Ultra-Wideband Microstrip Antenna with Coupled Notch Circuit

Marjan Mokhtaari and Jens Bornemann

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

***Abstract*— An ultra-wideband (UWB) microstrip antenna with notch capability and a bandwidth of 3 GHz to 25 GHz is presented. The notch is created by adding an electromagnetic band gap (EBG) structureed that is coupled to the antenna feed line via a ground plane slot. The design of these elements follows microwave filters design principles. The relevant parameters to design and tune the notch band are identified. The performance of the antenna is demonstrated through the reflection coefficient, gain, radiation patterns, and magnitude and group delay responses. The initial antenna design is verified by the commercial field solver packages CST and HFSS.**

I. Introduction

Ultra-wideband (UWB) links find increasing applications in short-range and high-bandwidth communication and surveillance links. Due to interference from other services, it is often desirable to block out narrow frequency bands from the UWB spectrum. The antenna is often tasked with providing both the wide frequency range and narrowband notch which should be tunable within a certain range.

Quarter-wavelength transmission lines or slots have been primarily used within antenna structures, ground plane or feed lines to suppress unwanted narrow-band signals, e.g. [1-4]; however, they are unable to either control the notch bandwidth or obtain a notched band at lower frequencies because of either small gap widths or large element size.

Therefore, this paper introduces a new solution to create a suppression region within the operating UWB range of the antenna. The concept is based on employing two single Electromagnetic Band Gap (EBG) structures coupled to the feed line of the antenna. They resemble non-resonating nodes as known from filter coupling configurations, e.g. [5]. The bandwidth and center frequency of the notched band is tuned and fine-adjusted by the EBG patch size, the via-hole diameter and the coupling coefficient, which is mainly implemented through a slot in the ground plane and gaps between patches and the feed line.

II. Design Procedure

Fig. 1 shows the basic geometry of the UWB microstrip antenna, the EBG patches, the coupling slot and all dimensions. The UWB antenna has been designed by selecting six points on a circular patch and optimizing the resulting polygon for maximum voltage standing wave ratio (VSWR) bandwidth on RT3003 substrate of 1mm thickness. Note that the coaxial-to-microstrip transition is included in all simulations. For the un-notched UWB antenna, Fig. 2 shows a comparison of VSWRs obtained with HFSS and CST which serves as validation of the design procedure. As computed by CST, the bandwidth extends from 3 GHz to above 25 GHz.

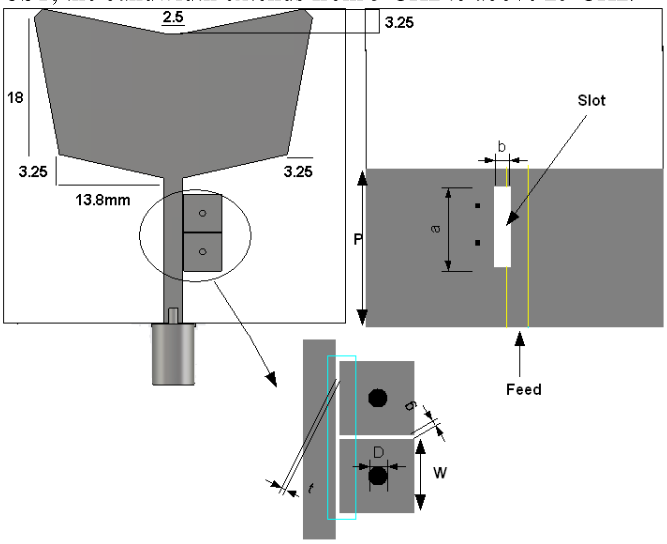


Fig. 1 Geometry and schematic views of front and back of the proposed notched UWB antenna in microstrip technology (g=100µm, t=90µm, P=19.7mm, a=2W+g+0.4mm).

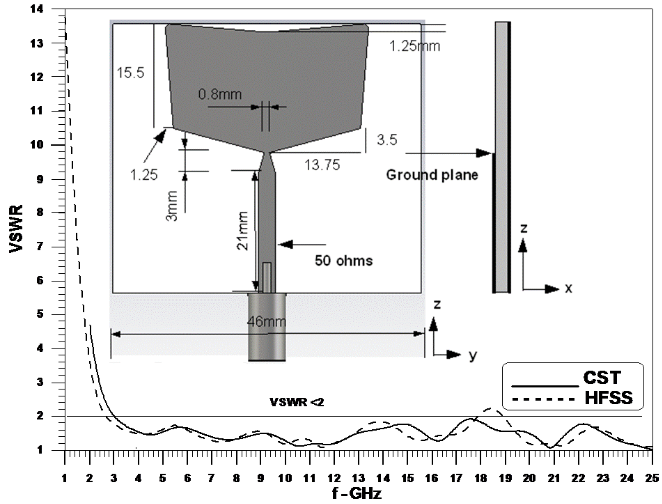
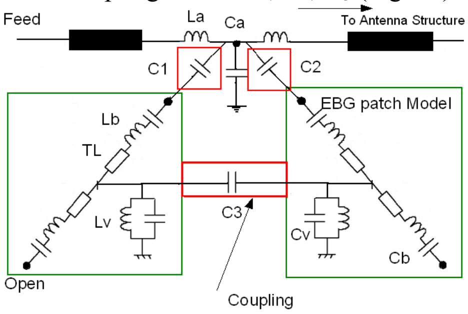


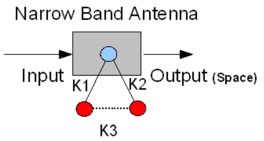
Fig. 2 VSWR performance and dimensions of the UWB antenna without notch circuit, including coordinate system.

From the design of microwave filters based on a model of resonating and non-resonating nodes, a notched frequency band in an ultra-wideband antenna can be developed [5, 6].

Fig. 3a shows the equivalent circuit of the coupling structure between the (horizontal) microstrip feed line and EBG patches, where capacitances C_1, C_2, C_3 represent the coupling values shown in the narrowband node representation of Fig. 3b. They are adjusted by the size and location of the ground-plane slot which satisfies coupling values K_1, K_2, K_3 (Fig. 3b).



(a)



(b)

Fig. 3 Lumped-element model of the line-to-EBG slot coupling structure (a) and its representation by nodes as in filter theory (b).

The initial dimensions of the two via-holed EBG patches can be determined by equivalent-circuit approximations [7, 8]. The width of the conductive patch is approximately selected as $\lambda g/7.5$, where λg is the effective wavelength at the center of the notched band. The physical dimensions are taken here as D=0.4mm, g=100um and t=90um (c.f. Fig.1). The slot width b is initially selected to achieve a notch bandwidth of approximately 25 percent.

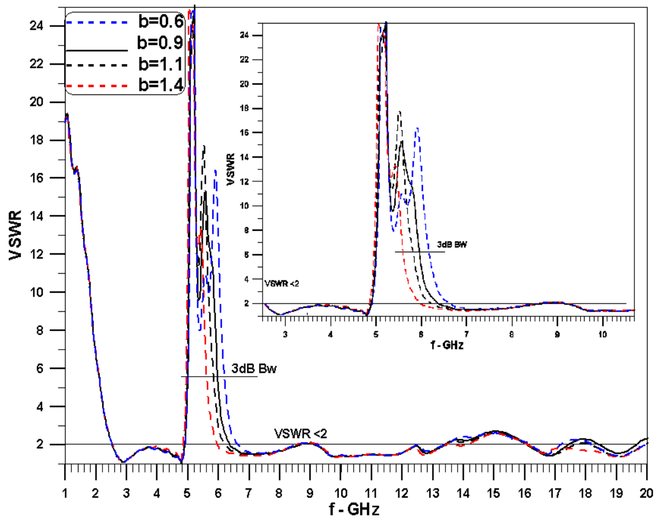
Fig. 4a shows the variation of the notched bandwidth with respect to slot width b, while the patch width is W=5mm and the via-hole diameter is D=0.4mm. From the inset in Fig. 4, it can be seen that the lower edge of the notched band remains constant while the upper edge reduces with increasing slot width b.

Fig. 4b shows that the center frequency of the notch can be increased by enlarging the via-hole diameter D. However, the notch bandwidth is reduced in the process and need to be readjusted according to Fig. 4a.

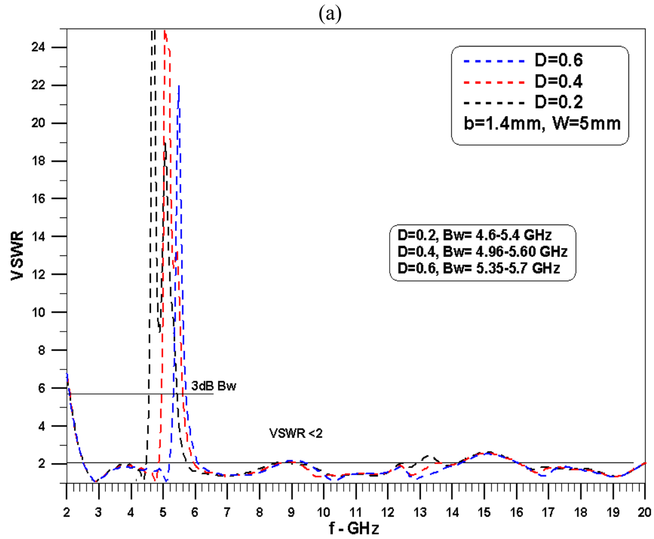
Fig. 5 shows the VSWR performances of the finalized designs. It exhibits a 3dB notched band for wireless communication channels from 5.2-5.8GHz and is achieved after final adjustment with b=2mm and W=4.1mm. Note that entire band covered starts at 2.5 GHz and extends beyond 25 GHz.

III. RESULTS

Fig. 6 shows the maximum gain in the E-plane with and without the notch-creating circuit. The influence of the notch is clearly observed. The maximum gain direction varies with frequency and, especially at higher frequencies, might move away from the preferred direction of $\theta=90^o$ and $\phi=90^o$. (Note that the coordinate system is displayed in the inset of Fig. 2.



(a)



(b)

Fig. 4 VSWR performances of proposed notched UWB antenna in Fig. 1 in terms of slot width b variations with W=5mm, D=0.4mm (a) and in terms of via diameter D with W=5mm, b=1.4mm (b); c.f. Fig. 1.

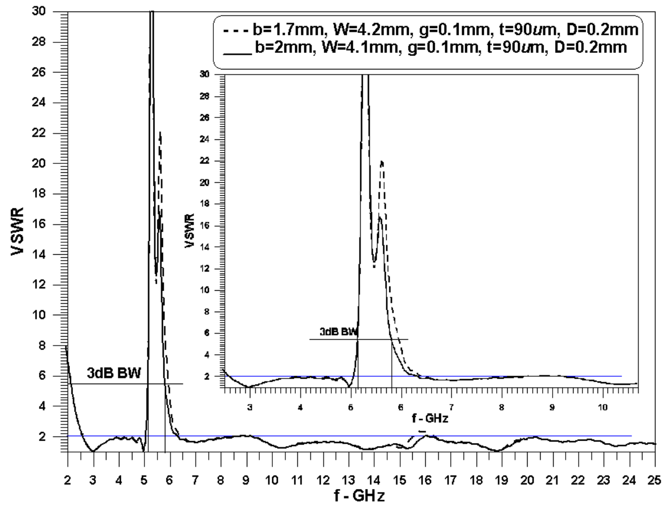


Fig. 5 VSWR performances of finalized designs of the notched UWB antenna. The 3dB notched region extends from 5.2GHz to 5.8 GHz and is achieved with b=2mm and W=4.1mm.

Angles are taken as per convention with θ down from the vertical *z* direction and ϕ from the *x* to the *y* axis..) Therefore, the maximum gain is displayed only in the E-plane.

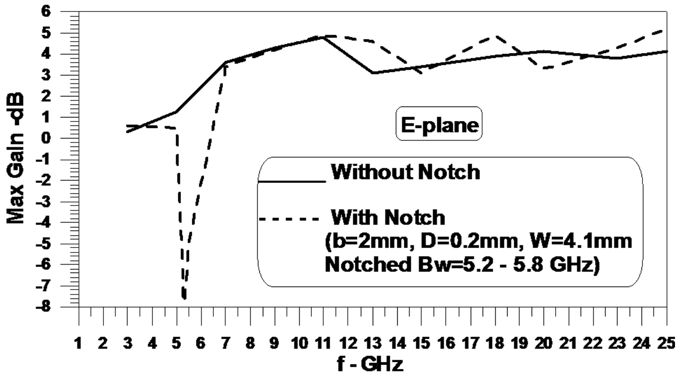


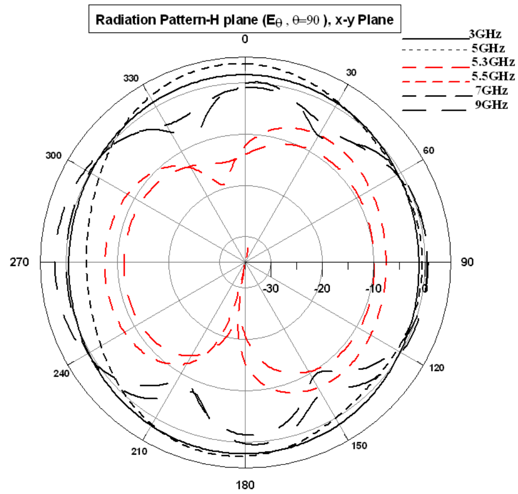
Fig. 5 Maximum gain in the E-plane of the proposed antenna with and without the notch circuit.

Fig. 6 shows the radiation patterns of the design in Fig. 1for the frequency range between 3 GHz and 9 GHz. The H-plane pattern (Fig. 6a) is omnidirectional for the lower frequencies and is reduced in magnitude in the notch band (red traces in Fig. 6). The E-plane patterns (Fig. 6b) are similar to that of a dipole except for in the notch band. Here interactions between the antenna and the notch circuit produce radiation, although reduced in magnitude, in the ±z directions. Above the notch band, e.g. 7 GHz and 9 GHz, the patterns start to depart from the omnidirectional characteristic. The H-plane cross-polar patters in Fig. 6c, when compared to Fig. 6a, indicate certain directions for possible dual-polarized applications.

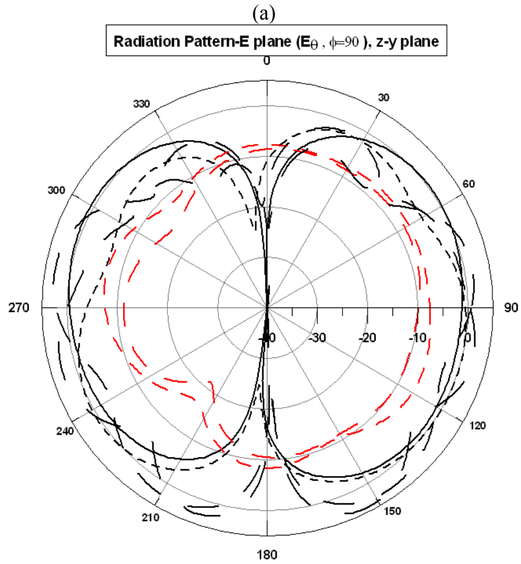
The remaining patters in Fig. 7 are for the frequency range of 11 GHz to 25 GHz. Obviously, omnidirectional characteristics can no longer be expected in this frequency range (Fig. 7a) and as the antenna size compared to the wavelength increases, an increasing number of minima is observed (e.g. Fig. 7b). However, some radiation in the direction of $\theta=90^{o}$ and $\phi=90^{o}$ is always obtained, even in the cross-polar pattern of Fig. 7c.

Therefore, for this direction, we are investigating the frequency response of the notched UWB antenna over a wide frequency band between 2GHz and 25 GHz. A pulse containing this frequency range is applied to the coaxial input port of the antenna, and its time-domain response is detected by a probe in the direction of $\theta=90^{o}$ and $\phi=90^{o}$. The frequency response is obtained from the Fourier Transforms of input and output pulses.

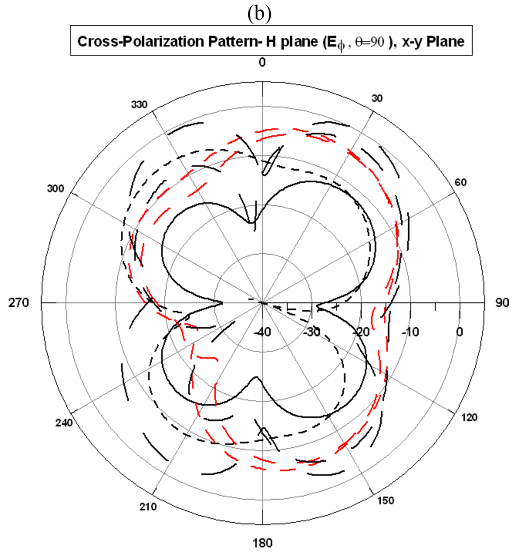
Fig. 8a depicts co- and cross-polarization performances. The polarization is predominantly vertical (E_θ) in the lower frequency range, and the sudden drop in amplitude is clearly observed within notched region. Within 3 GHz to 10 GHz, the response is similar to other printed-circuit UWB antennas (e.g. [9]). The cross-polar component (E_ϕ) increases with frequency and is at a level similar to that of the co-polar component at around 11 GHz, 22 GHz and 24.5 GHz. Thus these frequencies might be used for dual-polarization applications.



(a)

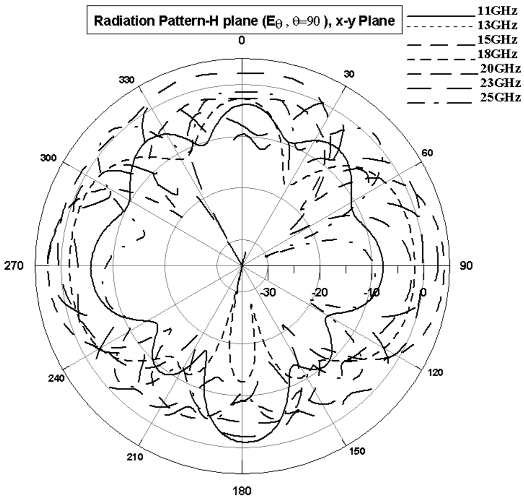


(b)

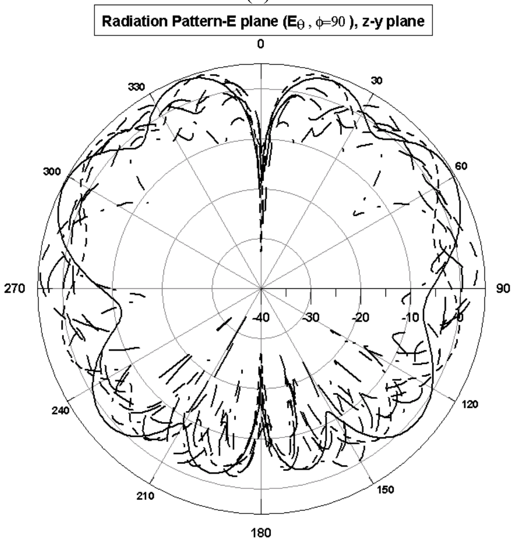


(c)

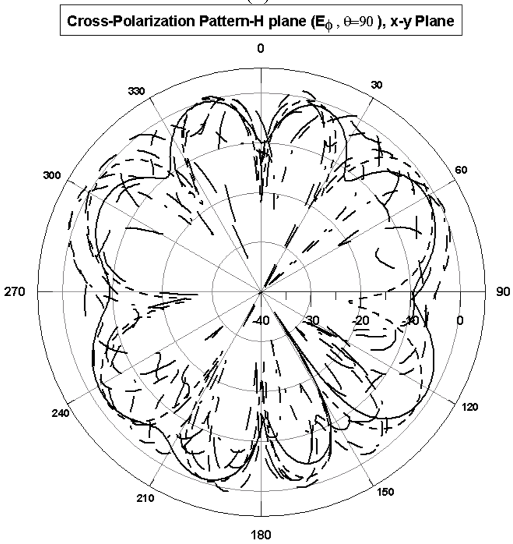
Fig. 6 Radiation patterns of the UWB antenna with coupled notch circuit in the 3 GHz to 9 GHz region (the red traces are identifying frequencies in the notch band); H-plane (a), E-plane (b), H-plane cross-polarization (c).



(a)



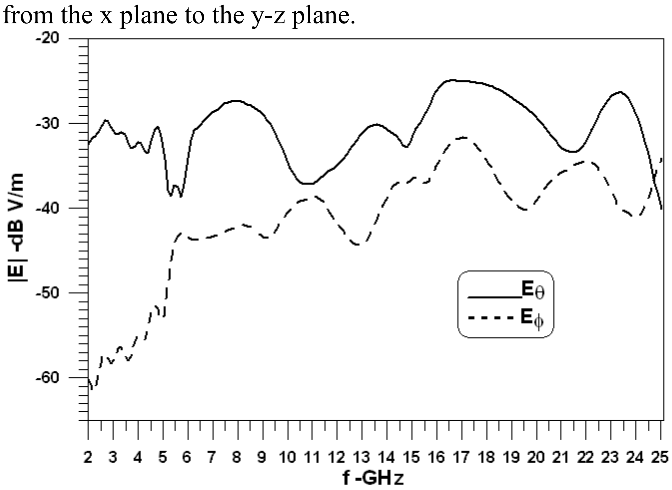
(b)



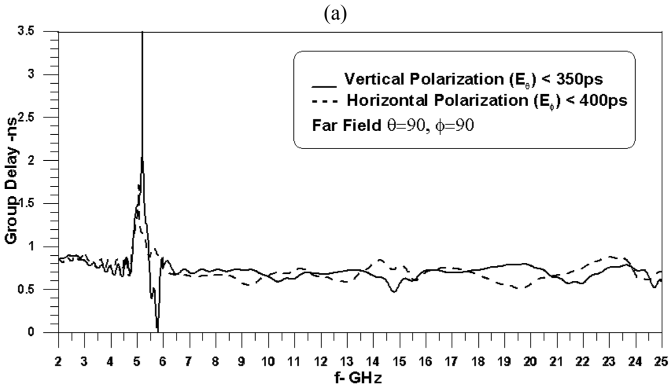
(c)

Fig. 7 Radiation patterns of the UWB antenna with coupled notch circuit in the 11 GHz to 25 GHz region; H-plane (a), E-plane (b), H-plane cross-polarization (c).

Note that the level of the cross-polar component occurs naturally in the feed line of the microstrip antenna (x direction) and that the co-polar component is obtained by a field rotation from the x plane to the y-z plane.



(a)



(b)

Fig. 8 Frequency response of the notched UWB antenna with probes located at $\theta=90^o$ and $\phi=90^o$; magnitude (a), group delay (b).

Fig. 8b shows the group delay responses of vertical and horizontal polarization at the distinctive far field probes' locations. The group delay variations in $\theta=90^o$, $\phi=90^o$ direction are less than 400 ps for both vertical and horizontal polarizations within the operating frequency range. These values are comparable with results reported in the literature, but it is noted that the ones presented here hold up to 25 GHz. Of course, as seen in Fig. 8b, the group delay behaviour changes dramatically within the notched band between 5.2 GHz and 5.8 GHz.

IV. Conclusions

A UWB microstrip antenna with a bandwidth between 3 GHz and 25 GHz is presented. A new coupled notch circuit is added whose design follows microwave filter design principles. The relevant parameters to design and tune the notch band are identified, and graphs are included to illustrate basic dependencies of the notched band on circuit parameters. Gain, radiation patterns and frequency responses demonstrate the performance of the notched UWB antenna. A direct comparison between HFSS and CST on the original antenna design shows excellent agreement up to 25 GHz and thus validates the design process presented in this paper.

ACKNOWLEDGMENT

The authors wish to acknowledge support for this work from the Natural Sciences and Engineering Research Council of Canada and the TELUS Research Grant in Wireless Communications.

REFERENCES

[1] Y. Zhang, W. Hong, Z.Q. Kuai, J-Y. Zhou, "A compact multiple bands notched UWB antenna by loading SIR and SRR on the feed line," in *Proc. Int. Conf. Microwave Mm-Wave Tech.*, 4p., 2008.

[2] E. Pancera, D. Modotto, A. Locatelli, F.M. Pigozzo, C. De Angelis, "Novel design of UWB antenna with band-notch capability," in *Proc. Europ. Conf. Wireless Techn*., pp. 58-50, 2007.

[3] B. Rahmati, H.R. Hassani, "Frequency notched wide band planar monopole antennas," *Progress in Electromagnetics Research C*, vol. 9, pp. 131-143, 2009.

[4] J. William 1, R.Nakkeeran, "A CPW-Fed UWB slot antenna with band notched design", in *Proc. Asia-Pacific Microwave Conf.*, pp. 1833-1836, 2009.

[5] S. Amari, U. Rosenberg, J. Bornemann, "Singlets, cascaded singlets and the non-resonating node model for advanced modular design of elliptic filters," *IEEE Wireless and Components Letters*, Vol. 14, pp. 237-239, Mar. 2004.

[6] S. Amari, G. Macchiarella, "Synthesis of inline filters with arbitrarily placed attenuation poles by using nonresonating nodes," *IEEE Trans. Microwave Theory Tech.*, vol. 53, pp.3075-3081, 2005.

[7] B.M. Iravani, S. Shahparnia, O.M. Ramahi, "Coupling reduction in enclosures and cavities using electromagnetic bandgap structures," *IEEE Trans. Electromag. Compat.*, pp. 292-303, 2006.

[8] K. Rambabu, M. Mokhtaari and J. Bornemann, "Simplified computation of electromagnetic band-gap properties of via-holed metal patches," *IEEE EMC-S Int. Symp. Dig.*, 4 p., 2007.

[9] H.-J. Lam, Y. Lu, H. Du, P.P.M. So and J. Bornemann, "Time-domain modelling of group-delay and amplitude characteristics in ultra-wideband printed-circuit antennas," in *Springer Proceedings in Physics 121*, P. Russer, U. Siart, Eds., pp. 321-331 Berlin, Germany: Springer-Verlag, 2008.