The Effect of Different Crossing Angles to the Stability and Similarity of Target Spectra in Forward Scattering Micro Radar Network

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Abstract - **This paper investigates the effect of different crossing angles of target spectra in Forward Scattering Micro Radar (FSMR). Target modeling and simulation signals have been executed using MATLAB Software to evaluate the performance of ground based Forward Scattering Radar (FSR) with omnidirectional antennas that operates at a low frequency bands (VHF and UHF). The obtained results show the effect of different crossing angles to the target spectra.**

Keywords – Forward Scattering Micro Radar, crossing angle, two-ray path propagation, trajectory

I. INTRODUCTION

The ground-based bistatic radar (BR) is generally used for the detection and classification of air target, maritime target and ground in defense applications. FSR is a subclass of bistatic radar (BR), happened when the angle of the target called bistatic angle, β is close to 180 degrees to the transmitter receiver baseline as shown in Figure 1. The desired radar signal is formed via the shadowing of the direct (transmitter-to-receiver) signal by the target body[1].

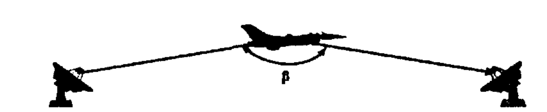


Figure 1: Forward scattering radar

Sensor networks for ground target detection are widely used for defense applications such as area and perimeter protection, border security and situational awareness [2]. Forward Scattering Micro Radar (FSMR) network comprise of a variety of sensors connected in a network as shown in Figure 2. It can detect an intruder which crosses the transmitter-receiver baseline. The sensor is placed on the ground with separate transmitting and receiving antennas facing each other separately [3].

In order to detect small and stealth target, the use of distributed FSR sensors network can offers a number of interesting features. The sensor can detect and classify the target even at low frequencies. Small and light weight characteristics enable the sensor to be freely dropped from remotely operated moving platform such as Unmanned Aerial Vehicle (UAV). Moreover, durable assembling and ability to spread in random order position make the sensor easily deployed on hazardous or remote areas [4-6].

In actual radar site, when FSR sensors are freely dropped there will be known and unknown sequence of moving target trajectory-angles. Besides that, the sensors are also exposed to other factors such as propagation effect, clutter and other external conditions which might influence target signature [9-10]. The analyses of propagation loss of radar systems usually utilize free-space propagation model with no ground reflection assumption and the two-ray path (TRP) model with ground reflection. The power budget analysis of ground FSR has been conducted in [7]. This gives an idea about dissimilar crossing angles from the baseline made by the target will produce different scattering angles and thus influence the target's power.

The main purpose of this paper is to analyze the effect and influence of moving ground target for different crossing angles in FSMR network at different system carrier frequencies within the VHF and UHF bands.

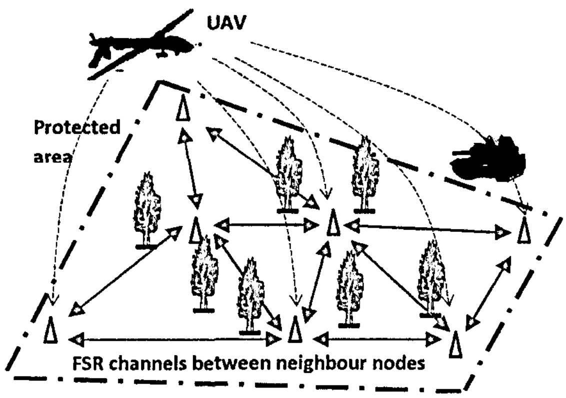


Figure 2: The concept of the FSMR network

II. SYSTEM CONCEPT

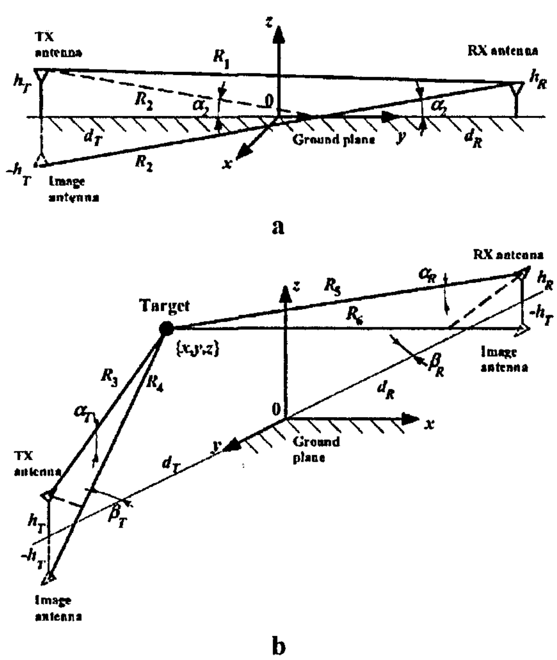


Figure 3: BR and FSR topology

a. for leakage signal
b. for target signal

Signal propagation for FSR topology based on two-ray path model is shown in Figure 3 and 4. The total length for baseline, $d = d_T + d_R$, h_T and h_R are the height for transmitter and receiver antenna from smooth and perfectly conductive ground surface. When there is no target presence, only two rays exist which are direct ray, R_1 and reflected ray from the ground, R_2 and sum of these rays will produce leakage signal [8].

$$R_1 = \sqrt{d^2 + (h_T - h_r)^2}$$

$$R_2 = \sqrt{d^2 + (h_T + h_r)^2} \quad (1)$$

At the receiving point, absolute phases of these rays experienced changes due to the variation of path length, $\varphi_1 = 2\pi R_1/\lambda$ and $\varphi_2 = 2\pi R_2/\lambda$. The signal amplitude for direct wave is also related with range, R_1 where by $U_1 = \lambda/4\pi R_1$. The signal amplitude for reflected wave with range R_2 is corresponding to the free space loss where $U_2 = \lambda/4\pi R_2$. However due to the ground reflection, there are some changes in magnitude and phase. Therefore total received signal is the sums of two rays are shown in equation below:

$$u_L = U_1 e^{j\varphi_1} + \Gamma . U_2 e^{j\varphi_2} \quad (2)$$

From the equation, Γ is the ground reflection coefficient that use for indirect rays and it depends on the ground properties, wavelength and antennas' polarization. For vertically polarized (VP) and horizontally polarized (HP) waves, respectively, where $\theta = \alpha_2 = \arctan(h_T + h_R)/d$ (Figure 3) and $\varepsilon_g = \varepsilon_r - j(\sigma/2\pi f \varepsilon_o)$ is the complex relative dielectric permittivity of the ground with relative dielectric constant ε_r and conductivity σ (depends on the types of ground surface).

When the target is located near the baseline, additional rays will be constructed for the target signal: Direct path $(R_3 - R_5), (R_3 - R_6)$ and reflected path $(R_4 - R_5)$, $(R_4 - R_6)$. The path lengths of these different rays are equal to:

$$R_3 = \sqrt{(d_T - y)^2 + (z - h_T)^2 + x^2}$$

$$R_4 = \sqrt{(d_T + y)^2 + (z - h_R)^2 + x^2}$$

$$R_5 = \sqrt{(d_R + y)^2 + (z - h_R)^2 + x^2}$$

$$R_6 = \sqrt{(d_R + y)^2 + (z + h_R)^2 + x^2} \quad (3)$$

β_T and β_R are the target's azimuth angle while α_T and α_R are the elevation angle of target with both types of angle are respected to the transmitter and receiver.

$$\phi_i = \frac{2\pi R_i}{\lambda}, \; U_i = \frac{\lambda}{4\pi R_i}, \text{ where } i=3,4,\ldots..6$$

$$\alpha_4 = arctan\frac{z-hT}{R_3}, \; \alpha_5 = arctan\frac{z-hR}{R_5},$$

$$\alpha_6 = arctan\frac{z-hR}{R_6}$$

$$\beta_4 = \beta_3 = arctan\frac{x}{d_T - y},$$

$$\beta_6 = \beta_6 = arctan\frac{x}{d_R + y} \quad (4)$$

By having their own magnitude and phase, the corresponding components of transmitted signal from four different rays may be written in a complex form as:

$$U_{3\text{-}5} = U_3\, e^{j(\phi_3 + \phi_5)} . \frac{\sqrt{4\pi(\lambda, \alpha_3, \beta_3, \alpha_5, \beta_5)\sigma_F}}{\lambda} . U_5$$

$$U_{3\text{-}6} = U_3\, e^{j(\phi_3 + \phi_6)} . \frac{\sqrt{4\pi(\lambda, \alpha_3, \beta_3, \alpha_6, \beta_6)\sigma_F}}{\lambda} . U_6 . \Gamma(\lambda, \alpha_6)$$

$$U_{4\text{-}5} = U_4\, e^{j(\phi_4 + \phi_5)} . \frac{\sqrt{4\pi(\lambda, \alpha_4, \beta_4, \alpha_5, \beta_5)\sigma_F}}{\lambda} . U_5 . \Gamma(\lambda, \alpha_4)$$

$$U_{4\text{-}6} = U_4\, e^{j(\phi_4 + \phi_6)} . \Gamma(\lambda, \alpha 4) \frac{\sqrt{4\pi(\lambda, \alpha_4, \beta_4, \alpha_6 \beta_6)\sigma_F}}{\lambda} . U_6 . \Gamma(\lambda, \alpha_6) \quad (5)$$

The total target's signal is:

$$U_{tg} = U_{3\text{-}5} + U_{3\text{-}6} + U_{4\text{-}5} + U_{4\text{-}6} \quad (6)$$

And when a ground target is taking into account, the total received power is

$$P_{tg} = | U_{tg} |^2 \quad (7)$$

In the following section, by consider TRP model for both leakage and target signal, the effect of ground characteristic to the stability and similarity of target power spectra is analyzed.

III. METHODOLOGY

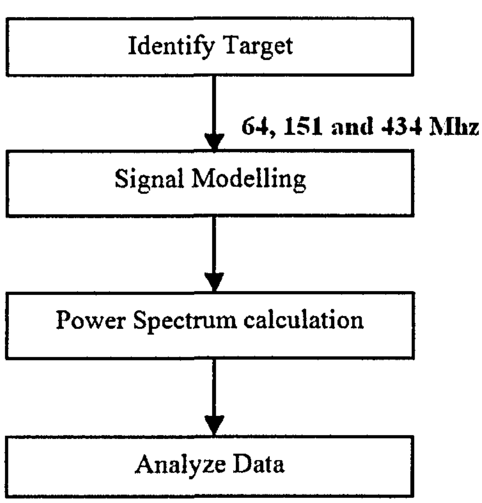


Figure 4: Block diagram of FSMR signal analysis

The block diagram of signal modeling for FSMR is shown in Figure 4. The objective of simulation is to produce target signatures data when a target crosses the baseline at 64, 151, and 434 MHz channels. The simulation signal modellings are radar cross section (RCS) and time domain signal. For better signal analysis, the time domain signature is then converted into frequency domain signal using the Fast Fourier Transform (FFT). Here, the similarity and stability for target spectra are analyzed.

IV. SIMULATION SETUP

The simulation was performed using MATLAB. Software version 2010b. In this paper, a situation is considered where different types of target are crossing the baseline with trajectory angles: 22.5°, 45°, 67.5° and 90° from the transmitter. Different dimensions of targets are used for target recognition possibility extracted from the received target signature.

The signals are simulated according to the two-ray path propagation model for the targets for the period of 60 seconds. The baseline was set 100m between transmitter and receiver and the target is crossing the middle of baseline with constant speed which is 10m/s. The heights of antenna from ground are varied 0.25 m for 64 MHz and 151 MHz and 0.2 m for 434 MHz

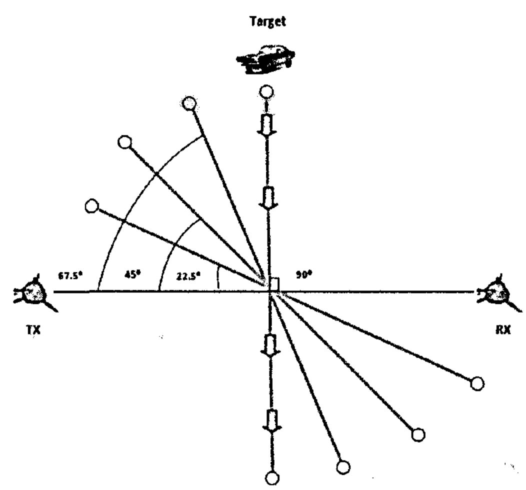


Figure 5: Concept of different crossing angles

The influence of different crossing angles are evaluated using point like target, square target(1m x1m) and large target (Hyundai Santa Fe : 4.501m x 1.674m). A rectangular plate target is illustrated in Figure 6.

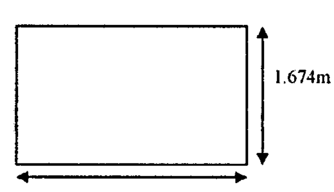


Figure 6: A rectangular plate target with dimensions of Hyundai Santa Fe

V. SIMULATION EVALUATION

According to the principle of FSR, radar signal is formed via the transmitting emission shadowing by the target body when the target crosses the baseline between the transmitter and receiver. RCS mainly depends on the target's physical cross section and the wavelength, and is independent of the target's surface shape. By taking three different targets' dimensions the received signals for 64MHz, 151 MHz and 434 MHz are plotted.

a. Point like target

isotropic < 1dB

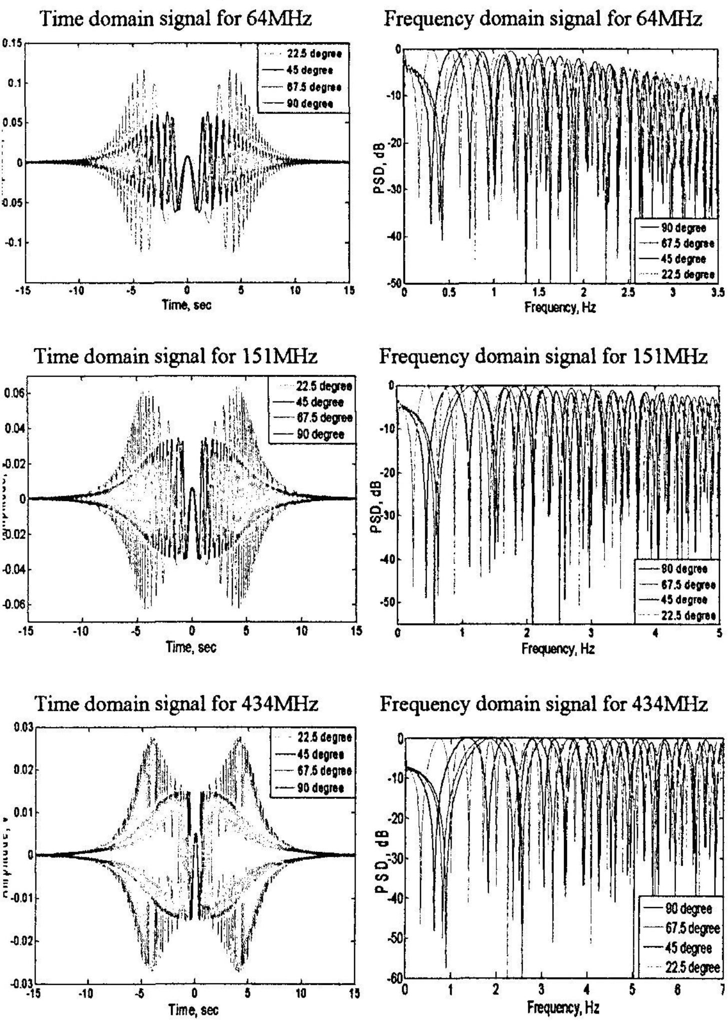


Figure 7: Point like target signals for different crossing angles at 64,151, and 434 MHz

Simulated point-like target can be considered as an isotropic antenna. As shown in figure 7, there are two – sided chirp signal and repetition with shifted scale between each target spectrum can be seen. The shapes are quite similar, but as the frequency increases, the power signals amplitude decreases.

b. Square target

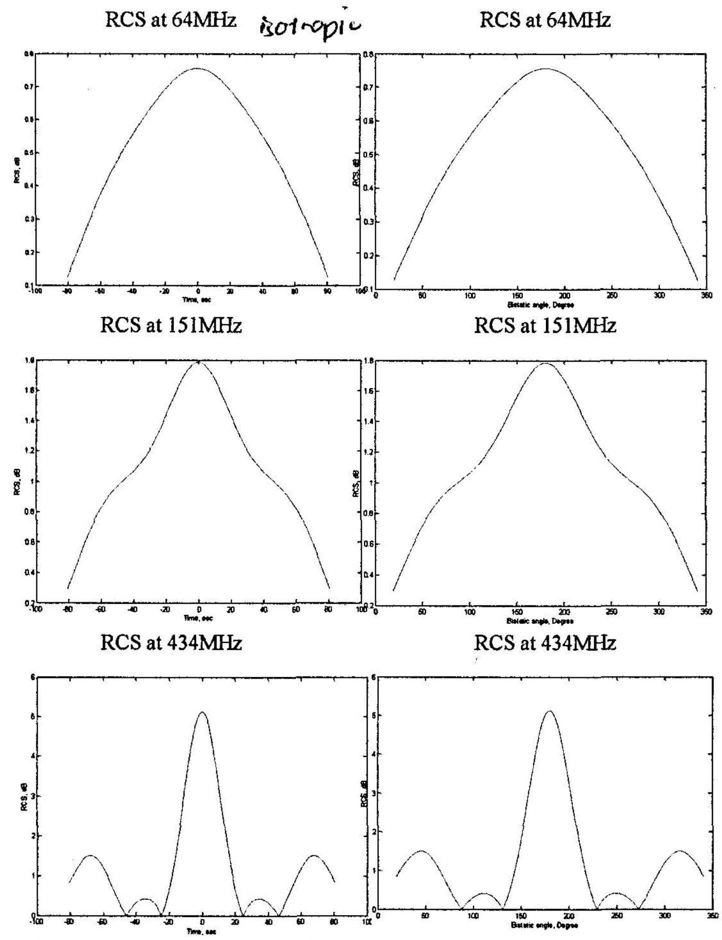
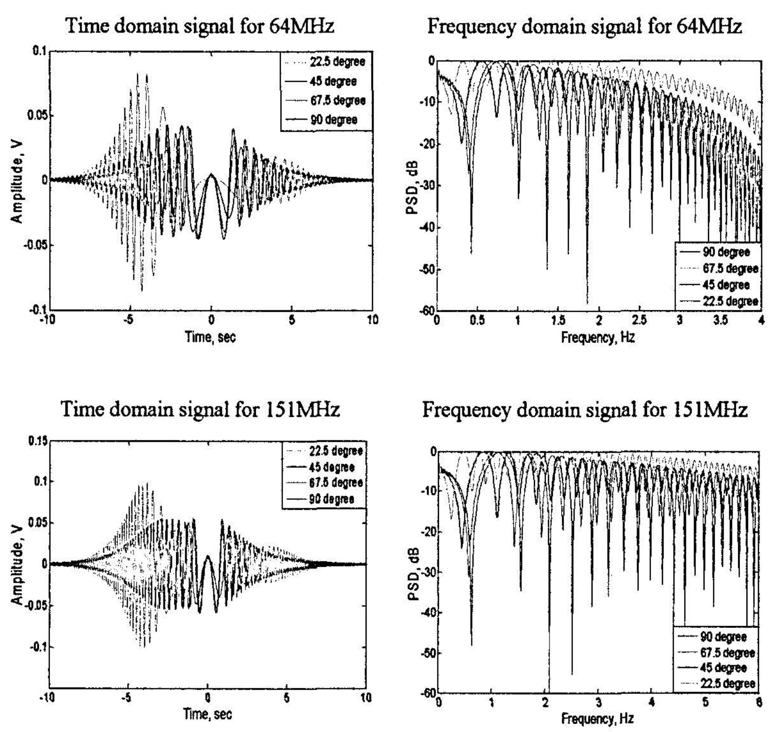


Figure 8: RCS radiation pattern for square target when crossing perpendicular to baseline of 100m at a speed of 10m/s



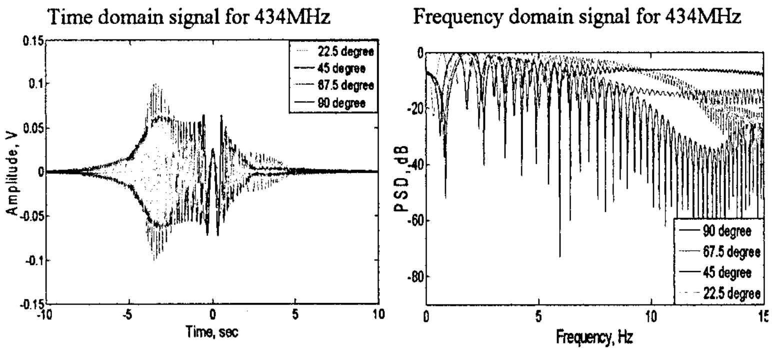
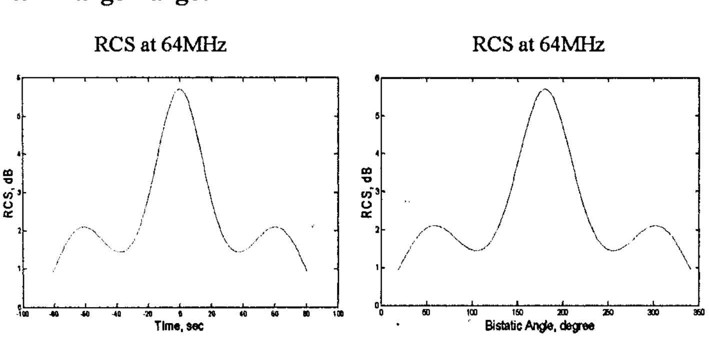


Figure 9: Signals of square target with 1m x 1m dimensions for different crossing angles at 64,151, and 434 MHz

As shown in Figure 8, the square target can be assumed that the value for RCS is 0.75dB at 64 MHz, and its radiation pattern is nearly isotropic. This target can be evaluated as point-like where the wavelength λ is more than characteristics target dimension. Nevertheless, there will be more side lobe when frequency increases as the RCS pattern is no longer isotropic. At 434 MHz frequency, the value of $\lambda \approx 0.72$ is closer to target dimension. Therefore RCS fall in resonance region where the RCS of target is tending to be larger than the physical size. It is proven that FS RCS is mainly depends on the target's physical cross section and the wavelength, independent of the target's surface shape.

Figure 9 illustrates the trend in power signals as a function of different crossing angles for square target. For every frequency, only 90 degree angle have two-sided chirp signal. This is because the target crosses the baseline perpendicularly (ideal case) where $d_T = d_R$. However, it can be seen that the discrepancies between target spectra become more visible at higher frequency. The power signals increase as target crosses closer to the transmitter and gradually decreases proportional to time . Thus, it can be analyzed that there are some impact of different crossing angles on square target. This can be explained by using target's RCS.

c. Large Target



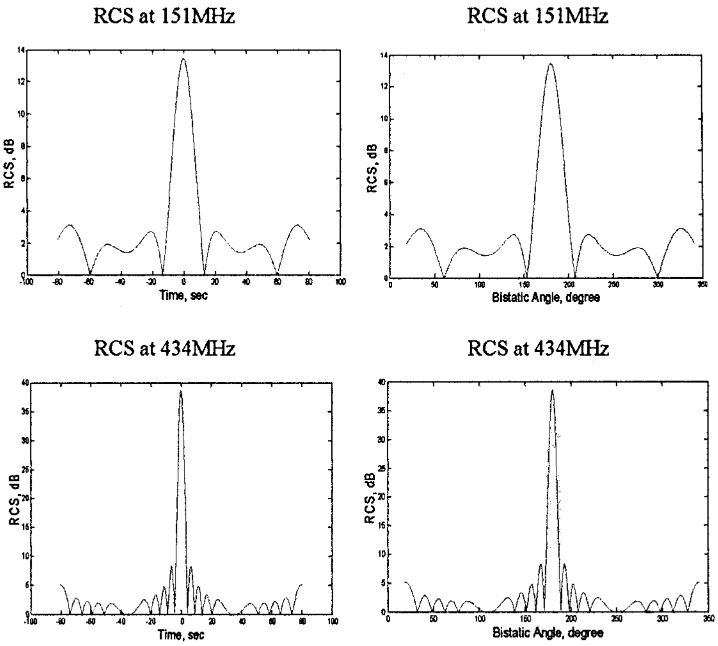
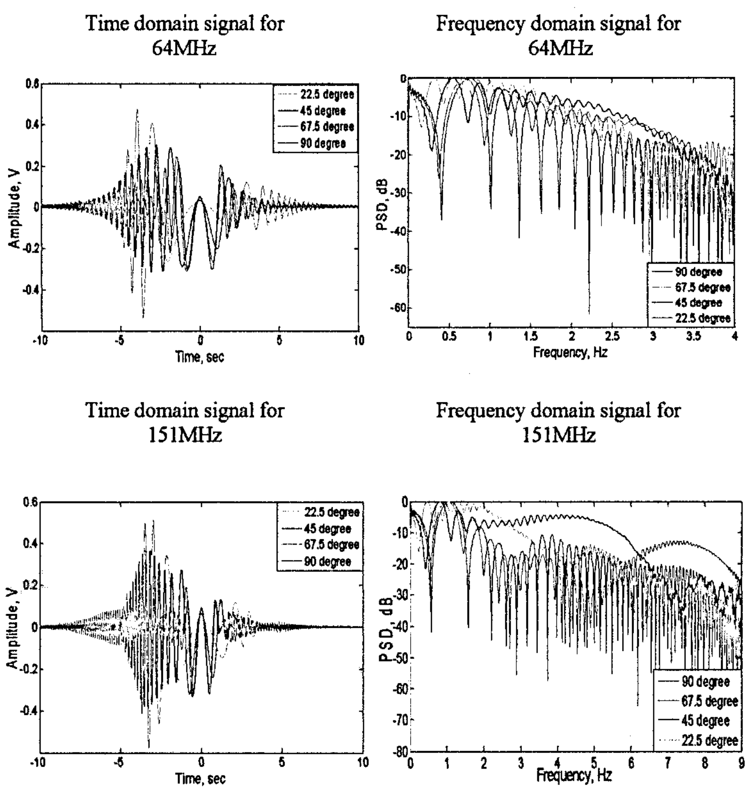


Figure 10: RCS radiation pattern for large target when crossing perpendicular to baseline of 100m at a speed of 10m/s



Time domain signal for
434MHz

Time domain signal for
434MHz

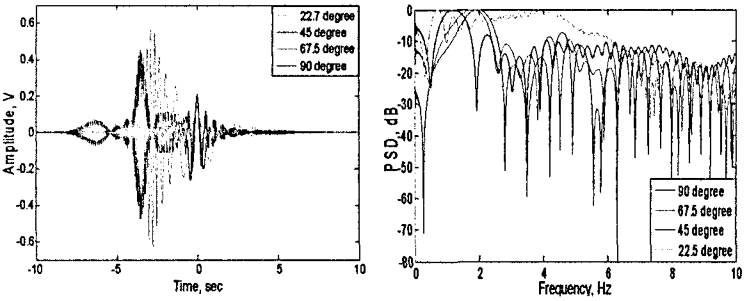


Figure 11: Signals of large target with 4.50 m x 1.674 m dimensions for different crossing angle at 64,151, and 434 MHz

Hyundai Santa Fe has been chosen as large target with a dimension of 1.406m x 4.77m. For large target RCS pattern, the signal indicates that the radiation pattern of the target is no longer can be considered as isotropic (Rayleigh region) even at low frequency of 64 MHz due to the reflected shadow signal from the transmitter. The large target produced more sides lobes compared to the square target as the dimension of target is larger than square which can fall under resonance region. The side-lobes of the RCS pattern are very different for each model giving the possibility of target recognition, if the difference in side-lobe could be extracted from the received target signature.

By referring to the Figure 11, even at low frequency, the shapes of target spectra tend to be similar but unstable. However, as consequences of reflected signal's blocking, a clearer dissimilarity and shifted signal between spectra can be seen as the frequencies increased. At 434 MHz, target's spectra distinctly show the differences. The simulation results demonstrate very much alike with the square target's results.

IV. CONCLUSION

The simulation results show that different crossing angles can affect the stability and similarity of target's spectra especially when the target RCS is approaching optical region. Therefore, for improvement of FSMR system, angle or space normalization process should be applied to target's spectra in order to minimize the effect of different crossing angles. Further research on how to use this simulation information for accurate target detection and classification will be very important in future.

REFERENCES

[1] Cheng, H., L. XiaoLiang, et al. (2010). Analysis of signal characteristic and resolution in ground forward scattering radar. Signal Processing (ICSP), 2010 IEEE 10th International Conference on.

[2] Cherniakov, M., M. Salous, et al. (2005). Analysis of forward scattering radar for ground target detection. Radar Conference, 2005. EURAD 2005. European.

[3] Gashinova, M., V. Sizov, et al. (2010). Signal detection in multi-frequency Forward Scatter Radar. Radar Conference (EuRAD), 2010 European.

[4] Long, T., C. Hu, et al. (2009). "Ground moving target signal model and power calculation in forward scattering micro radar." Science in China Series F: Information Sciences 52(9): 1704-1714.

[5]M. Cherniakov, "Bistatic Radar Principles and Practice", Chichester, John Wiley & Sons, 2007

[6] V.I Sizov, et al., "Forward scatter RCS estimation for ground targets", in Microwave Conference,2007. European, 2007

[7]M.Cherniakov, et al., "Forward scattering micro sensor for vehicle classification", in Radar Conference, 2005 IEEE International, 2005

[8] T. Rappaport, "Wireless communications: Principles and Practice", @nd ed, Prentice hall, 1996

[9]N.E.A. Rashid, et al., "Automatic target classification in a low frequency FSR network", in Radar Conference, 2008. EuRAD 2008. European, 2008

[10]R.S.A.R. Abdullah, et al., "Target prediction in Forward Scattering Radar", in Applied Electromagnetics, 2007.APACE 2007. Asia-Pacific Conference on, 2007