Tunable Notch Characteristics in Microstrip Ultra-Wideband Filters

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***Abstract*— Tunable notch characteristics are introduced in microstrip ultra-wideband (UWB) filters. The UWB design concept is based on harmonic characteristics of a half-wavelength 50Ω transmission line (at the lowest resonance frequency), which is grounded on both sides. The notch performance is first created by additional capacitive-coupled open stubs. Subsequently, these stubs are replaced by a varactor and bypass capacitors which, in combination with the biasing transmission line, provide transmission zeros in the lower stopband. The basic filter layout exhibits flexibility and compactness. Three different commercial field solvers are used to verify the overall performances of the proposed filters and their tunable notch characteristics.**

***Index Terms* — Microstrip filters, microstrip resonators, notch filters, ultra-wideband filters, varactors.**

I. Introduction

Ultra-wideband (UWB) applications attract increasing attention both in industry and academia. One of the key issues in the 3.1–10.6 GHz range is the interference from WLAN between 5 GHz and 6 GHz [1]. Therefore, general UWB filters, but especially those incorporating notch capabilities, are in demand. Several conventional UWB filter design approaches have been introduced, e.g. [2]-[4]. The introduction of tuneable harmonic stepped-impedance resonators initiated a new generation of UWB filter designs. However, the common critical issue in these approaches is their high manufacturing accuracy due to tightly coupled segments, which are required to perform over the entire bandwidth [5], [6]. Other designs, e.g. [7], focus on the utilization of defected-ground planes to enhance UWB band-stop specifications.

In order to pass the entire UWB frequency range but, at the same time, eliminate interference from other services within the band, a UWB filter is required to provide additional rejection capability in the passband. One solution to meet this specification is to utilize conventional open-ended quarter-wavelength transmission lines, which reject signals at that specific frequency [8], [9].

The aim of this paper is to present a compact UWB filter design approach in microstrip technology, which eventually leads to flexible and tunable notching capability within the passband. The design follows straightforwardly from work recently presented in [10]; however, it uses different coupling mechanisms to achieve tunability of the notch. In a separate design, this coupling is replaced by bypass capacitors and a varactor in order to provide capabilities for automatic tuning.

II. Design Procedure

The design strategy of the initial UWB filter, i.e. the one without notch characteristics, focuses on the resonance characteristic of a half-wavelength transmission line at the lowest resonance frequency. According to [10], the line is grounded on both sides. The fundamental, first and second harmonic resonances of this line are at 3.3 GHz, 6.6 GHz and 9.9 GHz, respectively, and are placed at the frequencies of reflection zeros according to a standard Chebyshev bandpass filter synthesis. The respective modes are excited by selecting the appropriate locations of input and output lines.

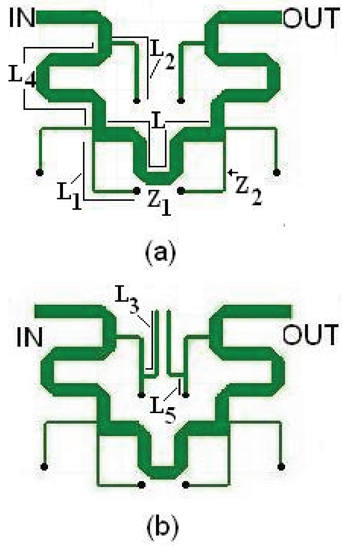

Fig. 1. Schematic views of the standard UWB filter (a) and the modification for notch filter applications (b).

Fig. 1a shows a modification of the seven-pole UWB filter originally presented in [10]. The lengths and impedance levels of the main line input and output ports as well as high-impedance lines, which are grounded at their ends, follow from [10]: length L is a half-, L_1 a quarter-wavelength at 6.6 GHz; Z_1=50Ω; Z_2≈100Ω with a minimum line width of 100μm, which is also the diameter of the vias; length L_4 is approximately a half-wavelength at 6.6 GHz. The only difference in Fig. 1a, compared to the filter in [10], is the quarter-wavelength (at 6.6 GHz) line L_2, which was formerly capacitively coupled.

A suppression (notch) band can now be created by inserting into the circuit of Fig. 1a a pair of open-ended (capacitive) coupled line sections L_3 as depicted in Fig. 1b. The length L_3 is initially determined as

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$$L_3 = (\lambda'/4) - L_5 \quad (1)$$

where λ' is the guided wavelength at the desired notch frequency. The 3dB bandwidth of the suppression (notch) region is adjusted mostly by L_5, but also slightly by L_3, which then changes in the opposite direction as the change in L_5. In addition, the reflection coefficients within the two passbands (initial UWB filter response now separated by the notch) are slightly adjusted by the gap 's' between the open-ended coupled segments of length L_3.

III. Results

This section presents a number of UWB filter designs as discussed in the previous section. The substrate material for all circuits is RT 6010 with relative permittivity of ε_r=10.2, a substrate height of 635µm and a metallization thickness of 35µm.

Fig. 2 shows a comparison of the filter in [10] and the modified UWB filter in Fig. 1a using the same structural parameters. The filter in Fig. 1a (solid lines) shows a better performance in the upper stopband. The 20dB band-stop region extends from 11 GHz to 14.15 GHz. The transmission zero at the upper roll-off moves slightly outward (about 400 MHz) for the modified UWB filter in Fig.1a. This is a result of the quarter-wavelength grounded segments L_2 and their loading impact on the main transmission line. The 3dB bandwidth is about 110 percent (3–10.4 GHz) to cover almost the entire UWB frequency range.

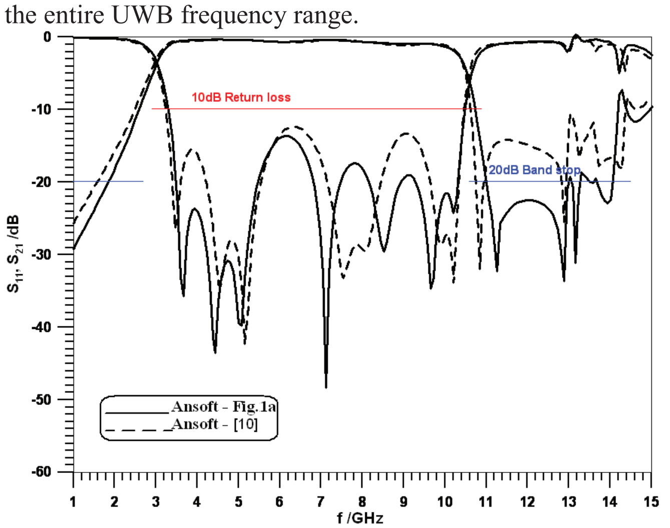


Fig. 2. Performances comparison between the UWB filter in [10] and that in Fig. 1a.

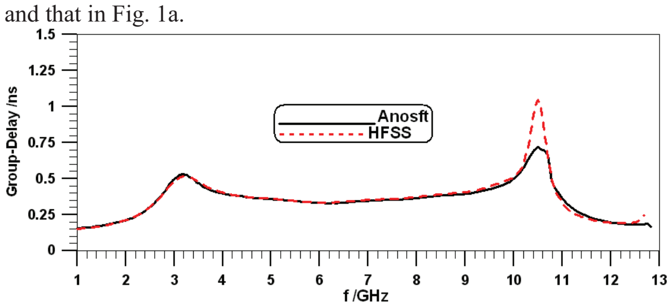
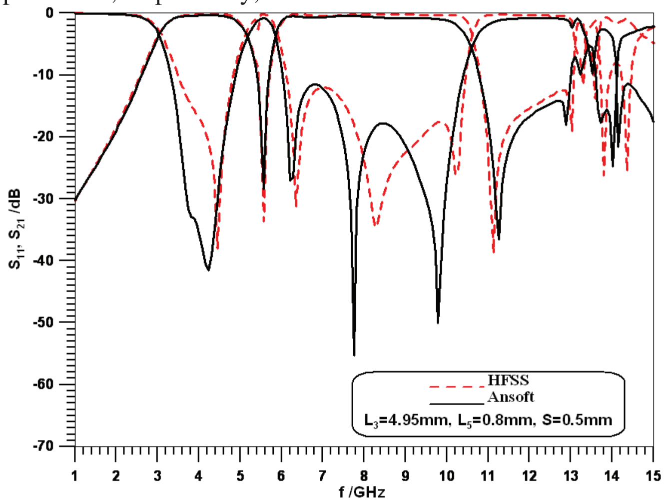


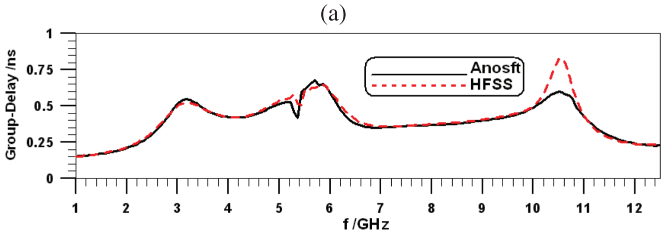
Fig. 3. Group delay performance for the UWB filter in Fig. 1a.

Fig. 3 shows the group delay response of the filter in Fig. 1a, confirmed by HFSS and Ansoft designer, and demonstrates its variation within the passband to be less than 200ps. Note that the dimensions of the filter structure in Fig. 1a are only 11mm x 8mm.

Fig. 4a displays the performance of the notched UWB filter shown in Fig. 1b, which is obtained only by adding the open-ended coupled-line sections L_3. According to (1), they add a stopband at 5.6 GHz to the UWB filter presented as solid lines in Fig. 2. The notched 3dB bandwidth in Fig. 4a is 800MHz, covering the frequency range from 5.2 GHz to 6 GHz, and the maximum attenuation is 30 dB. Other than that, the performance of the filter in Fig. 4a is similar to that in Fig. 2. From the filter's group delay performance in Fig. 4b, variations less than 100 ps and 200 ps for the first and second passbands, respectively, are observed.



(a)



(b)

Fig. 4. Scattering parameters (a) and group delay (b) of the proposed notched UWB filter in Fig. 1b.

TABLE I
VARIATION OF THE CENTER FREQUENCY OF THE NOTCHED BAND WITH PARAMETER L_3

L_3 (mm)	Notch frequency (GHz)
5.35	5.05
5.15	5.40
4.95	5.60
4.75	5.85
4.55	6.05

For the filter in Fig. 4, Table I shows the variation of the notched centre frequency in terms of the open-ended coupled section length L_3. Other parameters are L_5=0.8mm and s=0.5mm, where s is the spacing between the lines of length L_3.

Fig. 5 displays the filter performances based on the parameter variations in Table I. Upon change of the length L_3 from 5.35 mm to 4.55 mm, the notched centre frequency moves from 5.05 GHz to 6.05 GHz, but the 3dB bandwidth of the notched band remains approximately constant (about 800MHz) when compared with the filter in Fig. 4a. On the other hand, the attenuation in the upper bandstop region decreases with decreasing centre frequency of the notch.

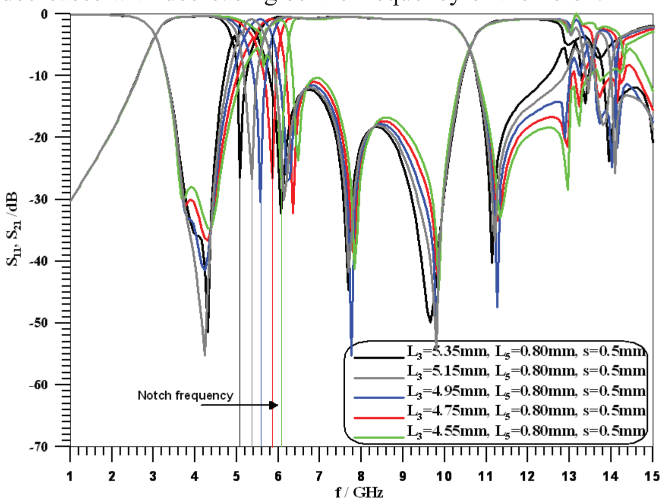


Fig. 5. Performances of the notched UWB filter in Fig. 1b in terms of varying length L_3 (Ansoft Designer).

In addition, the 3dB bandwidth of the notched band for the filter in Fig. 4 can be adjusted by length L_5 and a slight opposite change of length L_3 as depicted in Table II. Note that the spacing s between the lines of length L_3 are kept at s=0.5mm.

TABLE III
VARIATION OF THE 3DB NOTCH BANDWIDTH WITH PARAMETERS L_3 AND L_5

L_3 (mm)	L_5 (mm)	3dB Notch Bandwidth (GHz)
4.8	1.25	1.0
4.95	0.8	0.8
5	0.6	0.6
5.05	0.4	0.4

Fig. 6 shows the performances of the notched UWB filter in Fig. 4 based on the parameter variations in Table II. The 3dB bandwidth extends from 400 MHz to 1 GHz as only two parameters (L_3 and L_5) change, but the centre frequency of the notch remains at 5.6 GHz. The return loss in the upper passband decreases with length L_5 or, in other words, as the bandwidth of the notch increases. The attenuation in the upper bandstop region increases as the 3dB notch bandwidth decreases. Note that the dimensions of the aforementioned notched UWB filter remain the same as those of the filter in Fig. 2.

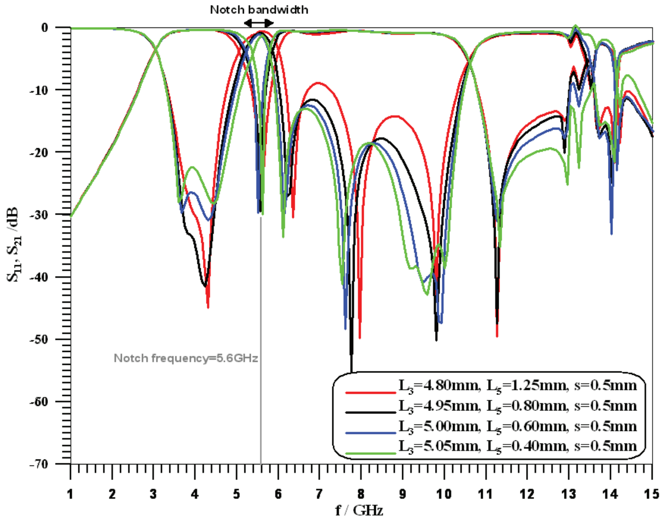


Fig. 6. Performances of the notched UWB filter in Fig. 1b in terms of varying lengths L_5 and L_3 (Ansoft Designer).

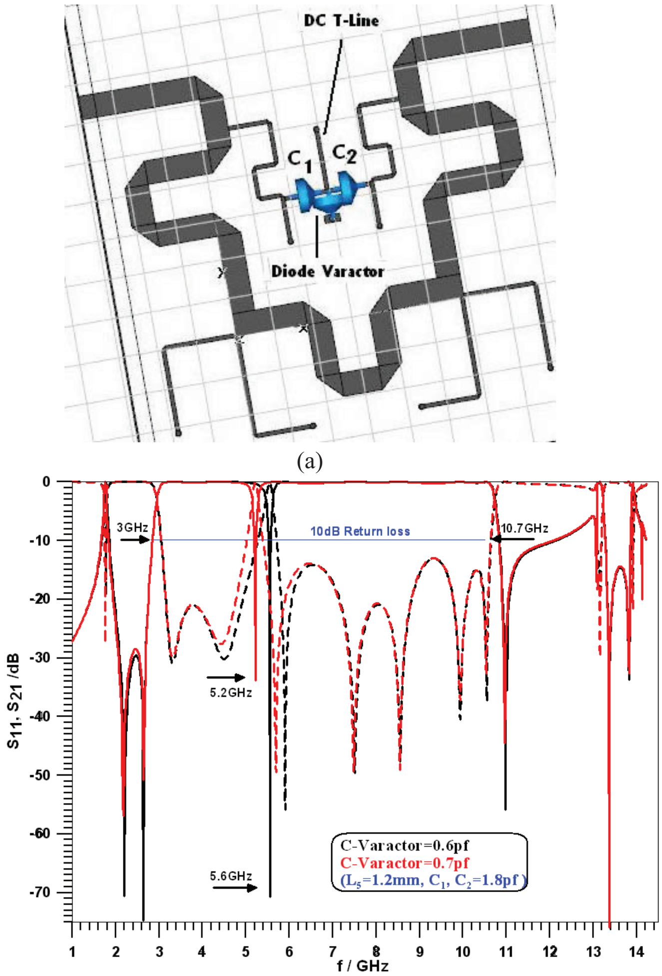


Fig. 7. New UWB filter with varactor-tuneable notch characteristics (a) and its performances from CST MWS (b) for two varactor capacitances (C_1=C_2=1.8pF, L_5=1.2mm).

Finally, the design proposed in Fig. 1b can be extended to include an electronically tunable notch filter. Fig. 7a shows the circuit layout using a varactor rather than the capacitive-coupled lines of length L_3. Due to the biasing of the varactor, bypass capacitors C_1 and C_2 are utilized to isolate the DC section. The bias is applied to the varactor through the substrate, and the related power supply provides an RF short to the biasing line.

The new configuration in Fig. 7a is compact, and the notch frequency can be tuned via DC biasing. Of course, the latter cannot be achieved by the design in Fig. 1b with a predefined length and gap between lines L_3, unless these parameters change for a new design. Similar to Fig. 1b, the notch bandwidth for the circuit in Fig. 7a varies with lines L_5.

Fig. 7b shows the performance of the new UWB filter with tuneable notch characteristics. The notch frequency changes from 5.6 GHz to 5.2 GHz when the varactor capacitance changes between 0.6pF and 0.7pF; the bypass capacitors and length L_5 are selected as 1.8pF and 1.2mm, respectively. The 3dB notch bandwidth remains at approximately 200 MHz. Another advantage of the tuneable filter configuration in Fig. 7a is the existence of two additional transmission zeros at the lower edge of the first passband which appear at 2.2 GHz and 2.6 GHz in Fig. 7b. They are attributed to the bypass capacitors which provide bypass coupling to the resonators. The disadvantage of this design is the appearance of a very narrow passband around 1.8 GHz due to the RF-shorted DC bias transmission line.

IV. CONCLUSIONS

Tunable or fixed notch characteristics are introduced in microstrip UWB filters. The filter design approach is based on the harmonic characteristics of a full-wavelength (at midband frequency) 50 Ω transmission line, which is grounded at both ends, and shorted quarter-wavelength segments along with half-wavelength main lines. The latter not only creates extra reflection zeros within the passband in order to extend bandwidth but also an attenuation pole in the upper stopband region. Additional open-ended coupled sections create a tuneable suppression band to eliminate unwanted wireless services. The characteristics of the proposed tuneable notched UWB filter with passive or varactor components allow not only fine adjustment of the notched centre frequency but also its bandwidth. The overall performance of the notched UWB filter displays lower-edge stopband enhancement. Moreover, its size is compact and it can be integrated with minimum fabrication cost. All filter designs show satisfactory performances, which are verified by using three different commercially available field solver packages.

ACKNOWLEDGEMENT

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