

Copyright © 2006 IEEE

Reprinted from
IEEE Microwave and Wireless Components Letters, Vol. 16, No. 3, March 2006

This material is posted here with permission of the IEEE. Such permission of the IEEE does not in any way imply IEEE endorsement of any of Universität Ulm's products or services. Internal or personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution must be obtained from the IEEE by writing to pubs-permissions@ieee.org.

By choosing to view this document, you agree to all provisions of the copyright laws protecting it.

Short-Circuited CPW Multiple-Mode Resonator for Ultra-Wideband (UWB) Bandpass Filter

Jing Gao, Lei Zhu, *Senior Member, IEEE*, Wolfgang Menzel, *Fellow, IEEE*, and Frank Bögelsack

Abstract—An ultra-wideband (UWB: 3.1–10.6 GHz) bandpass filter (BPF) on coplanar waveguide (CPW) is proposed, designed and implemented. A nonuniform CPW multiple-mode resonator with short-circuited ends is constructed and its first three resonant modes are properly allocated around the lower-end, center and higher-end of the specified UWB band. This CPW resonator is then driven at two ends by two parallel-coupled CPW lines with dispersive inductive coupling degree. By properly reallocating the enhanced coupling peak toward the UWB's center, a five-pole CPW BPF with one full-wavelength can be eventually constituted. Its UWB bandpass performance is characterized and optimized on the basis of a simple transmission-line network. Predicted results are confirmed by experiment. Measured results achieve the insertion loss <1.5 dB and group delay variation <0.35 ns in the realized 3.3 to 10.4 GHz UWB passband.

Index Terms—Coplanar waveguide (CPW), multiple-mode resonator and parallel-coupled line, ultra-wideband (UWB) bandpass filter (BPF).

I. INTRODUCTION

SINCE the Federal Communications Commission (FCC) released the unlicensed use of ultra-wideband (UWB: 3.1 to 10.6 GHz) wireless systems in February 2002 [1], many researchers have started exploring various UWB components, devices, and systems [2], [3]. As one of the key circuit blocks in the whole system, the UWB bandpass filter (BPF) has been recently studied through the use of the matured filter theory [4] and other techniques [5]–[9]. As the two most initial UWB filters, a microstrip line is simply mounted in a lossy composite substrate so as to realize high attenuation at high frequencies [5] while a dual-stopband ring filter [6] is constructed by allocating the lower and upper cut-off frequencies close to the two UWB ends, i.e., 3.1 GHz and 10.6 GHz. In [7], a simple composite UWB filter is made up by cascading lowpass and highpass filter structures together or embedding one into the other. In [8], a surface-to-surface or broadend coupled microstrip-coplanar waveguide (CPW) structure with tightened coupling degree is utilized to design an alternative class of UWB filters with one, two, and three sections. In [9], a compact UWB BPF on microstrip line is implemented on the basis of a single multiple-mode resonator (MMR) and an enhanced capacitive coupling element. Its basic idea was originated in [10] to achieve a broad fractional passband of 60%–80% in terms of the first two resonant

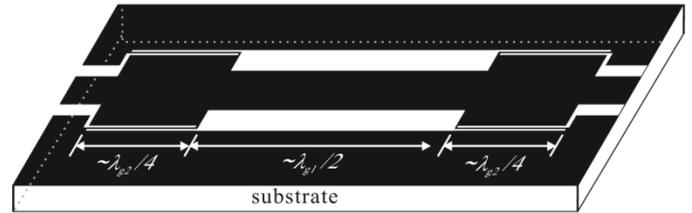


Fig. 1. Geometry of the proposed UWB BPF on coplanar waveguide (CPW).

modes existing in a nonuniform stepped-impedance resonator (SIR) [11].

In this letter, a novel UWB BPF on coplanar waveguide (CPW), as illustrated in Fig. 1, is proposed, designed, and implemented. First, an alternative CPW MMR with two short-circuited ends is constructed which consists of one high-impedance section in the middle and two low-impedance sections at the two ends. This MMR resonator is then characterized to allocate its first three resonant modes occurring near the lower-end, center, and higher-end of the targeted UWB passband. Meanwhile, a parallel-coupled or interdigital CPW line is utilized as an enhanced inductive coupling element to drive the above short-circuited CPW resonator at two ends, aiming at exciting the two additional poles below and above the UWB's center or 6.85 GHz. Finally, a five-pole CPW BPF with the FCC-specified UWB passband is designed and fabricated. Measured results achieve an insertion loss <1.5 dB and a group delay variation <0.35 ns within the realized UWB passband (3.3 to 10.4 GHz).

II. SHORT-CIRCUITED CPW MULTIPLE-MODE RESONATOR

As compared to a microstrip line, the coplanar waveguide (CPW) has an advantageous feature in that the strip conductor and ground planes can be easily linked together to make up a short-circuited end. This work presents a short-circuited MMR on CPW whose geometrical sketch is illustrated in Fig. 2(a). This short-circuited MMR is composed of three distinctive CPW sections with one high-impedance section in the middle and two identical low-impedance sections at the ends. Fig. 2(b) depicts its equivalent transmission line network, in which the two CPW step discontinuities are ignored in our following analysis since their effects in fact rarely affect the UWB passband behavior. To manifest its MMR characteristics for UWB filter design, the longitudinal resonant condition for all the modes needs to be established. For this purpose, the input impedance (Z_{in}) at the left short-end, looking into the right end, is indicated in Fig. 2(b) and it can be derived based on a simple cascaded transmission line theorem seen

Manuscript received August 26, 2005; revised November 18, 2005. The review of this letter was arranged by Associate Editor M. Mrozowski.

J. Gao and L. Zhu are with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore (e-mail: ezhul@ntu.edu.sg).

W. Menzel and F. Bögelsack are with the Microwave Techniques Department, University of Ulm, Ulm, Germany.

Digital Object Identifier 10.1109/LMWC.2006.869870

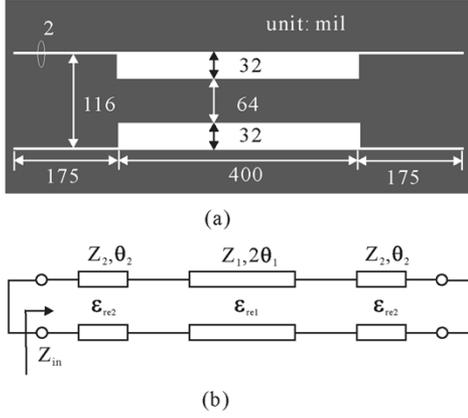


Fig. 2. (a) Geometry and (b) equivalent circuit network of the short-ended CPW MMR to be investigated.

in (1), shown at the bottom of the page, where $K = Z_1/Z_2$ is the impedance ratio of the middle and end CPW sections in this MMR. Under the resonant condition of $Z_{in} = 0$, a set of algebraic equations can be formed, thus solving all the resonant frequencies, including the three lowest ones, i.e., f_1, f_2 , and f_3 , that are of interest here. In this design, the lengths of three sections are readily selected as $\theta_1 \approx \theta_2 = \theta$. As such, f_1, f_2 , and f_3 can be simply derived from the three closed-form equations, i.e., $\theta(f_1) = \arctan \sqrt{K}$, $\theta(f_2) = \pi/2$ and $\theta(f_3) = \pi - \arctan \sqrt{K}$, respectively. In this way, we find that the lower and higher frequencies, f_1 and f_3 , are mainly determined by the ratio K , while the central f_2 is somehow affected by the actual lengths of three sections. To realize a UWB passband later on, the traverse slot/strip widths of the middle and end CPW sections should be properly chosen to allocate these three frequencies, f_1, f_2 , and f_3 toward the lower-end, center, and higher-end of such a UWB passband.

III. UWB FILTER ON CPW: GEOMETRY AND PRINCIPLE

Fig. 1 is the three-dimensional (3-D) view of the proposed UWB BPF on CPW using a short-circuited CPW resonator in the middle and a dispersive parallel-coupled CPW at the two ends [12]. To achieve the specified UWB passband, the three sections of this MMR are arranged with the lengths of about one quarter-, one half-, and one quarter-wavelength, i.e., $\lambda_{g2}/4, \lambda_{g1}/2$, and $\lambda_{g2}/4$, as marked in Fig. 1. In this way, the asymmetrical parallel-coupled CPW sections with short-circuited ends can be equivalently expressed as a K -inverter network with the impedance (K) and two unequal line lengths (ϕ_1 and ϕ_2) at two ends as discussed in [12]. Fig. 3(a) depicts the top view of this UWB filter with all the known dimensions except a varied coupled spacing or strip width (d). Its equivalent network topology is depicted in Fig. 3(b). One can figure out that the three cascaded sections with the phases, ϕ_2, ϕ_3 , and ϕ_2 , between the two K -inverters, make up the resultant MMR.

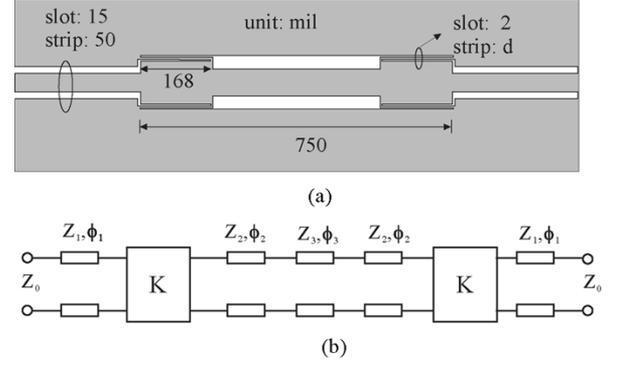


Fig. 3. (a) Geometry and (b) equivalent circuit network of the short-circuited UWB BPF on CPW.

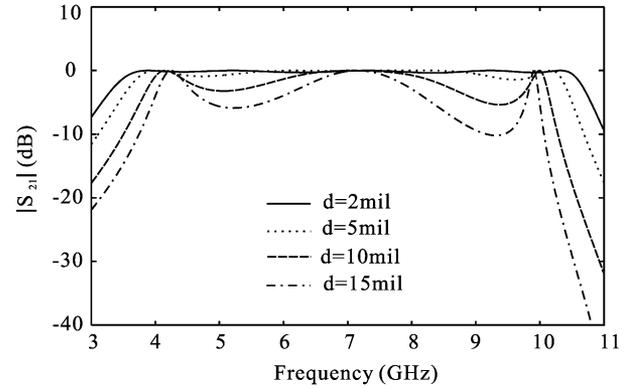


Fig. 4. Simulated S_{21} -magnitudes of the UWB filter in Fig. 3(a) under different strip spacing (d) in the parallel-coupled CPW section.

To carry out the optimization design of such a UWB filter using the transmission line topology in Fig. 3(b), all the electrical parameters of each single and coupled CPW section are numerically extracted by applying our in-house program based on the self-calibrated method of moments [13]. As all the dimensions of this MMR are determined in Section II, the coupled spacing (d) is then properly adjusted with the target of minimizing the insertion loss within the UWB passband. Fig. 4 depicts the four separate curves of frequency response of S_{21} -magnitude under $d = 15, 10, 5$, and 2 mil (optimized case). At $d = 15$ mil, the three maximum S_{21} -magnitude peaks are located at $4.2, 7.0$, and 9.8 GHz, respectively, while the poor transmission with high insertion loss is observed in the frequency range away from these resonant frequencies. As d is reduced, the coupling degree of the parallel-coupled CPW gains a gradual increment in extent so as to raise the S_{21} -magnitude and reach its maximum 0-dB line at $d = 2$ mil. Moreover, as the coupling is enhanced, the lower and higher cut-off frequencies are found to shift down and up simultaneously to 3.1 GHz and 10.6 GHz, thus achieving a good UWB passband at $d = 2$ mil.

$$Z_{in} = jZ_2 \cdot \frac{2(K \tan \theta_1 + \tan \theta_2) \cdot (K - \tan \theta_1 \tan \theta_2)}{K(1 - \tan^2 \theta_1) \cdot (1 - \tan^2 \theta_2) - 2(1 + K^2) \tan \theta_1 \tan \theta_2} \quad (1)$$

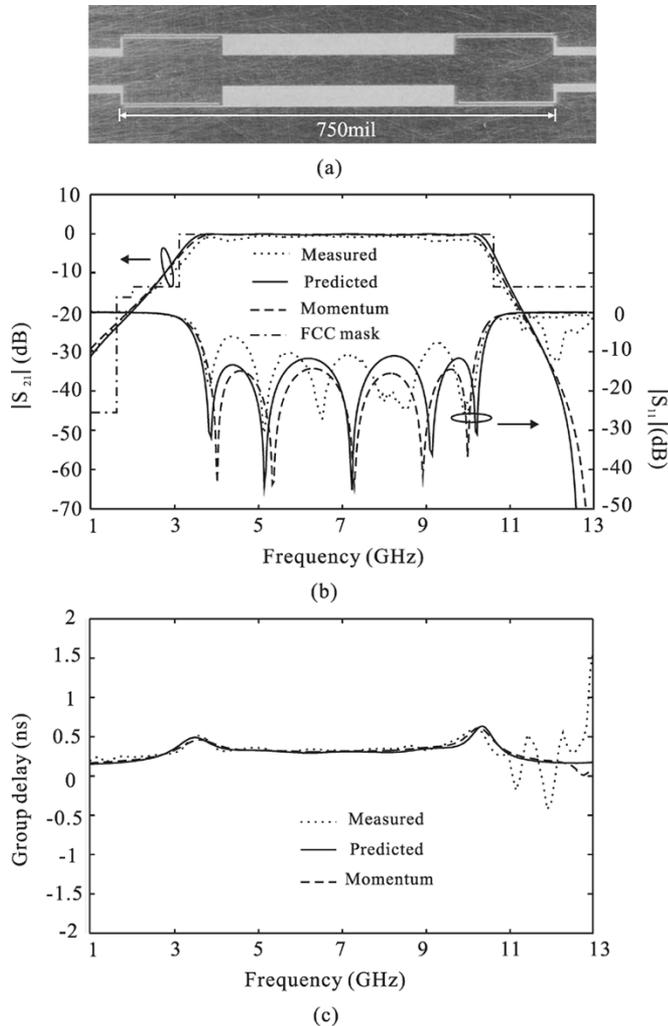


Fig. 5. (a) Photograph, (b) S -parameter magnitudes, and (c) group delay of predicted, simulated, and measured results of the optimized UWB filter.

IV. EXPERIMENTAL VERIFICATION

To verify the predicted electrical performance based on the simple network in Fig. 3(b), the optimized UWB filter ($d = 2$ mil) is simulated again over its entire layout using the Agilent Momentum software and its circuit sample is then fabricated on the Duroid 6010 substrate with the thickness $h = 25$ mil and permittivity $\epsilon_r = 10.8$. The designed UWB filter occupies the overall length of 750 mil that is about one guided-wavelength at 6.85 GHz as marked in the photograph in Fig. 5(a)–(c) which shows the three separate graphs that are obtained using the simple cascaded network, direct electromagnetic simulation, and microwave experiment in the 1.0 to 13.0 GHz frequency range. First of all, it can be seen that the network-predicted results are in very reasonable agreement with those from the two other techniques over the plotted wideband which also accorded

the FCC-defined UWB mask for indoor wireless communication. In the realized UWB passband of 3.3 to 10.4 GHz, the measured maximum S_{21} -magnitude, $|S_{21}|$, achieves 1.5 dB as compared to 0.2 dB in simulation as can be found in Fig. 5(b). The measured group delay varies from 0.32 to 0.67 ns. In other words, the maximum variation in group delay achieves 0.35 ns, indicating a good linearity of the developed UWB BPF as well.

V. CONCLUSION

In this letter, a novel UWB filter formed on coplanar waveguide (CPW) is presented, designed, and implemented. With the proposal of an alternative MMR with two short-circuited ends, a five-pole UWB passband is realized as demonstrated in both simulation and experiment. It has been exhibited that the three poles are contributed by the first three resonant modes in the proposed MMR resonator and that the two additional ones are brought out by the dispersive CPW coupled lines. Measured results of a fabricated UWB filter on CPW show that the actual UWB BPF has an insertion loss of less than 1.5 dB and a maximum group delay variation of 0.35 ns in the realized UWB passband of 3.3 to 10.4 GHz.

REFERENCES

- [1] *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, FCC ET-Docket 98-153, Feb. 14, 2002.
- [2] G. R. Aiello and G. D. Rogerson, "Ultra-wideband wireless systems," *IEEE Microw. Mag.*, vol. 4, no. 2, pp. 36–47, Jun. 2003.
- [3] Z. Irahauten, H. Nikoogar, and G. J. M. Janssen, "An overview of ultra wide band indoor channel measurements and modeling," *IEEE Microw. Wireless Compon. Lett.*, vol. 14, no. 8, pp. 386–388, Aug. 2004.
- [4] G. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*. Norwood, MA: Artech House, 1980.
- [5] A. Saito, H. Harada, and A. Nishikata, "Development of bandpass filter for ultra wideband (UWB) communication," in *Proc. IEEE Conf. Ultra Wideband Syst. Tech.*, 2003, pp. 76–80.
- [6] H. Ishida and K. Araki, "Design and analysis of UWB bandpass filter with ring filter," in *IEEE MTT-S Int. Dig.*, Jun. 2004, pp. 1307–1310.
- [7] C.-L. Hsu, F.-C. Hsu, and J.-T. Kuo, "Microstrip bandpass filters for ultra-wideband (UWB) wireless communications," in *IEEE MTT-S Int. Dig.*, Jun. 2005, pp. 679–682.
- [8] K. Li, D. Kurita, and T. Matsui, "An ultra-wideband bandpass filter using broadend-coupled microstrip-coplanar waveguide structure," in *IEEE MTT-S Int. Dig.*, Jun. 2005, pp. 675–678.
- [9] L. Zhu, S. Sun, and W. Menzel, "Ultra-wideband (UWB) bandpass filters using multiple-mode resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 15, no. 11, pp. 796–798, Nov. 2005.
- [10] L. Zhu, H. Bu, and K. Wu, "Aperture compensation technique for innovative design of ultra-broadband microstrip bandpass filter," in *IEEE MTT-S Int. Dig.*, vol. 1, Jun. 2000, pp. 315–318.
- [11] M. Makimoto and S. Yamashita, "Bandpass filters using parallel coupled stripline stepped impedance resonators," *IEEE Trans. Microw. Theory Tech.*, vol. MTT-28, no. 12, pp. 1413–1417, Dec. 1980.
- [12] J. Gao and L. Zhu, "Asymmetric parallel-coupled CPW stages for harmonic suppressed $\lambda/4$ bandpass filters," *Electron. Lett.*, vol. 40, no. 18, pp. 1122–1123, Sep. 2004.
- [13] L. Zhu and T. Yakabe, "Fullwave MoM-SOC technique for extraction of equivalent circuit models coplanar waveguide discontinuities: CPW- and CSL-mode cases," *IEICE Trans. Electron.*, vol. E86-C, no. , pp. 2292–2299, Nov. 2003.