Compact Microstrip Bandpass Filter With Two Transmission Zeros Using a Stub-Tapped Half-Wavelength Line Resonator

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***Abstract*—A compact microstrip bandpass filter is developed using a half-wavelength ($\lambda/2$) transmission line resonator with a pair of tap-connected open-ended stubs. Such paired stubs with total length of about $\lambda/2$ constructs an equivalent line resonator. Together with two separated $\lambda/4$ line resonators, the three transmission poles can be achieved inside the passband. Meanwhile, two stub lengths are adjusted slightly longer and shorter than $\lambda/4$ to realize the two transmission zeros at both low and high rejection bands. Further, the long tapped-stub is kept wider than its short counterpart to improve the low rejection behavior. A filter sample is designed and fabricated to provide an experimental verification on the proposed filter.**

***Index Terms*—Planar bandpass filter, size-compactness, stub-tapped resonator, transmission zero.**

I. Introduction

PLANAR bandpass filter [1] has been extensively studied and exploited as a key circuit block with operating functions of in-band transmission and out-of-band rejection. To meet the requirements in modern wireless communication, much effort has been made in the past years to develop a variety of compact bandpass filter with sharp and deep rejection outside the passband by generating transmission zeros or attenuation poles [2]–[6]. In addition to the popular cross-coupling mechanism as detailed in [2], a simple stub-tapped scheme [3] was recently proposed to achieve a single transmission zero at the particular frequency in which the attached open-ended stub is attributed to zero impedance at the tapped point of a $\lambda/2$ line resonator (in equivalence, two separated $\lambda/4$ line resonators). With the use of this stub-tapped line resonator, a four-pole bandpass filter with double transmission zeros was built up [3]. On the other hand, a tap-connected line resonator with two unequal stub lengths was extensively studied in [4]–[6] to build up an alternative type of planar bandpass filters with double or multiple out-of-band transmission zeros, in which each resonator can produce two transmission zeros but only one transmission pole.

In this letter, a compact three-pole microstrip bandpass filter with two transmission zeros is developed by combining the above-described two schemes. It is realized by tap-connecting a pair of unsymmetrical open-ended stubs with unequal stub lengths and widths at the central point of a $\lambda/2$ line resonator. Our main effort is made here to physical investigation on the mechanism of such a filter on a basis of its equivalent cascaded network. To improve the low rejection-band performance, the width of the longer tapped-stub is here selected much wider than that of its short counterpart. After our simulated results are obtained to demonstrate the existence of three transmission poles and two attenuation poles within and outside the passband, respectively, a filter circuit is optimally designed, fabricated and measured.

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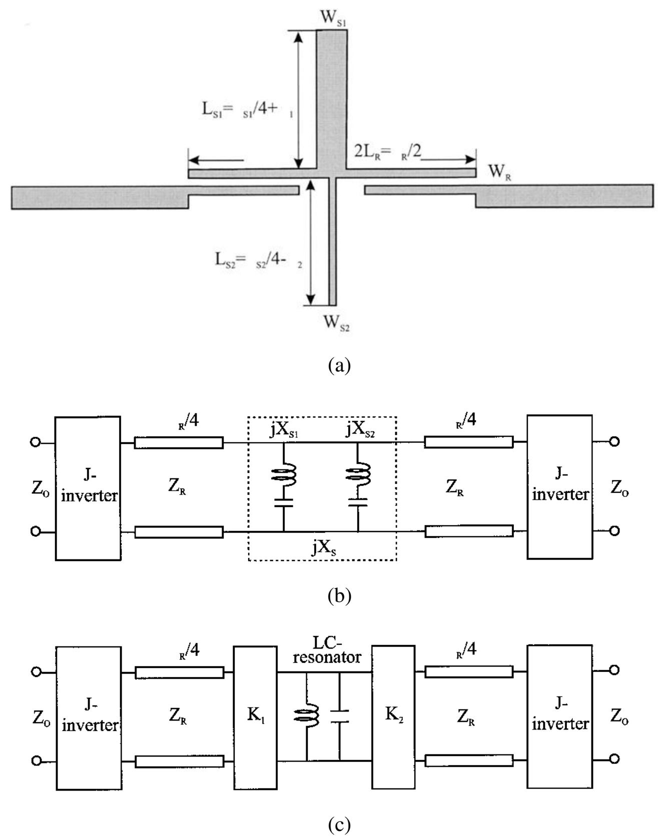


Fig. 1. Schematic layout and its equivalent circuit network of the three-pole microstrip filter with low/high transmission zeros. (a) Schematic layout. (b) Initial equivalent network. (c) Resultant equivalent network.

II. Mechanism of Stub-Tapped Bandpass Filter

Fig. 1(a) depicts the schematic layout of the proposed bandpass filter in which the $\lambda/2$ microstrip line resonator

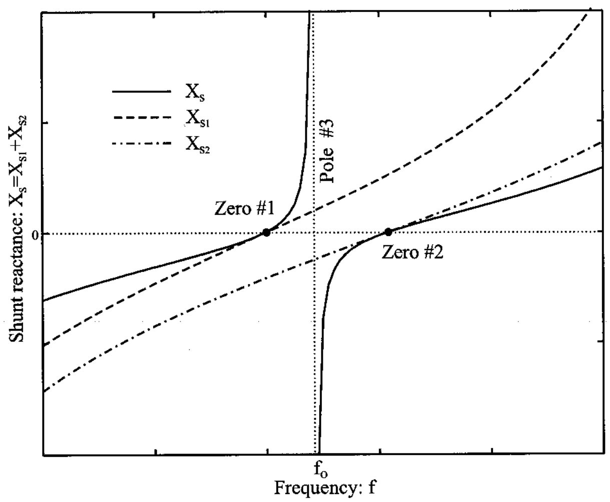


Fig. 2. Sketch for frequency-dependent shunt reactance (Xs) of a pair of unsymmetrical open-ended stubs at the tapped point of a line resonator.

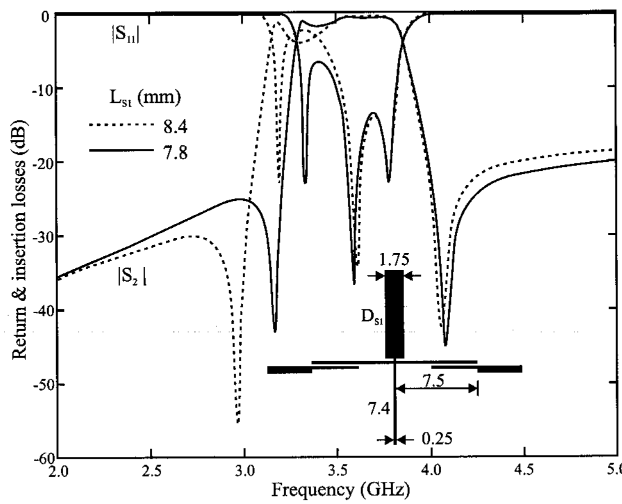


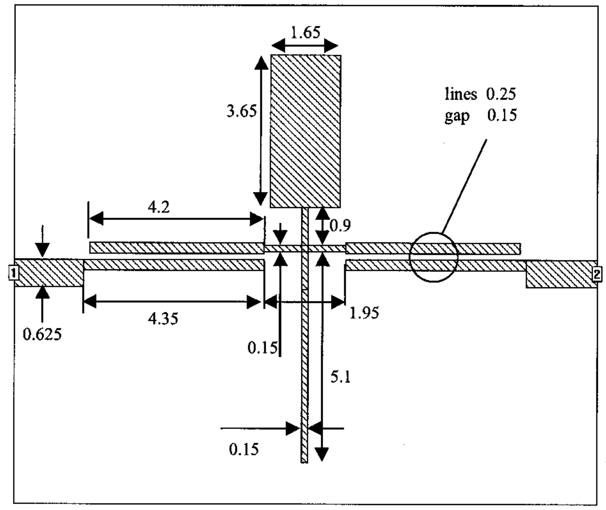
Fig. 3. Simulated return and insertion losses of the stub-tapped microstrip bandpass filter with two unequal stub widths.

(horizontal) is simultaneously tap-connected at its central point with a pair of unsymmetrical open-ended stubs, while it is capacitively coupled to the two external lines. Here, the $\lambda/2$ microstrip line itself is perceived as the two separated $\lambda/4$ line resonators [3] while the paired open-ended stubs are linked together to constitute an additional equivalent $\lambda/2$ line resonator [4]–[6]. In particular, the upper and lower open-ended stubs are constructed with two different electrically line lengths, slightly longer and shorter than $\lambda/4$ at the center frequency, as illustrated in Fig. 1(a). As such, the two transmission zeros can be placed at the low and high rejection bands, respectively. The upper stub with the longer electrical length is further widened to separate the lowest transmission zero and pole such that the low-band rejection behavior can be reasonably improved based on our theoretical analysis.

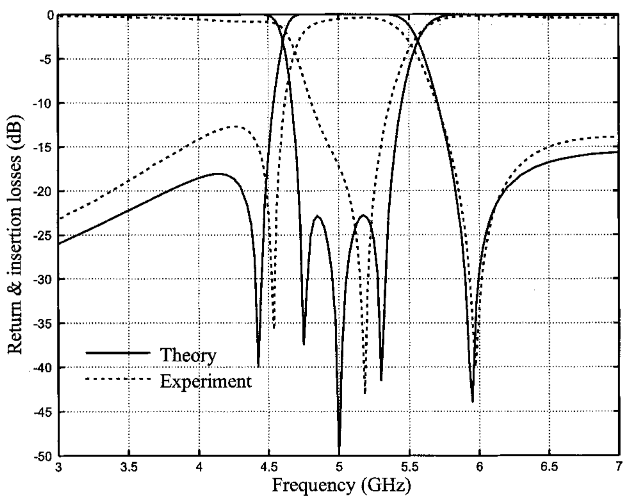
To provide a physical insight into its mechanism, the initial equivalent circuit network of this filter is described in Fig. 1(b). The two open-ended stubs are represented by two equivalent LC networks, one inductive and one capacitive at the central frequency. Together with two equivalent J-inverters formed by parallel-coupled lines, such two resonators allow realizing the two transmission poles. To evaluate the distinct behavior of these paired stubs in a comprehensive manner, the two shunt-connected individual reactances, X_{S1} and X_{S2}, corresponding to the upper and lower stubs as in Fig. 1(a), are then put together to derive the overall equivalent shunt reactance, X_S. Looking at the sketch in Fig. 2, both X_{S1} and X_{S2} themselves appear to quasi-linearly rise up from negative to positive region as the frequency increases around the central frequency. However, the resulting X_S tends to move upward at first in an exponential function of frequency beyond the first null (Zero #1), suddenly fall down from positive infinity to negative infinity, and then rapidly rise up again till the second null (Zero #2) appears. Intuitively, it can be understood that the infinite value of X_S brings out the third transmission pole (Pole #3) of this stub-tapped line resonator at the frequency (f_0). Alternatively, the whole shunt-connected LC block in Fig. 1(b) can be perceived as the cascaded topology of a single equivalent LC resonator and two equivalent K-inverter quantities at its two sides. In this case, the two K-inverters represent the slope of two reactances, X_{S1} and X_{S2}, around the central frequency. As such, the resultant equivalent network can be obtained as depicted in Fig. 1(c), in which the two transmission zeros are taken into account the two K-inverters as in [3]. This resultant network exactly indicates the equivalent topology of the three-pole bandpass filter with a $\lambda/2$ and two $\lambda/4$ transmission line resonators.

III. Theoretical and Experimental Results

Our next effort is shifted to theoretical and experimental characterization of the proposed bandpass filter in terms of its two-port scattering matrix. All the filter structures discussed as below are formed on the RT/Duroid 6010 substrate with $\epsilon_r = 10.8$ and h $= 50$ mil. Fig. 3 illustrates two sets of simulated results of the filter with using the *Agilent Momentum* software. Both results consistently demonstrate the actual existence of three transmission poles within the passband and two transmission zeros at low and high rejection bands. As the top stub length (L_{S1}) is shortened, both lowest transmission zero/pole tend to simultaneously shift up to high frequencies while the remaining zero/poles are almost kept unchanged, as shown in Fig. 3. Otherwise, the return loss $(|S_{11}|)$ in the passband is found to fall down while the insertion loss $(|S_{21}|)$ at the low rejection band rises up for the case of two unchanged stub widths (W_{S1} and W_{S2}). To further provide an evident validation, a filter circuit is optimally designed using the *Sonnet em Suite* software and its relevant layout with the detailed dimension is depicted in Fig. 4(a). Fig. 4(b) describes the simulated and measured S-parameters, exhibiting almost agreeable electrical performance. Some slight discrepancy between them can be still observed, and this may be attributed to the unexpected tolerance in the modeling and fabrication of tapped-junction and parallel-coupled line sections.



(a)



(b)

Fig. 4. Theoretical and experimental results of an optimally designed stub-tapped microstrip filter sample. (a) Dimensional layout. (b) Return and insertion losses.

IV. Conclusion

A compact bandpass filter is developed using a stub-tapped $\lambda/2$ line resonator. Extensive analysis is at first implemented to explain physically its distinct operating mechanism on a basis of equivalent network topology. Our work here has demonstrated that the two $\lambda/4$ uniform line resonators and an additional $\lambda/2$ tapped-stub resonator are attributed to the three-pole bandpass filtering characteristics while the two unsymmetrical tapped-stubs bring out the two transmission zeros at low and high rejection bands. A prototype bandpass filter is designed, fabricated and measured to provide an evident validation in experiment. It is our belief that such a tapped-connected line resonator be potentially useful as an attractive line resonator element for development of high-performance and size-miniaturized multiple-pole bandpass filter with good out-of-band rejection.

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