The Effect of Different Ground Characteristic to the Stability and Similarity of Target Spectra in FSR Micro-Sensor Network

Arifah Aziela Bt Jamaludin

Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM)
40450 Shah Alam, Selangor. Malaysia
azielaarifah@yahoo.com

Abstract—**This paper investigates the effect of different ground characteristic to the target spectra for the performance evaluation of ground base forward scattering radar (FSR) micro-sensor network based on the simulation model. The obtained results show the stability and similarity of target spectra when the conductivity and permittivity of different ground exists. This analysis result gives the idea of which kind database should the system has and at the same time can reduce the misclassification in the FSR micro-sensor network system.**

*Keywords— **FSR micro-radar, ground characteristic, two ray path propagation***

I. INTRODUCTION

The ground-based bistatic radar (BR) is generally used for the detection and classification of air target, maritime target and ground in defence 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 [1].

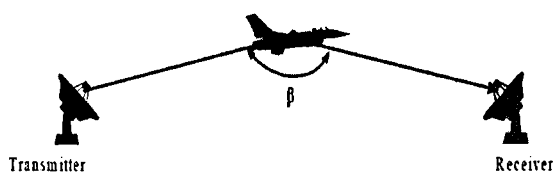

Figure 1: Forward Scattering Radar

Sensor networks for ground target detection are widely used for defence applications such as area and perimeter protection, border security and situational awareness [2-5]. The concept of FSR radar micro-sensor network capable for situational awareness is illustrated in Figure 2. When ground targets such as humans and vehicles entering the network coverage area, it able to detect and recognise the targets even though the target is small and stealth [6]. 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 [7].

The FSR sensor is using omnidirectional antenna due to the random position when it is freely dropped and placed on the ground [8]. In a real case scenario, the positions and orientation of the sensors and other factors such as target's moving trajectory and environmental effect for example ground reflectivity is uncontrollable. Therefore, the influence of these factors should be investigated.

It is expected that due to different ground characteristic and propagation paths, there will be some effect to target's signature transmitted power at the receiver will be affected. Hence, the main purpose of this paper is to investigate and analyse the effect of different ground characteristic to the similarity and stability of target's spectra in order to improve the performance of detection and classification of FFSR micro-sensor network.

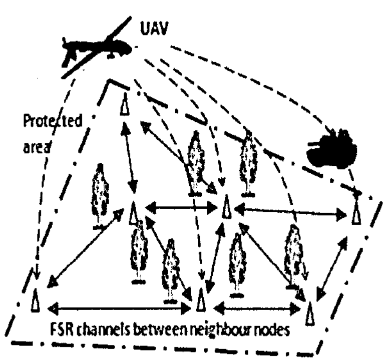

Figure 2: The concept of FS micro-sensor radar network

II. SYSTEM CONCEPT

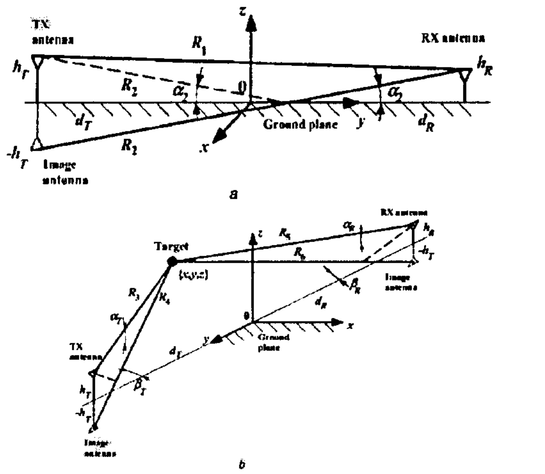

Figure 3: Two ray path model a) leakage signal b) target signal

The wave propagation for FSR micro-radar network based on two ray path model is discussed. Based on the two ray path model in figure 3 and 4, total length for baseline is $d = d_T + d_R$, h_T and h_R respectively are TX and RX elevations to the ground surface. From the model, there are two ray path of propagation when no target presence; direct ray from TX, R_1 and ray reflected from the ground, R_2. Total of these two rays is called leakage signal [8]. The path lengths of these two rays R_1 and R_2 are:

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

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

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 [8]. Therefore total received signal is the sums of two rays are shown in equation below:

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

From the equation, Γ is the ground reflection coefficient that use for indirect rays and it depends on the ground properties. In general, the ground reflections vary with the polarization of the wave and the ground permittivity [9]. The reflected wave from ground with angle of incident θ, is depends on the polarization of antenna. By derive the Maxwell's equation, ground reflection coeffient equations are:

$$\Gamma_v(\theta) = \frac{\varepsilon_g \sin\theta - \sqrt{\varepsilon_g - cos^2\,\theta}}{\varepsilon_g \sin\theta + \sqrt{\varepsilon_g - cos^2\,\theta}}$$

$$\Gamma_h(\theta) = \frac{\sin\theta - \sqrt{\varepsilon_g - cos^2\,\theta}}{\sin\theta + \sqrt{\varepsilon_g - cos^2\,\theta}} \qquad (3)$$

For vertically polarized (VP) and horizontally polarized (HP) waves, respectively, where $\theta = \alpha_2 = \arctan(h_T + h_R)/d$ (fig 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).

The above 2 ray model approach can be extending to four rays when there is a target presence near the baseline. Figure 4 shown that the transmitted power arrives at receiver via four different paths: 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 [5]:

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

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

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

$$R_6 = \sqrt{(d_R + y)^2 + (z + h_R)^2 + x^2} \qquad (4)$$

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 [5]:

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

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

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

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

The total target's signal is: (5)

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

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

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

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

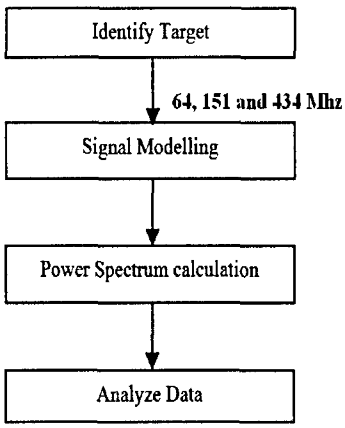

Figure 4: FSR signal analysis flow diagram

Figure 4 shows the flow chart of analysing the effect of different ground reflection to the target spectra. Target is simulated using signal modelling at different frequency (64MHz, 151MHz, and 434MHz). The simulated time domain signal is then converted into the frequency domain signal using the Fast Fourier Transform (FFT) in order to see the effect more clearly. Here, the similarity and stability for target spectra is analysed.

IV. SIMULATION SETUP

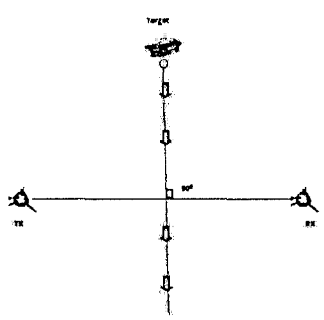

Figure 5: FSR configuration

Simulation was carried out using MATLAB Software version 2010b. The baseline is set to be 100m between transmitter and receiver with constant speed 10m/s. Various types of ground characteristic (concrete dry, average ground and wet ground) are used in this analysis. The target signals are simulated according to the two-ray path propagation model for the period of 60 seconds. The heights of antenna from ground are varied from 0.2m up to 0.3m depends on the frequency use. Different target's dimension is used: point target (RCS=1 m^2), square target (1mx1m) and large target (Mitsubishi Pajero: 2.2m x 1.7m). The target is simulated based on ideal case scenario where the target is crossing perpendicularly in the middle of the baseline with constant speed.

V. SIMULATION EVALUATION

By using three different dimensions of targets, the received signals for 64MHz, 151 MHz and 434 MHz are plotted. Due to the target motion the signal Doppler frequency shift occurs and can be approximated as a two sides chirp signal, with zero Doppler when the target crosses the baseline. For better signal analysis, the time domain signatures are converted into the frequency domain using power spectrum estimation technique. Different scaling-like factor with similar shape spectrum will be produced.

Important parameter for signal model is time moment when the target crosses the baseline of FSR. We predict the existence of target base on the high zero Doppler frequency (reflect to maximum Radar Cross Section) when the target is exactly on the transmitter – receiver baseline. Doppler frequency at the receiver will increase as the target move away from the baseline.

A. Point Like Target

The influence of different ground characteristic is evaluated based on three different targets. Figure 7 shows the target signature and spectra for point like target at three different frequencies. A simulated point-like target signal can be considered as an isotropic antenna where the RCS=1 dBsm is applied at all frequencies. Therefore, it can be expected that RCS at 64MHz is equal. The results suggest that at 64MHz, the power spectra at different ground characteristic have a similar shape and stable repetition. But as the frequency is increased, we can see slightly shifted in the main lobe between each target spectrum. However, it will not give any effect to the system performance most of the information about the target use for further analyse contains in the side lobes of the spectra.

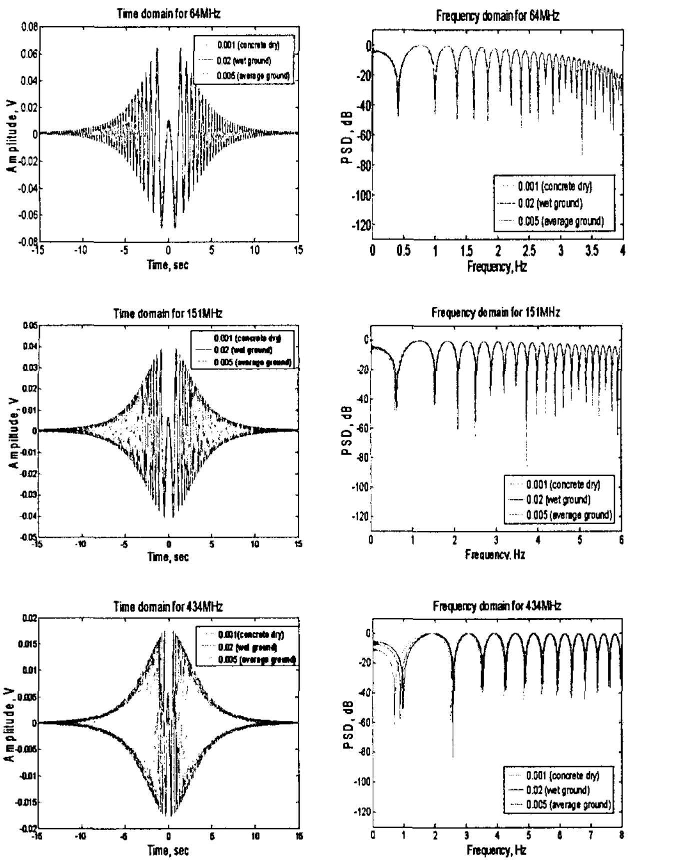

Figure 7: Signals of point target with RCS = 1dBsm for different ground characteristic at 64MHz, 151MHz and 434MHz

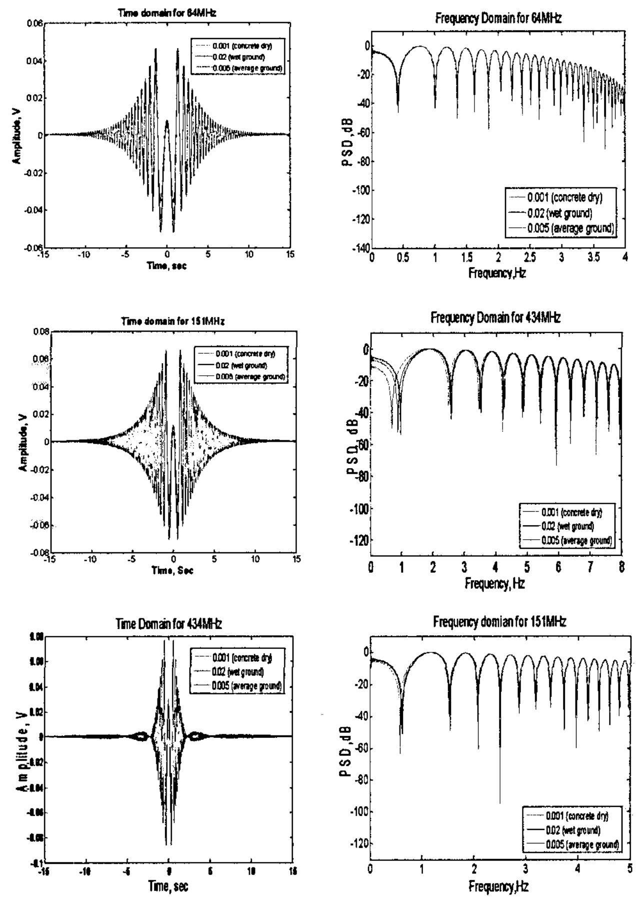

Figure 8: Signals of square target with 1m x 1m dimension for different ground characteristic at 64MHz, 151MHz and 434MHz

B. Square Target (1m x 1m)

The simulation is once again been evaluated by using a square target with dimension of 1m x 1m. From the simulation result in Figure 8, it is shown that the target spectra for square target are similar to the spectra of point like target. We can see that at 64MHz, the main lobes for power spectrum are overlapping very well and it can be considered as isotropic case. But as the frequency is increased, the differences between target spectra became more visible. At 434MHz channel, it can be observed that there are some shifted at the first few lobes. This can be explained by looking at the RCS in Figure 9. However, the shapes of target spectra for square target are also similar and stable. Hence, it can be concluded that the system performance has not been affected by different ground characteristic.

The result above can be explained by looking at the RCS of the target as shown in Figure 9. At 64MHz, the value for RCS = 0.75dB and the pattern can be considered as isotropic since the wavelength λ is more than target dimension. Therefore RCS for low frequency is situated in Rayleigh region [10]. Hence, as the frequency increased, the radiation pattern of RCS is varied. The number of side lobe for higher frequency is increased. At frequency of 434MHz, the value of RCS is closer to the target dimension. Therefore, it is situated in resonance region where the RCS of target is assumed to be larger than the physical size [10].

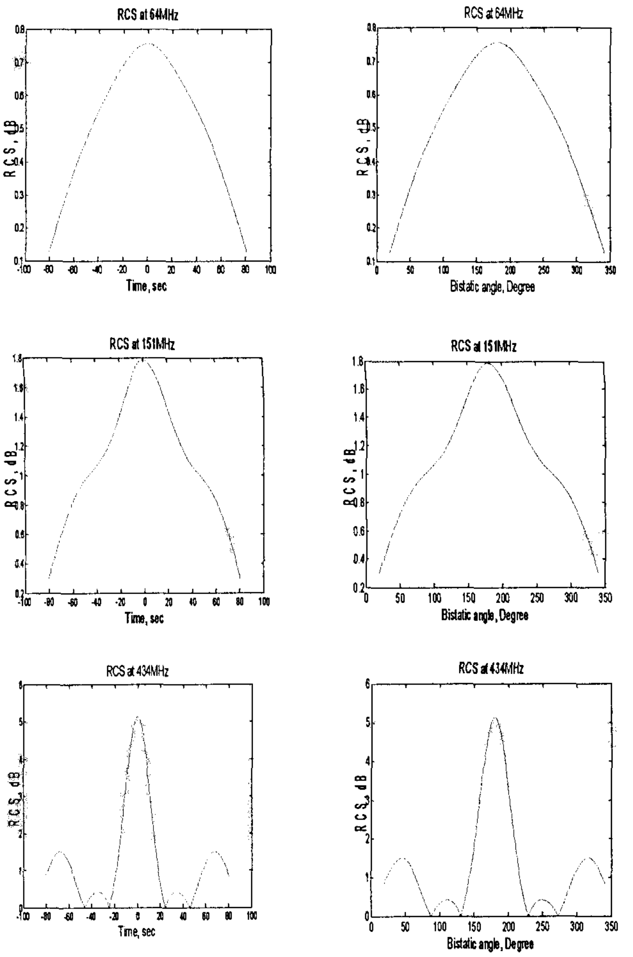

Figure 9: Radar Cross Section for square target 1m x 1m dimension when crossing a baseline of 100m at a speed of 10m/s

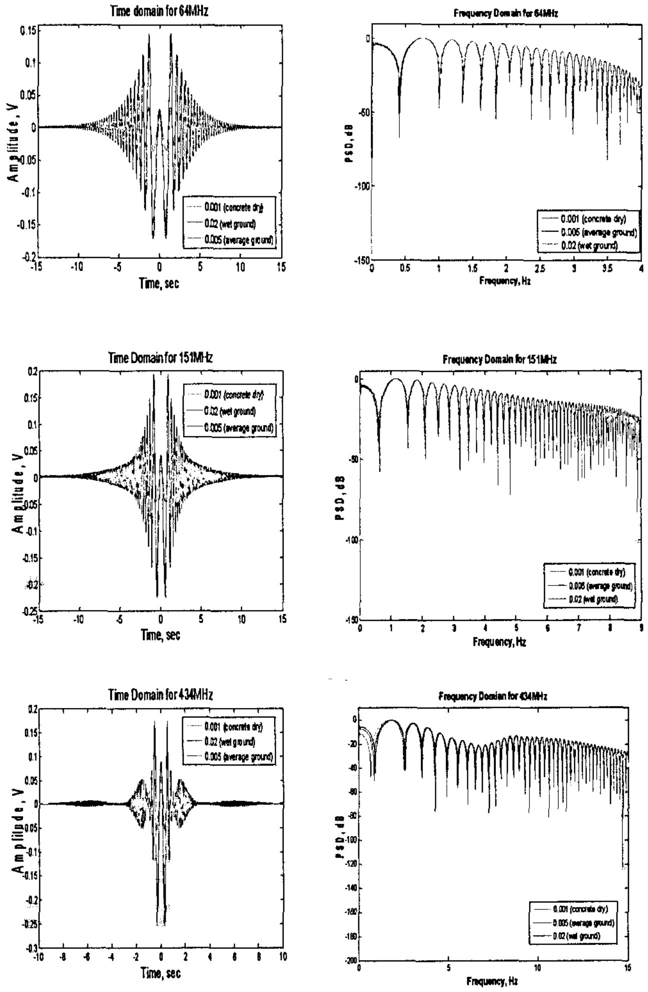

Figure 10: Signals of large target with 2.2m x 1.7m dimension for different ground characteristic at 64MHz, 151MHz and 434MHz

C. Large Target (2.2m x 1.7m)

The effect of different ground characteristic is also been simulated by using a large target with the dimension of 2.2m x 1.7m. By referring to Figure 10, at low frequency (64MHz), we can observe there are repetitions in the spectra. These three plots exhibit almost no difference, revealing that the reflections from the ground-air interface are almost the same for conductivities of 0.001 S/m and 0.005 S/m and 0.02 S/m at 64MHz and 151MHz frequency. However the as the frequency increase at 434MHz, it enhance the detect ability of target hence it can be seen clearly that the target spectra have more similarity repetition lobe but the spectra become unstable. There is also phase shifted in target signature. This can be explained by looking at the RCS for of the target in Figure 11.Based on the two ray path model, phase difference between target signatures caused by different path length and the path length is affected by ground reflection coefficient [11].

The RCS radiation patterns for all frequencies are shown in Figure 11. For large target RCS pattern, the signal indicates that it is no longer can be no longer considered as isotropic even at low frequency of 64 MHz .The radiation pattern has a clear main lobe compare to square target. The number of side lobes is proportional to the frequency which contains more information about the target. We can see that at 434MHz, the target is fall under optical region.

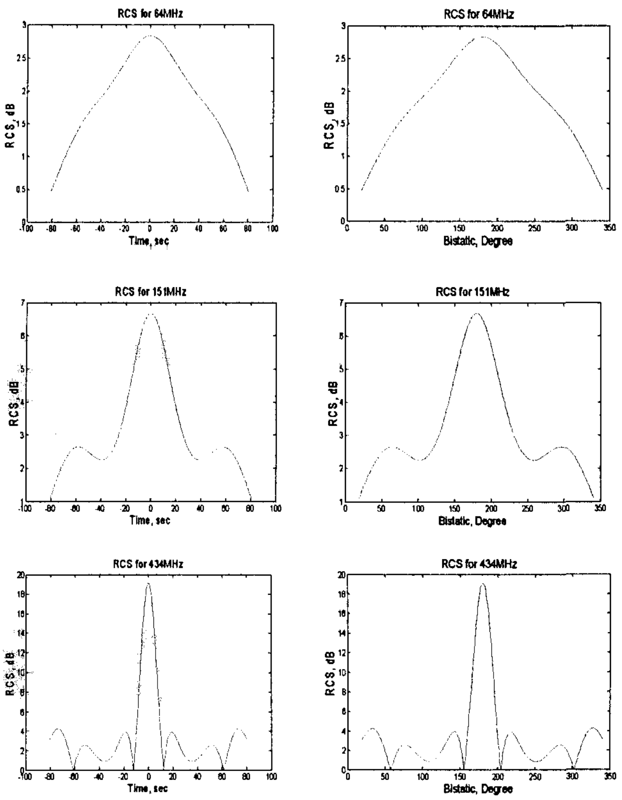

Figure 11: RCS radiation pattren for large target (2.2m x 1.7m) when crossing pependicular to baseline of 100 m at a speed of 10 m/s

VII. CONCLUSION

The result from the analysis suggests that different ground characteristic can affect the stability and similarity of target's spectra only for large target and at high frequency. In order to improve the performance, further analysis should be conducted using real measurement signal. A part from that, an appropriate method for example spectra normalisation should be applied in order to achieve stability of the spectra.

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