A Compact Wideband Microstrip Filter Using Folded Multiple-Mode Resonator

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Abstract—A compact wideband microstrip filter using a folded multiple-mode resonator is proposed. The filter contains only one resonator, which operates as not only a resonant element but also an open stub. The filter simultaneously realizes a broad passband, a compact size, and two transmission zeros at both the lower and upper stopbands. The transmission zero mechanism is investigated in detail through the simple transmission line equation. A lucid equivalent circuit is given both for analysis and initial design of the proposed filter. The fabricated filter shows the merits which are listed as follows: compact size and sharp skirts.

Index Terms—Folded multi-mode resonator, transmission zero, wideband bandpass filter (BPF).

I. INTRODUCTION

TODAY, wideband applications are renewing the interest in the design of planar wideband filters with low loss and high rejection performance, and especially, since the Federal Communications Commission allocated 7.5 GHz of spectrum for unlicensed use of ultra-wideband (UWB) devices [1], many efforts have been carried out to produce various kinds of wideband bandpass filters (BPFs) [2]–[10]. These wideband filters can be classified as two basic kinds. One of them is based on the design of a single stepped impedance resonator and strong I/O coupling [2], [3], which is referred to as classical multiple-mode resonator filter, hereafter, and the filters in [4]–[6] are all evolved from this basic form. The other kind of filter is firstly proposed as an optimum distributed highpass filter [7], and then, further developed to be used for wideband filter applications [8]–[10]. Both kinds of filters have been found effective for UWB filter applications. In [11], a single stub-tapped half-wave resonator was used to realize a narrowband filter with two transmission zeros, and then, this filter was modified to implement a wide passband in [12]. However, the passband of the filter in [12] contains only three poles, limiting the achievable bandwidth. Besides, the design of the structure of the so-called compact microstrip resonant cell, which is used to realize transmission zeros, seems a little complicated. In this letter, a compact folded multiple-mode resonator filter is proposed. The proposed folded multiple-mode resonator can be perceived as a transformed classical multiple-mode resonator since they have similar structures and resonant characteristics. The proposed resonator folds two wings of the classical multiple-mode resonator, as shown in Fig. 1, and makes the filter length as short as only three quarters of the operation wavelength. On the other hand, the proposed resonator can also be seen as a stub loaded resonator, which has periodic transmission zeros. Compared with filters in [4]–[6], additional stubs for introducing transmission zeros are no longer necessary. Compared with the stub-loaded filter in [12], because five transmission poles are involved in the passband, the achievable bandwidth of the proposed filter is wider. Furthermore, the structure and design method of the proposed filter is very simple and comprehensive.

The mechanism of the folded multiple-mode resonator filter is investigated in detail, and finally, the filter is fabricated and tested.

II. CIRCUIT ANALYSIS

A comparison of two wideband filters, which are referred to as classical multi-mode resonator filter [2], [3] and folded multi-mode resonator filter, respectively, is shown in Fig. 1. At the central frequency of a passband, e.g., \( f_0 = 5.3 \) GHz, each filter consists of one half-wave \( (\lambda_0/2) \) low-impedance line and two identical quarter-wave \( (\lambda_0/4) \) high-impedance lines, as well as two \( \lambda_0/4 \) feeding lines which can provide two additional transmission poles within the passband. The only difference between the two filters is that the two high-impedance lines of the proposed folded resonator are on the same side of the low-impedance line, and thus, reducing the resonator size to only three quarters of the classical multi-mode resonator.

To provide a physical insight into the mechanism of the proposed filter, two equivalent circuits of both filters are described in Fig. 2. Choosing the same electrical parameters for the two circuits, e.g., the length and impedance of each transmission line element, and ignoring the discontinuity of each junction, the circuit responses of the two filters are shown in Figs. 3 and 4, which are obtained under weak coupled excitation and strong coupled excitation, respectively. It can be seen that these two resonators exhibit very similar resonant characteristics either within or beyond the passband. While the ports are weakly coupled, each filter has three transmission poles within the passband; while the ports are strongly coupled, two additional poles are excited among those original three poles, aiding to create a wider passband. On the other hand, within the interested frequency range from 0.2 to 15 GHz, only one transmission zero is found from the classical multiple-mode resonator filter, while three more
transmission zeros are observed from the proposed filter. Intuitively, the generation of these three additional transmission zeros is caused by the wide open stub. In [11], the shunt open stub was perceived as an LC network to explain the generation of two transmission zeros below and above the passband. However, it will be shown in a simpler manner that a single stub can simultaneously provide transmission poles and zeros.

Without regarding the coupled feeding lines, the open circuit impedance parameter $Z_{21}$ of the folded resonator can be expressed in terms of $ABCD$ matrix

$$Z_{21} = \frac{1}{C} \tag{1}$$

where $C$ is derived as follows:

$$C = \frac{T_1 \sin^2 2\theta + T_2 \cos^2 2\theta + T_3 \cos 2\theta}{\cos 2\theta} \tag{2}$$

where $\theta$ is the electrical length of the high-impedance line, and $T_1$, $T_2$, and $T_3$ are coefficients composed of $Z_H$ and $Z_L$. From (1) and (2), it can be known that, for the folded resonator, $Z_{21}$ has two zeros near the center frequency $f_0$

$$\theta_{z1} = \frac{\pi}{4}, \quad \theta_{z2} = \frac{3\pi}{4}. \tag{3}$$

Since $S_{21}$ has the same transmission zeros as $Z_{21}$, there must be two transmission zeros on both sides of $f_0$

$$f_{z1} = \frac{f_0}{2}, \quad f_{z2} = \frac{3f_0}{2} \tag{4}$$

while the classical multi-mode resonator has no such zeros. The transmission zeros indicated in (4) are completely consistent with those in Figs. 3 and 4. The locations of $f_{z1}$ and $f_{z2}$ largely depend on the length of the low-impedance line (open stub) while they are independent of the high impedance lines. Obviously, when the fractional bandwidth of the filter is less than 100%, these two zeros (the first two of those periodic zeros) can create a sharper skirt either below or above the passband.
III. SIMULATED AND MEASURED RESULTS

According to a given specification, the initial filter dimensions can be chosen by designing the equivalent circuit shown in Fig. 2, and then, a fine tuning process can be carried out with EM simulation (the EM simulation in our case are carried by IE3D software). The optimized filter dimensions of a wideband microstrip filter are given in Fig. 5.

There are two points in addition should be noted. The first point is that, in order to suppress the first spurious frequency at around 11 GHz (the fourth resonance of the resonator), which can be found in Figs. 3 and 4, a U shaped slot is embedded in the central part of the low-impedance line [9]. This will not affect the passband performance because the current flows largely along the edges of the low-impedance line. The second point should be noted is that, between the 50 Ω line and thin feeding line, a short section in triangular shape is inserted for matching the I/O impedance. Changing the area of this short triangular section will alter the input impedance and help to realize a better filtering response. The EM simulated and measured results of the filter are shown in Figs. 6 and 7, where good agreement can be observed. The poor performance of the measured S11 is due to our poor soldering craft. Besides, the input and output being too close would also result in isolation problems. A photograph of the fabricated filter is given in Fig. 8. The 3 dB bandwidth of the fabricated filter covers a wide range from 3.78 to 6.98 GHz, and the fractional bandwidth achieves 60%. Two transmission zeros are generated at 2 and 8 GHz, respectively.

IV. CONCLUSION

A compact wideband microstrip filter with two close-to-band transmission zeros has been proposed and designed using the folded multiple-mode resonator. A wide passband of 60% fractional bandwidth is obtained at 5.3 GHz. The simulated and measured results of the proposed filter are in good agreement. Theoretically, the higher the impedance $Z_L$, the wider the passband, but the positions of zeros $f_{z1}$ and $f_{z2}$ formulated in (4) indicate an extreme bandwidth of 100%. By increasing $Z_L$ and strengthening external coupling, a 95% bandwidth can be achieved, which is applicable for most signals that occupy 500 MHz in the UWB, though it can not cover the full UWB. Since the final filter dimensions are initiated from an equivalent circuit, the design method is very simple and effective. In addition, the overall length of the constituted filter block is only $3\lambda/4$ at the center operating frequency.

REFERENCES