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Analysis of Frequency Notched UWB Planar Antennas: Determination of Notch Frequency and Effect of Parasitic Elements

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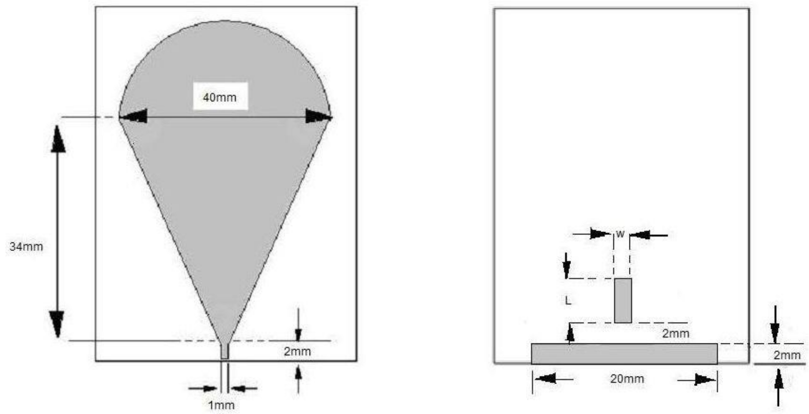
ABSTRACT

Ultra-Wideband Antennas (UWBs) operate in a large bandwidth which may contain other standard narrowband transmission bands within it. In order to mitigate interference within these bands frequency notching can be applied. This paper presents the modelling and testing of a UWB planar antenna which was frequency notched by the addition of a hardwired patch. Analysis of the results led to the derivation of a empirical model by which the notch frequency can be estimated as a function of the dimensions of the patch. In addition, simulation results obtained when the parasitic elements of the hardwire connection were included are also given. These results are shown to correlate very closely with measurements.

Keywords: *UWB, Frequency Notch, Planar Antenna, Parasitic Elements*.

1. INTRODUCTION

There are several techniques for band notching planar antennas. Most of these involve cutting either a sector [1], a horizontal slot [2], or a U-slot [3], [4], [5], [7] and [9], in the main radiating element.The antenna analysed in this work was presented in [8] as an UWB antenna. It is being reproduced in Figure 1.. The patch was hardwired to the main antenna by a very short length of copper wire as illustrated in Figure 2.



(a) Main radiator side **(b) Patch and ground plane (underside).**

Figure 1: Frequency notched UWB planar antenna [8], [9]

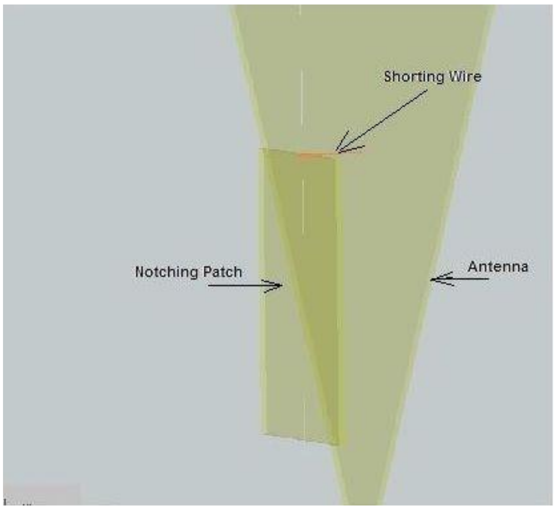


Figure 2: Detail showing connecting wire between patch and main antenna.

Although the purpose of the planar antenna referred to in this text was operation as an UWB radiator, the analysis and conclusions derived here can be equally applied to other planar antennas, as they relate specifically to the inherent operation of the antenna itself.

The main antenna is UWB in nature and its 10dB bandwidth covers a frequency spectrum extending from 3.1 to 10.6GHz. The antenna is frequency notched [9] by the addition of a patch on the underside of the main radiator (Figure 2) so that it is rendered insensitive to frequencies in the range 5.15 to 5.83GHz (to comply with the IEEE 802.11a standard).

In this paper, it is shown that the notched frequency can be determined through the physical dimensions (namely, its length and width) of the patch, as these are strictly related to the resonant frequency of the patch. In fact the notch frequency occurs at that frequency which causes the patch to resonate and, conversely, the patch resonates when its dimensions match the wavelength of the frequency of radiation.

This paper also studies the effect of the parasitic elements of the hardwired connection between the patch and the main radiator. At very elevated radiation frequencies (GHz range) even short lengths (in the region of 1mm) of wire present sufficient inductance to perturb the overall performance of the antenna. Moreover, the patch and the main radiator also exhibit a very small capacitance between them. This was evident when simulation results were compared to the actual measurements.

The shift of the notch frequency between the simulations and the actual measurements was clear enough evidence that the simulation model needed further refinements to better represent the antenna behaviour. The refinements consisted in having the *hard wire* connection and the patch modeled as a series combination of an inductance and capacitance instead of as an ideal conductor.

2. METHOD TO DETERMINE THE EFFECT OF PATCH DIMENSIONS

2.1 Simulation results

The simulation results are represented graphically in Figures 3 and 4. Figure 3 represents the simulation results obtained for S_{11} and shows the dependence of the notch frequency on the length of the patch. The results indicate, as expected, that the frequency is strongly dependent on the length of the patch and moreover it is clear that the longer the patch is the lower the frequency. It must also be pointed out that the effect of the patch on the overall shape of the S_{11} curve is not critical as, outside the notch band, the antenna retains its UWB properties.

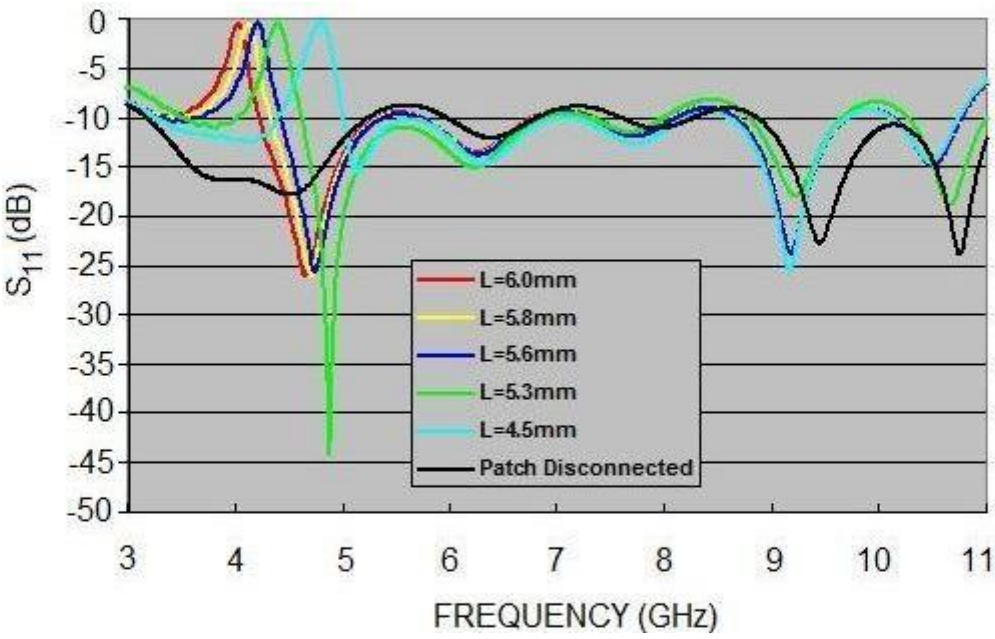


Figure 3: Evaluation of the effect of length of patch on the notch frequency.

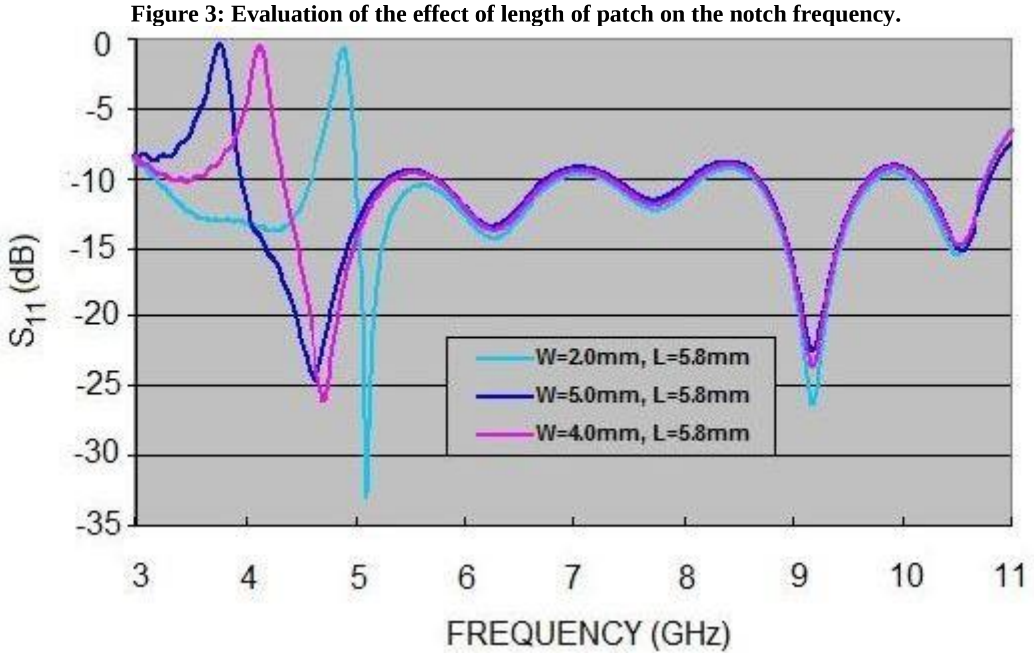


Figure 4: Evaluation of the effect of width of patch on the notch frequency.

Figure 4 shows the simulation results obtained for the frequency notched antenna and compares the effect of changes in the width of the patch on the notch frequency (keeping the length of the patch constant at 5.8mm). It is clear that the width of the patch also strongly affects the notch frequency.

2.2 Analysis of simulation results

The table below was compiled in an attempt to analyse the simulation results. Of importance is the parameter L_t that represents the perimeter of the patch. An explanation of these results follows.

Table 1: Analysis of results to determine the effect of patch dimensions.

Patch length (P/mm)	Patch width (W/mm)	Total length (P_t /mm) [=2L+2W]	Notch frequency (F_n/GHz)	Notch wavelength (λ_n/mm) [=c/ F_n]	λ_n / L_t
4.5	4.0	17.0	4.8087	62.4	3.7
5.3	4.0	18.6	4.4092	68.0	3.7
5.6	4.0	19.2	4.2276	71.0	3.7
5.8	4.0	19.6	4.1308	72.6	3.7
6.0	4.0	20.0	4.0460	74.1	3.7
5.8	2.0	15.6	4.88	61.5	3.9
5.8	4.0	19.6	4.1308	72.6	3.7
5.8	5.0	21.6	3.7676	79.6	3.7

From the simulation results it is very clear that the notch frequency is a function of both the patch width and its length. When this was studied closer, by observing both the E-field and surface current distributions, it was observed that at the notch frequency the E-field was very intense along the edge of the patch with a maximum observed at the edge opposite the *hard wire* connection. This is demonstrated in Figure 5, which is a plot of the E-field for a patch of length 5.8mm and width 4mm. This therefore seems to indicate that the patch is resonating at the frequency whose wavelength corresponds to approximately twice P_t.

This is further corroborated by an analysis of the surface current (Figure 6). In this case the current has a peak at the hard wire connection and drops to zero at the edge opposite to the connection. As expected this is exactly 180^o out of phase with the E-field component.

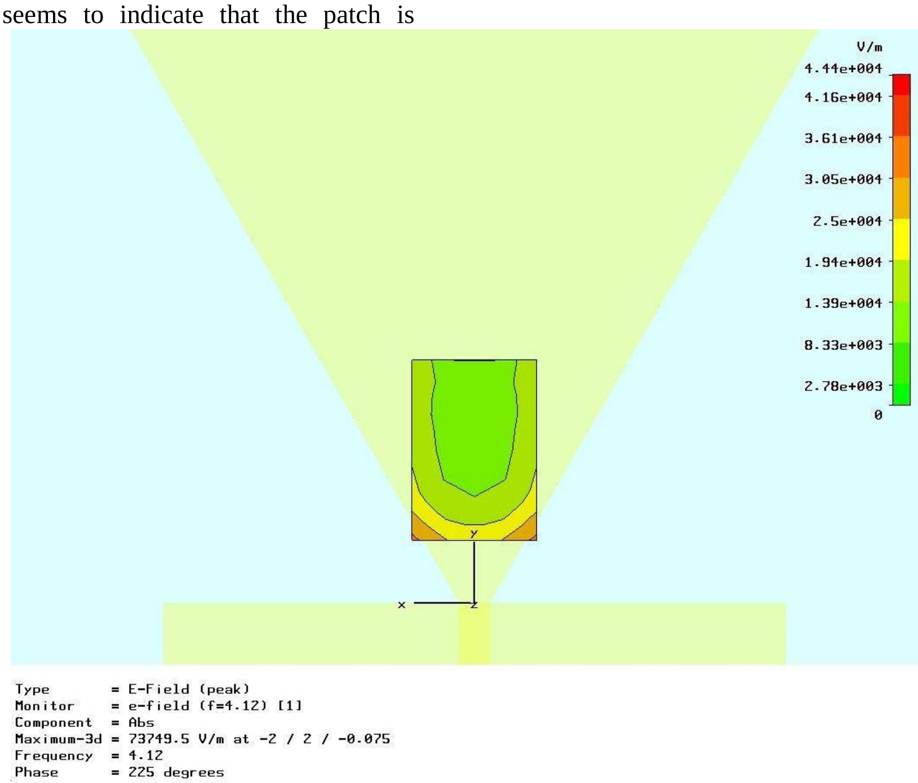


Figure 5: E-Field on the patch at the notch frequency.

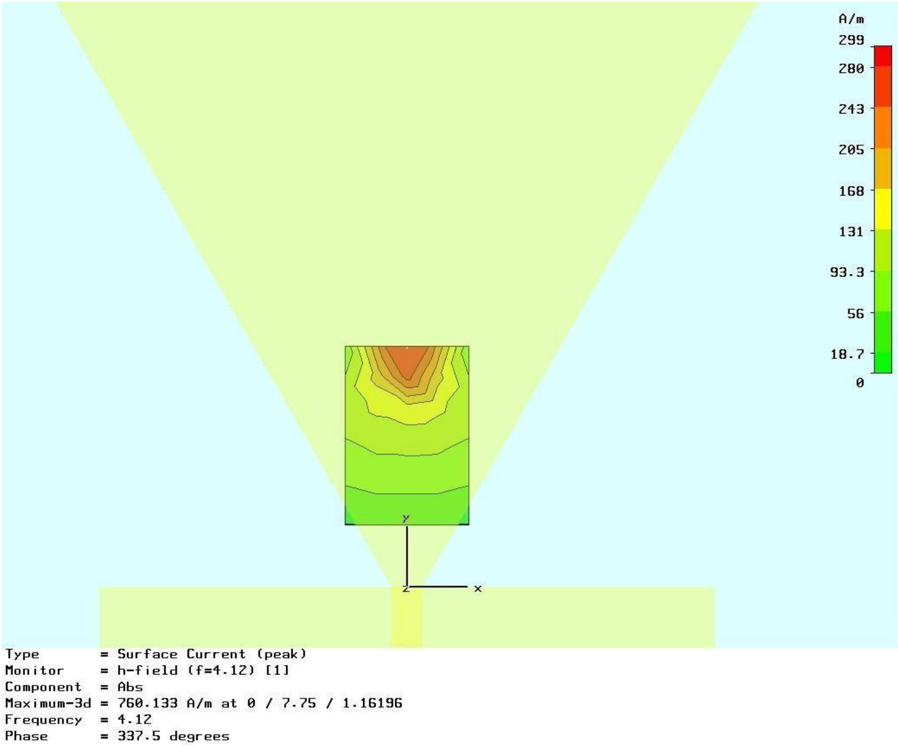


Figure 6: Surface Current on the patch at the notch frequency

Using the results tabulated in Table 1 an empirical model for the notch frequency F_n can be derived:

$$F_n = \frac{c}{2P_t 1.03\sqrt{\varepsilon_{eff}}} \quad (1)$$

The justification of including $\sqrt{\varepsilon_{eff}}$ in equation (1) is that there is a direct relation between the wave speed and the permittivity of the substrate in which the wave is traveling (a similar model was derived in [6]). The 1.03 factor may be explained as being a correction factor for the wavelength in relation to the actual perimeter of the patch.

It is relevant to note that similar results were obtained on planar antennas which were frequency notched by having either sectors [1], or U-slots [3], [4], [5], [6], [7] and [8] or horizontal slots [2] cut in the main antenna radiator. In all these cases the parameter of relevance to the frequency notch was the length of the perimeter of the slots.

3. MEASUREMENTS

Figure 7 is a plot of the measured S_{11} response overlaid with the simulation results for the notched antenna with a patch of width 4mm and length 5.8mm. The measured results replicate the simulation results to the extent that the slight degradation in the response at the higher end of the UWB is evident on both.

It is evident that between the two plots there is a very marked upward shift of the notch frequency of approximately 1.2GHz. This shift was found to be consistent as it appeared on all the antennas tested.

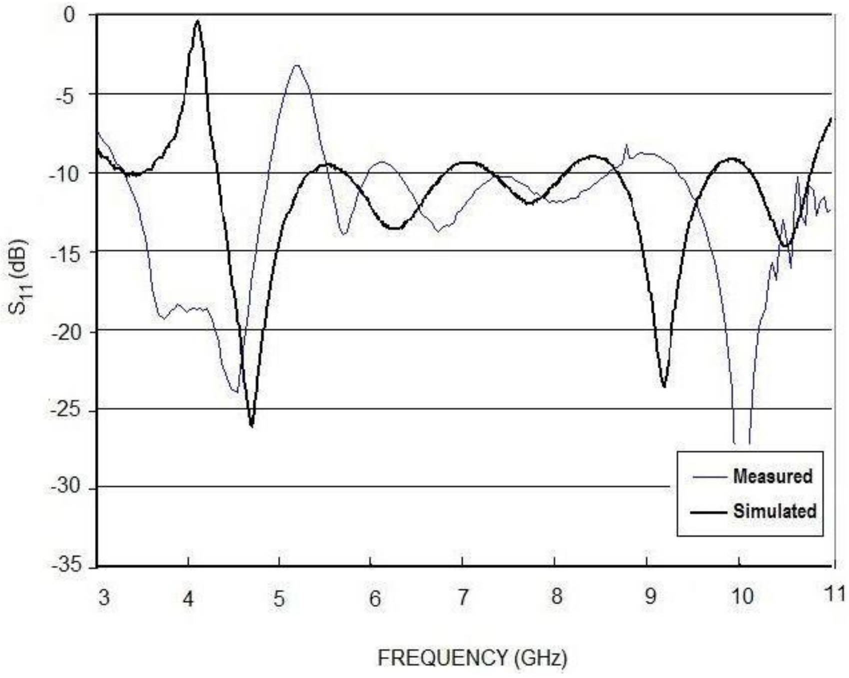


Figure 7: Comparison of the simulation results and actual measurements.

For the simulation results presented in Figures 3 and 4 the conductor between the patch and the main radiator was modeled as a perfect conductor. However at gigahertz frequencies the reactance due to the intrinsic inductance of even short pieces of perfectly conducting material cannot be neglected. In order to estimate a value for the inductance, *L* (in Henrys), of a piece of straight circular conductor of length, *l* (in metres), and diameter, *d* (in metres), equation (2) [12] below was used.

$$L = \frac{\mu_o l}{2\pi}\left[ln\left(\frac{4l}{d}\right)\right] \quad (2)$$

Substituting the relevant quantities in equation (2), a value of 0.67 nH is obtained for *L*. In addition to this intrinsic inductance due to the conductor, the parasitic capacitance due to the patch was also evaluated. This capacitance exists due to the overlapping areas between the patch and the main radiator. In order to estimate a value for this capacitance, denoted as *C*, the standard capacitance equation (3) was used.

$$C = \frac{\varepsilon_o \varepsilon_r A}{d} \quad (3)$$

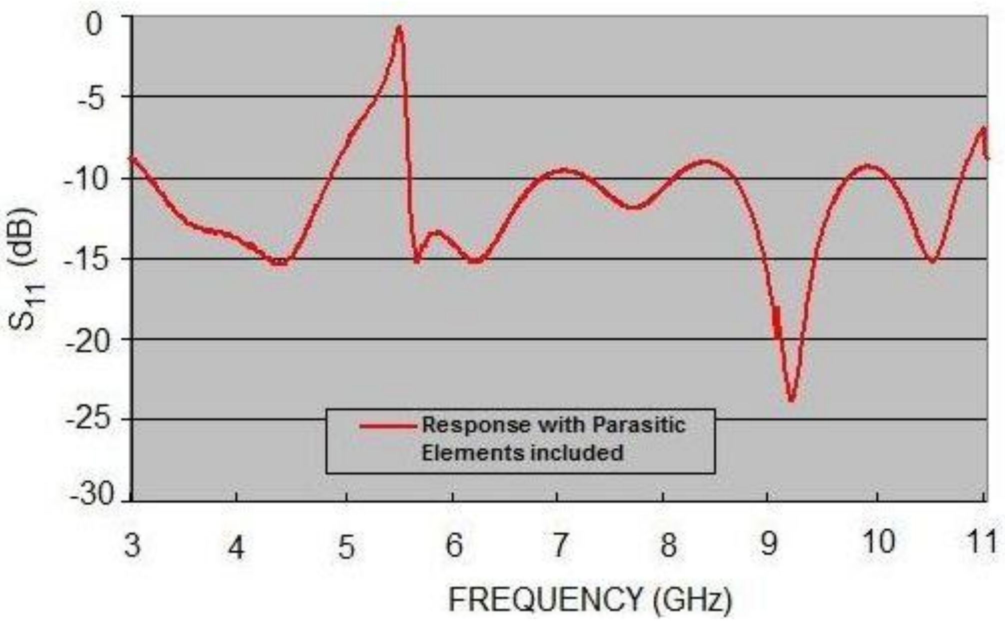


Figure 8: Simulation response with parasitic elements included.

In this case, substituting the relevant quantities in equation (3) gives a capacitance of 0.62 pF (for a patch of width 4 mm and length 5.8 mm). In the simulation model, the perfect conductor between the patch and the main radiator was substituted with a series combination of L and C with the values calculated. The simulation results for S_{11} obtained are depicted in Figure 8. These results show that the notch frequency has shifted upwards to 5.5 GHz which is much closer to the value of 5.23 GHz obtained through measurements (Figure 7) and clearly indicate that parasitic elements need to be included in the simulation model to render the better estimation of the actual results.

4. CONCLUSION

This paper has presented the results obtained on a frequency notched UWB planar antenna. From an analysis of the simulation results an empirical model was derived that relates the notch frequency to the physical dimensions of the patch. This model can be used on any frequency notched antenna as it was derived on the basis of how the patch behaves at its resonant frequency.

Following a comparison of the measured performance with simulated results, it was clear that the simulation model was not an accurate replica of the real antenna. Parasitic elements that represent the inductance and capacitance of the connecting wire and patch respectively were thus included to improve the estimation model.

REFERENCES

H. G. Schantz, "Frequency Notched UWB Antennas," *Proceedings of the IEEE Conference on UWB Systems and Technology*, Dec. 2003.

B. Rahmati and H. R. Hassani, "Frequency Notched Wide Band Planar Monopole Antennas," *Progress in Electromagnetics Research C*, vol. 9, pp. 131-143, 2009.

H. J. Visser, "Design and Optimisation of a Planar UWB Antenna with Frequency Band-Notch Function," TNO-Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, [Online] (Updated on 3rd Sep. 2007) Available at http://www.cst.com/content/documents/events/ugm2007/05-visser.pdf. (Accessed on 20th Jul. 2012).

W. S. Lee, D. Z. Kim, K. J. Kim, K. S Son, W. G. Lim and J. W. Yu, "Multiple Frequency Notched Planar Monopole Antenna for Multi-band Wireless Systems," *IEEE Microwave and Wireless Components Letters*, vol. 15, no. 9, Sep. 2005.

W. C. Kim and W. G. Yang, "Design and Implementation of UWB CPW-Fed Planar Monopole Antenna with Dual Band Rejection Characteristics," *Ch. 12: Ultra Wideband Communications: Novel Trends – Antennas and Propagation*, Edited by M. Matin, InTech Publication Aug. 2011.

K. L. Wong, "High-Performance Ultra-Wideband Planar Antenna Design," Dept. of Electrical Engineering National Sun Yat-Sen University Kaohsiung, Taiwan. [Online]. (Updated on November, 2005). Available at http://www.ansoft.com/converge/high-performance-uwb-planar-antenna-design-prowong-nsysu.pdf (Accessed on 20th Sep. 2012).

C. Y. Hong, C-W Ling, I-Y Tarn and S-J Chung, "Design of a Planar Ultrawideband Antenna with a New Band-Notch Structure," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 12, Dec. 2007.

L. Spiteri, C. J. Debono and A. Muscat, "A Planar antenna for UWB applications," Proceedings of the *16th Conference on Microwaves, Radar and Wireless Communications* (MIKON 2006), ISBN 83-906662-8-6, 2006.

L. Spiteri, C. J. Debono and A. Muscat, "Frequency notched planar antenna for UWB applications," *Proceedings of the International Symposium on Antennas and Propagation* (ISAP 2008), ISBN 978-986-84787-0-1, pp 437-440, October 2008.

F. Yu and C. Wang, "Design of a CPW-fed Dual Band-Notched Planar Wideband Antenna for UWB Applications," *Ch. 13: Ultra Wideband Communications: Novel Trends – Antennas and Propagation*, Edited by M. Matin, InTech Publication Aug. 2011.

K. F. Lee, S. L. S. Yang, A. A. Kishk and K. M. Luk, "The Versatile U-Slot Patch Antenna," *IEEE Antennas and Propagation Magazine*, vol. 52, no. 1, Feb. 2010.

F. Losee, "RF Systems, Components, and Circuits Handbook," Ch. 14, pp 427, Artech House Inc., 1997.