Ultra-Wideband Bandpass Filter With Hybrid Microstrip/CPW Structure

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***Abstract*—A novel ultra-wideband (UWB) bandpass filter (BPF) is presented using the hybrid microstrip and coplanar waveguide (CPW) structure. A CPW nonuniform resonator or multiple-mode resonator (MMR) is constructed to produce its first three resonant modes occurring around the lower end, center, and higher end of the UWB band. Then, a microstrip/CPW surface-to-surface coupled line is formed and modeled to allocate the enhanced coupling peak around the center of this UWB band, i.e., 6.85 GHz. As such, a five-pole UWB BPF is built up and realized with the passband covering the entire UWB band (3.1–10.6 GHz). A predicted frequency response is finally verified by the experiment. In addition, the designed UWB filter, with a single resonator, only occupies one full-wavelength in length or 16.9 mm.**

***Index Terms*—Hybrid microstrip/coplanar waveguide (CPW), multiple-mode resonator (MMR), surface-to-surface coupled line, ultra-wideband (UWB) bandpass filter (BPF).**

I. Introduction

Since the U.S. Federal Communications Commission (FCC) released the unlicensed use of the ultra-wideband (UWB) (3.1–10.6 GHz) for indoor and hand-held systems in 2002 [1], significant research activities and interests have been recently aroused in academic and industrial circles toward exploring various UWB components and devices [2]. As one of the essential component blocks, attempts to developing a UWB bandpass filter (BPF) were made in [3]–[7] in order to achieve such a specified UWB passband with a 110% fractional bandwidth at the central frequency of 6.85 GHz. In [3], an initial UWB filter is presented by mounting a microstrip line in a lossy composite substrate and the reported insertion loss is higher than 6.0 dB. In [4], a microstrip ring UWB filter is constructed by simultaneously exciting and allocating transmission zeros below 3.1 GHz and above 10.6 GHz. Due to its nature of dual-stopband, this filter with multiple ring resonators usually has narrow lower and upper stopbands as well as large size ones. In [5], a composite UWB filter is proposed by combining lowpass and highpass filter structures or embedding one into the other. In [6], a broadside-coupled microstrip-coplanar waveguide (CPW) structure with tightened coupling degree is utilized to design an alternative UWB filter with one, two, and three sections. In [7], a novel compact UWB BPF on microstrip line is constituted using a single multiple-mode resonator (MMR) that is driven at two sides by two identical parallel-coupled lines. The basic principle of this UWB filter originated in [8] and [9] to explore compact and broadband BPFs with the bandwidth of 60% ∼80%.

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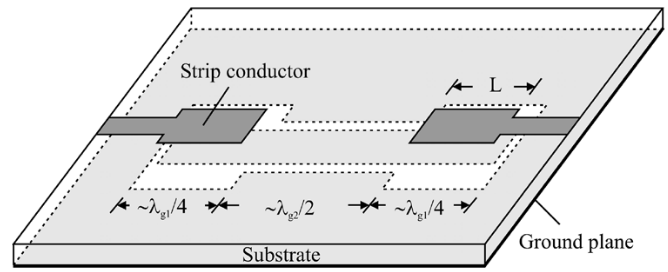

Fig. 1. Three-dimensional view of the proposed UWB BPF based on hybrid microstrip/CPW structure.

In this work, a novel MMR-based UWB BPF, as illustrated in Fig. 1, is proposed and implemented using the hybrid microstrip/CPW structures. In this way, a CPW nonuniform or MMR is formed on the ground plane to excite and allocate the first three resonant modes occurring around the lower end, center and higher end of the concerned UWB passband. Meanwhile, a surface-to-surface [10] or broad-side [6] coupled microstrip/CPW structure is characterized, aiming to allocate its coupling peak with enhanced extent around the UWB's center or 6.85 GHz. This proposed UWB filter can address the two problematic issues which exist in the initial UWB filter [7], i.e., an insufficiently tight coupling degree between two side-to-side coupled microstrip lines and parasitic radiation loss from a wide strip conductor or patch in the central part of the MMR on the microstrip line. In our design, this UWB filter is formed on the RT/Duroid 6010 with $\varepsilon r = 10.8$ and $h = 0.635$ mm, and its performance is optimized via Agilent ADS Momentum. Both predicted and measured results exhibit a good UWB passband with five transmission poles, maximum insertion loss of 0.5 dB, and maximum group delay variation of 0.30 ns within the entire UWB passband.

II. UWB Bandpass Filter: Schematic and Principle

Let's start to construct and characterize a CPW MMR and a surface-to-surface microstrip/CPW coupling structure [10]. As shown in Fig. 2(a), the proposed open-ended MMR resonator on CPW is composed of one central CPW with narrow slot width or low impedance and two identical CPWs with wide slot width or high impedance at two sides under the fixed strip width. Fig. 2(b) depicts its equivalent transmission line topology with three cascaded sections. To determine the frequencies of the three resonant modes, the input admittance (Y_i) at one of the open ends, looking into the MMR, must be zero, $Y_i = 0$. Thus, all those

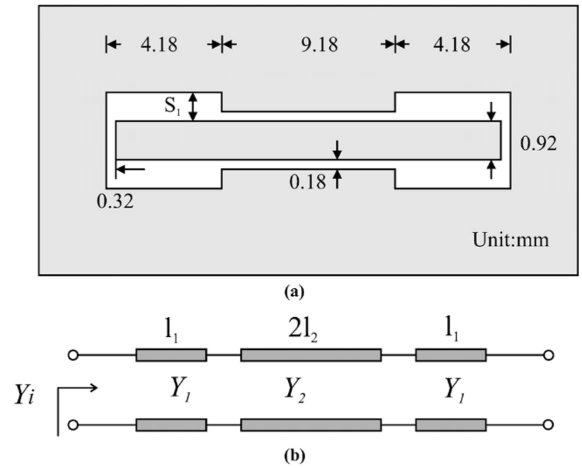

Fig. 2. Proposed MMR on coplanar waveguide. (a) Layout. (b) Equivalent transmission line network.

TABLE I
CALCULATED FIRST THREE RESONANT FREQUENCIES (f1, f2, f3) VERSUS SLOT WIDTH (S1) FOR THE MMR RESONATOR IN Fig. 2

S_1(mm)	0.18	0.58	**0.98**	1.10	1.38	1.78
f_1(GHz)	3.67	4.01	**4.12**	4.13	4.15	4.16
f_2(GHz)	7.29	7.10	**6.84**	6.76	6.60	6.34
f_3(GHz)	10.91	10.12	**9.55**	9.40	9.13	8.74

resonant frequencies can be solved from a transcendental equation.

Table I tabulates the first three resonant frequencies (f_1, f_2, f_3) versus slot width (S_1) under the fixed slot width of 0.18 mm in the middle. As shown in Fig. 2(a), the three sections in this MMR are selected in such a way that the middle section has about one half guided-wavelength or $L_2 \approx \lambda_{g2}/2 = 9.18$ mm and the two side sections have about one quarter guided-wavelength or $L_1 \approx \lambda_{g1}/4 = 4.18$ mm at 6.85 GHz (UWB's center), respectively. As S_1 is widened, the first resonant frequency (f_1) quickly increases at the beginning and then becomes saturated around 4.12–4.16 GHz. On the other hand, the second and third ones, f_2 and f_3, seem quasilinearly decreased with S_1 in the small and large degree of deviation, respectively. To achieve a UWB passband covering 3.1 to 10.6 GHz, the first three frequencies are targeted to be equally spaced in the UWB band with the locations above 3.1 GHz, near 6.85 GHz, and below 10.6 GHz. According to this criteria, the three frequencies of 4.12, 6.84, and 9.55 GHz under $S_1 = 0.98$ mm can be recognized as the best in all the cases listed in Table I.

Fig. 3(a) shows a hybrid microstrip/CPW surface-to-surface coupling structure that was initially studied in [10] to make up a broadband microstrip-to-CPW transition with the use of its frequency-dispersive and enhanced coupling extent. In this structure, the upper microstrip conductor is vertically coupled with the central strip conductor of the lower CPW on ground plane via electromagnetic coupling. Its coupling behavior can be characterized in terms of an equivalent unified J-inverter network as illustrated in Fig. 3(b). The J-inverter admittance in fact represents the coupling extent and its maximum peak is properly allocated near 6.85 GHz by selecting the coupling length

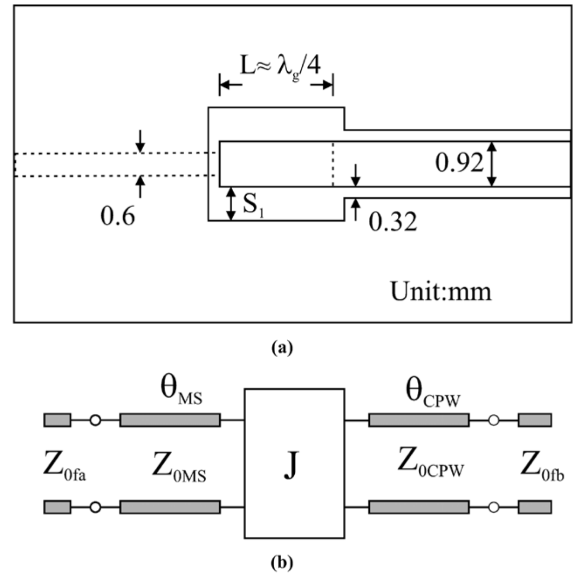

Fig. 3. Surface-to-surface microstrip/CPW coupling structure. (a) Layout. (b) Equivalent J-inverter network.

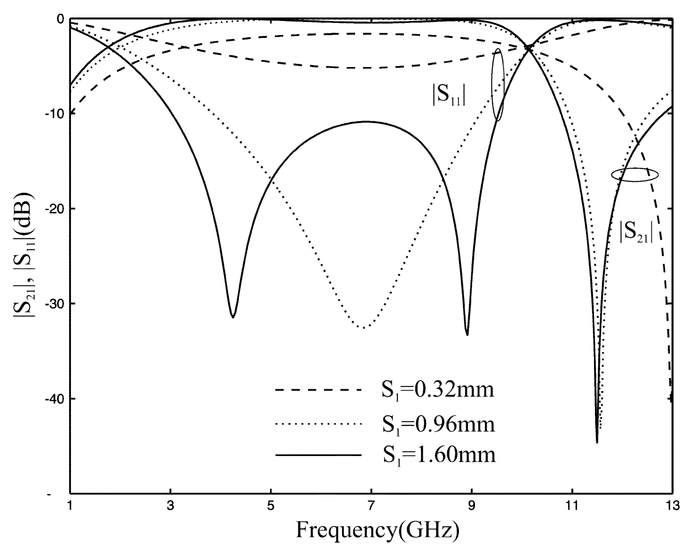

Fig. 4. Simulated S-parameters of the coupling structure in Fig. 3.

close to $L \approx \lambda_g/4$ in Fig. 3(a). Fig. 4 is the frequency-dependent S-parameters of this coupling structure under different slot widths (S_1). As S_1 is widened, the J-admittance peak is observed to rise up significantly as studied in [10]. Plus, the two quarter-wavelength resonators [9] [phases: θ_{MS} and θ_{CPW} in Fig. 3(b)], the two transmission poles can be excited in the two sides of 6.85 GHz when $S_1 = 1.60$ mm. As a result, a five-pole UWB BPF can be expected to be constructed using the above resonator and coupling elements.

Fig. 1 is the three-dimensional (3-D) schematic of the proposed hybrid microstrip/CPW UWB BPF, in which the MMR resonator on CPW is electromagnetically coupled to the two microstrip feeding lines via surface-to-surface coupling structures. Fig. 5 shows the simulated S-parameters under the two coupled strip lengths, i.e., $L = 0.06$ and 3.70 mm, in relation to the two distinct cases with very weak and optimized coupling degrees, respectively. The dashed S_{21}-magnitude in $L =$

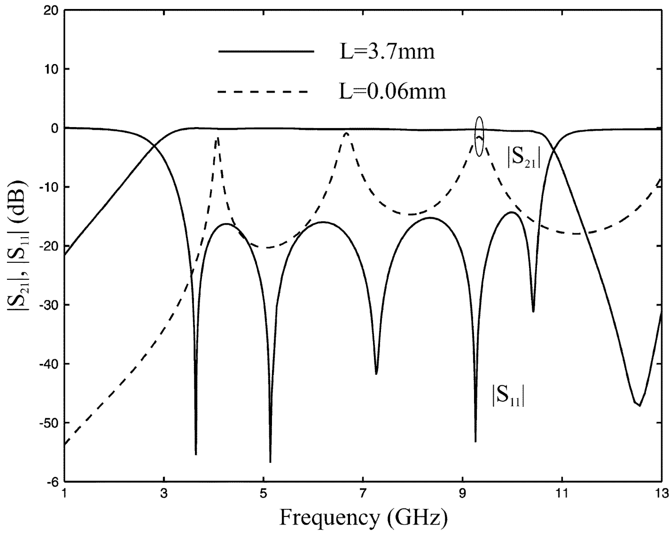

Fig. 5. Frequency responses of the proposed UWB BPF with the fixed slot with of $S_1 = 1.1$ mm and different lengths of $L = 0.06$ and 3.7 mm in the microstrip/CPW coupling sections.

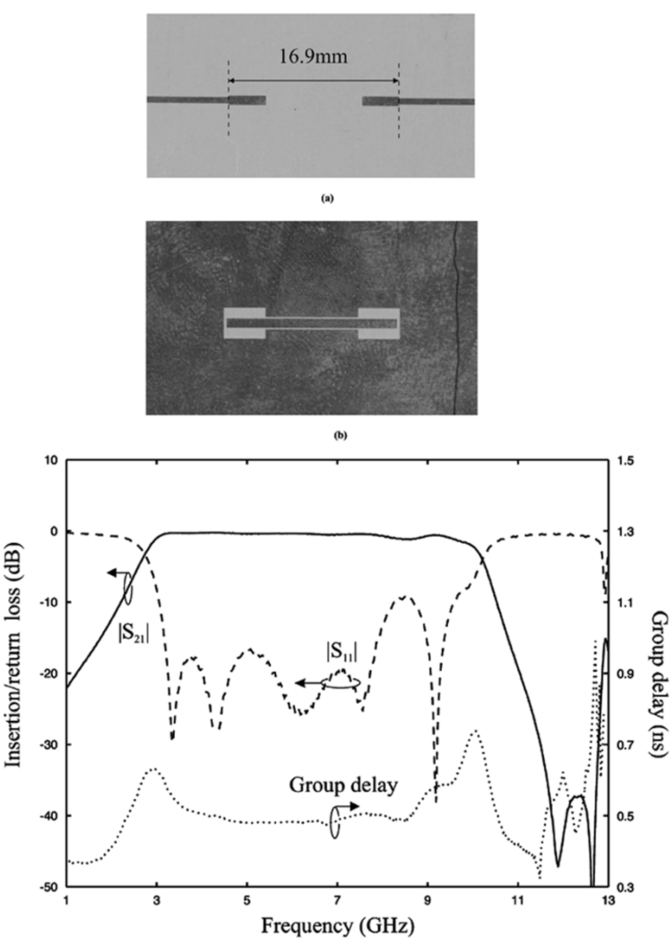

Fig. 6. Photographs and measured results of a fabricated UWB filter. (a) Top view. (b) Bottom view. (c) Measured S-magnitudes and group delay.

0.06 mm shows that the first three resonant modes of the designed MMR resonator occur at 4.13, 6.76, and 9.40 GHz, and they are quasiequally distributed within the UWB band. As L is properly strengthened to 3.7 mm, the two portions of S_{21}-magnitude among the three resonant frequencies continue to move up so as to achieve an almost flat frequency response close to the 0 dB-line over the UWB passband. Meanwhile, the S_{11}-magnitude in the UWB passband achieves higher than 13.5 dB with the five transmission poles.

III. Experimental Verification

In final, an UWB BPF is fabricated to provide an experimental verification on the above theoretically-predicted frequency response. Fig. 6(a) and (b) are the top- and bottom-view photographs of the fabricated filter blocks. The overall length of 16.9 mm is found much smaller than those reported in [3]–[6] under the condition of five poles. Fig. 6(c) depicts the measured S-parameters and group delay. Entirely speaking, the measured S-parameters are in good agreement with the predicted ones in Fig. 5 over the wide frequency range except a little high return loss of $9.2S$dB around $8.5S$GHz. The measured group delay ranges between $0.46 \sim 0.74$ ns, with the maximum variation of <0.30 ns over the UWB passband.

IV. Conclusion

In this letter, a novel UWB BPF with a hybrid microstrip/CPW structure is presented. A MMR on CPW is configured to properly excite and equally space the first three resonant frequencies within the UWB passband. In the meantime, a tightened surface-to-surface microstrip/CPW with relaxed tolerance is constructed to drive this MMR at its two sides. As such, an attractive UWB passband with five transmission poles, insertion loss of <1.0 dB, group delay of 0.46–0.74 ns are realized in theory and confirmed via experiment. In addition, the proposed UWB filter has a very small overall length of 16.9 mm that is approximately equal to one full wavelength at 6.85 GHz.

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