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Compact Microstrip Narrow Bandpass Filter with Good Selectivity and Wide Stopband Rejection for Ku-Band Applications

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Abstract—A new microstrip narrow bandpass filter with good selectivity and wide stopband rejection for Ku-band application is proposed in this letter. The characteristic of the triple-mode stub-loaded resonator has been investigated. The resonance frequencies of the degenerate modes can be adjusted easily to satisfy the bandwidth of the narrow bandpass filter. Two parallel-coupling feed structures with cross-coupling have been used to generate two transmission zeros at the lower and upper stopband, which can improve the filter selectivity. To validate the design theory, a new microstrip Ku-band narrow bandpass filter has been designed, fabricated, and measured. Simulated and experimental results are provided with good agreement.

1. INTRODUCTION

Many standards have been developed for wireless communications that are promising for industrial, scientific, medical and commercial applications. Ku-band is widely used in traditional geosynchronous earth orbit satellites and video broadcasting systems for telephone communications, analogue television distribution and various military applications. To achieve this goal, the Ku-band bandpass filters have become one of the most important circuit components. There are many methods proposed to design Ku-band bandpass filters [1–10].

A waveguide filter with high power capacity and very low insertion loss at Ku band is designed in [1]. However, the waveguide structure is large and not flexible. Thus, substrate integrated waveguides, i.e., metallic sidewalls of the waveguide are replaced by conducting via array, are spotlighted as an attractive candidate to realize high performance miniaturized circuits. The substrate integrated waveguides provide easy integration of planar circuits with the waveguide, while still maintaining low loss and high power handling capability of the waveguide. Due to these advantages, a variety of RF bandpass filters have been realized using SIW technology [2, 3]. In [2], a novel compact Ku-band bandpass filter based on substrate integrated circular cavities is proposed. This filter takes advantages of high flexibility and simple structure. However, the selectivity of the filter is not ideal because of no transmission zeros. In [3], a new compact bandpass filter using stepped impedance hairpin resonators with multilayer configuration based on low temperature co-fired ceramic technology for Ku-band application is presented. Two pairs of transmission zeros are achieved by introducing the cross coupling and asymmetric I/O structure, which can improve the performance of the filter. However, the two designed methods are based on multilayer manufacturing technology which will increase the fabrication cost. In [4] and [5], two microstrip Ku-band bandpass filters have been designed using high-temperature superconducting technology. To reduce manufacturing costs, a microstrip Ku-band bandpass filter is proposed in [6] and [7]. But, the 3-dB fractional bandwidth (FBW) is not narrow enough and the stopband rejection not ideal.

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In this letter, we present a new microstrip narrow bandpass filter with good selectivity and wide stopband rejection for Ku-band application. The characteristic of the triple-mode stub-loaded resonator has been investigated. The resonance frequencies of the degenerate modes can be adjusted easily to satisfy the bandwidth of the narrow bandpass filter. Two parallel-coupling feed structures with cross coupling have been used to generate two transmission zeros at the lower and upper stopbands, which can improve filter selectivity. To validate the design theory, a microstrip Ku-band narrow bandpass filter has been designed, fabricated, and measured. Good agreement between measured and simulated results is achieved.

2. MODIFIED TRIPLE-MODE RESONATOR

As portrayed in Fig. 1(a), conventional non-degenerated dual-mode stub-loaded resonator in [8–10] is formed by an open-ended stub tapped at the center of a $\lambda/2$ resonator. Due to its symmetrical structure, even/odd-mode approach can be deployed to analyze its resonant properties. When the central plane behaves as an electrical wall (E.W.), the half bisection of this resonator is a $\lambda/4$ resonator with the length as L_{e2}, thus

$$f_{odd} = \frac{c}{4L_{e2}\sqrt{\varepsilon_{eff}}} \tag{1}$$

where c is the free-space speed of light and ε_{eff} the effective permittivity. On the other hand, if the central plane is swapped to a magnetic wall (M.W.), its half bisection becomes a $\lambda/2$ resonator with the length of $(L_{e1} + L_{e2})$

$$f_{even} = \frac{c}{2\left(L_{e1} + L_{e2}\right)\sqrt{\varepsilon_{eff}}} \tag{2}$$

In the design, these two fundamental even- and odd-modes are designed based on the prescribed central frequency and bandwidth. Moreover, a transmission zero emerges due to the virtual ground created by the shunt stub, and it can be flexibly allocated at either lower or higher side of the desired passband where its length is longer or shorter than $\lambda/4$.

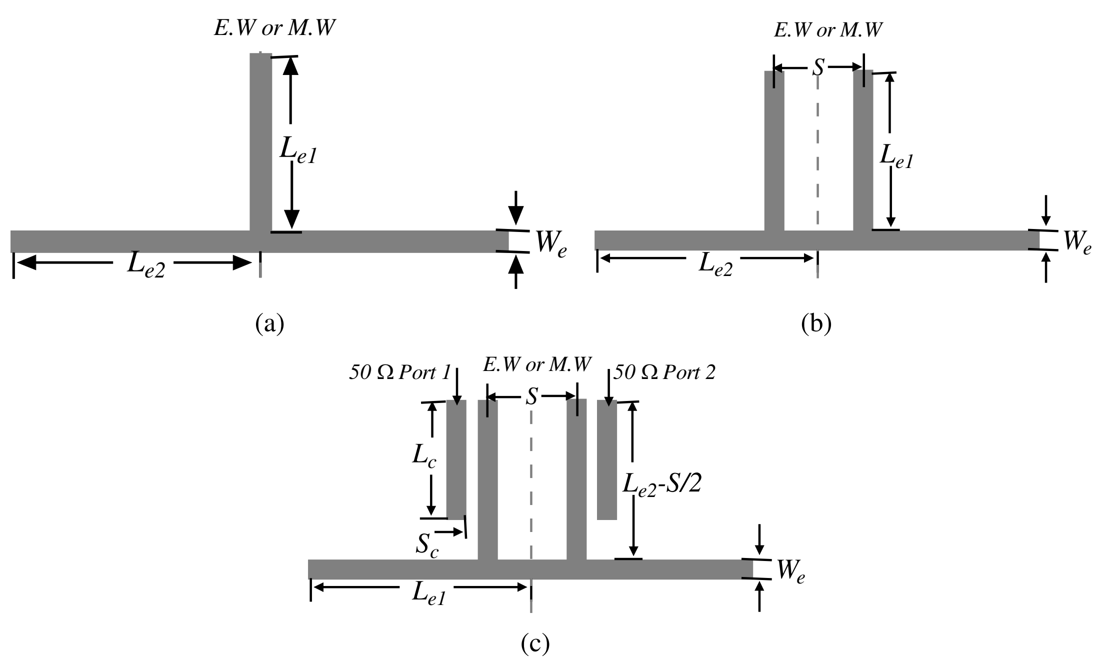

Figure 1. (a) Initial dual-mode stub-loaded resonators in [8]. (b), (c) Proposed triple-mode stub-loaded resonators and triple-mode bandpass filters with parallel-coupling feed structures.

By splitting a single stub in Fig. 1(a) to two closely spaced stubs with a gap(s) in Fig. 1(b), a novel triple-mode resonator can be constituted. As compared with dual-mode resonator, this triple-mode resonator possesses one more odd-mode. In fact, as the central plane behaves as E.W., the half bisection is composed of two microstrip lines with (L_{e2}-$s/2$) and L_{e1} which are cascaded via a shorted ground microstrip line ($s/2$). It is different from the $\lambda/4$ resonator short-circuited at center of the dual-mode filter in Fig. 1(a).

In analysis of the practical triple-mode resonator in Fig. 1(b), a parasitic coupling path between two stubs in proximity must be taken into account. Its emergence unfortunately degrades rejection skirt at vicinity of a transmission zero as investigated. But, these two open-ended stubs with length of L_{e1} are readily flared apart to fully eliminate these harmful parasitic coupling while two microstrip line sections with length (L_{e2}-$s/2$) in two sides in Fig. 1(b) are rotated inwards so that they are arranged parallel with each other as shown in Fig. 1(c). As a result, the transmission zero produced by two uncoupled $\lambda/4$ stubs in the initial stub-loaded resonator is not affected at all. Moreover, a single transmission zero is gradually split to two zeros varied length Lc, while in-band and upper-stopband frequency responses keep almost identical. This is primarily realized by making use of closely-spaced mutual coupling among the four microstrip conductors in the I/O coupling area.

3. FILTER DESIGN

The Ku-band bandpass filter has been designed on a substrate Rogers/Duroid 5880 with a dielectric constant of 2.2, thickness of 0.508 mm, and loss tangent of 0.0027. The structural parameters for the Ku-band bandpass circuit are (as illustrated in Fig. 2): $w_0 = 0.76$ mm, $w_1 = 0.10$ mm, $w_2 = 0.10$ mm, $w_3 = 0.10$ mm, $w_4 = 0.25$ mm, $w_5 = 0.4$ mm, $l_1 = 1.50$ mm, $l_2 = 2.10$ mm, $l_3 = 3.25$ mm, $l_4 = 3.00$ mm, $l_5 = 4.70$ mm, $l_6 = 1.10$ mm, $l_7 = 3.40$ mm, $g_0 = 0.1$ mm, $g_1 = 0.5$ mm, $g_2 = 0.7$ mm.

Finally, the fabricated Ku-band narrow bandpass filter is measured with an Agilent 87222ES vector network analyzer. Simulated and measured scattering parameters are described in Fig. 3 with good agreement. Referring to Fig. 3, the fabricated Ku-band narrow bandpass filter has a passband from 16.11 GHz to 16.31 GHz, and the 3 dB fractional bandwidth (FBW) is 1.23%. The lower- and upper-stopbands with -10 dB attenuation are up to 8 GHz, 24 GHz, respectively. In addition, the proposed Ku-band narrow bandpass filter can generate two transmission zeros at 15.28, and 16.50, and two transmission poles at 15.20, and 16.26, which give much improved selectivity. The deviations of the measurements from the simulations are attributed to the fabrication tolerance as well as the SMA connectors. Fig. 4 shows a photograph of the fabricated microstrip Ku-band bandpass filter. The overall size is about $9.7 \times 8.0\,\text{mm}^2$. Comparisons with other reported Ku-band bandpass filters are listed in Table 1. It shows that our proposed microstrip Ku-band bandpass filter has good selectivity and wide stopband rejection.

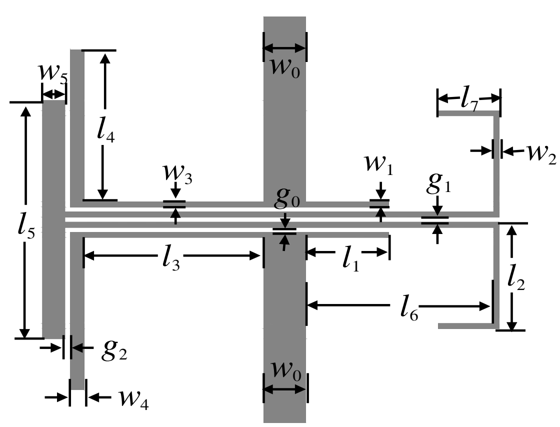

Figure 2. Layout of the proposed microstrip narrow Ku-band bandpass filter.

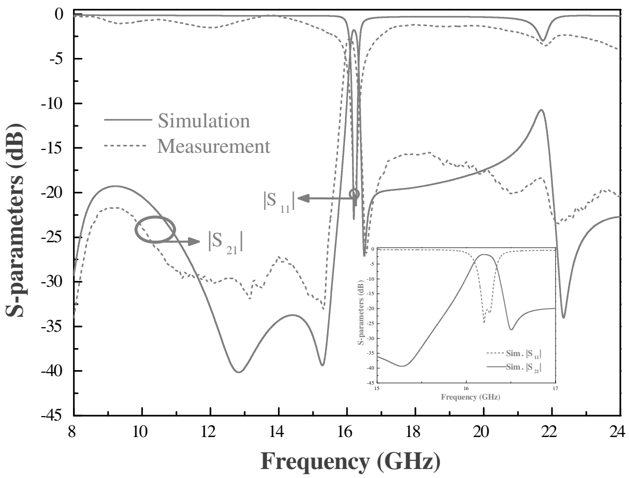

Figure 3. Simulated and measured S-parameters of the proposed microstrip narrow Ku-band bandpass filter.

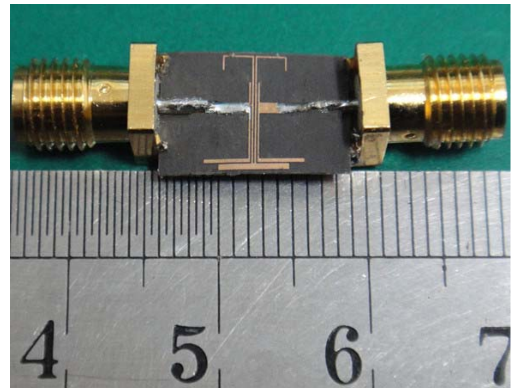

Figure 4. Photograph of the fabricated microstrip narrow Ku-band bandpass filter.

Table 1. Comparisons with other reported Ku-band bandpass filter.

Ref.	Circuit Dimension	Insertion Loss (dB)	Transmission Poles	Roll-off Rate (dB/GHz)	3-dB (FBW)	3-dB Lower Stop-band Bandwidth (GHz)	3-dB Upper Stop-band Bandwidth (GHz)
[1]	3-D	0.65	No	77	4.9%	0.5	0.3
[2]	3-D	0.85	No	12	14.4%	3.1	4.4
[3]	3-D	2.10	Lower/Upper	64	2.5%	3.2	2.8
[4]	2-D	1.10	No	220	0.6%	0.5	0.5
[5]	2-D	0.40	Lower	146	4.2%	0.9	0.9
[6]	2-D	0.46	Lower/Upper	14	24.0%	12.6	10
[7]	2-D	0.70	Lower/Upper	21	19.8%	1.2	0.8
This work	2-D	2.42	Lower/Upper	83	1.2%	7.7	8.0

Roll-off Rate is defined as $|\alpha_{\max}\text{-}\alpha_{\min}|/|f_s - f_c|$, where $\alpha_{\max}$ is the 25 dB attenuation point and $\alpha_{\min}$ is the 3 dB attenuation point; f_s is the 25 dB stopband frequency and f_c is the 3 dB cutoff frequency. Roll-off Rate for reported ones is estimated from the figures in papers.

4. CONCLUSION

A new microstrip narrow bandpass filter with good selectivity and wide stopband rejection for Ku-band application has been proposed and designed. The triple-mode stub-loaded resonator is used to provide two transmission poles and a pair of transmission zeros on both sides of the passband to improve the filter selectivity. Good agreement between simulation and measurement results demonstrates the validity of the method. The proposed filter is very useful for modern Ku-band wireless communication systems due to its simple topology, compact size, and excellent performance.

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