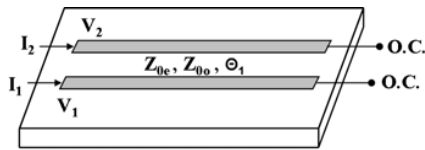


Fig. 2 Two-port network of the proposed end open coupled lines

Using (3) and (4) to reduce the (1) and (2), the reduction equation  $V_1$  and  $V_2$  are expressed as:

$$V_1 = Z_{11} I_1 + Z_{12} I_2 \quad (5)$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2 \quad (6)$$

We can analyze the end open coupled line characteristics of this two-port circuit by calculating the image impedance [7].

The image impedance in terms of the Z-parameters is

$$Z_i = \sqrt{Z_{11}^2 - \frac{Z_{11} Z_{12}^2}{Z_{22}}} = -j \sqrt{Z_{0e} Z_{0o}} \cot \Theta_1 \quad (7)$$

when  $Z_i$  is real and positive, indicating a passband. When  $Z_i$  is equal to  $\pm j\infty$  and  $\text{Re}(Z_i)$  is equal to 0, it indicates an attenuation pole. However, the end open coupled line is an all stopband circuit. To excite the resonator response of the end open coupled line, it needs to add an additional electric length  $\Theta_2$ . It is noted that  $\Theta_1(\Theta_3)$  plus  $\Theta_2(\Theta_4)$  equals  $\lambda_g/2$ . As the EOCF designed at center frequency  $f_0 = 2.75$  GHz, the whole physical length of the one resonator is 41.7 mm, i.e. approximately  $\lambda_g/2$ . The EOCF can excite fundamental mode and several spurious modes, as  $f_0$ ,  $2f_0$ ,  $3f_0$  and so on.

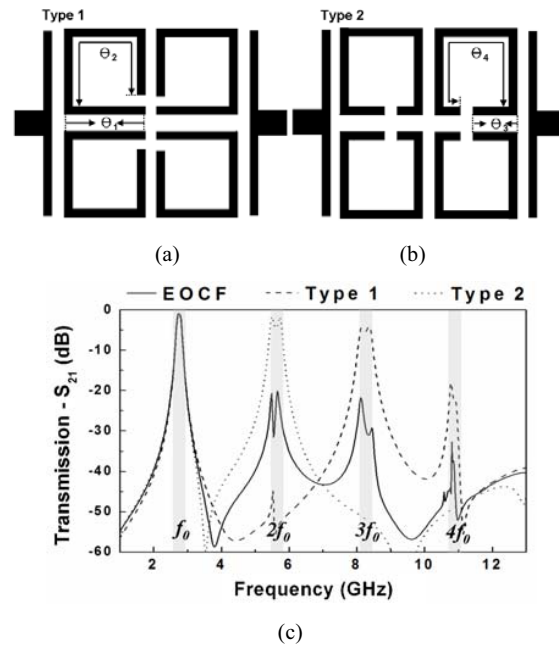


Fig. 3 Layout of the end open coupled filter for suppressing (a) the second spurious mode and (b) the third spurious mode. (c) Simulated results of Type 1, Type 2, and Mixed structure

In type 1, each resonator structure consists of an end open coupled line with  $\Theta_1$  and an additional electric length  $\Theta_2$ , as shown in Fig. 3(a). The  $\Theta_1$  designed at  $f_1 = 5.5$  GHz is close to a quarter-wavelength of an end open coupled line. Therefore as  $\Theta_1$  is  $\pi/2$ ,  $3\pi/2$ ,  $5\pi/2$ , and so on, the  $Z_i$  is equal to 0 to generate the attenuation poles. Fig. 3(c) shows the simulated filter responses of the type 1 structure. An attenuation pole with -55 dB exists at the frequency of 5.5 GHz, thus the second spurious mode ( $2f_0$ ) of EOCF can be suppressed. Similarly, in type 2, the  $\Theta_3$  designed at  $f_2 = 8.25$  GHz is close to a quarter-wavelength of an end open coupled line. Therefore as  $\Theta_3$  is  $\pi/2$ ,  $3\pi/2$ ,  $5\pi/2$ , and so on,  $Z_i$  is equal to 0 to generate the attenuation poles, as shown in Fig. 3(b). Fig. 3(c) shows the simulated filter responses of the type 2 structure. An attenuation pole with -52 dB

attenuation is existed at the frequency of 8.25 GHz, thus the third spurious mode ( $3f_0$ ) of EOCF can be suppressed. To verify the relationship between the electrical lengths of the end open coupled lines ( $\Theta_1$  and  $\Theta_3$ ) and the positions of the attenuation poles, Fig. 4 shows the current distributions of Type 1 and Type 2 at 5.5 and 8.25 GHz, respectively. For Type 1, the end open coupled line is designed at 5.5GHz, to prevent the I/O ports transmitting energy into the resonators. Similarly, for Type 2, the end open coupled line is designed at 8.25GHz, to prevent the I/O ports transmitting energy into the resonators.

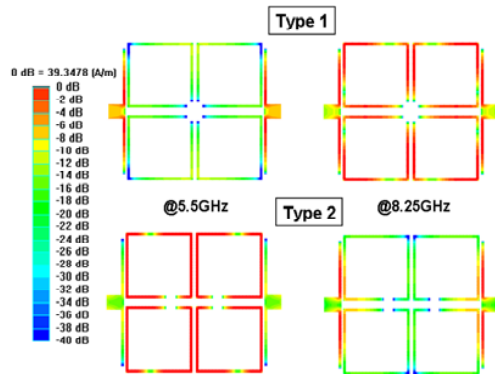


Fig. 4 The Current distributions of Type 1 and Type 2 at 5.5 and 8.25 GHz

According to the above analysis, the current distribution gives a direct insight to understand the direction of the design low noise EOCF. Combining the type 1 and type 2 structures, the two longer end open coupled resonators (R1 and R2) placed on the left side are used to suppress the  $2f_0$  and the two shorter end open coupled resonators (R3 and R4) located on the right side are used to suppress the  $3f_0$ , as shown in Fig. 1. Fig. 3(c) shows the simulated frequency response of the designed EOCF. The designed EOCF has a center frequency  $f_0$  of 2.75 GHz,  $S_{21}$  of -1.2 dB, a fractional bandwidths (FBW) = 5% and a wide spurious suppression region from 2.96-13 GHz with rejection greater than 20 dB.

### B. Characteristic of Spurious Suppression

Fig. 5(a) shows the layout of the conventional cross-coupled filter. The cross-coupled filter is constructed with four half-guide-wavelength resonators [2]. As shown in Fig. 5(b), cross-coupled filter exhibits a rapid attenuation rate, but the spurious response can not be suppressed effectively. In contrast, the EOCF suppresses the spurious response effectively with rejection greater than 20 dB.

In the past, Shibata et al. proposed an analysis method for microwave filter in time domain, and used parallel-coupled line structure to design a BPF [7]. However, the responses of the BPF exhibited serious noise interference, and illustrated undesired oscillation phenomenon on the waveform in time domain. In our design, in order to verify the influence of the

spurious response, the frequency response is transformed from frequency domain to time domain, as shown in Fig. 6. Obviously, the response of the conventional cross-coupled filter exhibits the unwanted oscillation in the waveform. The oscillated ripple is formed by the spurious responses; moreover, this ripple influences the signal transmission and increases the noise interference. In contrast, the simulated result of the EOCF demonstrates an ideal response with the minimum distortion.

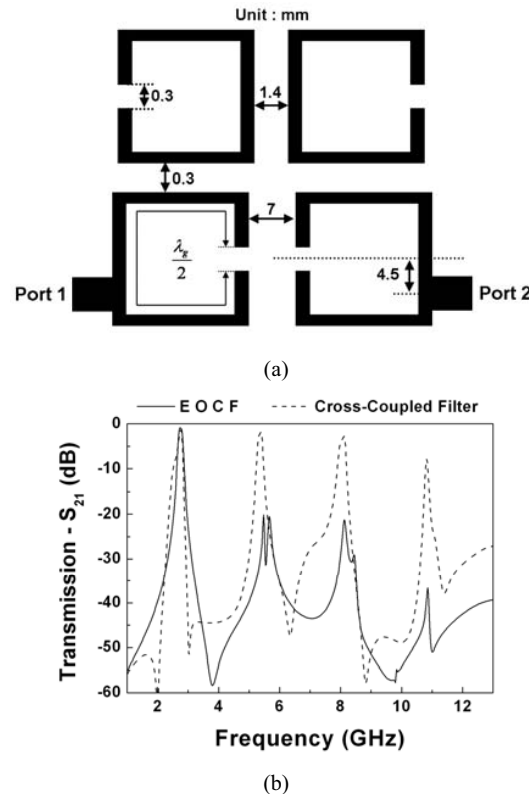


Fig. 5 (a) Layout of the conventional cross-coupled filter. (b) Comparison of the simulated results between the EOCF and the conventional cross-coupled filter in frequency domain

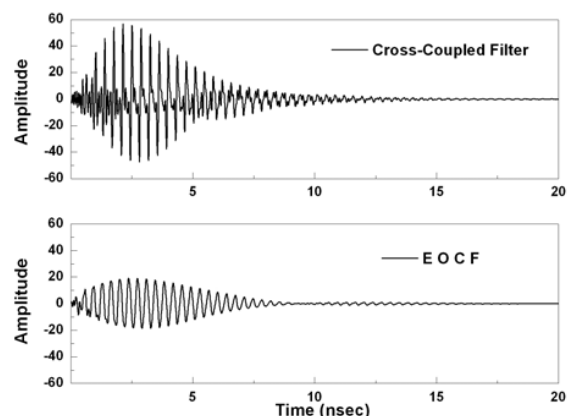


Fig. 6 Comparison of the simulated results between the EOCF and the conventional cross-coupled filter in time domain

### III. EXPERIMENTAL RESULTS AND DISCUSSION

Based on the above design guide, the designed EOCF was fabricated by using the printed circuit technology. The coupling I/O ports are designed for 50Ω. Photograph of the fabricated EOCF is shown in Fig. 7(a). The whole size of the fabricated filter is 23.2 mm × 24.4 mm, i.e. approximately  $0.29\lambda_g$  by  $0.3\lambda_g$ , where  $\lambda_g$  is the guided wavelength at the 2.75 GHz. The measured frequency response of the proposed dual-band BPF was characterized in an HP 8510C network analyzer (VNA). Fig. 7(b) shows the simulated and measured results of designed EOCF. The fabricated EOCF has good measured results, including a center frequency of 2.75 GHz,  $S_{21}$  of -2 dB, FBW= 5.9% and a wide spurious suppression region from 3-13 GHz with rejection greater than 20 dB. The measured results verify the possibility of the proposed design concept. Although the measured results are somewhat different than the simulated results in the higher band, it can be considered as fabrication error. The proposed EOCF still shows a good performance of the signal transmission with low noise characteristic.

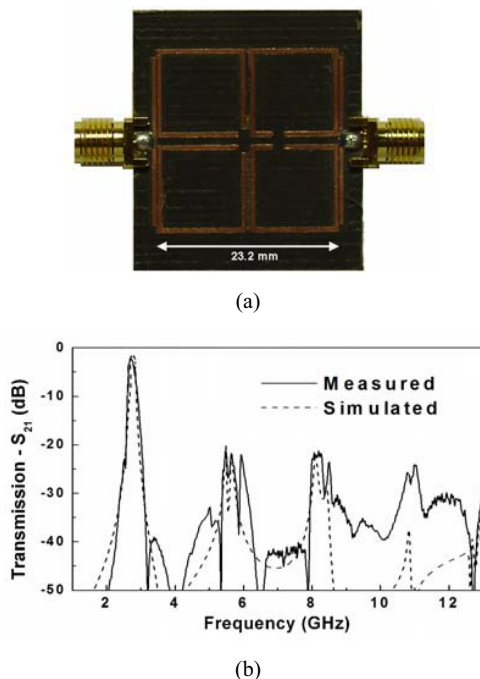


Fig. 7 (a) Photograph and (b) simulated and measured results of the fabricated end open coupled filter

### IV. CONCLUSIONS

In this paper, we proposed a low noise microwave bandpass filter by suppressing the unwanted spurious response. The end open coupled line is useful to improve the influence of the noise interference. Impedance matrix analysis of the end open coupled lines clarified the characteristic of the attenuation poles completely. Type 1 and Type 2 are combined to form the end open coupled filter, and suppress the second and third spurious

response, respectively. Current distributions verify the concept of the attenuation poles of the end open coupled lines. The influences of the spurious responses are indicated clearly by comparing the responses between the cross-coupled filter and EOCF in time domain. The spurious suppression region of the end open coupled filter is wide and greater than 20 dB from 3-13 GHz. The measured results actually verify the design concepts and exhibit low noise characteristic for microwave communication systems.

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