Ultra-Wideband and Notched Wideband Filters With Grounded Vias in Microstrip Technology

Marjan Mokhtaari and Jens Bornemann
Department of Electrical and Computer Engineering, University of Victoria
Victoria, BC, Canada V8W 3P6
marjan@uvic.ca

Introduction

Microwave filter designs have been at the forefront of research in both industry and academia due to increasing specification levels and demand for advanced communication systems. Among other emerging technologies, wireless ultra-wideband (UWB) applications have drawn considerable attention since the release of the 3.1 to 10.6 GHz frequency band [1]. Planar UWB microstrip filters, which possess compact size, low cost, flexible layout and easy fabrication, are preferably integrated in low power transceiver systems.

Conventional procedures on the design of UWB filters have been discussed in many references, e.g. [2] – [4]. The introduction of tunable harmonic stepped-impedance resonators initiated a new generation of UWB filter designs. However, this process requires high manufacturing accuracy between coupled segments in order to cover the entire band [5]. Recent designs focus on the utilization of defected-ground planes to enhance out-of-band characteristics, e.g. [6].

Another frequently addressed issue in UWB filter synthesis is the creation of a narrow stopband to eliminate interference from other services such as WLAN. In this case, a UWB filter is required to provide rejection capability in a band from 5 to 6 GHz [1]. One solution to this specification is to employ open-ended quarter-wavelength transmission lines which provide appropriate rejection at that specific frequency range [7] – [8].

In this paper, simple designs of UWB filters, with and without notching capability, are presented in microstrip technology. Section II describes the design procedures along with the proposed configurations. Section III reports the performances of the proposed filters and their verification using various electromagnetic-(EM)-field-based modeling tools.

Design Strategy

The design concept of the new UWB filters is based on the resonance characteristic of a half-wavelength (at fundamental resonance) transmission line, which is grounded on both sides. The fundamental, first and second harmonic resonances of this line at approximately 3, 6 and 9 GHz, respectively, are placed at the frequencies of reflection zeros according to Chebyshev bandpass filter synthesis. This is achieved by properly selecting the locations to excite the modes on the employed line.

Fig. 1 shows the schematic view of a three-pole UWB filter. The lengths L and L_1 are half and a quarter of the wavelength at the center frequency at $f_0 \approx 6$ GHz, respectively, so that the entire length ($L+2L_1$) forms a full-wavelength grounded transmission line at center frequency. The impedance Z_2 of the main transmission line between input and output is selected as 50 Ω at the center frequency. The folded high-impedance segments, which are connected to ground at their ends, have an impedance of $Z_1=100$ Ω in order to match with the folded center transmission line and to accomplish a compact size. The minimum width for the high-impedance segments is selected as 100 μm. This limit is reached if a substrate with higher permittivity is used that would require a 100-Ω-width smaller than 100 μm. In that case also the impedance of the folded center line (L) of the grounded resonator will approach

978-1-4244-2642-3/08/$25.00

a value slightly smaller than 50 Ω. However, the input and output lines remain at 50 Ω. In order to keep fabrication expenses low, the diameter of the vias is always assumed to equal the line width of the high-impedance sections (L_1).

In order to extend the bandwidth, additional resonators must be employed. Fig. 2a displays the same UWB filter structure as in Fig. 1, but with added, capacitively coupled quarter-wavelength sections L_2 (shown in Fig. 2b) and with approximately half-wavelength 50 Ω transmission lines (L_4), both at center frequency (6.4 GHz). Thus lengths L_4 operate as quarter-wavelength impedance inverters at 3.2 GHz and as half-wavelength resonators at 6.4 GHz. The impedance values of the coupled sections (L_2) are selected similar to those of the folded high-impedance segments (L_1) in Fig. 1. The reflection coefficient and bandwidth within passband are adjusted mostly by lengths L_4, but also by L_5 and the gap s between the capacitively coupled segments, which are connected to ground on the same sides.

The proposed UWB filter in Fig. 2a is flexible and can be converted to a UWB filter with a suppression (notch) band centered at 5.6 GHz. This is achieved by a pair of open-ended coupled lines L_3 depicted in Fig.2b. The length L_3 is approximately defined as $L_3 = (\lambda'/4) - L_5$ where λ' is the guided wavelength at 5.6 GHz.

Results

This section presents designs of the three filter variants discussed in the previous section. The substrate material is selected as RT 6010 with relative permittivity ε_r=10.2, a substrate height of 635 μm and a metallization thickness of 17 μm.

Fig. 3a shows the performance of the UWB filter in Fig. 1. This simulated performance is independently verified by three different EM packages, Ansoft Designer, IE3D and CST Microwave Studio. The 3dB bandwidth is 102 percent, covering the range from 3.1GHz to 9.5 GHz. The simulated insertion loss within the passband is less than 1dB. The transmission zero appearing at 12.5 GHz is due to the fact that the input/output placements along the grounded transmission-line resonator create an out-of-phase feeding scenario similar to that discussed in [9]. It occurs at a frequency for which one of the ports is assumed to be open. This means that length L_1 is equal to half a wavelength at the transmission zero frequency, which is approximately twice the center frequency of f_0=6.3 GHz. The 20dB stopband region extends from 11.5 GHz to 13.2 GHz. The slight additional bandwidth obtained at the upper band edge from IE3D is due to the utilization of a different configuration of vias available in IE3D. Fig. 2b displays the group-delay performance. Its variation is less than 50 ps within the passband. The dimensions of the entire filter structure are compact (7 mm × 5 mm) as shown in the inset of Fig. 3a.

Fig. 4a shows the reflection and transmission performances of the filter in Fig. 2a. Compared with the response of the filter in Fig. 3, Fig. 4a shows an extended bandwidth of 7.4 GHz (or 110 percent) to cover almost the entire ultra-wide band. The 3dB bandwidth extends from 3 GHz to 10.4 GHz. The four additional reflection zeros in the passband (compared to Fig. 3a) are due to the quarter-wavelength coupled sections (L_2) as well as the 50 Ω half-wavelength lines (L_4), which act as inverters in the lower passband and as a resonator at around center frequency. The sharp transmission zero at the upper edge of the passband at 10.8 GHz results from the center-coupled segments, which are grounded on the same sides. The 10 dB stopband region extends from 10.6 GHz to 14.4 GHz. Ansoft Designer, HFSS and Sonnet confirm the filter performance. The slight shift of the upper edge transmission zero in Sonnet is due to a less accurate mesh size due to the maximum available memory. Fig. 4b shows the group delay response and demonstrates its variation within the passband to be less than 200ps. Note that the dimensions of the entire filter structure are only 11mm × 8mm.

The last example is schematically shown in the inset of Fig. 5a. Only by adjusting the open-ended coupled-line sections L_3 according to Fig. 2b, it adds a stopband at 5.6 GHz to the UWB filter structure used in Fig. 4. The 3dB bandwidth of the stopband region is 1 GHz, covering the frequency range from 5 GHz to 6 GHz. Note that otherwise, the performance for the filter in Fig. 5a is very similar to that in Fig. 4b, especially in the lower and upper stopbands. And the passband return loss is slightly better, except at the lower edge of the second passband. This can be improved by also adjusting the other parameters in the filter structure. In this design, they were not changed – only the center open-ended stubs were added. Three different EM packages confirm the performance of the proposed notched UWB. The slight shift of the location of the notched frequency and upper-edge transmission zero in Sonnet are again attributed to limited available memory. The group delay performance in Fig. 5b shows that the phase variations are less than 100 ps and 250 ps for the first and second passbands, respectively.

Acknowledgements: The work is supported by the Natural Sciences and Engineering Research Council of Canada and the TELUS Research Grant in Wireless Communications.

References

[1] Federal Communications Commission (FCC), Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, First Report and Order, FCC 02-48, 2002

[2] G.L. Matthaei, L. Young, E.M.T. Jones, Microwave Filters, Impedance Matching Networks and Coupling Structures, New York: McGraw-Hill, 1964.

[3] R. Gómez-García, J.I. Alonso, “Systematic method for the exact synthesis of ultra-wideband filtering responses using high-pass and low-pass sections”, IEEE Trans. Microwave Theory and Tech., Vol. 54, pp. 3751-3764, Oct. 2006.

[4] H. Ishida, K. Araki, “Design and analysis of UWB bandpass filter with ring filter”, IEEE MTT-S Int. Microwave Symp. Dig., pp. 1307-1310, Fort Worth, USA, June 2004.

[5] H. Wang, L. Zhu, “Aperture-backed microstrip line multiple-mode resonator for design of a novel UWB bandpass filter”, Proc. Asia Pacific Microwave Conf., Vol. 1, 4p , Suzhou, China, Dec. 2005.

[6] G.-M. Yang, R. Jin, C. Vittoria, V. G. Harris, N. X. Sun, “Small ultra-wideband (UWB) bandpass filter with notched band”, IEEE Microwave Wireless Components Lett., Vol. 18, pp. 176-178, Mar. 2008.

[7] H. Shaman, J.-S. Hong, “Ultra-wideband (UWB) bandpass filter with embedded band notch structures”, IEEE Microwave Wireless Comp. Lett., Vol. 17, pp. 193-195, Mar. 2007.

[8] K. Li, D. Kurita, T. Matsui, “UWB bandpass filters with multi notched bands”, Proc. 36th European Microwave Conf., pp. 591-594, Manchester, UK, Sep. 2006.

[9] M. Mokhtaari, J. Bornemann, S. Amari, “New reduced-size step-impedance dual-band filters with enhanced bandwidth and stopband performance”, 2006 IEEE MTT-S Int. Microwave Symp. Dig., pp. 1181-1184, San Francisco, USA, June 2006.

Figures

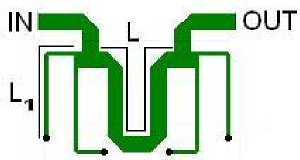

Figure 1. Schematic view of a three-pole UWB microstrip filter with vias.

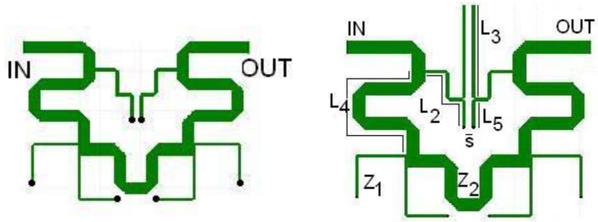

Figure 2. Seven-pole UWB filters without (left) and with a notch band (right).

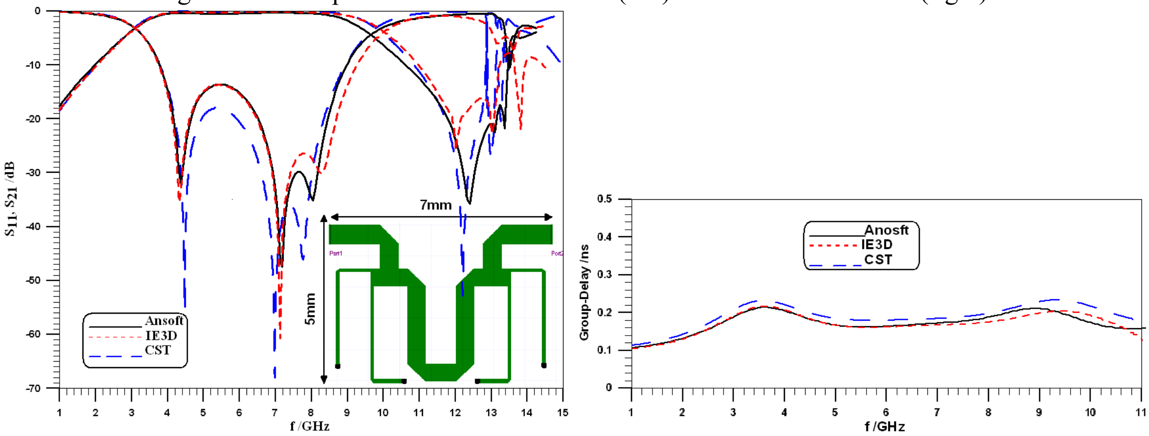

Figure 3. Performance of a three-pole UWB filter (Fig. 1): S parameters (left); group delay (right).

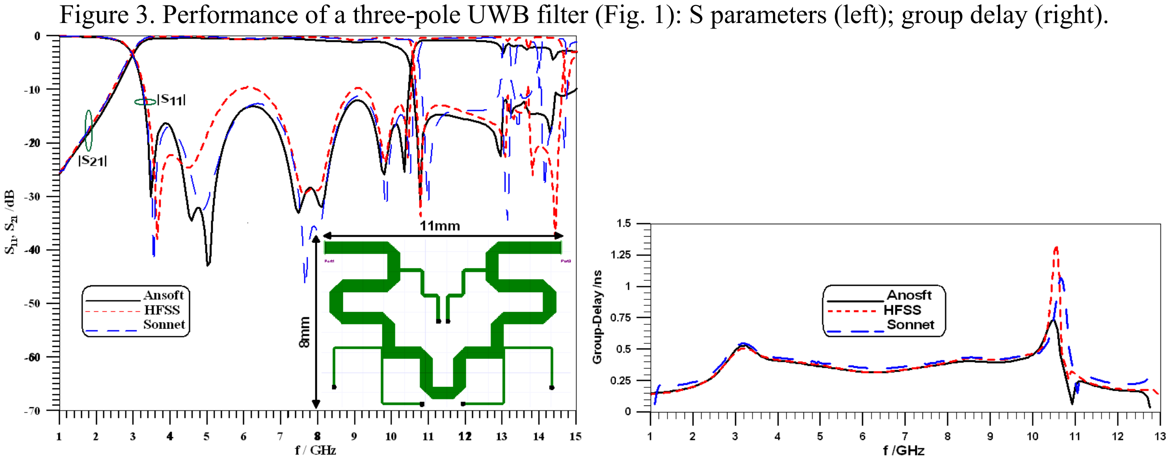

Figure 4. Seven-pole UWB filter (Fig. 2a): S parameters (left); group delay (right).

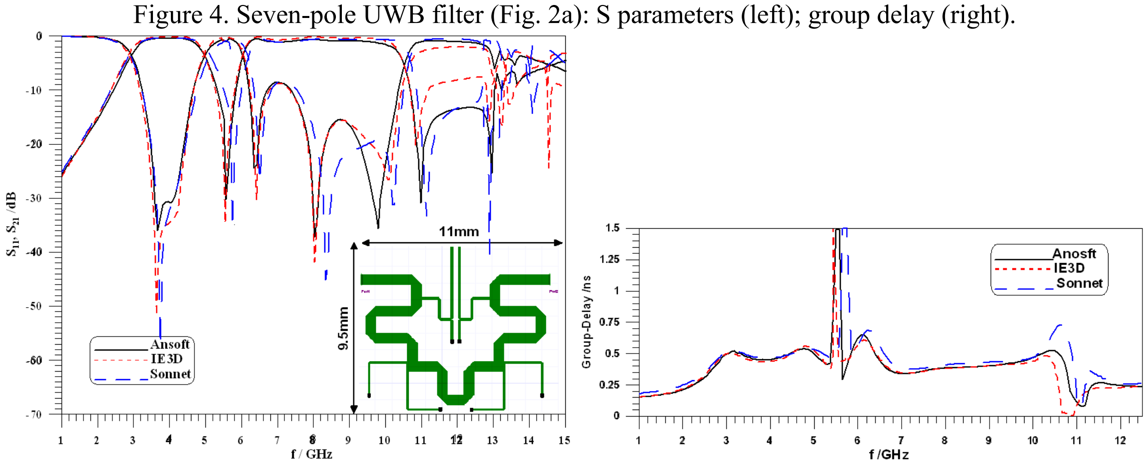

Figure 5. Performance of the notched UWB filter (Fig. 2b) with stopband at 5.6GHz: S parameters (left); group delay (right).