IJCSMS International Journal of Computer Science & Management Studies, Special Issue of Vol. 12, June 2012
ISSN (Online): 2231 –5268
www.ijcsms.com

Performance Analysis of FMCW Sub Surface Penetrating Radar

Vikas Malik[1], Tejender Malik[2], Vikas Nandal[3]

[1]M.Tech. Student, UIET Rohtak
vikasmalik2@rediffmail.com

[2]AP, Electronics & Comm. Deptt, MRIEM Rohtak

[3]AP, Electronics & Comm. Deptt., UIET Rohtak

Abstract

This paper explains a approach towards the implementation of a frequency modulated continuous wave (FMCW) standard system in Advanced Design System (ADS) software for Sub surface penetrating radar (SSPR). For performing experiments built-in Design Guide has been used as reference. As, there is no model created especially for SSPR investigation in ADS, therefore, the purpose of this paper is to give an idea on how SSPR experiment results can be simulated and analyzed without having to perform the actual experiment. ADS is used for Simulations to see how the components change affects the baseband spectrum. In this paper the basic spectrum analysis is investigated to see the relationship of the components that can be tuned for further simulations.

Keywords: *frequency modulated; Advanced Design System; sub surface penetrating radar.*

I. INTRODUCTION

A. Sub surface penetrating radar (SSPR) was initially designed for locating targets deep underneath the ground or detecting targets that are not visible [1]. The first use of electromagnetic signals was to determine the presence of remote terrestrial metal objects and generally attributed to Hulsmeyer in 1904, but the first description of their use for location of buried objects appeared six years later in a German patent by Leimbach and Lowy [3]. SSPR can be defined as radar whose goal is to detect and identify structures within the ground. The properties of such a radar are restricted to the frequency, bandwidth, and other parameters that are required to detect the desired target, either natural or man-made, in the presence of a lossy, possibly inhomogeneous medium. The most important applications of SSPRs are highway constructions, identify defects behind retaining walls, locating moisture damage, detecting corrosion of reinforcing steel in concrete, assessing the thickness of pavement layers and detecting objects such as pipes, cables, mines and unexploded ordnance buried under the ground [4]. SSPR must achieve certain criteria in order to operate successfully, that include a sufficient signal to clutter ratio, signal to noise ratio (SNR), resolution of the target and also depth resolution of the target [4,5].

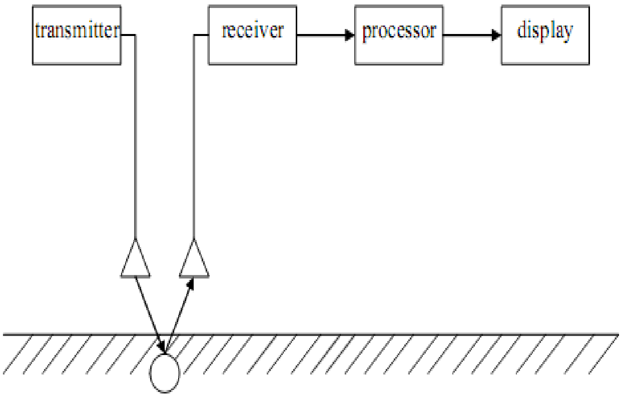


Figure 1. Block diagram of a generic radar system

It can be seen from Figure 1 that the source of energy is transmitted to a target and in SSPR, this can be from either amplitude, frequency or a phase modulated signal.

B. *Frequency modulated continuous wave* Frequency modulated continuous wave (FMCW) is a method to generate wave signals to SSPR system. By using the frequency sampling technique, more samples can be obtained for a specific specimen. FMCW uses the frequency difference to get the distance or velocity information from the signal after it is being reflected by a target. The sawtooth signal is often used as the signal modulation where the frequency sweep is from Fmin to Fmax and returns to Fmin as shown in Figure 2 [6]. The transmitter frequency changes with respect to time for a linear change, the target return will be at a time t given by :

$$\tau = 2R/c \qquad (1)$$

Where R is the range from antenna to target in m and c is the speed of light in ms-1 [5]. At the receiver end, the transmitted signal is mixed with the target return signal producing an intermediate frequency (IF) also known as the beat frequency, fb = dτ and the expression can be expanded as :

$$f_b = \frac{4Rf_m\Delta f}{c} \qquad (2)$$

Where *d* is the rate of frequency change and *f m* is the modulating frequency .

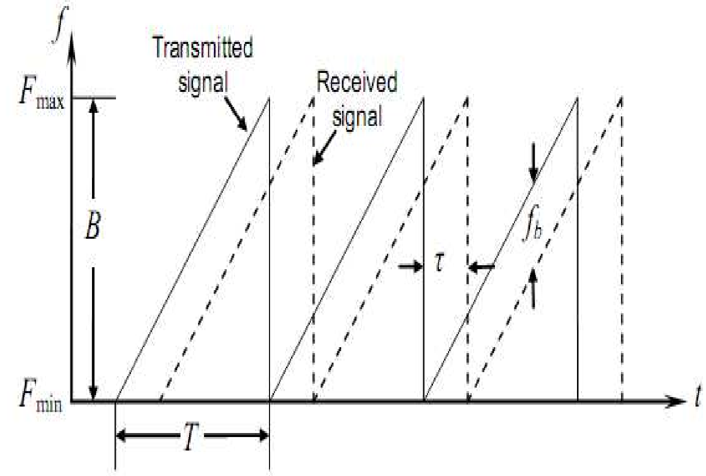


Figure 2. FMCW radar signal behaviour

Advantages of FMCW include simple configuration, low cost and compact system design. In general, FMCW gives only the information of target range. Thus, the target's angular position is needed to determine the exact target location within the detection range. One of the different techniques that can be used to obtain the angular position is by rotating the radiated beam mechanically, also known as rotating antenna. SSPR has been able to project images of railroad track substructure conditions on a top-of-rail non-destructive basis continuously [7]. The sub-structure properties observed include thickness of the ballast and sub-ballast layers, different layers of thickness along the track, amount of water trapped in the ballast, and soft sub-grade caused by high water content. Optram Right-of-Way Infrastructure Management (ORIM) software can be used for analysis after receiving the radar images generated by data automatic processing [7].

C. Advanced Design System Advanced Design System (ADS) by Agilent Technologies is a design software widely used for radio frequency (RF) and microwave applications. The system designs can be done in a circuitry system or stripline method. ADS is suitable for firsttime users up till advanced designers as it is user-friendly and the parameters used for simulations can be expressed accordingly by keying in equations manually or by using the easy-to-use built-in tools [8].

D. Spectrum Analysis For this paper, the basic spectrum analysis is investigated to see the relationship of the components that can be tuned for further simulations. The baseband spectrum is observed to look at the bandwidth of the signal and carrier spectrum shows the frequency range of the carrier signal. In this paper, the simulation is done in such a way that the carrier signal is downconverted by modulating the spectrum with the baseband signal and the result will be represented in the IF signal [9].

II. ADS BUILT-IN DESIGN SIMULATION

FMCW System in ADS

ADS is a simulation software that has many built-in system models in it. The standard FMCW model that can be obtained in ADS consists of the following components as shown in Figure 3. In the ideal model, a continuous signal wave is generated as the source and the signal is mixed using the down converter with the reflected wave obtained from the receiving antenna. A power amplifier of 20 dB gain is connected before the transmitting antenna and a low noise amplifier (LNA) of 20 dB gain is connected after the receiving antenna. A coupler is connected at the front-end of the system to direct the signal from the source to the transmitting block and also to be amplified before mixing the signal for down-conversion process. For this standard model, a moving target is used and assumed that the antenna is moving along with the target from a certain distance and at a certain velocity.

The two test points, Test Point A (TPA) and Test Point B (TPB), are for simulation purposes. At TPA, the generated spectrum is the result of mixing the amplified source signal with the output from the receiving block. This baseband spectrum is down-converted from RF to IF signal. The output of the receiving block is simulated at Point B where the reflected signal received at the receiving antenna is noisefiltered by the LNA and amplified.

The results at the two test points are shown in Figure 4. The model was simulated at a frequency of 10 GHz and the results were observed. Figure 4(a) shows the baseband spectrum which is the amplified signal at RF from the receiving block while Figure 4(b) shows the carrier spectrum where the mixed signal is translated in IF signal.

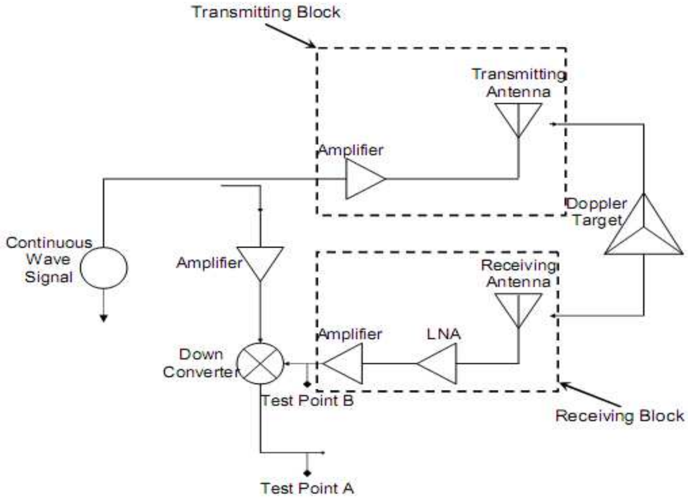
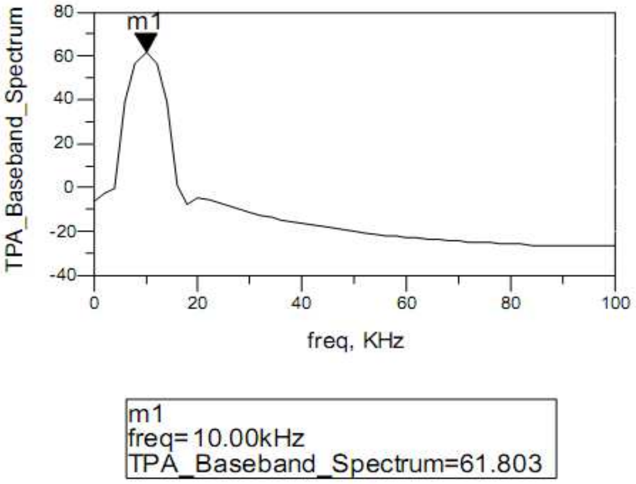
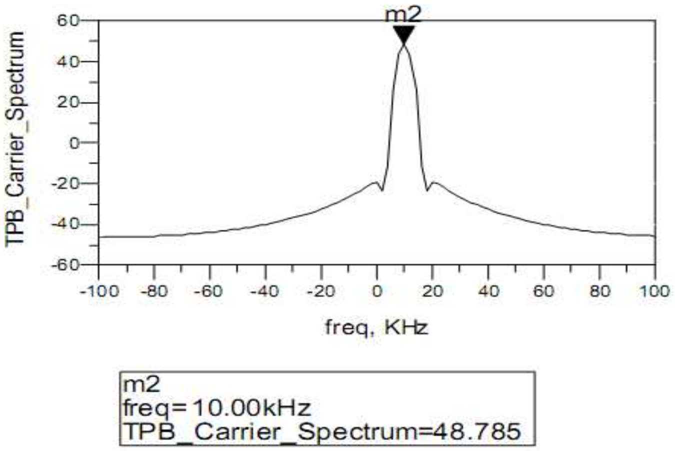


Figure 3. Block diagram of an ideal FMCW system in ADS

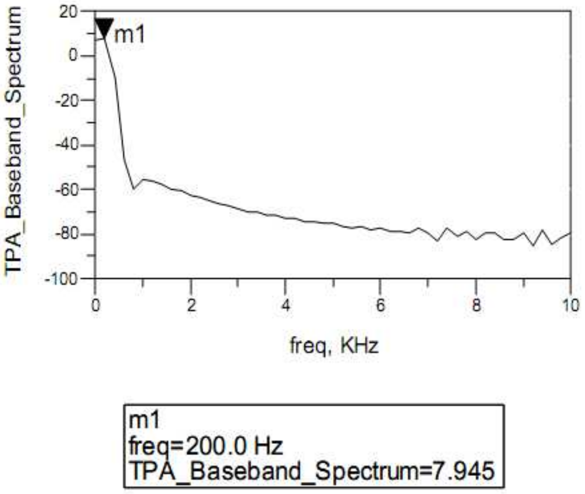


(a)

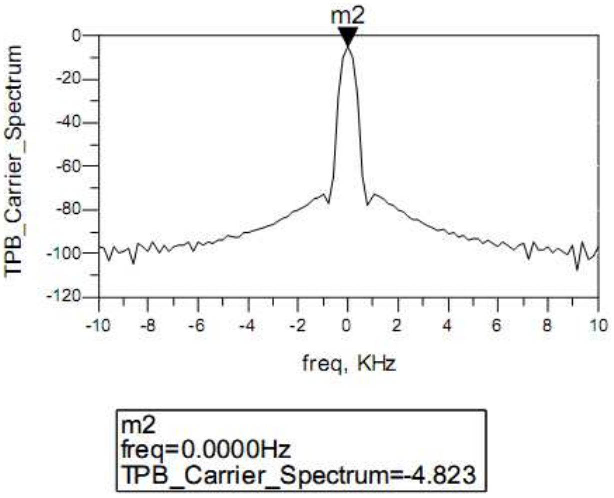


(b)

Figure 4. Simulation at carrier frequency = 10 GHz with Doppler target (a) Baseband spectrum at Test Point A (b) Carrier spectrum at Test Point B



(a)



(b)

Figure 5. Simulation at carrier frequency = 1 GHz with stationary target (a) Baseband spectrum at Test Point A (b) Carrier spectrum at Test Point B

III. PROPOSED FMCW MODEL FOR SSPR

From the ideal model found in the ADS Design Guide shown in Figure 3, the circuit is modified to suit the SSPR model. First, the moving target is changed to a stationary target model. The carrier frequency is set to 1 GHz. The range from arget to antenna is set to 40 cm. The continuous sinusoidal wave signal is also changed to a sawtooth signal, suitable for an FMCW system, with a peak voltage of 1 V. After simulation, the results obtained at the two test points are shown n Figure 5. The baseband spectrum shows the bandwidth of he baseband signal, which is about 7 kHz, with the highest signal obtained at a frequency of 200 Hz with a 7.9 dB in magnitude, as seen in Figure 5(a). Notice that there are ripples at higher frequencies in both spectrums due to having the sawtooth signal as source [5]. On the other hand, Figure 5(b) shows the carrier spectrum obtained at the receiving block output before it is down-converted with the amplified sawtooth signal from the source with peak of -4.8 dB. A multivibrator oscillator is then connected to the sawtooth generator with 10 ns delay. Figure 6 shows the modified system with added components and a stationary target which replaces the Doppler target model. The peak power is reduced for both spectrums and more ripples were observed probably due to the multivibrator oscillator since it contains harmonic factors and is only suitable for continuous sinusoidal wave signal [8].

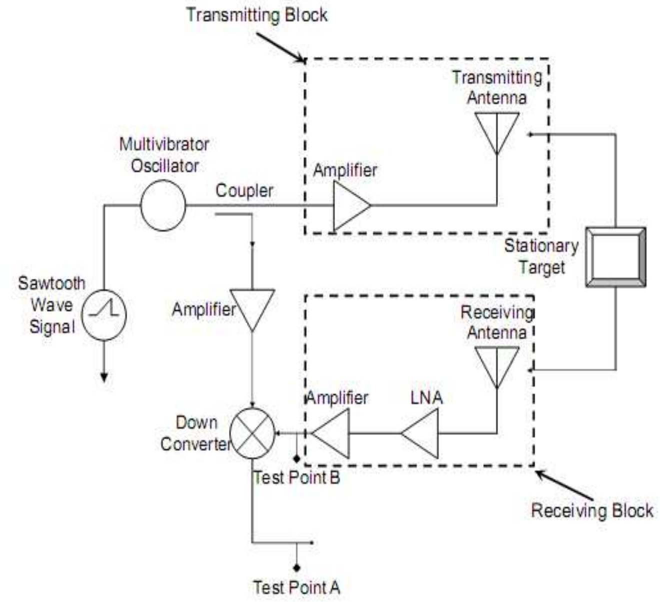


Figure 6. Modified FMCW system with multivibrator oscillator connected at the front-end transmitting block

In Figure 7, it is shown that the peak power for the baseband spectrum is reduced to -30.1 dB and carrier spectrum has a peak signal of -35.1 dB.Different kinds of oscillators were then implemented in the circuit to get the best spectrum line. After a few experiments, the best result was obtained using a voltage-controlled oscillator (VCO). The spectrum line has lesser ripples as the VCO is more suitable for frequency oscillation controlled by a DC voltage input. Frequency modulation can also be achieved in VCO by feeding modulating signals into it [9]. Therefore, from the previous block diagram shown in Figure 6, the multivibrator oscillator is replaced with a VCO and the sawtooth peak signal is increased to 5V to improve the power signal. The modified block diagram is shown in Figure 8 where the VCO is connected directly right before the coupler so that the signal from its output can be directed to the transmitting block and for the down-conversion process. The results of the simulation are shown in Figure 9.

The spectrum line becomes more stable after implementing VCO in the circuit system and the power signal also improved for both spectrums. For the baseband spectrum, the peak signal is achieved at 200 Hz whereas for the carrier spectrum, the peak power signal is obtained at a frequency of 2.4 kHz.

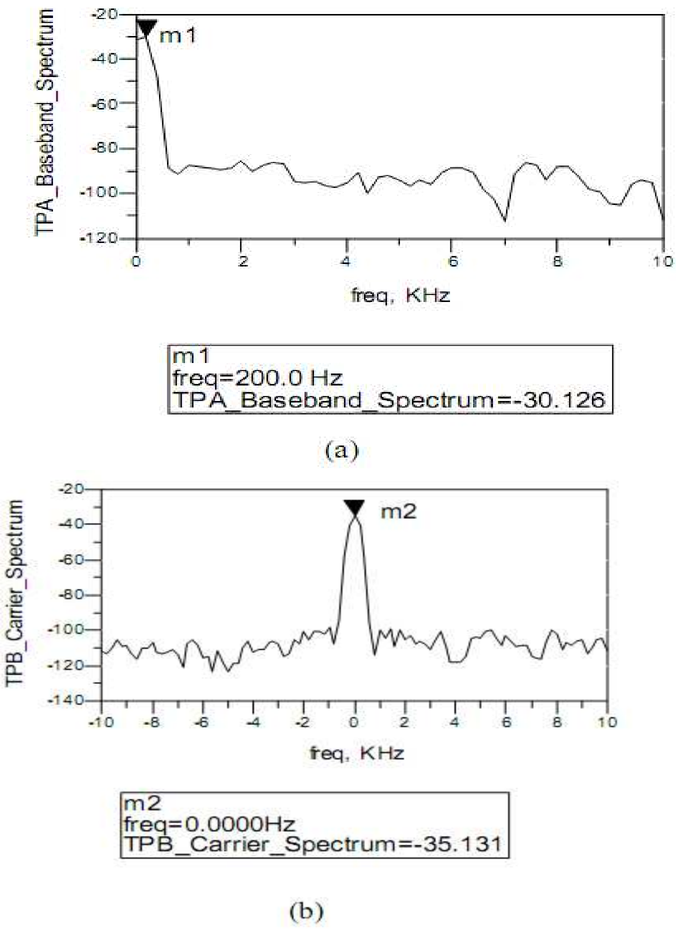


Figure7. Simulation with added multivibrator oscillator (a) Baseband spectrum at Test Point A (b) Carrier spectrum at Test Point B

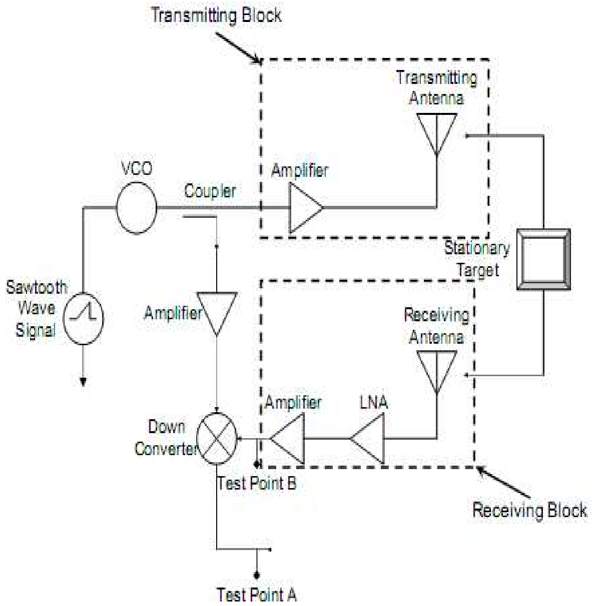


Figure 8. Block diagram of FMCW system with VCO implemented

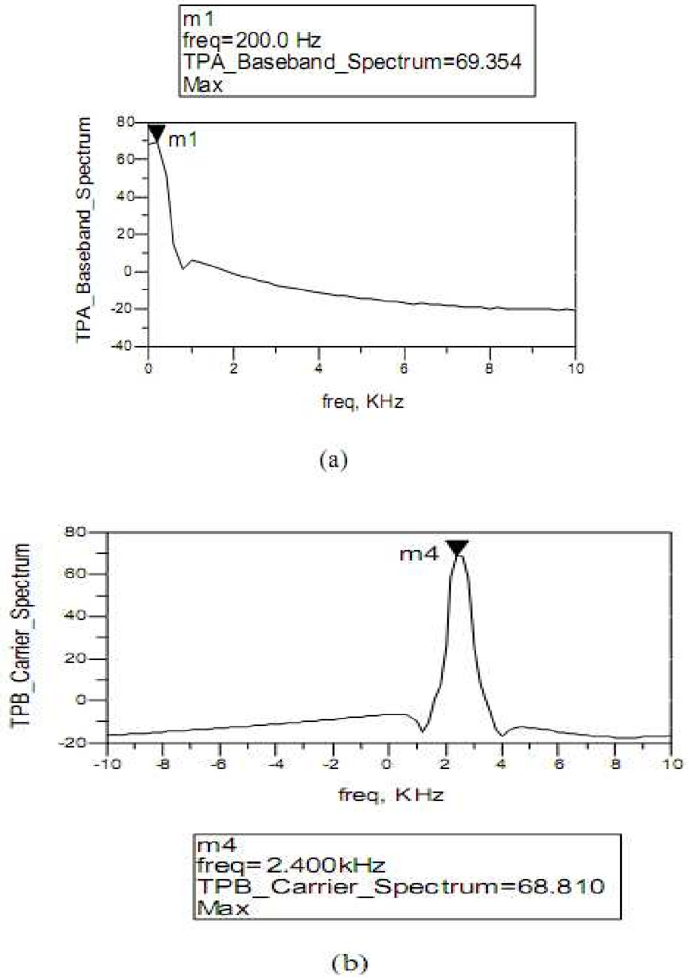


Figure 9. Simulation after multivibrator oscillator is replaced with VCO (a) Baseband spectrum at Test Point A (b) Carrier spectrum at Test Point B

IV. RESULTS:

The best result was obtained when we use a voltage controlled oscillator (VCO). The spectrum line has lesser ripples as the frequency oscillation of VCO can easly be controlled by a DC voltage input. Frequency modulation can also be achieved in VCO by feeding modulating signals into it.Therefore, from the previous block diagram shown in Figure 6, the multivibrator oscillator is replaced with a VCO and the sawtooth peak signal is increased to 5V to improve the power signal. The modified block diagram is shown in Figure 8 where the VCO is connected directly right before the coupler so that the signal from its output can be directed to the transmitting block and for the down-conversion process. The results of the simulation are shown in Figure 9. The spectrum line becomes more stable after implementing VCO in the circuit system and the power signal also improved for both spectrums. For the baseband spectrum, the peak signal is achieved at 200 Hz whereas for the carrier spectrum, the peak power signal is obtained at a frequency of 2.4 kHz.

V. CONCLUSION

Even though there is not yet a built-in tool for SSPR simulation in ADS, the components can be rearranged and the desired simulation can be obtained to fulfill the SSPR investigation criteria. In this paper, the block diagram for FMCW SSPR has been constructed to achieve the desired result. It is shown that the power spectrum is more stable after implementing VCO to the system. The peak of baseband and carrier spectrum also increased to 69.3 dB and 68.8 dB, at the frequency of 200 Hz and 2.4 kHz, respectively. However, further experiments need to be done to achieve the accurate SSPR simulation results, specifically the signal attenuation and permittivity variations so that in future research, different materials can be used as the target, where the permittivity, height and thickness can be introduced.

References

[1] M. Skolnik, Radar Handbook (3 rd ed.). New York, NY : McGraw-Hill, 2008.

[2] L. Liu, Y. Su, C. Huang, J. Mao, "Study about the radiation properties of an antenna for ground penetrating radar", IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications Proceedings, vol. 1, pp 391394, Hunan, China, 2005.

[3] D.J. Daniels, D.J. Gunton, H.F. Scott, "Introduction to subsurface radar", IEE Proceedings F Radar & Signal Processing, vol. 135, Pt. F, No. 4, Killingworth, UK, 1988.

[4] L. Peters, Jr., J. J. Daniels, J. D. Young, "Ground penetrating radar as a subsurface environmental sensing tool", IEE Proceedings, vol. 82, No. 12, pp. 1802-1822, Columbus, OH, 1984.

[5] D. Daniels, Ground Penetrating Radar (2 nd ed.). London, UK : The Institution of Electrical Engineers, 2004.

[6] N. Maaref, P. Millot, C. Pichot, O. Picon, "Ultra-wideband frequency modulated continuous wave synthetic aperture radar for through-thewall localization", IEE Proceedings of European Radar Conference, pp. 609-612, Toulouse, France, 2009.

[7] G. R. Olhoeft, S. Smith, J. P. Hyslip, E. T. Selig, "GPR in railroad investigations", Proceedings of the 10th International Conference on Ground Penetrating Radar, pp. 635-638, 2004.

[8] Agilent | Overview : Advanced Design System (ADS). [Online].Available:http://www.home.agilent.com/agilent/product.jspx?cc=US&lc=eng&ckey=1297113&nid=-346.0.00&id=1297113, 2000.

[9] Radio Frequency (RF) Carrier Signal. [Online]. Available: http://www.digitalradiotech.co.uk/carrier.htm , 2000.