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STUB-TAPPED LINE RESONATOR FOR INNOVATIVE DESIGN OF COMPACT MICROSTRIP BANDPASS FILTER WITH DOUBLE TRANSMISSION ZEROS

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Abstract: **A novel λ/2 line resonator is proposed and developed towards building up a compact parallel-coupled microstrip bandpass filter with double out-of-band transmission zeros. By tap-connecting a pair of unsymmetrical open-end stubs at its center, such a line resonator allows not only bringing out three transmission zeros within the passband and also generating two transmission zeros at low and high rejection bands. After its operating principle is intuitively explained and qualitatively studied based on its equivalent network topology, extensive work is undertaken to improve the low rejection-band behavior by widening the electrically long tapped-stub. In final, a filter sample is optimally designed, fabricated and measured to provide an experimental verification on the proposed filter.**

Key Words: Microstrip bandpass filter, stub-tapped resonator, transmission zero and size-compactness.

1. INTRODUCTION

Planar bandpass filter [1] has been commonly recognized as one of key passive circuit blocks with the operating functions of in-band transmission and out-of-band rejection. To meet the requirements in modern wireless communication, great effort has been recently made to make up a variety of compact bandpass filters with sharp and deep rejection outside the passband by alternately generating transmission zeros or attenuation poles [2-5]. In addition to the popular cross-coupling scheme among resonators [2], a simple stub-tapped scheme [3] was proposed to achieve a transmission zero at the particular frequency in which the attached open-end stub contributes to zero impedance at the tapped point of a λ/2 line resonator (in equivalence, two separate λ/4 line resonators). In the meantime, an alternative similar technique was recently developed in [4, 5] to utilize a single tap-connected line resonator with two unequal stub lengths for simultaneously producing both low and high transmission zeros outside the passband of concern.

In this work, a compact three-pole microstrip bandpass filter with double transmission zeros is proposed and developed by combining these two techniques together and it is constructed by tap-connecting a pair of unsymmetrical open-end stubs with unequal stub lengths and widths at the central point of a λ/2 line resonator. Our main effort is at first made here to physical explanation and investigation on the operating principle of such a filter on a basis of its equivalent cascaded network. Next, the tapped-stub with electrically longer length is largely widened so as to improve the low rejection-band performance. After our simulated results are obtained to demonstrate the actual existence of three transmission poles and two attenuation poles within and outside the passband, respectively, a microstrip filter is optimally designed and then its sample is fabricated and measured for an experimental validation.

2. STUB-TAPPED LINE RESONATOR FILTER

Fig. 1(a) depicts the schematic layout of the proposed bandpass filter in which the λ/2 microstrip line resonator in horizon is simultaneously tap-connected at its central point by a pair of unsymmetrical open-end stubs while capacitively coupled with the two external microstrip lines through the parallel-coupled line. Of importance in concept, the λ/2 microstrip line itself needs to be alternatively perceived as the two cascaded λ/4 line resonators as in [3] while the paired open-stubs linked together to equivalently constitute an additional λ/2 line resonator [5]. Further, the upper

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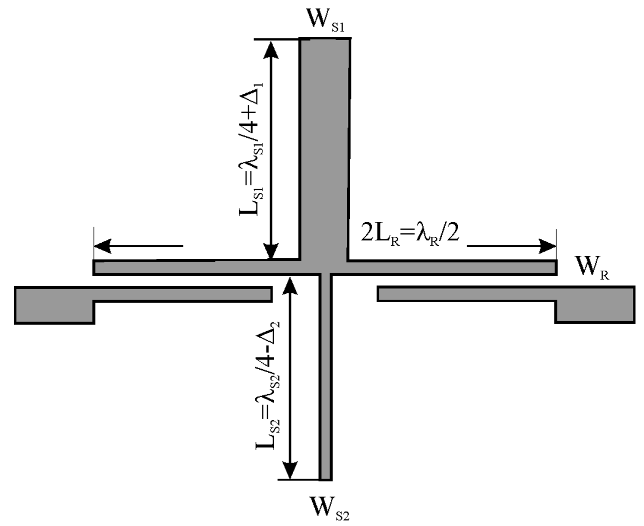
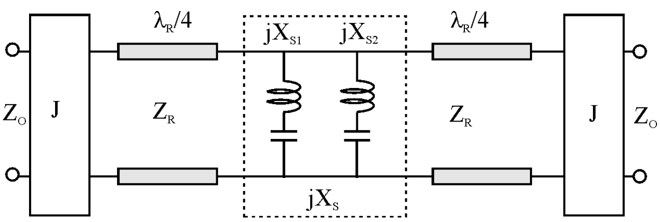
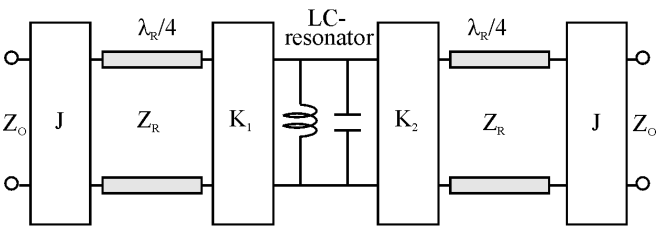
and lower open-end stubs are separately constructed with electrically line lengths slightly longer and shorter than λ/4 at the central frequency, as illustrated in Fig. 1(a), resulting in the emergence of two transmission zeros at the low and high rejection bands, respectively [5]. Of paired open-end stubs, the upper one with longer electrical length is then widened to relocate the low transmission zero and pole separately with each other such that the low-band rejection behavior can be reasonably improved based on our theoretical analysis.



(a) schematic layout



(b) initial equivalent network



(c) resultant equivalent network

Fig. 1 Layout and its equivalent circuit network of the proposed microstrip bandpass filter.

To provide in depth a physical insight into its principle, the initial equivalent circuit network of this filter is described in Fig. 1(b), in which the stub-tapped line resonator is characterized as the two cascaded λ/4 transmission line resonators with a pair of inductively shunt LC networks at their connection location. Together with equivalent J-inverter quantities of parallel-coupled lines, such two resonators of course allow realizing the two transmission poles at the beginning. To evaluate the affection of the paired stubs, the overall shunt reactance, X_S, is then derived from the two calculated individual reactances, X_{S1} and X_{S2}, corresponding to the upper and lower opened stubs as in Fig. 1(a).

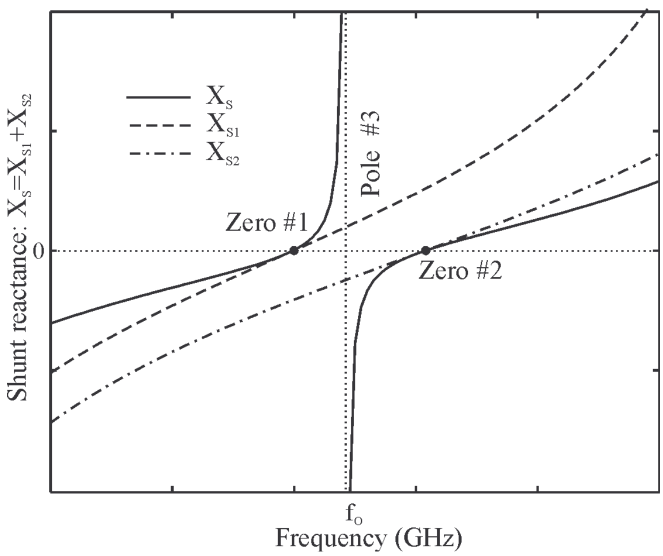


Fig.2 Shunt reactance (Xs) of at the tapped-point

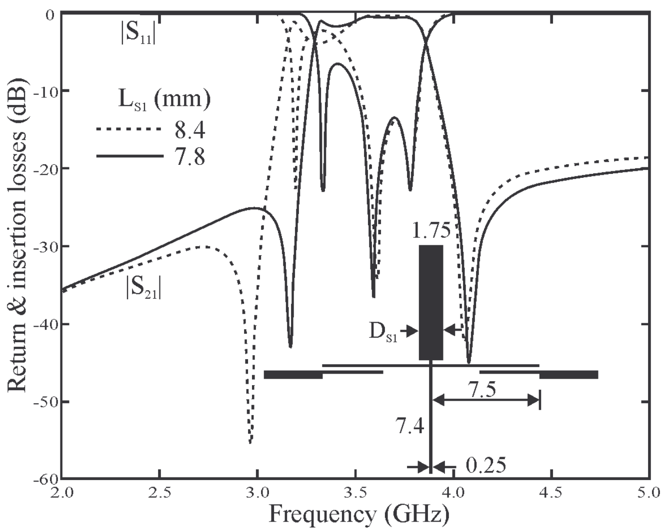


Fig. 3 Simulated return and insertion losses

Looking at the sketch in Fig. 2, X_{S1} and X_{S2} are observed to quasi-linearly rise up from negative to positive region as the frequency increases around the central frequency. By putting them together in the

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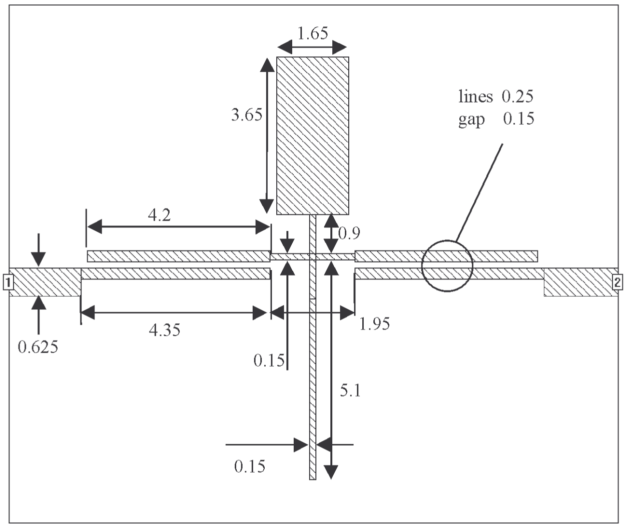
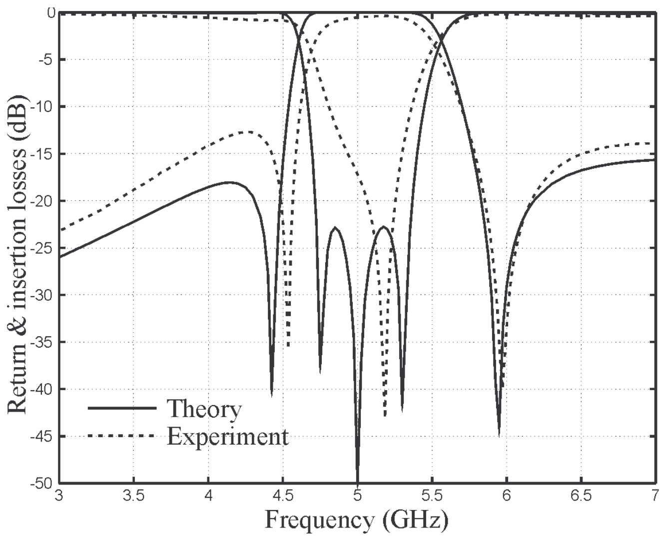
shunt form, the resulting X_S appears to move up rapidly in an exponential function of frequency beyond the first null (Zero #1), suddenly fall down from positive infinity to negative infinity, and then rapidly rise up again till the second null (Zero #2). Accordingly, it can be well understood that the infinite X_S brings out the emergence of the third transmission pole, marked by "Pole #3" in Fig.2, for the stub-tapped line resonator at the frequency (f_0). Accordingly, the whole shunt-connected LC block in Fig. 1(b) can be alternatively perceived as a single equivalent LC resonator driven by two K-inverter quantities at its two sides. It results in deriving the resultant equivalent network of this filter as depicted in Fig. 1(c), in which the above-described two transmission zeros are included in the two K-inverter blocks. Such a network exactly indicates the equivalent topology of the three-pole bandpass filter with a λ/2 and two λ/4 transmission line resonators.

3. Simulated and Measured Results

Our attention is now moved toward theoretical and experimental characterization of the bandpass filtering behavior in terms of its two-port scattering matrix. Fig. 3 illustrates two sets of simulated results of the filter, formed on the dielectric substrate of RT/Duroid 6010 with ε_r=10.8 and h=50 mil, by utilizing the *Agilent Momentum* software. These results consistently demonstrate the existence of three transmission poles within the passband and two transmission zeros at low and high rejection bands for both cases. Such two transmission zeros are found really useful to improve the out-of-band performance with sharp rejection skirt. As the stub length (L_{S1}) is shortened, both lowest transmission zero/pole tend to shift up to high frequencies while the remaining zero/pole 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 the unchanged stub widths (W_{S1} and W_{S2}). To further provide an evident validation, a filter sample 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, showing almost agreeable electrical performance. The slight discrepancy between them can be still observed and it may be attributed to sensitive dependence on the unexpected tolerance in the modeling and fabrication of tapped-junction and parallel-coupled line sections.



(a) layout



(b) results

Fig. 4 Theoretical and experimental results of an optimized stub-tapped microstrip filter sample.

4. Conclusions

A compact microstrip bandpass filter is developed through the effective use of a novel stub-tapped line resonator. Extensive analysis and investigation are carried out to explain physically its distinct operating principle on a basis of equivalent network topology. Our work here demonstrates that the two λ/4 uniform line resonators and an additional λ/2 tapped-stub resonator dominantly lead 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, respectively. A microstrip bandpass filter is then optimally designed, fabricated and measured to validate the attractive performance of the proposed filter in experiment. Such a tapped-connected line resonator should be potentially useful as an attractive line resonator for development of high-performance and size-miniaturized multiple-stage bandpass filter with good out-of-band rejection.

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