Ultra Wideband Radar: Radar Cross Section Perspective

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Abstract

This work evaluates the ultra wideband radar performance from its cross section perspective. The Ultra wideband radar performance evaluated in this project was carried out as a function of SNR where the RCS took into consideration aspect angle effect on the SNR. The dependence of the radar cross section RCS on frequency and aspect angles was shown in the project as well as the performance of the ultra wideband radar as a function of SNR-range. The highpoint of the project was to model an optical radar system where the SNR performance is measured as the target moves through a specified angle path from 0 to 270 degrees. There was no ready algorithm to carry this out, but a method was developed which allowed evaluation of this performance from existing formulas. The findings of this project which include SNR-aspect results of two different scatterers have been analysed in later sections of the work. The applications based on the findings of this work have been listed to include cabin cruiser and automobile detections.

Key words: Ultra wideband, radar, radar cross section, aspect angle, SNR, range.

Background

This project investigates the performance of the ultra wideband radar from a cross section point of view. The ultra wideband technology itself got applied at about 1989 by the United States department of defence but work on this technology started in the 1960s (Terence W. Barrett, 2000). Radar itself is an acronym for radio detection and ranging and it is used in many applications ranging from civilian to military. The radar cross section is the probability of detection of a target when different factors in transmission have been put into consideration which this project has covered. Just as we have the ultra wideband radar, we have the narrow band radar system as well with the frequency and ranging playing a major differentiating factor between the two. In this project, the performance of the ultra wideband has been concentrated on and this has been shown in the project as we move on.

In pure communication systems, the ultra wideband has an advantage of having a higher informational capacity than the narrowband based on the Shannon's theorem of channel capacity but this is at the expense of range as it has a low power allocation. This limitation also draws an advantage form the fact that it helps in preserving the battery life of equipments. Some work has also been carried out into the design of joint UWB radar-communication system by (Christian Sturm et al 2010) having a transmitter and two receiver system whereby one of the receivers is a radar receiver which depends on the multipath propagation echo while the second receiver is for the data communication systems. This is a research area which is being explored.

This research field of radar cross section has gained a wide attention from radar researchers and engineers as it is useful in design. In (Bassen R. Mahafza, 2000), the cross section of the radar has been carried out by displaying the individual contributions of shapes to a complex object and this can be seen in the radar subsection of the (Bassen R. Mahafza 2000). In (David K. Barton et al, 2007), various targets' cross sections have been computed to provide an insight into different radar design to suit particular purposes. In (Ingo Harre, 2004) as well, the RCS has been fully analysed by the authors to demonstrate the behavioural pattern of different radar environments. Many other literatures in the reference section of this project have all contributed to this area of research but in this work we have demonstrated the performance of the radar using the RCS, SNR, frequency and range information obtained from various simulations as a result of the objectives to provide information to the radar engineer especially for design purposes. The ultra wideband radar has resolution abilities (J. Immoreer et al, 2001) which make this radar applicable in areas where we need a clear distinction between a target and clutters.

MATLAB simulations have been used in this project to achieve the underlying aim of this project which is to investigate the performance of the practical Ultra wideband radar cross section for the purpose of design.

Data Analysis

SNR-range behaviour

Figures 1 to 3 show the performance of the ultra wideband radar and the results are explained as follows.

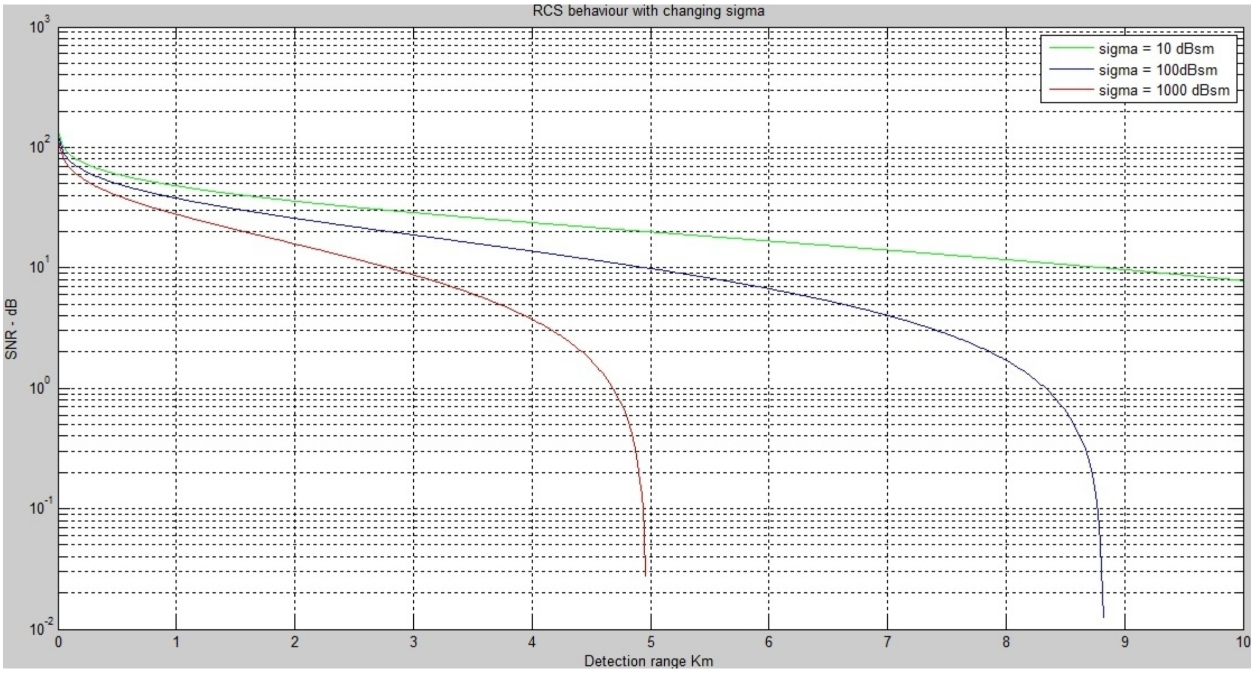

Figure 1. SNR-range performance over a changing RCS

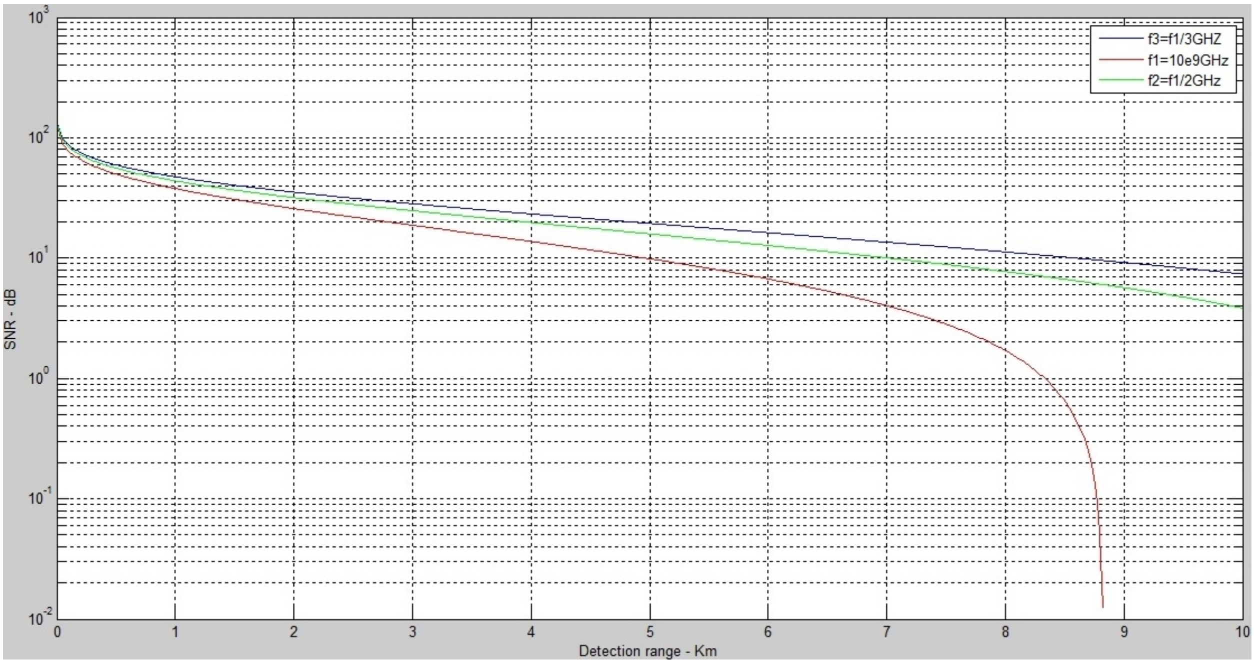

Figure 2: SNR-range performance over a changing frequency

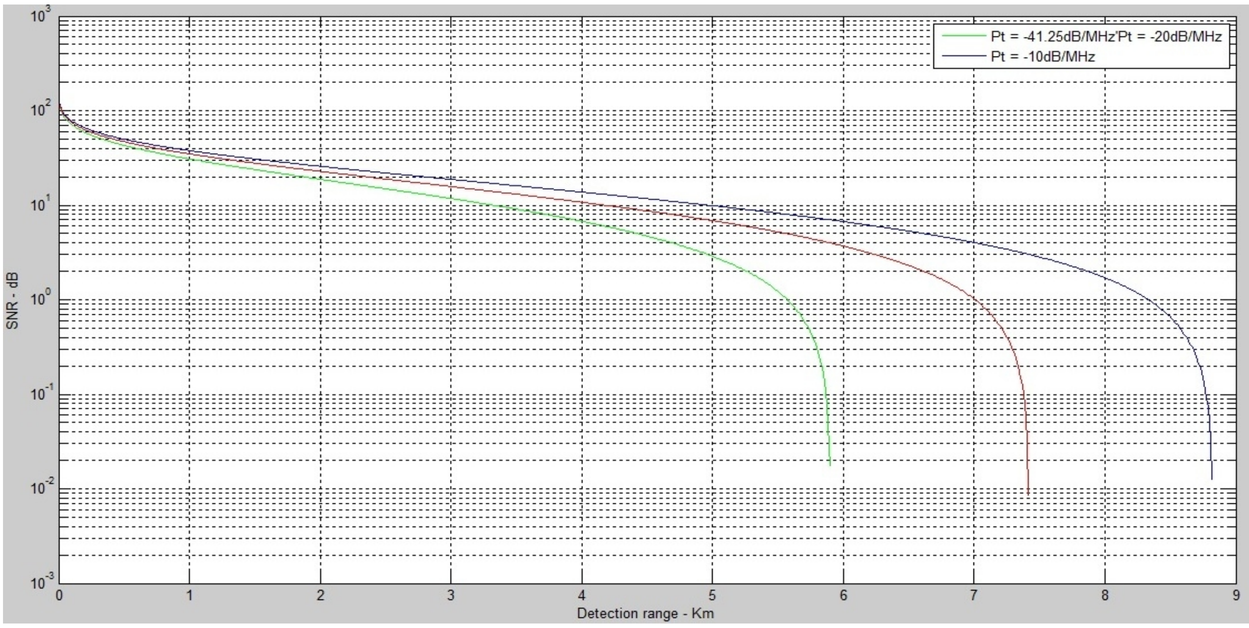

Figure 3. SNR-range performance over changing transmit power

In figure 1, we have three radar cross section values of 1000dBsm, 100dBsm and 10dBsm and the way they affect the performance of the system is displayed. Of the three values, it is obvious that the target that backscatters at 1000dBsm is a large object which makes it the most easily detectable and so on till the least one with 10dBsm. SNR is related to RCS directly from the radar SNR equation in the section 3 of this work. Taking a look at the radar cross section values, we discover it requires an almost stable SNR value at the point of transmission to detect a target with small RCS value. Lets now take the values into consideration, we have deliberately chosen the RCS values of 10,100 and 1000 because of their mathematical power relationship as $1000 = 10^3$ and $100 = 10^2$ and this means that the performance should be consistent throughout the graphical plot. But then if we again look at what point on the graph the 1000dBsm we require the most minimal SNR value at a particular range to cause backscattering from the target, much effort was not made by the radar signal as this is evident from the short distance it travelled. In figure 1 where the size of the second target is small compared with the first of 1000dBsm, we see an almost times two effort by the radar system to backscatter from this target. What this means is that at point 5meters on the range axis after a steep drop in the first case of 1000dBsm, the radar experiences almost the same condition when approaching the 10Km point on the graph. A close observation shows that instead of having the value ideally being close to 10Km on the graph since we expect that the backscatter of a 10^3 dBsm target should be consistent in behaviour terms as the mathematical power drops by a value in the second case, we didn't exactly see this as the value was instead near 9meters thereby suggesting that at the same SNR over a distance in the presence of losses and noise figure, the performance reduces rapidly and continues until a negligible value is reached.

Also importantly, please note that on the graph, at 5meters and 9meters mark of the two different targets, we have two different SNR values at which we experience backscattering minimally and SNR values lower than these for the two targets will produce no significant result. We also observe that from the SNR equation where we see that SNR is inversely proportional to the fourth power of range, the graph confirms that as the value as the value of SNR reduces, the range increases and vice versa. The minimum SNR value at 5Km and at 1000dBsm is approximately is 0.16dB and at 9meters for the 100dBsm, the value is approximately 0.19dB.

Tables 1 to 3 compare the obtained values at this point about the ultra wideband radar.

RCS at 1000dBsm	RCS at 100dBsm
Minimum SNR=0.16dB	Minimum SNR=0.19dB
Maximum range=5Km	Maximum range=9Km

Table 1. Performance of the UWB radar with varying RCS

At Pt=-41.25dB/MHz	At pt=-20dB/MHz	At Pt=-10dB/MHz
Maximum SNR=10^2 dB	Maximum SNR=10^2 dB	Maximum SNR=10^2 dB
Minimum SNR=0.17dB	Minimum SNR=0.22dB	Minimum SNR=0.19dB
Range=5.8Km	Range=7.5Km	Range=8.8Km

Table 2. Performance of the UWB radar with varying transmit power

At freq=10GHz	At freq=5GHz	At freq=3.3GHz
Maximum SNR=10^2 dB	Maximum SNR=10^2 dB	Maximum SNR=10^2 dB
Minimum SNR=0.187dB	Minimum SNR=6dB	Minimum SNR=8Db
Range=8.9Km	Range= above 10Km	Range=above 10Km

Table 3. Performance of the UWB radar with varying frequency

Looking at the maximum range ability of this radar, we will see that the difference between them in terms of range is 4Km. We then note that the ultra wideband radar even at very low signal to noise ratio value can cause backscattering (echo) from targets but with a limiting factor of range which makes one imagine the effect the UWB would have on the entire radar technology with improved transmit power and signal to noise ratio.

We have been considering the other two values of 10^3 and 10^2 dBsm RCS values but we also have on the graph the result of making the RCS value 10dBsm. The behaviour is slightly the same as the case of the other two only this time because of the size of the target that possesses this RCS, the minimum SNR needed to cause a backscattering will occur at a value either at $10^{-2} dB$ or below, also the range goes more than the set 10Km at SNR of about 8dB.

In table 3, which is the graph where we investigate the performance of the UWB radar over changing frequencies within the ultra wideband. We have the upper limit frequency at 10GHz instead of 10.6GHz for the purpose of simulation and result approximation. This we see as we have made $f_1 = 10GHz$, $f_2 = f_1 / 2GHz$ and $f_3 = f_1 / 3GHz$. Recall that with higher frequency come shorter wavelength as well from $\lambda = c / f$ and this is related to range as we will see shortly. At f_1, the SNR rapidly declines with increased range and terminates somewhere around 9meters with SNR at that range being about 0.189dB from the $10^2 dB$ initial value. The same occurs at f_2 and f_3 but only this time, the SNR continues to drop but so steeply as in f_1. The range improvement goes from $f_3 \rightarrow f_1$. Then again because the values of f_2 and f_3 are close when compared with f_1 and the two of them, we notice that the performance at those two frequencies are almost the same. This demonstrates to us that for better range performance, it's better to use the mode 1 ultra wideband frequencies. Mode 1 frequencies range from 3.1GHz to about 4.7GHz but then in communications according to Shannon's theorem of channel capacity where you have capacity directly proportional to bandwidth (frequency), it is evident that the upper limit frequency of the ultra wideband will have a higher informational capacity. Now let's look at the range-wavelength theoretical relationship in order to fully understand the effect of frequency on the range performance.

$C = \frac{range}{time}$, $C = \lambda f$, $\lambda f = \frac{range}{time}$, and $\lambda = \frac{range}{(time \times f)}$

C, λ and f are speed of electromagnetic wave, wavelength and frequency respectively.

Please note: The above analogy was drawn up when analysing this part of the project. It might not be seen like this in other works as we tried to break it down to suit this work.

From the last relationship, we see that the wavelength is directly proportional to range (meters). The performance evaluated is acceptable to us based on this because f_1 being the largest frequency has the shortest range followed by f_2 and then f_3. There are joint radar and communication systems therefore depending on the purpose of the radar system; we choose frequencies to match because as we have already seen in this section as well, resolution is better at higher frequencies.

In figure 3, we look at the SNR-range performance when we distort the default transmit power of -41.25dB/MHz at RCS value of 100dBsm and frequency of 10GHz. We know that the equation

$SNR = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 KTBFLR^4}$ can be rewritten as $R = \sqrt[4]{\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 KTBFLSNR}}$ and from here we also know that Range is directly proportional to the fourth root of transmit power; a performance which is evident from the table in table 2 and the equation proves that for us to have radar range ability doubled, we need to increase the transmit power by a 16 fold.

4.4 QUANTIFICATION OF PERFORMANCE ANALYSIS

From the computation under the investigative method subsection of section 3 of this work, the formula in MATLAB was made to give us the SNR-aspect angle performance of the system. We already saw some behaviour from objective 1 to 3 but this time, we want to know how this system will perform as the target moves across the selected angle path.

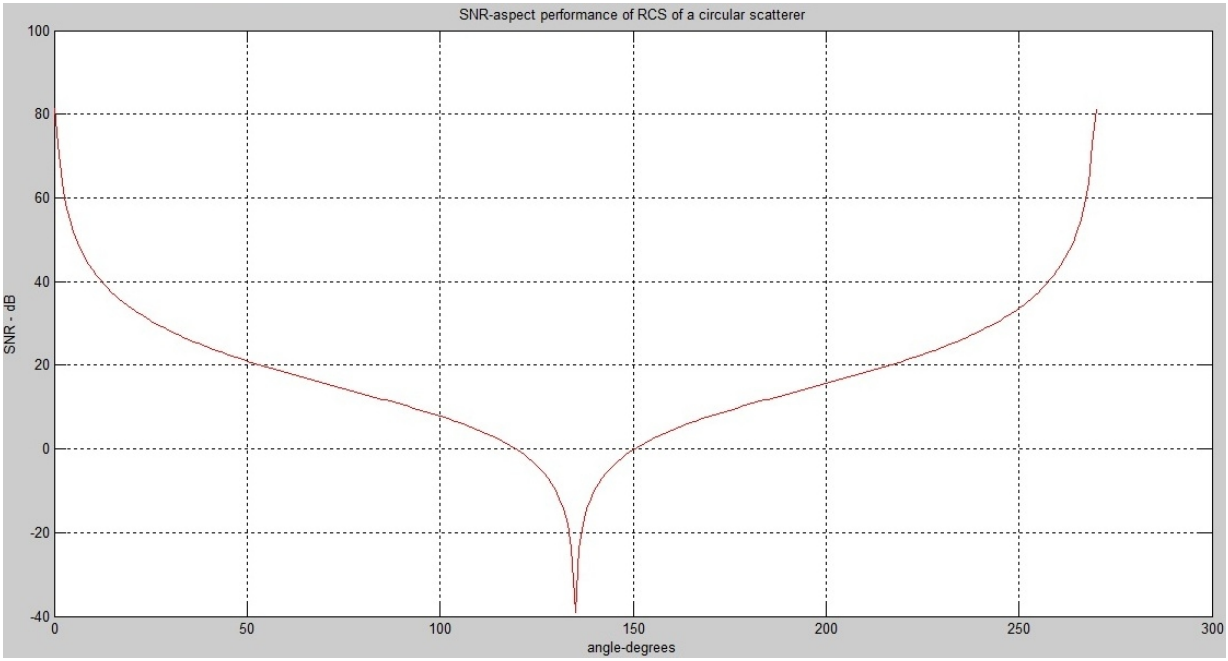

Figure 4. SNR performance with respect to aspect angle when the RCS is a function of the aspect angle using two different circular scatterers of 3meters spacing at 10.6GHz

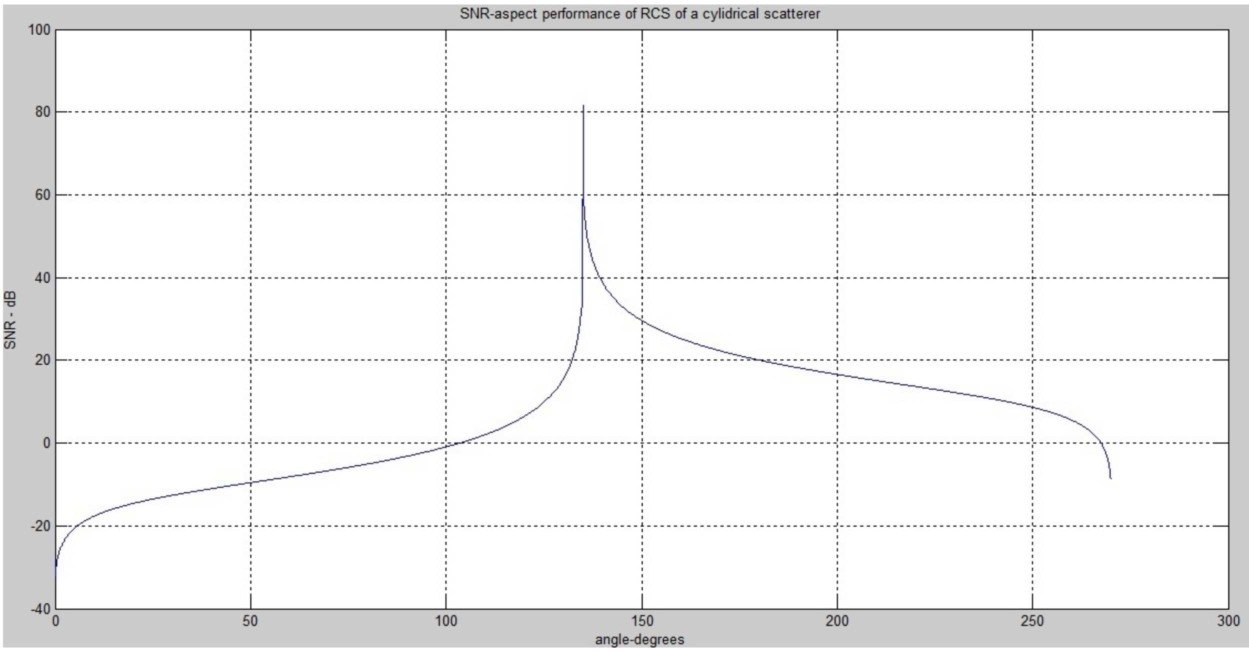

Figure 5. SNR performance with respect to aspect angle when the RCS is a function of the aspect angle using a cylindrical scatterer

Figures 4 and 5 give us a display of the SNR-aspect angles when RCS is a function of aspect angle as we see from the formula derived for this in section 3 of this work. The first point of observation is that the values of their peak SNR at the same spacing value of 3meters and same frequency of 10GHz remain almost the same with the cylindrical scatterer having a slightly higher value but this value is negligible.

Circular Scatterer	Cylindrical Scatterer
At 10GHz	At 10GHz
Maximum SNR=80dB	Maximum SNR=81dB
Circle Minimum SNR=-39dB	Cylinder Minimum SNR=-27dB

Table 4. SNR performance values of the circular and cylindrical scatterers

We also take note of the effect of interference in fig 4 where it is evident that as the SNR values continues to decrease, interference increases and in this case, upon receiving the signal, other processes have to be carried such as filtering and pulse compression. This interference effect is not uniform as well but we will not be concentrating on that for now.

From the table above, we observe that even when their peak SNR values are the same, their minimum SNR values differ largely with the cylinder producing higher values. For analysis sake, we will use the formula $\sigma = 4\pi R^2 \left(\frac{P_r}{P_t} \right)$. When we compute the values in the table into this formula we will see that the cylinder has higher values of RCS (sigma) than the circle scatterer. Therefore in practise, a complex object made up of a combination of these scatterers will have a mixed RCS performance with the cylindrical surface giving us a higher detection probability when compared with the circular surface and at better SNR when compared with the circular scatterer as well. From the formula, we have RCS of circle and cylindrical scatterers to be -139.6dBsm, -418.9dBsm and then -612.69dBsm, -958.31dBsm respectively.

5. Conclusion

In this work, we have looked at the ultra wideband radar system with a focus on cross section of targets. We saw the behavioural pattern of the radar system in the presence of aspect angle changing from 0 to 270 degrees as well as changing scatterer spacing. The ultra wideband radar system even at low SNR values can cause a backscatter even in the presence of relatively high noise and loss values relative to gain. Two scatters dominated the project and after comparing the values from the results obtained in the project, we conclude that when we have a complex target comprising of circular and cylindrical surfaces, depending on position relative to radar propagation path, the cylinder will be more detectable considering that we obtained RCS values to be between -139.6dBsm and -418.9dBsm for the cylindrical scatterer and then -612.69dBsm and -958.31dBsm for the circular scatterer. RCS fluctuations increase with increased spacing and frequency. We also conclude that the interference which causes fluctuations as well is a function of aspect angle, frequency and spacing because the higher any of these quantities, the more interference effects we observed.

References

Bassen R. Mahafza*; radar systems analysis and design using MATLAB*, Colsa Corporation, Huntsville, Alabama Chapman &hall, ISBN 1-58488-182-8

Christian Sturm, Thomas Zwick; *joint radar sensing and communications based on OFDM signals for intelligent transportation networks;* institute fur Huchfrequenz technik and elektronic, kar (gruhe institute of technology Kaiserstrabe 12, 7631, Karlsruhe, Germany

David K. Barton, Sergey A. Leonov; *radar technology encyclopaedia (electronic edition),* Artech house, Boston.London ISBN 0-89006-893-3

Ingo Harre*; rcs in radar range calculations for maritime targets,* Bremen, Germany (vs 0-20040206)

J. Immoreer; (Moscow state aviation institute), Wu Shunjun (national lab radar signal processing, Xidian Univeristy); *ultra wideband radar systems for increase information about targets,* Xian, Shannx, 710071, China

Terence W. Barrett; *history of ultra wideband (UWB) radar and communications; pioneers and innovations,* UCI, 1453 Beulah road, Vienna, VA 22182 USA