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Metallic Cylinder Reflected Power Measurement For 93.1GHz Frequency Modulated Continuous Wave Radar Calibration

P. N. Ja'afar[1], S. M. Idrus[1*], S. Ambran[1], N. A. Yusri[1], N. Mohamed[1], A. Hamzah[1], N. Shibagaki[2], K. Kashima[2], T. Hayashi[3]

[1]Universiti Teknologi Malaysia, Johor Bahru, 81310 Johor, MALAYSIA

[2]Hitachi Kokusai Electric Inc., Tokyo 187-8511, JAPAN

[3]Link Laboratory Inc., Tokyo 185-0014, JAPAN

*Corresponding Author

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Abstract: A metallic cylinder is one of the best materials and shapes to calibrating radar system performance. In addition to its reflective properties, metallic cylinders allow for accurate modeling for prediction of radar cross-section (RCS). This study presents the measurement of a metallic cylinder with a diameter of 4cm and a height of 3cm as a target, analyzed in the millimeter-wave (mm-wave) spectrum. The experiment was conducted in the real airport environment at Kuala Lumpur International Airport, Malaysia, under clear sky conditions. The measurement was carried out at 93.1 GHz utilizing a Frequency Modulated Continuous Wave (FMCW) radar to consistently detect the target. The RCS of the metallic cylinder was measured at different angles relative to the runway pavement. The results showed that the measurements exhibited smaller RCS value at longer ranges, with an average of –43.47 dBsm, compared to –30.16 dBsm at shorter ranges, indicating a total change of 13.31 dBsm. The reflectivity characteristics of the radar target, theoretical measurements of the metallic cylinder, incident angles from the radar target, and measurement evaluations are presented in this paper.

Keywords: FMCW radar, foreign object debris detection system, radar cross section, calibration, millimeter-wave, runway airport

1. Introduction

Detection of foreign objects debris (FOD) on runway surface is vital for a safe airport operation. Its presence on the airport runway and taxiway can be the primary cause of disruption to flights and airport operations if it is not removed instantly. Since FOD can cause harm, it must be removed via a manual or automated detection system. Generally, manual detection is reliant on airport operators to perform manual inspection while automated detection systems can carry out rapid detection continuously without assistance from any airport personnel on-site. In addition, an automated detection system is more efficient since it can avoid unnecessary runway closure due to inspection [1]–[3]. To deal with this issue, the Frequency-Modulated Continuous Wave (FMCW) radar ranging method and frequency modulation method are used as the transmission signal [4]–[6]. Besides promoting a low-cost systems measurement technique, FMCW radar is also able to determine a very small range to the target accurately [7]–[9].

During conducting the experiment on real airport conditions, one of the key elements that might degrade the radar performance is the slope of the standard airfield runway pavement. According to International Civil Aviation Organization (ICAO) Annex 14 specifications [10], the uneven slope of a runway is designed to provide a drainage gradient so that water will run off the surface to a drainage system and avoid stagnant water. One of the methods to test

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*Corresponding author: sevia@utm.my

the system performance is by conducting calibration on the FOD detection system which is done to aim the compute radar echo for target properties study. Considering the target physical form, the metallic cylinder is one of the simple shapes to use as reference targets. The target material is particularly efficient to backscatter higher reflection, besides being one of the major targets that must be identified on runway according to The Federal Aviation Administration (FAA) specifications and guidelines [11]. The main problem of radar sensors in this application is the ground pavement that may obstruct the detection of FOD which is commonly due to the low target radar cross-section (RCS) of such objects. Recent works on FOD detection utilizing automated radar systems are available in the literature, however, there is no reference yet on the calibration considering various target ranges on runway pavement [12]–[14].

In this paper, instead, a calibration of the metallic cylinder is presented, focusing on nine ranges from radar to the target across a wide spectral band. The experiment was conducted on Kuala Lumpur International Airport (KLIA) runway which the radar frequency operating at 93.1GHz FMCW. To avoid inconsistent reflectivity, all measurements are carried out under clear sky conditions. A 4cm diameter and 3cm height metallic cylinder were chosen as the radar target for the calibration measurement. The size is preferred due to its good reflectivity from radar. Therefore, it is good to be used as the main target for the RCS calibration process. This paper is organized as follows. The experimental setup for all measurements is described in Section 2. Section 3 discusses the findings and then presents the results of the measurements. Finally, Section 4 concluded the main results of this work.

2. Experimental Work

The experiment was conducted in a real busy airport condition at Kuala Lumpur International Airport (KLIA) which involves radar antenna unit (RAU) as the main receiving system, runway pavement as the main subject, and metallic cylinder as the target. The radar detection system used is operating at 93.1 GHz on RAU located 185-meter from runway centerline considering the uneven surface of the ground. The first measurement was set aligned with the runway pavement where is positioned at 90° from the RAU point of view. The following measurement was placed at an additional of 30° and 60° from the first measurement demonstrating measurement point 2 and measurement point 3, respectively. These measurements focus on three different locations to validate the consistency of the target's RCS values against the angle of power transmitted from the antenna. Fig. 1 illustrates the overall arrangement of three measurement points.

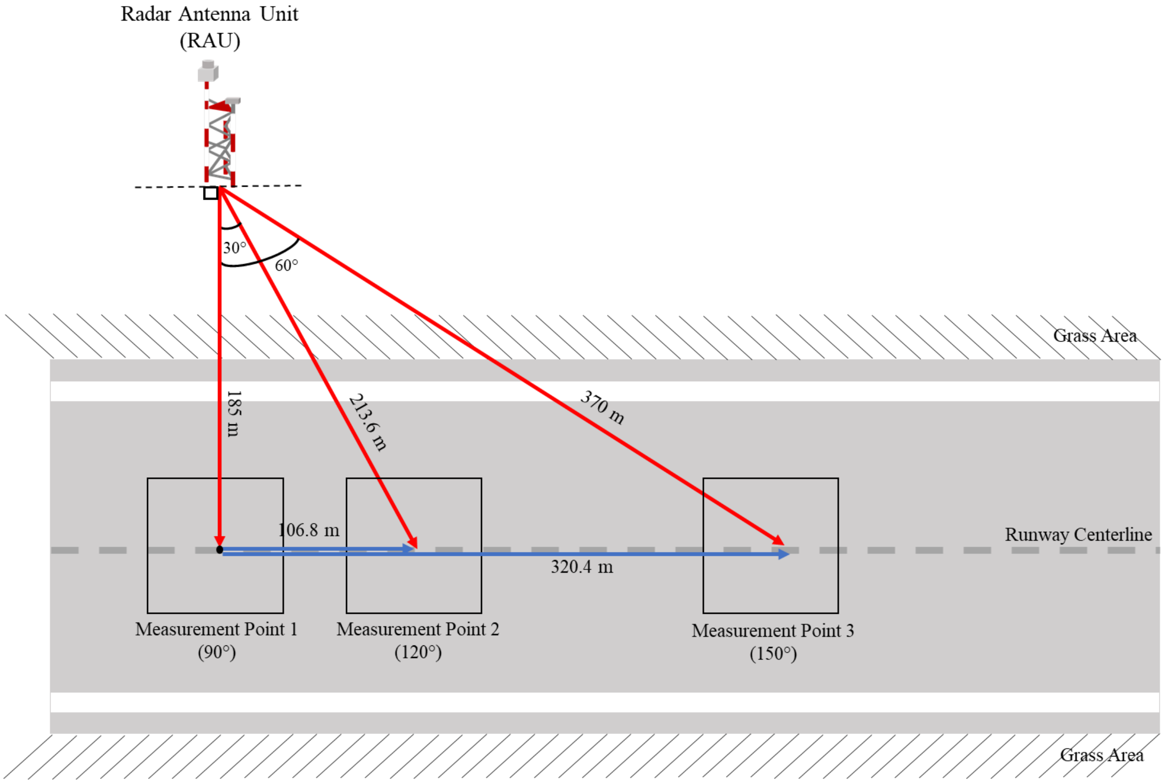

Fig. 1 - Experimental setup for the target positions at all measurement

In every measurement point, nine identical metallic cylinders that were placed in a 3x3 arrangement were located 15-meter apart from each other as shown in Fig. 2. The arrangement was set to investigate the changes of identical target's RCS at various positions which varies in the range between RAU and the target on the runway. As can be seen, the P1 to P3, P4 to P6, and P7 to P9 are located near the RAU, centerline of the runway, and far from RAU, respectively.

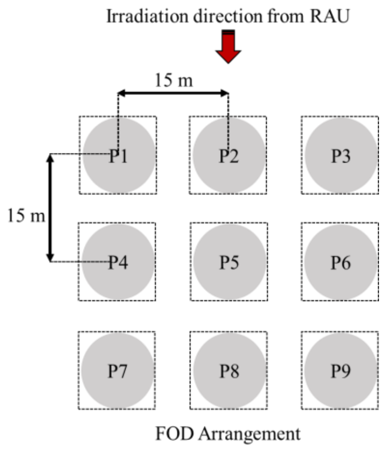

Fig. 2 - Arrangement of metallic cylinders at every measurement point

The dependency of reflected power is projected to be decreased as the radar range increases. It is proven through the basic principle of radar equation as derived in Equation (1) [15]:

$$P_r = \frac{P_t \,.\, G \,.\, \sigma \,.\, A_e}{(4\pi)^2 R^4} \tag{1}$$

where the received power back from the target by the radar, P_r is formulated by the derivation of transmitted power P_t, gain of the radar transmit antenna, G, target's radar cross-section, σ, effective area of the radar receiving antenna, A_e, and range from radar to the target, R.

The measurements are focused on the three different locations to observe the effect of FOD cross-section values against the ground slope. Generally, the RCS of the target metallic cylinders is liable on the radar frequency, the angle aspects of incidence, and receiver polarization. The backscatter properties of this simple geometry shape which is cylinder will be vary depending on its size and the system wavelength. However, in this measurement, the size of cylinders was controlled at one size only which is 4cm diameter and 3cm height. Only the location and position of the target's placement will be manipulated to study the reflectivity of the radar target at different angles. Three ranges of arrangement position with 15 meters distance from the edge of the runway are selected which involves the position of three different positions as illustrated in Fig. 3. From the side view of measurement work as figured, the position of FOD at P1 to P3, P4 to P6, and P7 to P9 are located at 15m, 30m, and 45m from the edge of the runway respectively. The reflectivity measurement was done by analyzing the RCS value of the metallic cylinder at all positions, considering clear sky conditions.

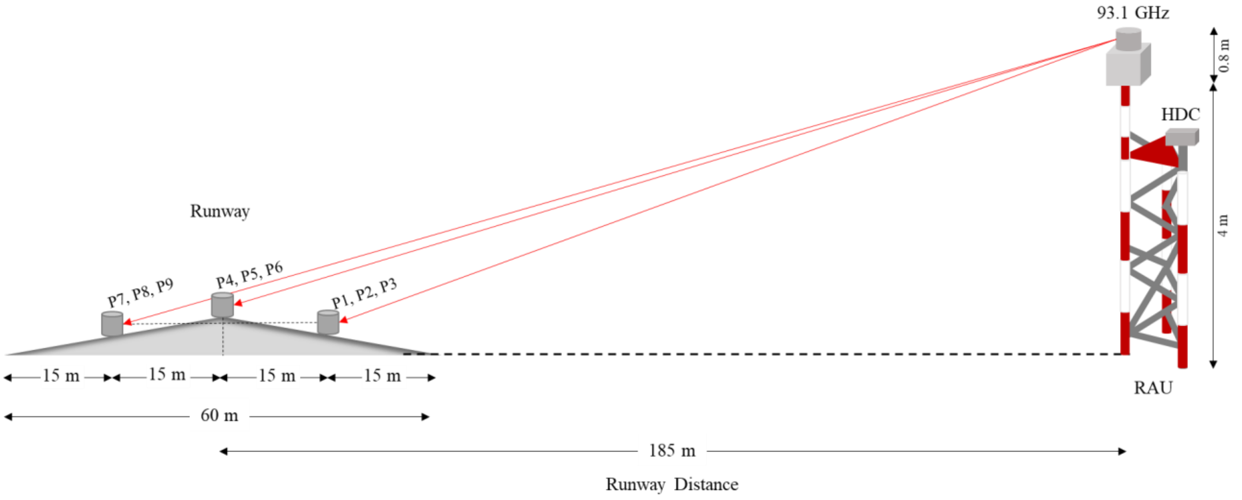

Fig. 3 - Side view of radar tower and KLIA runway

3. Result and Discussion

The images of the radar position indicator (PPI) for three measurement angles were recorded in Fig. 4, where it is representing the radar display used for the FOD detection system in KLIA. From the PPI displays, the value of RCS can be defined once the system spotted any FOD detected. As can be seen in the figure, the green line indicates the angle of radar direction which is 90, 120, and 150 degrees in this case. The detected FODs show higher reflectivity that can be distinguished with the base runway ground.

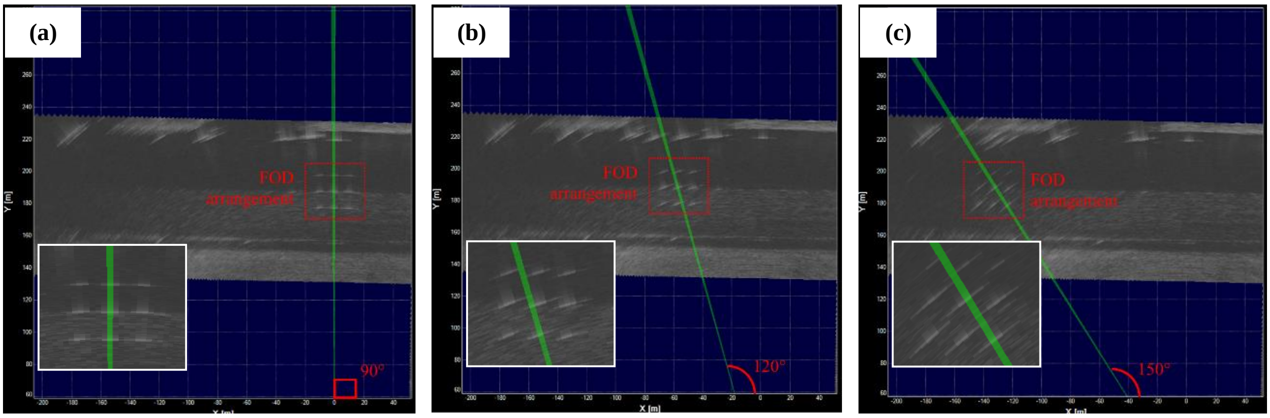

Fig. 4 - Radar PPI at RAU 2-3 for angle of (a) 90°; (b) 120°; (c) 150°

As tabulated in Table 1, the RCS measurement for three ranges distance from RAU is recorded and analyzed for runway slope study purposes. As the distance from the RAU to the target increased from 15m to 45m with an increment of 15m from the runway edge, it is found that the reflected power scattered due to power losses along with the distance travel by the mm-wave which makes its RCS values reduced from –30.16 dBsm to –43.47 dBsm with a total change of 13.31 dBsm. The value of RCS shows that the higher the range between RAU and the target, the smaller the values of the received power, considering the loss during the EM wave travel along with the distance and its incident angle.

Table 1 - RCS measurement at different ranges from runway edge near RAU to the target

Measurement Point (Incidence angle of RAU to the runway)	Average RCS at Various Position (dBsm)		
	15m from runway edge (P1, P2, P3)	30m from runway edge (P4, P5, P6)	45m from runway edge (P7, P8, P9)
1 (90°)	– 29.81	– 30.53	– 42.37
2 (120°)	– 30.13	– 28.03	– 39.79
3 (150°)	– 30.53	– 34.81	– 48.26
Average RCS (dBsm)	– 30.16	– 31.12	– 43.47

Average RCS at P1 to P3, P4 to P5, and P7 to P9 of all measurement points are – 30.16 dBsm, – 31.12 dBsm, and – 43.47 dBsm, respectively. As depicted in Fig. 5, the graph plotted shows the comparison between the RCS values received from the radar echoes versus the FOD position placed on KLIA runway pavement ground in the case of three measurement points which are 90°, 120° and 150°. It can be noticed that consistent reflected power is obtained. As can be seen on the plotted graph pattern, it is worth mentioning that the changes in radar range will affect the reflected power of the target. Based on the observation made, the RCS values for P1 to P3 are almost identical at all positions even though it was placed at different angles of radar point of view. This is anticipated due to the position of the FOD being placed near to the radar and thus its RCS values are similar regardless of different angles. As can be seen at the angle of 90 degrees, the reflected power for P4 to P6 that is located on the runway centerline is almost similar to the RCS value for P1 to P3 as the position is near to the RAU. However, the measurements at the angle of 150 degrees showed a decrement in reflected power due to the angle seen from the radar being wider than other angles. In the case of the target at P7 to P9, it is expected to obtain a lower value of RCS due to the positions being further from RAU besides its position behind the runway slope. The RCS values at angle 150 degrees for P4 to P9 showed consistent lower values compared to other angles. It can be observed that the values are decreased as the distance from RAU to the target increases, considering the slope of the runway. From this finding, it can be found that the measurement is successful for radar system calibration considering the range from radar to the FOD target as well as the effect of runway slope pavement.

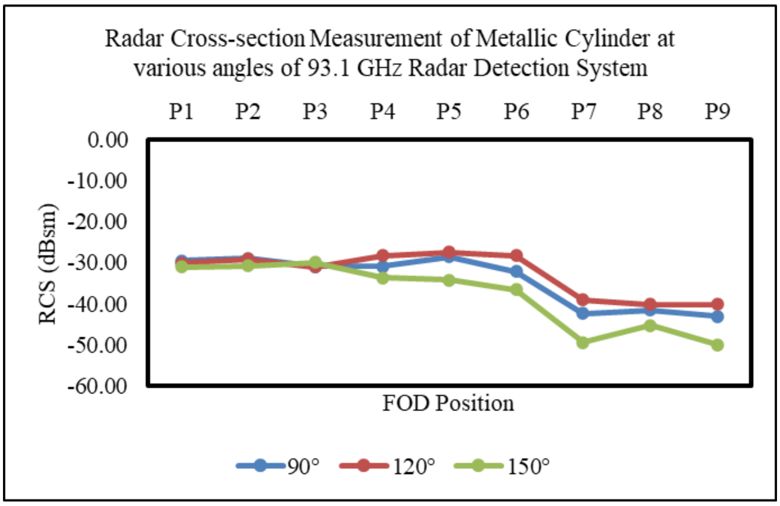

Fig. 5 - Comparison of RCS metallic cylinders measurement on various target's position and angle of RAU to the runway pavement

4. Conclusion

This paper presents the calibration study of the RCS metallic cylinder considering the incidence angle of radar to the slope of runway pavement at KLIA. The experimental findings showed that the slope of ground runway pavement can effectually affect the target's RCS in the case of the range between RAU and runway. The RCS exhibited a smaller value with an average of –43.47 dBsm at a longer range compared to –30.16 dBsm at a shorter range. This result is considering the incidence angle from mm-wave radar to the target of the cylinder in nine positions placed on the runway. Moreover, the slope of runway pavement is able to reduce the RCS in the boresight direction by an average of 13.31 dBsm in a 93.1 GHz bandwidth. By considering the same target examined, as the range between a transmitter to runway increases, the power received by the target will be reduced due to the power loss along with the distance travel. This direct radar system detection for metallic cylinder RCS on various angles is of considerable interest in this work.

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