A Novel Ultra-Wideband (UWB) Bandpass Filter (BPF) With Pairs of Transmission Zeroes

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***Abstract*—A novel, compact, and highly selective ultra-wideband bandpass filter was developed on a microstrip line and presented in this letter for use in wireless communication applications. The basic filter is composed of five short-circuited stubs separated by nonredundant connecting lines that contribute to the filter selectivity as well. In addition, a cross-coupling between the feed lines (input and output) was introduced which generated new pairs of attenuation poles at each side of the passband. As a result, the filter exhibited extremely sharp rejection skirts around the target passband without the need for increasing the number of transmission line sections. The filter was successfully designed, simulated, and fabricated. The theoretical, EM-simulated, and experimental performance is presented in this work where excellent agreement between them was obtained.**

***Index Terms*—Bandpass filters (BPFs), cross-coupling, transmission line filters, microstrip filters, transmission zeroes, ultra wideband (UWB) filters.**

I. Introduction

THE U.S. Federal Communications Commission (FCC) approved the unlicensed use of ultra-wideband (UWB) (range of 3.1–10.6 GHz) for commercial purposes in early 2002 [1]. Since then, academic and industrial research into various UWB devices has risen and the development of new UWB filters has increased via different methods and structures [2]–[11]. A UWB filter was developed in [2] using a lossy composite substrate that absorbs high frequency signals. However, the filter lacked sharpness at the lower frequency and suffered from large insertion loss of more than 6 dB and quite poor impedance matching, specifically at the high frequency. Ishida and Araki designed an UWB filter with 83% relative bandwidth using a dual-mode ring resonator with open-circuited stub [3]. Due to the nature of the dual-band operation, the filter exhibited poor performance at the higher and lower frequency ends outside of the band, but it had good insertion loss in the passband. Recently, a new technique was used in [4] to design a compact BPF with a fractional bandwidth (FBW) of about 100%. The filter was designed using a combination of lowpass filter (LPF) with conventional stub highpass filter (HPF). As a result of the use of low degree HPF, the filter lacked selectivity or sharpness at the lower frequency. In [5], an UWB bandpass filter (BPF) was developed using a broadside-coupled microstrip-coplanar waveguide structure where a conventional high rejection filter was added to achieve a good out-band performance. Alternatively, two UWB filters using suspended stripline were designed by Menzel *et al.* in [6]. The first of the two filters included additional capacitive coupling to improve the upper passband slope while the second filter was a combination of a low-pass and a high-pass filter. Soon after, a novel UWB BPF was developed by Zhu *et al.* [7] using a single multiple-mode resonator (MMR). The basic concept behind this UWB filter design was first introduced in [12] and recently implemented by using CPW in [8] and by using hybrid microstrip/CPW structure in [9] by allocating the first three resonant modes of the MMR inside the chosen UWB passband. The need for a filter with both excellent performance and compact size, which is preferable for future wireless applications and technologies, has not yet been met by the developed filters mentioned.

The aim of this work was to attempt to develop a novel, compact, and high-selective UWB BPF for use in wireless systems. A cross-coupling between the feed lines (input and output) was to be introduced in order to allow the filter to exhibit new pairs of attenuation poles at each side of the passband. Therefore, the filter would exhibit an ideal performance with only a few resonators. The proposed filter is demonstrated in Fig. 1 and was to be constructed on a low cost GML 1000 substrate with a relative dielectric constant of 3.05 and a thickness of 0.508 mm. The predicted and experimental results that were obtained are presented in this letter.

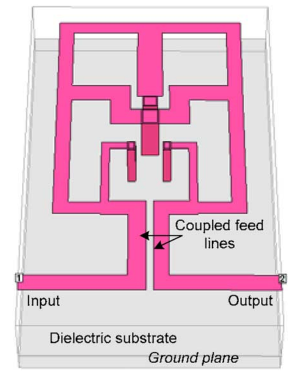

Fig. 1. Proposed UWB BPF with coupled feed lines on microstrip substrate.

II. UWB BPF Development

A. Optimum Filter Design

Without the cross coupling between input and output (I/O) feed lines, the proposed filter, shown in Fig. 1, is based on a cir-

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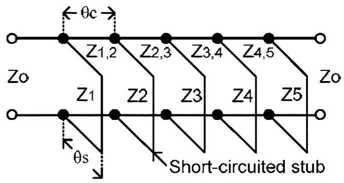

Fig. 2. General circuit model for the proposed UWB BPF without coupled feed lines.

cuit model for an optimum distributed HPF of which the connecting lines, or unit elements, are nonredundant [13]. The filter was designed to have a cascade of five shunt short-circuited stubs with electrical length of θs separated by non-redundant connecting lines with electrical length of θc as shown in Fig. 2. As a result, the filter can exhibit a high selectivity at the band edges, which is equivalent to that of a nine-pole (or an order $N = 9$) Chebyshev filter. The electrical length of the connecting lines (θc) is twice that of the stubs (θs) at the lower cut off frequency. The characteristic impedances of the short-circuited stubs are defined by Z1 to Z5, and the characteristic impedances of the connecting lines are defined by Z1,2 to Z4,5. The terminal impedance is defined as Zo. In order to achieve 10-dB attenuation at 3.1 GHz and 10.6 GHz as desired, the electrical length was chosen to be 44.3° for the short-circuited stubs and 88.6° for the connecting lines at 3.4 GHz. The filter was synthesized to obtain the desired circuit parameters. The obtained characteristic impedances are $Z1 = Z5 = 78.02\ \Omega, Z2 = Z4 = 43.8\ \Omega, Z3 = 39.6\ \Omega, Z1,2 = Z4,5 = 56.94\ \Omega$, and $Z2,3 = Z3,4 = 60.37\ \Omega$. The filter was realized on a microstrip substrate with a relative dielectric constant of 3.05 and thickness of 0.508 mm. Since the values for the characteristic impedances of the connecting lines are all near to each other, a modification was made to the microstrip design so that the connecting lines would have the same physical width, resulting in simplification of the design structure and reduction of the fabrication cost. In order to reduce the size of the filter, the microstrip design was further modified by being folded with 90° angles.

B. Attainment of New Transmission Zeroes

The optimum filter design obtained above has two inherent transmission zeroes (attenuation poles) located around the passband at dc and at twice the midband frequency due to the use of short-circuited stubs [13]. In order to produce transmission zeroes at other desired frequencies to improve filter selectivity, each of the short-circuited stubs may be replaced with two-section open-circuited stubs [11]. However, by using this technique the size of filter is increased significantly. To overcome this problem and to offer an alternative, a new technique has been developed, which is to introduce a cross coupling between the I/O feed lines. The new technique is very simple for implementation. This has been achieved by placing two sections of the feed lines of length L parallel to each other separated by spacing S as depicted in Fig. 3. This arrangement allows for source-load coupling. The new transmission zeroes can be located at the desired frequencies by adjusting the length of the parallel sections of the feed lines and the spacing S. To obtain the new transmission zeroes with good performance inside and outside the target

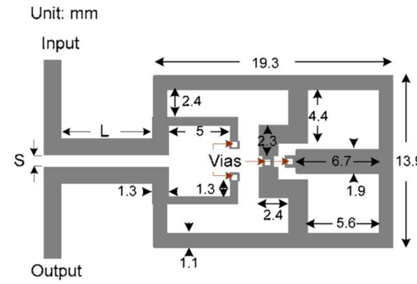

Fig. 3. Layout of the proposed UWB BPF.

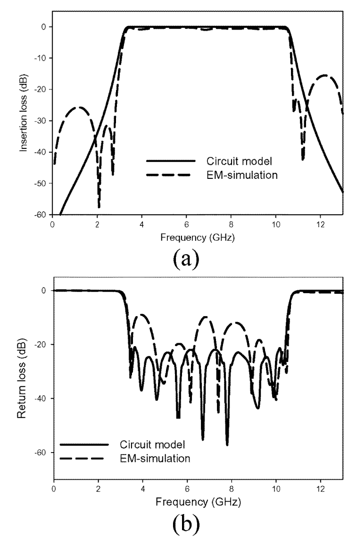

Fig. 4. (a) Insertion loss and (b) Return loss of theoretical (circuit model) and full-wave EM simulation of the design layout for $L = 5.5$ mm and $S = 0.3$ mm.

passband, L and S were chosen to be 5.5 mm and 0.3 mm, respectively. Fig. 4 demonstrates the simulated results of the general circuit model and the full-wave EM simulation for the microstrip design which includes a parallel-coupled section of feed lines. The EM simulation was performed using a commercially available tool [14]. As shown in the EM simulation results, the filter exhibited new pairs of transmission zeroes in each of the stopbands around the UWB passband, resulting in extremely high selectivity without the need to increase the degree of the filter which would increase the insertion loss and the filter size.

Fig. 3 represents the final layout of the filter including the physical dimensions for a proof of concept demonstration.

III. Fabrication and Measured Performance

The filter was fabricated on a microstrip substrate with a relative dielectric constant of 3.05 and thickness of 0.508 mm by using print-circuit-board (PCB) technology and the fabricated filter with attached SMA connectors is photographed in Fig. 5. The complete filter, including the feed lines, occupies a compact size of 13.9 mm by 26.1 mm which amounts to 0.49 λg by 0.93 λg, where λg is the guided wavelength of a 50-Ω line at the center frequency on the substrate. A HP network analyzer was utilized to obtain the measured performance. Fig. 6 illustrates the predicted and the measured results for the proposed UWB BPF. Excellent agreement was obtained where both filters exhibited an excellent UWB bandpass performance with FBW of

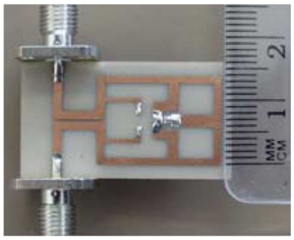

Fig. 5. Photograph of the fabricated UWB filter.

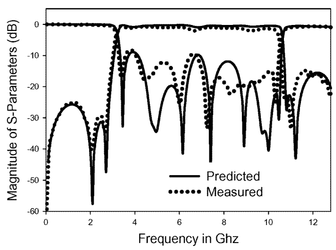

Fig. 6. Predicted and measured results.

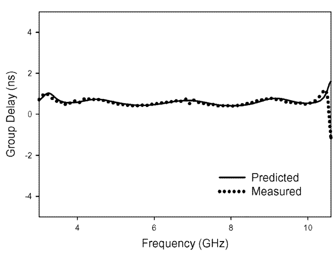

Fig. 7. Predicted and measured group delay.

about 110% at a midband frequency of 6.85 GHz. Both the simulated and measured results showed two new pairs of attenuation poles at the lower and upper stopbands which improved the passband performance by sharpening the rejection skirts. In addition, the new transmission zeroes also improved the filter performance outside the passband by widening the lower and upper stopbands. This indicates that this design technique is superior to that used in [11] where the measured passband was decreased and the size was increased. The selectivity is also better than the higher degree of the same type of filter developed in [10]. The proposed filter exhibited low insertion loss which includes the losses from the SMA connectors of about 1.1 dB at the midband frequency and a flat group delay of about 0.6 ns at the midband frequency as demonstrated in Fig. 7.

IV. Conclusion

A novel and compact UWB BPF with FBW of about 110% has been proposed, designed, and demonstrated in this letter. The filter design consists of five short-circuited stubs separated by nonredundant connecting lines. A cross-coupling between the input and output feed lines was introduced to allow the filter to be capable to exhibit two new transmission zeroes in each side of the UWB passband. The new transmission zeroes enhanced the selectivity of the low and high side skirts and increased the bandwidth of the lower and upper stopbands with only a few resonators. The predicted results were confirmed by the experiment, where excellent agreement was obtained. Due to its simple structure, compact size, and excellent performance, the proposed filter is attractive for use in future UWB wireless technologies.

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