UWB Bandpass Filter with Wide Stopband Using Lumped Coupling Capacitors

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***Abstract* —This paper introduces an improved performance ultra-wideband bandpass filter by using lumped capacitors as an external coupling to stepped impedance DGS lowpass filter structure. The filter has a passband from 3.1 to 10.6 GHz and a wide stopband up to more than 20 GHz. Insertion loss less than 0.6 dB. The filter has a length of just 13 mm. The experimental results agree well with the predicted ones.**

***Index Terms* — Bandpass filter, DGS filter, microstrip filter, UWB filter.**

I. INTRODUCTION

Ultra wideband (UWB) wireless communication systems with 3.1-10.6 GHz frequency band have gained an increased interest in recent years [1], they are characterized by higher data rates and lower transmitted power. Filters represent an essential component of such systems. Various filter structures have been proposed in the literature, e.g. [2]-[12]. The combination of a lowpass and a highpass filters is a classical structure for such kind of filters [2], [3]. It occupies, however, a large area, which may increase the losses of the filter. In [4], an UWB filter was built by cascading various ring filters, while, in [5] and [6], UWB filters were designed using multi-mode resonators. An UWB filter introduced in [7] was designed by employing quasi lumped microstrip resonators built on both sides of the substrate. Recently, ultra-wideband bandpass filters have been designed by using low-pass filters structures capacitively coupling to the I/O ports [9], [10]. In [11] an ultra wideband bandpass filter has been introduced using a lowpass filter structure where the frequencies lower than 3.1 GHz are attenuated using quarter wavelength stubs connected to the ground by via holes. Fabrication of such a structure is however complex due to the used via holes.

Increasing the coupling between the UWB filter structure and the I/O ports has been always an important issue. In [8] an interdigital coupling structure was proposed. A compact UWB bandpass filter using this coupling structure was presented in [9], however, the size of the interdigital coupling structure has enlarged the overall filter. In [6], [7], and [10] broadside coupling has been used to inherent the capacitive coupling between the filter structure and the I/O ports.

The quasi lumped element based on the defected ground structures (DGSs) have been proposed to improve the rejection in the stopband of lowpass filters (LPF) [13]-[18]. On the other hand lumped capacitors are used in filter application mainly for minimizing the size of the resonators, and for tuning their resonant frequencies, e.g. [19] and [20].

In this paper, an ultra wideband bandpass filter is presented. The filter is realized by coupling a DGS lowpass filter capacitively to the I/O ports by using a ceramic multilayer capacitor. The filter is built on an RT Duroid RO4003 substrate with a thickness of 0.813 mm and a relative dielectric constant ε_r of 3.38.

II. FILTER DESIGN

To design the ultra wideband bandpass filter with a frequency range from 3.1 to 10.6 GHz using a lowpass filter [9], [10], two steps are necessary: We firstly design a low-pass filter with a cut-off frequency of 10.6 GHz as shown in Fig. 1.

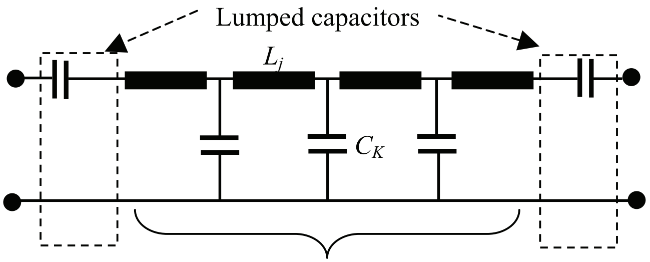

Fig.1. UWB filter using coupled lowpass filter

In general, the cut-off frequency of the low-pass filter can be adjusted by setting proper values of the lumped elements of the filter [21].

The shunt capacitive elements of the filter are realized by short sections of low-impedance transmission lines. The low impedance sections are implemented by using wide patches. Characteristic impedance Z_o and effective dielectric constant ε_{reff} of these transmission lines can be determined using a commercial simulator [18]. The transmission line lengths l_k of the filter capacitive elements, assumed to be much shorter than the wavelength, are calculated from

$$C_k = \frac{l_k}{Z_{ok}.v_{ph,k}}, \tag{1}$$

Series inductances are realized by DGS sections.

The DGS is modelled as a parallel LC resonant circuit [17], where the circuit elements are given by:

$$C_p = \frac{5f_c}{\pi\left(f_p^2 - f_c^2\right)}pF, L_p = \frac{250}{C_p\left(\pi f_p\right)^2}nH \tag{2}$$

where f_c and f_p (given in GHz) are the 3 dB cut-off frequency and the corresponding pole of the DGS, respectively. These are obtained from the simulated response of a DGS circuit element [17]. At any frequency $f < f_p$, the parallel circuit behaves as an inductor and its value in nH is

$$L_j = \frac{L_P}{\left[1-\left(\frac{f}{f_p}\right)^2\right]} \tag{3}$$

where the indices k and j correspond to elements with capacitive and inductive character, respectively. C_k and L_j are the capacitance and inductance of the equivalent circuit of the filter. The phase velocity is calculated by

$$v_{ph,k} = \frac{c}{\sqrt{\varepsilon_{eff}}} \tag{4}$$

By determining all filter components, the lowpass filter can be combined, however, some optimization can be done to take into account the involved discontinuities and to achieve good matching in the passband.

The second step is to suppress transmission in the frequency band below 3.1 GHz. This has been done using an interdigital coupling structure [9], and by overlapping a section of the original input and output lines of the low-pass filter by new input and output lines on the other side of the substrate [10]. These coupling sections, however, occupy large area; therefore we have replaced these structures by a ceramic multilayer capacitor with SMD termination. The capacitor itself has dimensions of 0.8 mm in length and 0.5 mm in width, and capacitive value of 1 pF [22].

III. EFFECT OF CAPACITANCE ON LPF RESPONSE

To study the effect of the capacitance value on the performance of the filter, four different values of the capacitances, i.e., 0.7, 0.9, 1.3, and 1.7 pF, are used to couple the LPF to the I/O ports. Fig. 2 shows the simulated filter response for different coupling capacitance values. By increasing the capacitance values, the coupling is increased owing to an improvement in the passband matching and shifts the cut-off frequency to a lower frequency. For capacitance values less than 0.5 pF, the simulated response of the UWB filter is not satisfactory due to weakness in the coupling between the LPF and I/O ports, as shown in Fig. 3.

From the above analysis 1 pF capacitor was chosen as it is suitable for our application, in which compromising between the required bandwidth and matching within the passband should be done.

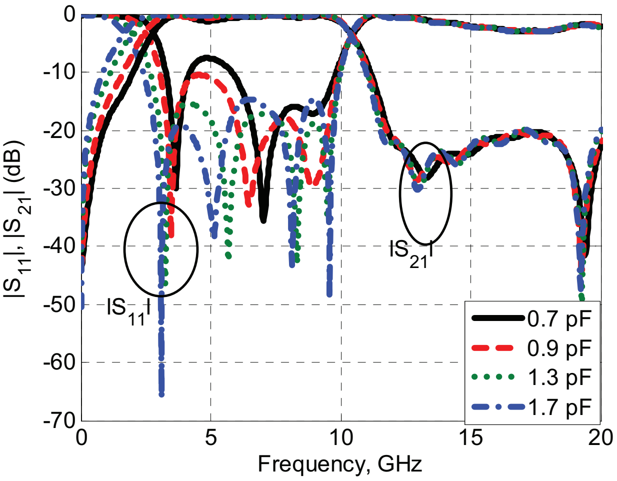

Fig. 2. S_{11} and S_{12} at four coupling capacitance values: 0.7, 0.9, 1.3, and 1.7 pF.

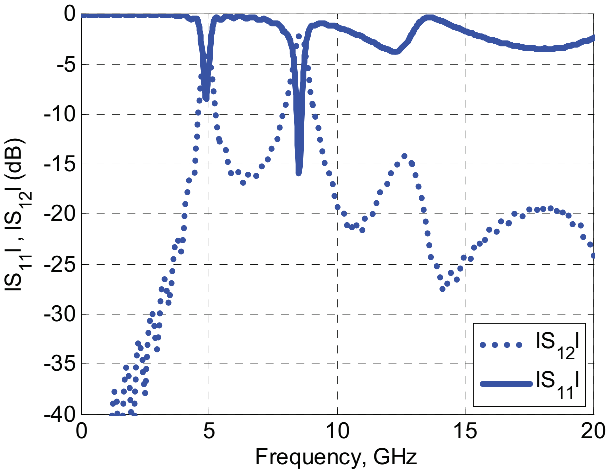

Fig. 3. Simulated insertion and return loss of the 0.1pF capacitor.

III. EXPERIMENTAL RESULTS

The proposed filter has been optimized, fabricated, and measured. Fig. 4 shows the top and bottom layout and its dimensions of the simulated filter structure, while, Fig. 5 shows the photograph of the fabricated structure. The measured and simulated insertion and return loss of the filter are shown in Fig. 6. The maximum insertion loss within the passband is better than 0.6 dB. The filter has a stopband attenuation better than 20 dB up to 20 GHz. Fig. 7 shows the group delay of the filter within the passband with a maximum variation less than 0.1 ns.

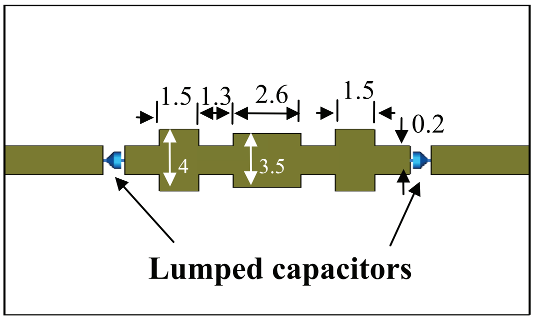

Fig.4.a. layout of the proposed microstrip UWB filter (top view), all dimensions are in mm .

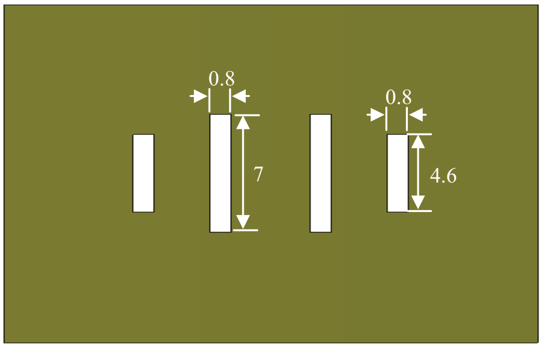

Fig. 4.b. layout of the proposed microstrip UWB filter (bottom view), all dimensions are in mm .

VI. CONCLUSION

An improved performance ultra wideband bandpass filter has been presented. This filter has been designed by coupling a DGS lowpass filter to the I/O ports using surface mounted capacitors, to minimize the size of the filter. The coupling capacitor value affects the performance of the filter and controls the lower cutoff frequency. A wide stop-band with a rejection higher than 20 dB up to 20 GHz has been achieved.

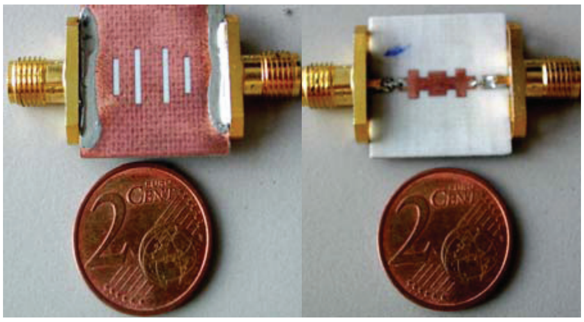

Fig. 5. Photograph of the fabricated UWB filter

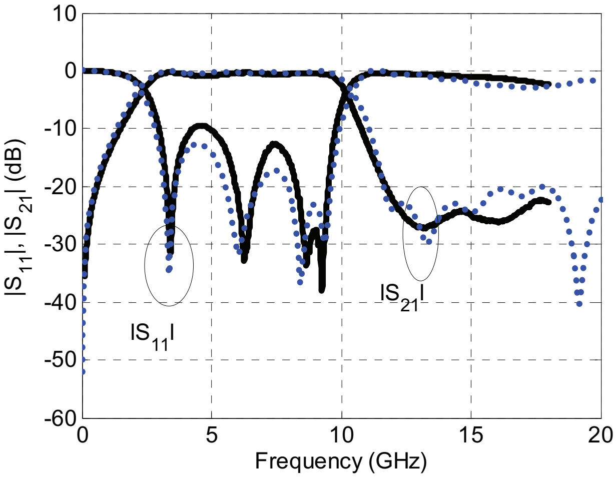

Fig. 6. Simulated (dashed) and measured (solid) insertion and return loss of the UWB filter.

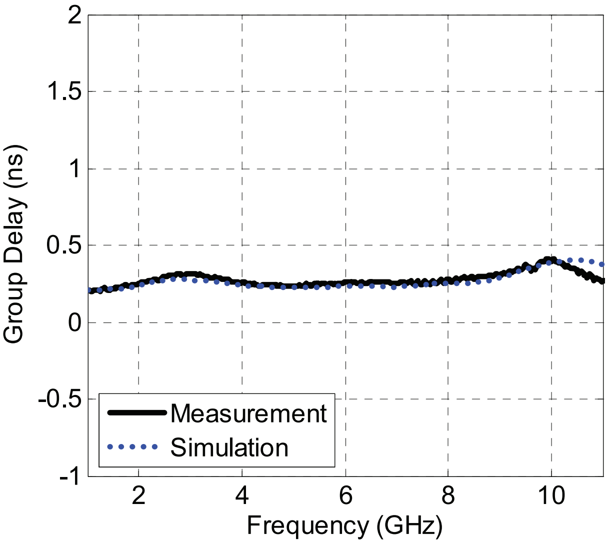

Fig. 7. Measured and simulated group delay of the UWB filter.

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REFERENCES

[1] Federal Communication Commission, “Revision of part 15 of the commission’s rules regarding ultrawideband transmission systems,” *Tech. Rep, ET-Docket* 98-153, FCC02-48, Apr. 2002

[2] W. Menzel, M. S. Tito, and L. Zhu, ‘‘Low-loss ultra-wideband (UWB) filters using suspended stripline,’’ *Asia-Pacific Microw. Conf. APMC.* Suzhou, China, pp. 2148-2151, Dec. 2005.

[3] Y. S. Lin, W. C. Ku, C. H. Wang, and C. H. Chin, ‘‘Wideband coplanar-waveguide bandpass filters with good stopband rejection,’’ *IEEE Microw. Wireless Compon. Let.*, Vol. 14, No. 9, pp. 422-424, sep. 2004.

[4] H. Ishida, and K. Araki, ‘‘Design and analysis of UWB bandpass filter with ring filter,’’ *2004 IEEE MTT-S Int. Symp. Dig.*, pp.1307-1310, June 2004.

[5] L. Zhu, S. Sun, and W. Menzel, ‘‘Ultra-wideband (UWB) bandpass filter using multiple-mode resonator,’’ *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 11, pp.796-798, Nov 2005.

[6] H. Wang, L. Zhu, and W. Menzel, ‘‘Ultra-wideband bandpass filters with hybrid microstrip/CPW structure,’’ *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 12, pp. 844-846, Dec. 2005.

[7] T. N. Kuo, S. C. Lin, and C. H. Chen, “Compact ultra-wideband bandpass filters using composite microstrip-coplanar-waveguide structure,” *IEEE Trans. on Microwave Theory and Techniques*, Vol. 54, No.10, pp. 3772-3778, Oct. 2006.

[8] S. Sun, and L. Zhu, ‘‘Capacitive-ended interdigital coupled lines for uwb bandpass filters with improved out-of-band performances,’’ *IEEE Microwave and Wireless Components Letters,* Vol. 16, No. 8, pp. 440-442.

[9] S.Sun, L.Zhu, ‘‘Multimode-resonator-based bandpass filters,’’ *IEEE Microwave Magazine*, Vol. 10, No. 2, pp. 88-98, Apr. 2009.

[10] A. Balalem, W. Menzel, J. Machec, A. Omar, ‘‘A simple ultra-wideband suspended stripline bandpass filter with very wide stop-band,’’ *IEEE Microwave and Wireless Components Letters*, Vol. 18, No. 3, pp. 170-172, March 2008.

[11] R. Li, and L. Zhu, ‘‘Compact UWB bandpass filter using stub-loaded multiple-mode resonator,’’ *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 1, pp. 40-42, Jan 2007.

[12] M. Uhm, K. Kim, and D. S. Filipovic, ‘‘ Ultra-wideband bandpass filter using quarter-wave short-circuited shunt stubs and quarter-wave series transformers,’’ *IEEE Microwave and Wireless Components Letters,* Vol. 18, No. 10, pp. 668-670, Oct. 2008.

[13] D. Ahn, J.S. Park, C.S. Kim, J. Kim, Y. Qian and T Itoh, “A design of the low-pass filter using the novel microstrip defected ground structure”, *IEEE Trans. Microwave Theory Tech.,* vol.49, n0.1, pp. 86-93,Jan. 2001.

[14] F.R. Yang, Y. Qian and T. Itoh, “ A novel uniplanar compact PBG structures for filter and mixer applications”, *IEEE Microwave Theory Tech. Symposium,* MTT (S)-1999.

[15] J. S. Yun, G. Y. Kim, J.S. Park, D. Ahn, K. W. Kang and J. B. Lim,“ A design of the novel coupled line bandpass filter using defected ground structure”, *IEEE Microwave Theory Tech. Symposium,* MTT(S)-2000.

[16] F.R. Yang, R. Coccioli, Y. Qian and T. Itoh, “Analysis and application of coupled microstrips on periodically patterned ground plane”, I*EEE Microwave Theory Tech. Symposium,* MTT (S)-2000.

[17] A. Abdel-Rahman, A. K. Verma, A. Boutejdar and A. S. Omar, “Control of Band Stop Response of Hi- Low Microstrip Lowpass Filter Using Slot in Ground Plane”, *IEEE Trans. Microwave Theory Tech.,* vol. 52, No. 3, pp. 1008-1013, Mar. 2004.

[18] Computer Simulation Technology MICROWAVE STUDIOTM, Version –5.

[19] M. Makimoto, and M Sagawa, ‘‘Varactor tuned bandpass filter using microstrip-line ring resonators,’’ *1986 IEEE MTT-S Digst, Int. Microw. Sypo* .June 1986, pp.411-414.

[20] X. H. Wang, B. Z. Wang, H. Zhang, and K. J. Chen, ‘‘A tunable banstop resonator based on a compact slotted ground structure,’’ *IEEE Transaction on Microwave Theory and Techniques,* Vol. 55, No. 9, pp. 1912-1918.

[21] G. Matthaei, L. Young, and E. M. T. Jones, Microwave Filters, Impedance-Matching and Coupling Structures. Norwood, *MA: Artech House*, 1980.

[22] Newark Co. Data sheet for 30K5556 Ceramic Multilayer capacitor,*www.Newark.com.*