International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Report ITU-R M.2501-0
(12/2021)

Technical and operational characteristics of the foreign object debris detection system operating in the frequency range 92-100 GHz

M Series

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International Telecommunication Union

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REPORT ITU-R M.2501-0

Technical and operational characteristics of the foreign object debris detection system operating in the frequency range 92-100 GHz

(2021)

Scope

This Report provides the technical and operational characteristics of foreign object debris (FOD) detection system operating in the frequency range 92-100 GHz for sharing and compatibility studies between FOD detection system and passive services, as well as among active services.

Keywords

Foreign Object Debris, FOD, Radiodetermination, RADAR

Related ITU Recommendations and Reports

Recommendation ITU-R F.699 – Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz

Recommendation ITU-R F.1332 – Radio-frequency signal transport through optical fibres

Report ITU-R F.2239 – Coexistence between fixed service operating in 71-76 GHz, 81-86 GHz and 92-94 GHz bands and passive services

Glossary/abbreviations

CW	Carrier wave
dBc	Decibels versus the carrier level
dBsm	Decibels per square metre
EESS	Earth exploration satellite service
FFT	Fast Fourier transform
FMCW	Frequency modulated continuous wave
FOD	Foreign object debris
IF	Intermediate frequency
KLIA	Kuala Lumpur International Airport
MASPS	Minimum aviation system performance specification
PP:	Plan position indicator
RAU	Remote Antenna Unit
SNR	Signal to noise ratio
UTM KL	Universiti Teknologi Malaysia Kuala Lumpur

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1 Introduction

Foreign object debris (FOD), defined as "*Any object located in an inappropriate location in the airport environment that has the capacity to injure airport or airline personnel and damage aircraft*" [1], can cause damage to aircraft as well as injury airport employees. Since FOD directly costs the global aviation industry $1.26 billion annually and indirect costs, such as flight delays, cost the global aviation industry $13.9 billion annually [2], new technologies for FOD have been developed to continuously inspect for and detect FOD. The guidance and specifications for procuring airport FOD detection equipment was published in 2009 in which four types of detection systems are addressed [1]. Millimetre-wave FOD radars operating in the frequency band 78-81 GHz which can provide high detection sensitivity, short detection response time, sufficient coverage of surveillance area and high location accuracy have been well designed and tested and commercialized for safety airport operation.

FOD Hazards can severely injure airport or airline personnel or damage equipment. Types of potential damage include [1]: cutting aircraft tires; being ingested into engines; or becoming lodged in mechanisms affecting flight operations. Personnel injuries can occur when jet blast propels FOD through the airport environment at high velocities.

Dark-coloured items made up nearly 50% of the FOD collected. Common FOD dimensions are 3 cm by 3 cm or smaller. Typical FOD includes the following:

– aircraft and engine fasteners (nuts, bolts, washers, safety wire, etc.);
– aircraft parts (fuel caps, landing gear fragments, oil sticks, metal sheets, trapdoors, and tire fragments);
– mechanics' tools;
– catering supplies;
– flight line items (nails, personnel badges, pens, pencils, luggage tags, soda cans, etc.);
– apron items (paper and plastic debris from catering and freight pallets, luggage parts, and debris from ramp equipment);
– runway and taxiway materials (concrete and asphalt chunks, rubber joint materials, and paint chips);
– construction debris (pieces of wood, stones, fasteners and miscellaneous metal objects);
– plastic and/or polyethylene materials;
– natural materials (plant fragments and wildlife); and
– contaminants from winter conditions (snow, ice).

With respect to the frequency allocation of millimetre-wave frequencies, the frequency bands 92-94 GHz, 94-94.1 GHz, 94.1-95 GHz, 95-100 GHz are already allocated to the radiolocation service on a primary basis. The wideband spectrum at these frequency bands can be applied for ground-based aeronautical radar applications, but a few FOD detection systems are demonstrated using a limited bandwidth of 94 GHz band. To facilitate high performance FOD detection systems which utilize such wideband spectrum resource, the technical and operational characteristics of FOD detection systems operating in the frequency range 92-100 GHz are provided in this Report.

2 System overview of foreign object debris detection system operating in the frequency range 92-100 GHz

Figure 1 illustrates the concept of the FOD detection system for runways. To balance the radar performance improvement and the system cost reduction, the high-accuracy and high-stability frequency modulated continuous wave (FMCW) radar signals are generated and up-converted to optical signals at the airport operation centre and transmitted through the optical fibre to the multiple FOD radars placed along the runway area.

FIGURE 1

Schematic illustration of foreign object debris detection system in runway at airport

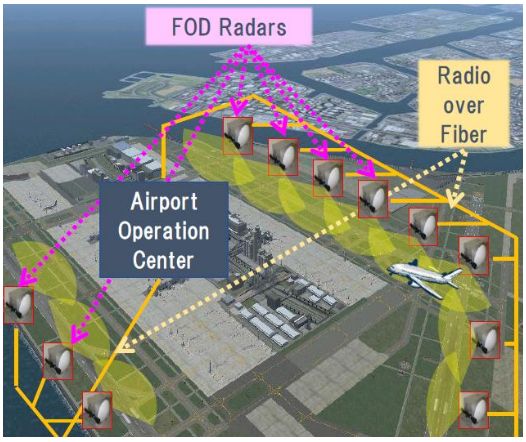
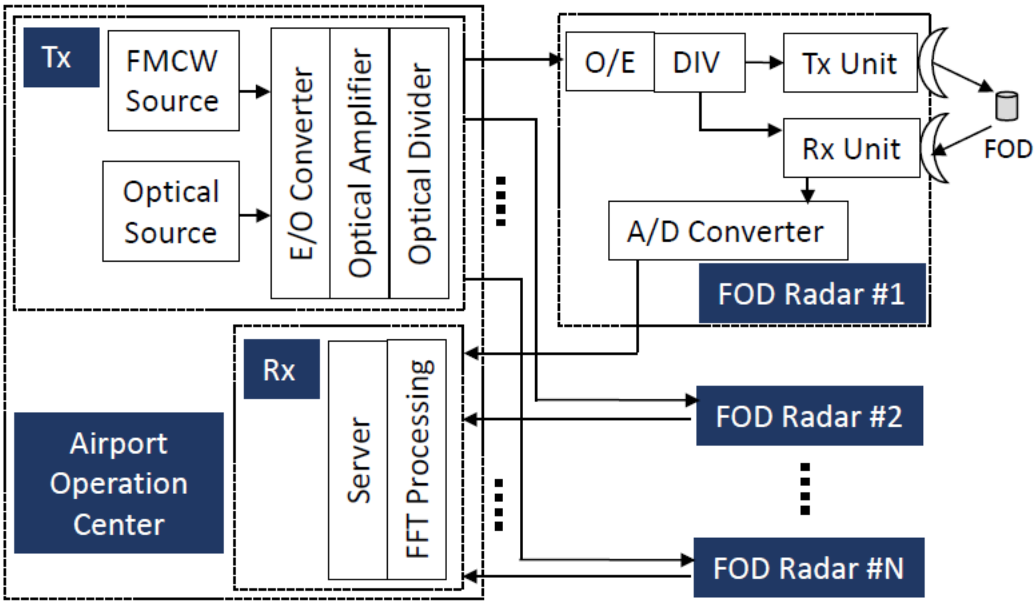


Figure 2 shows the overall configuration of FOD detection system which consists of the airport operation centre and FOD radars. The FOD radars along the runway are connected to the airport operation centre through the optical fibre cables which are already installed in the runway area. The electrical FWCW signals are converted into the optical FMCW signals using the optical source at the airport operation centre. The optical FWCM signals are optically amplified, demultiplexed by the optical divider and distributed to FOD radars through optical fibre cables. The optical FMCW signals are received by each FOD radar and they are converted into the electrical FMCW signals and radiated into the air. Then the FMCW signals reflected by the obstacles in the runway are received and down converted into IF signals. The IF signals are converted into the digital signals by A/D converter. The airport operation centre receives the digital signals from each FOD radar, and these digital signals are processed by fast Fourier transform (FFT) technology. FFT processing signals are displayed and stored in the server.

FIGURE 2

Block diagram of foreign object debris detection system which consists of airport operation centre and foreign object detection radars



3 System characteristics

3.1 Overview of foreign object debris detection system characteristics operating in the frequency range 92-100 GHz

The technical and operational characteristics of FOD detection system is summarized in Table 1. Figure 3 shows the channel plan for FOD radars which utilize the frequency bands allocated for radiolocation services in the range of 92-100 GHz. However, the frequency band 94-94.1 GHz is also allocated for Earth exploration satellite (active) and space research (active) services. The channel plans which exclude the use of the band 94-94.1 GHz are also provided in Fig. 3, where a guard band of 10 MHz is inserted in the lower frequency of 94 GHz and in the upper frequency of 94.1 GHz. The single channel operation of FOD radars may cause the frequency interference between FOD radars installed at the different runway. The FOD radar using multichannel plan may be introduced for the airport with several runways to provide the interference free operation. Table 2 summarizes the channel plan, channel number, channel bandwidth, range resolution and their frequency bands. Since the range resolution depends on the operational bandwidth, the airport operator may deploy FOD radars, taking into account channel plans provided by Fig. 3, with different performance depending on the requirement with respect to obstacle detection.

TABLE 1

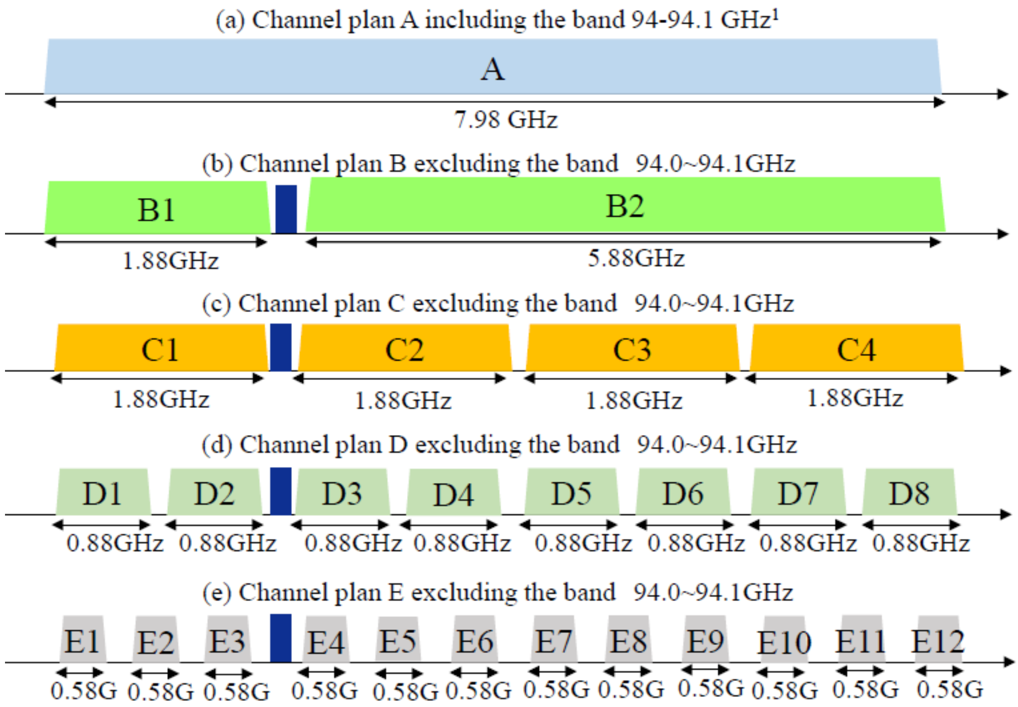
Technical and operational characteristics of foreign object debris detection system operating in the frequency range 92-100 GHz

Parameters	Values
Frequency range (GHz)	92-100
Channel plan	See Fig. 3
Channel bandwidth (GHz)	0.58-7.98
Output power (mW)	100-200
Spectrum envelope	See Annex 2
Sweep frequency (kHz)	1.250
Antenna type	Cassegrain
Antenna gain (dBi)	44
Antenna pattern	Recommendation ITU-R F.699
Antenna height (m)	4-8
Full width at half maximum antenna gain (3 dB beamwidth) (degrees)	Elevation: 1.0, Azimuth: 1.0
Antenna rotation speed (rpm)	15
Detection distance (m)	200-500
Antenna elevation angle (degrees)	−1.8 (see Annex 3)
Radiated rotation angle in azimuth (degrees)	±60
Radar cross section specification (dBsm) [(1)]	−20
Emission bandwidth (−3 dB) (MHz)	1 (see Annex 2)
Emission bandwidth (−20 dB) (MHz)	3.5 (see Annex 2)
Adjacent channel leakage ratio (dBc)	< −70
Receiver noise figure (dB)	10
I/*N* protection criteria (dB)	−6

(1) dBsm = decibels per square metre.

FIGURE 3

Channel plan for foreign object debris detection system operating in the frequency range 92-100 GHz



(1) This channel plan will be used if mitigation techniques are available to resolve the coexistence issues with Earth exploration satellite service (EESS) (active).

TABLE 2

Channel number, channel bandwidth, range resolution and frequency bands of each channel plan

Channel plan	Channel number	Channel bandwidth (GHz)	Range resolution (cm)	Frequency band (GHz)
A [(1)]	1	7.98	3	92.01-99.99
B	2	1.88, 5.88	4.5, 12	B1: 92.01-93.89, B2: 94.11-99.99
C	4	1.88	12	C1: 92.01-93.89, C2: 94.11-95.99, C3: 96.01-97.89, C4: 97.91-99.79
D	8	0.88	24	D1: 92.01-92.89, D2: 92.91-93.79, D3: 94.11-94.99, D4: 95.01-95.89, D5: 95.91-96.79, D6: 96.81-97.69, D7: 97.71-98.59, D8: 98.61-99.49
E	12	0.58	50	E1: 92.01-92.59, E2: 92.61-93.19, E3: 93.21-93.79, E4: 94.11-94.69, E5: 94.71-95.29, E6: 95.31-95.89, E7: 95.91-96.49, E8: 96.51-97.09, E9: 97.11-97.69, E10: 97.71-98.29, E11: 98.31-98.89, E12: 98.91-99.49

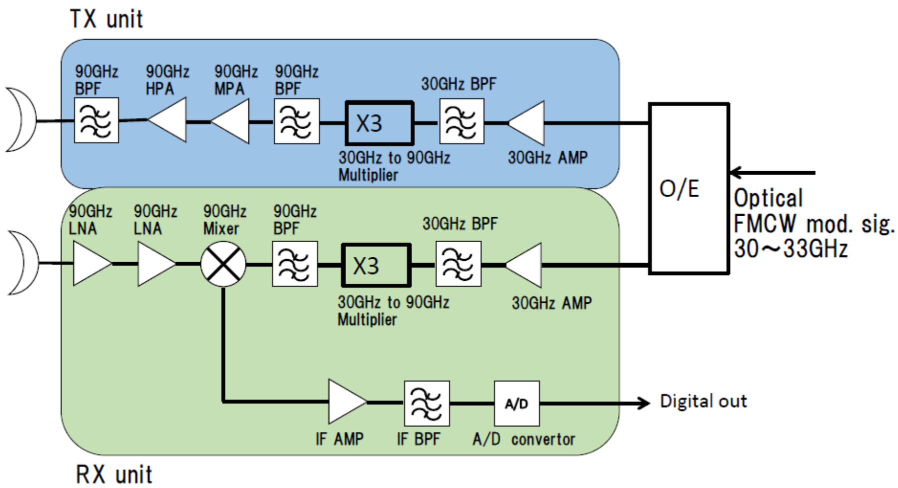
(1) This channel plan will be used if mitigation techniques are available to resolve the coexistence issues with EESS (active).

3.2 Performance of foreign object debris transceiver

Figure 4 shows the configuration of FOD radar which is connected through the radio over fibre links to the airport operation centre. To improve the receiving sensitivity, the Bi-Static type configuration is adopted. The optical FMCW signal whose subcarrier frequency is 30 GHz from the airport operation centre is converted to the electrical FMCW signal by photo detector, and the 30-GHz FMCW signal is amplified, tripled, again amplified and then radiated to the air. The radiated FMCW signal from Tx unit is reflected if the target object is on the runway and RX unit finally receives reflection signal. The received signal is down converted to the IF signal using the 90-GHz FMCW signal from the airport operation centre, and the IF signal is converted to digital signal by the A/D converter and transmitted to the airport operation centre and to process information on locations of the target objects. The measured spectrum envelope of FOD radar and CW spectrum and the adjacent channel leakage ratio at an offset frequency of 10 MHz are shown in Annex 2. The emission bandwidth of CW is obtained from Fig. 13.

FIGURE 4

Block diagram of foreign object debris transceiver

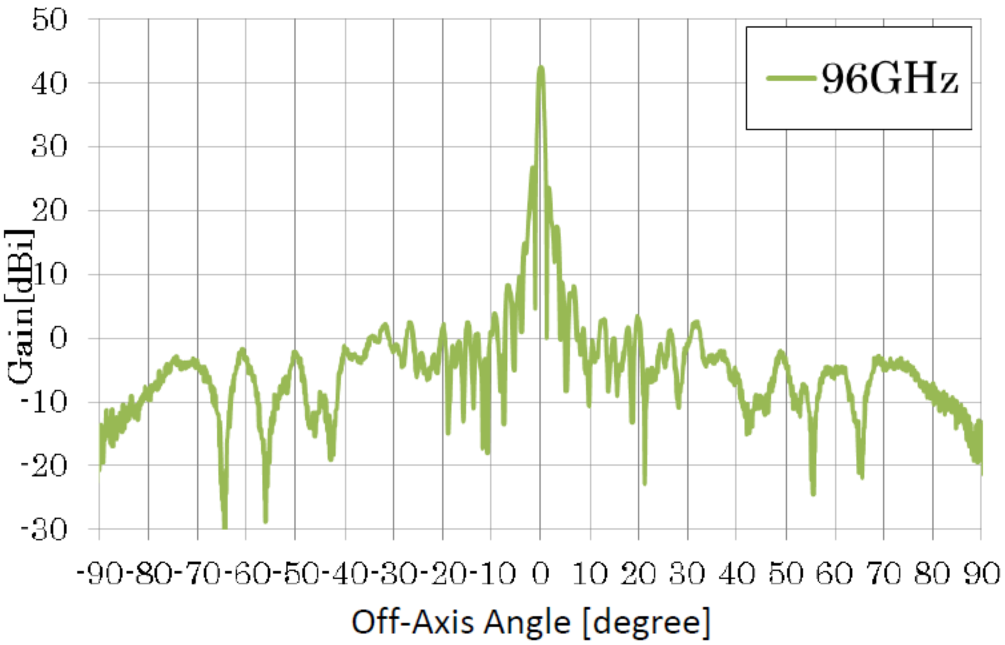


3.3 Example of measured antenna pattern at 90-GHz

Figure 5 shows the antenna pattern at 96-GHz. The antenna gain is about 44 dBi. The antenna whose height is about 8 m is mechanically rotated. The measured data at 92 GHz, 94 GHz, 96 GHz, 98 GHz and 100 GHz is provided by the following Table.

FIGURE 5

Antenna radiation pattern of 44 dBi at 96-GHz



4 Summary

The technical and operational characteristics of FOD detection system operating in the frequency range 92-100 GHz as well as the field trials of FOD detection system in some countries are provided for the airport safety operation in the world.

5 Bibliography

[1] Airport Foreign Object Debris (FOD) Detection Equipment, FAA Advisory Circular (AC) 150/5220-24, "Airport Foreign Object Debris (FOD) Detection Equipment" 30 September 2009.

[2] Current Airport Inspection Practices Regarding FOD (Foreign Object Debris/Damage), The National Academies PRESS, http://nap.edu/14572.

Annex 1

Field trial of foreign object debris detection system at Narita Airport in Japan

To demonstrate the fundamental characteristics of FOD detection system at the airport, four FOD units are installed along the runway B and one control unit near the control tower of Narita International Airport, as shown in Fig. 6. Figure 7 shows the location of the four FOD units. The layout plan including the location of existing facilities is decided to reduce the installation cost of FOD detection system. The exiting power supply facilities and optical fibre infrastructure at the airport are utilized to perform the total cost reduction of the system.

FIGURE 6

Field trial at Narita airport

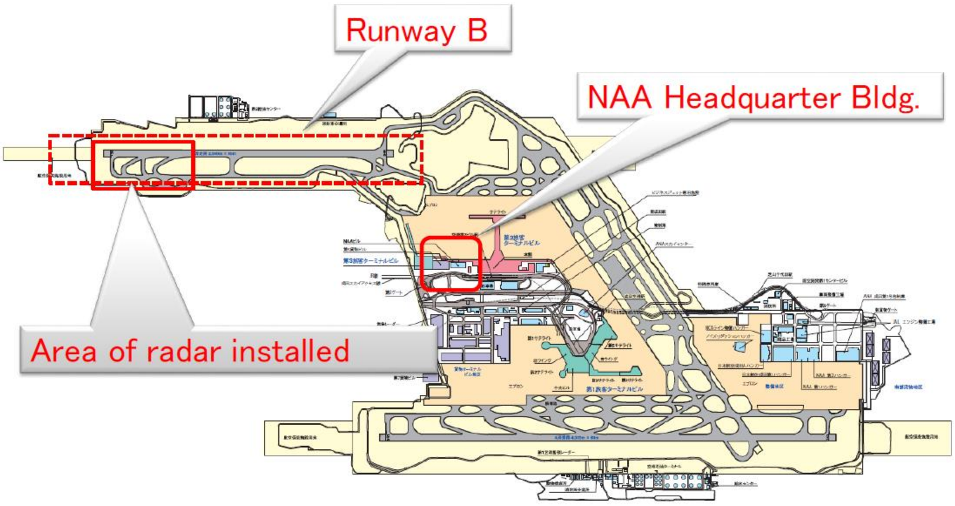


FIGURE 7

Foreign object debris unit layout at Narita airport runway B

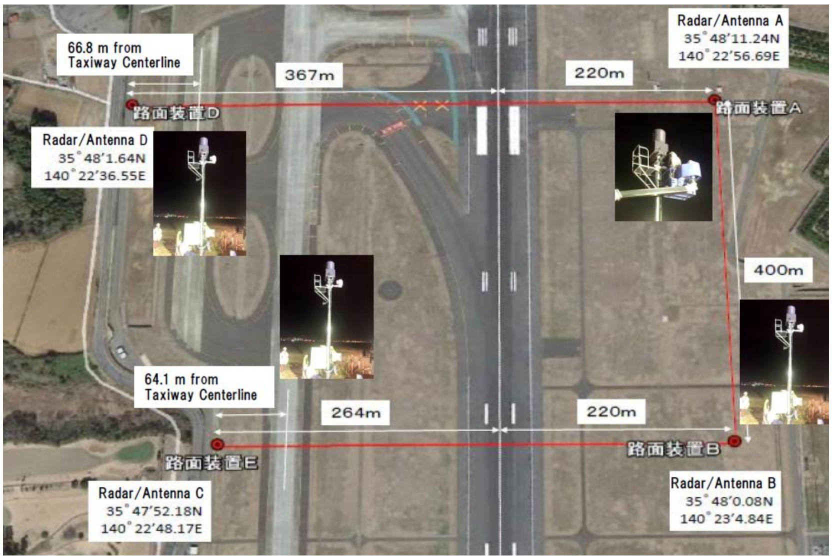
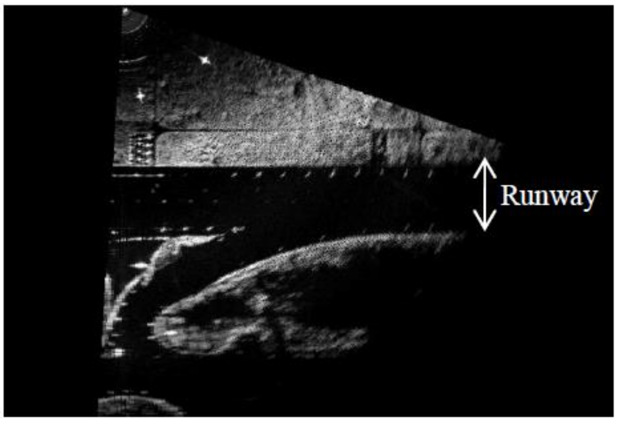


Figure 8 shows the radar plan position indicator (PPI) scope obtained from the four radar units. Reflections from boarder areas between the runway and the grass are measured by FOD units. A maximum distance measured by one FOD unit is about 500 m in this field trial. By installing multiple FOD units in the runway area, as shown in Fig. 7, it is possible to expand the detection area. The detection signal at each FOD unit is sent to the control tower and those signals are simultaneously processed to achieve larger-area detection.

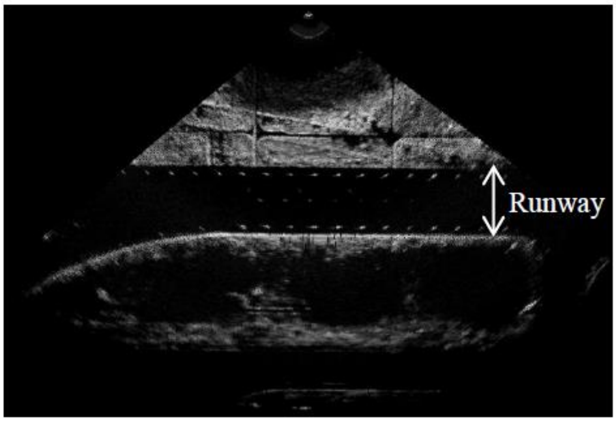
FIGURE 8

Radar plan position indicator scope

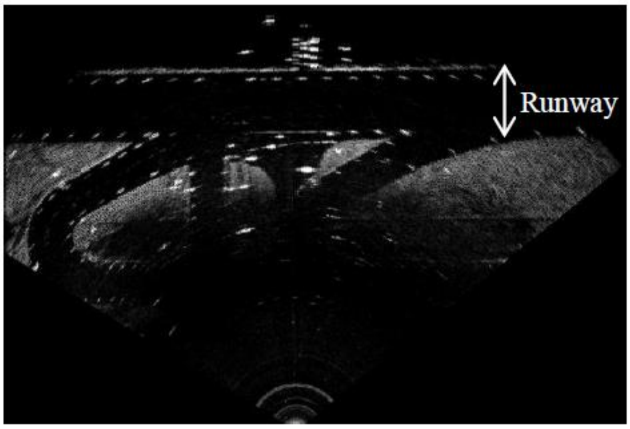
(a) Unit A



(b) Unit B



(c) Unit D



(d) Unit E

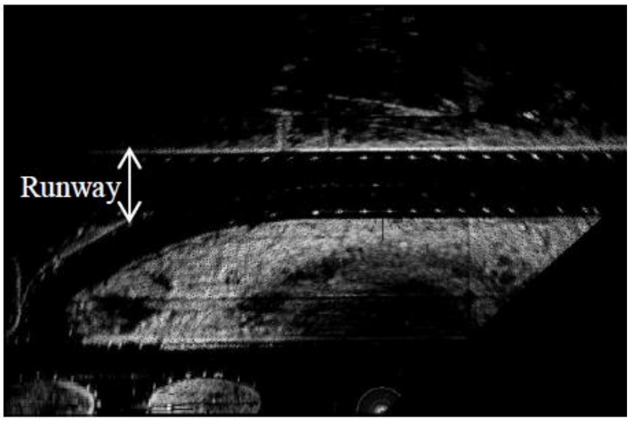


Figure 9 shows the measured PPI scope of FOD unit E when there are various objects such as radar cross section of 30 dBsm and 5 dBsm reflectors, that of 0 dBsm and −20 dBsm metallic cylinders and human beings on the runway. The experimental result show that these objects are clearly discriminated.

FIGURE 9

Radar plan position indicator scope of foreign object debris unit E when there are various objects on the runway

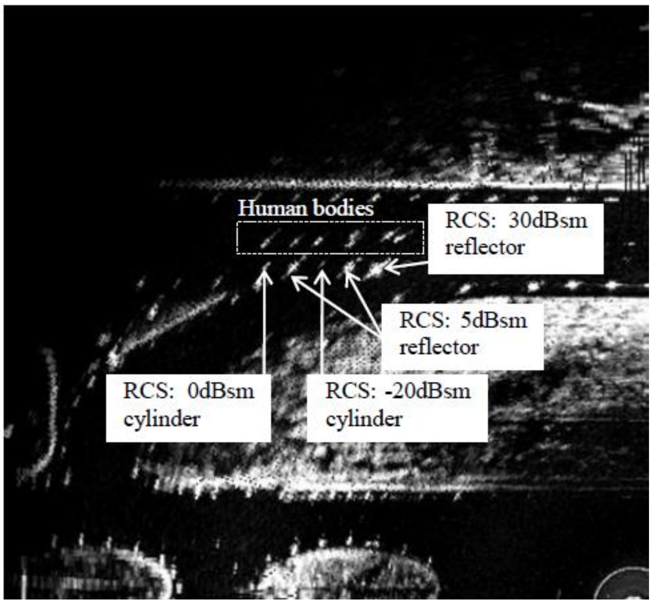


Figure 10 shows the measured result of a moving −20 dBsm metallic cylinder object on the runway of Narita International Airport. The spectrum at around 426 m from FOD unit is measured by reflection form the runway light. Signal to noise ratio (SNR) above 15 dB is obtained when a −20 dBsm metallic cylinder is placed at 442 m which is far from FOD unit. The SNR of FOD unit is not deteriorated in the range of up to 500 m.

FIGURE 10

Measured spectrum of a moving −20 dBsm metallic cylinder object

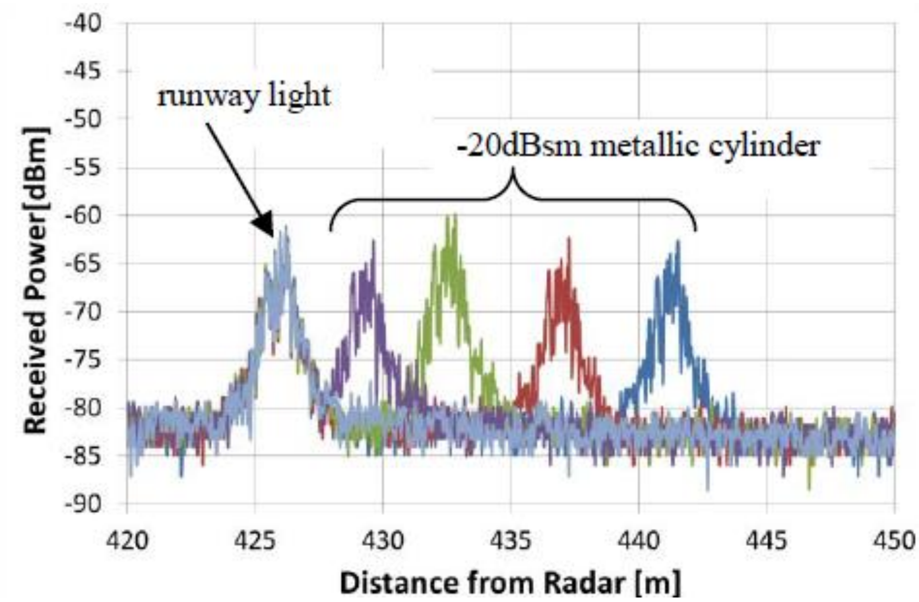
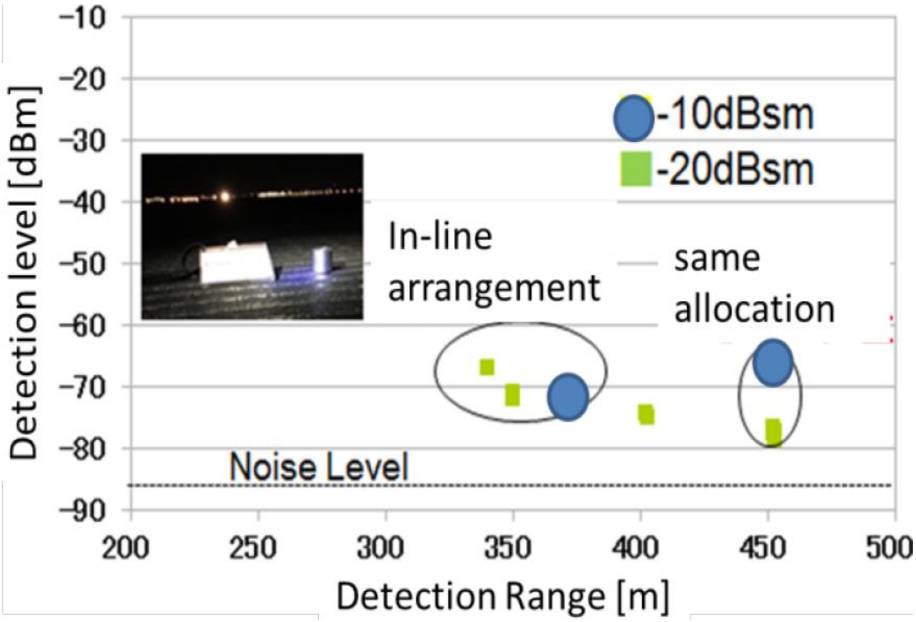


FIGURE 11

Detection level of −10 dBsm and −20 dBsm foreign objects



Annex 2

Measured spectrum envelope of foreign object debris detection system

The spectrum envelope in the frequency range 89.5-99.5 GHz is shown in Fig. 12. The centre frequency is 94.5 GHz. CW spectrum of FMCW is also measured in the condition of resolution bandwidth =1 MHz and video bandwidth =1 MHz, and one example CW spectrum whose frequency is 93.4 GHz is shown in Fig. 13. The adjacent channel leakage ratio is −74.6 dBc at an offset frequency of 10 MHz which can be used for interference evaluation to EESS (active), EESS (passive) and radio astronomy service. The emission bandwidths of CW which are 3 dB and 10 dB below from the peak value at the centre frequency of 93.4 GHz are 1 MHz and 3.5 MHz, respectively.

FIGURE 12

Spectrum envelope of frequency modulated continuous wave signal in the frequency band 92-97 GHz

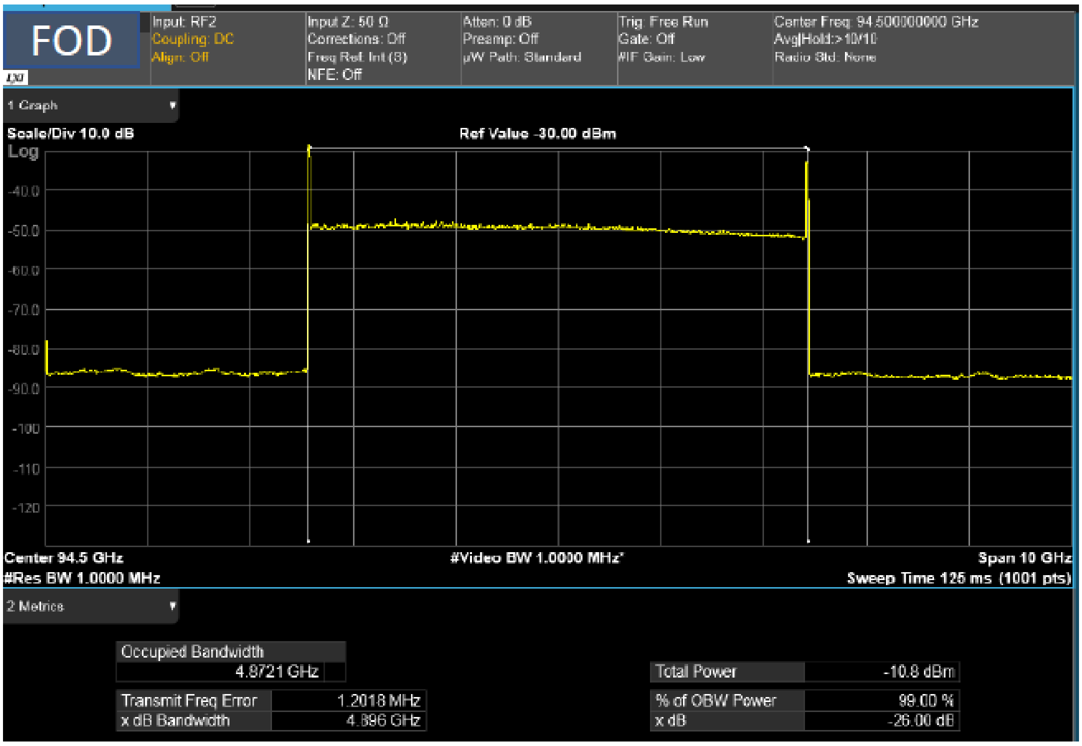
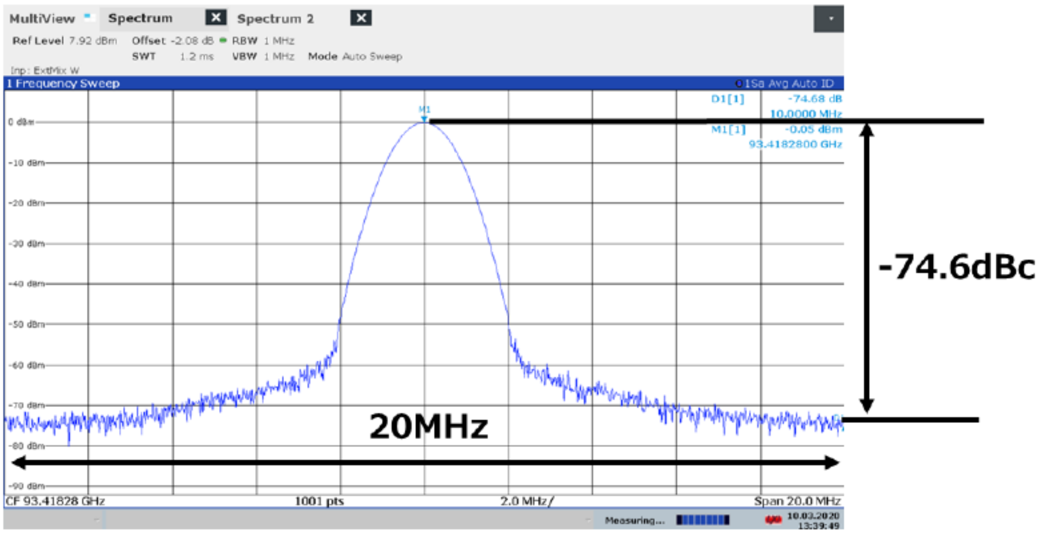


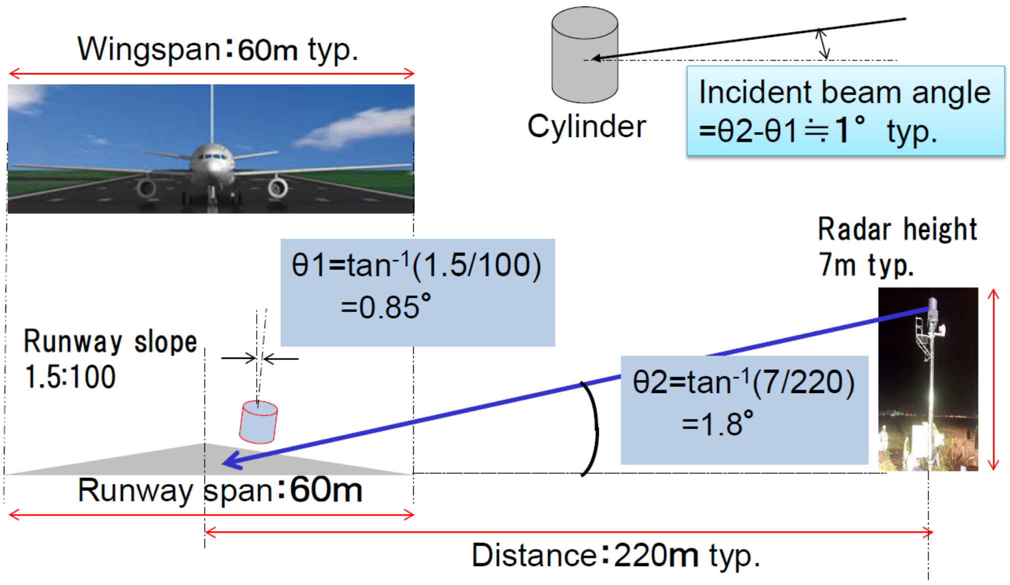
FIGURE 13

Adjacent channel leakage ratio at an offset frequency of 10 MHz



Annex 3

Relationship between antenna elevation angle and incident beam angle to foreign object debris on runway



Annex 4

Field trial of foreign object debris detection system at Universiti Teknologi Malaysia and Kuala Lumpur International Airport

For reliable and secure installation of the radar system, pre-evaluation of the portable radar system has been performed and evaluated under tropical weather conditions. The radar system evaluation has been conducted at Kuala Lumpur International Airport and Universiti Teknologi Malaysia Kuala Lumpur (UTM KL) in Malaysia, as shown in Fig. 14. Other equipment used in the radar system evaluation are a weather logger, GPS logger, laser range meter and a portable personal computer.

FIGURE 14

Radar system evaluation in Malaysia, at Universiti Teknologi Malaysia campus (left) and Kuala Lumpur International Airport (right), Malaysia

a. Experimental work at Universiti Teknologi Malaysia Kuala Lumpur Campus

To evaluate in the real conditions, the radar system was tested in the field at UTM KL as depicted in Fig. 15. The radar system was set at a courtyard of the campus building with heading to a football field. The obtained range spectrum is also shown in the Figure. A broad peak observed at 24-m and 85-m indicators are caused by oscillation noises of an IF amplifier set after the mixer. These stable noise components can be mitigated by post processing. Sharp peaks at 10 m and around 50 m are reflected signal from a sign pole, football goal posts and rugby goal posts in the grass field. Strong peak at 87 m is provided by a barrier wall between the grass field and campus. This barrier wall is configured by mesh wires with a radius less than 1 cm with a mesh pitch of 15 cm×8 cm. Even the radius is just two to three times larger than the wavelength of the radar signal (approximately 3 mm), clear reflection is observed. It might be caused by the large cross section area of the mesh barrier.

The PPI image is also shown in Fig. 16, where the mesh barriers clearly observed along with the grass field. Two-dimensional PPI image helps identifying the objects and their locations. Polarization imaging is also shown in the same Figure. In general, the polarizations of the Tx and Rx antennas should be same for increase of the received signal intensity. When the Tx antenna polarization is set perpendicular to the Rx polarization, the differential reflectivity coefficients, which are caused by surface structures such as a direction of the vertical surface of the target, might be obtained. Figure 5 also shows the polarization differential image, as calculated by subtraction between the perpendicular and parallel-polarization PPI images. The barrier walls have strong reflection with perpendicular polarization to the incident radar signals. This polarization rotation could be caused by the configuration of the barrier.

FIGURE 15

Location for foreign object debris detection systems measurements conducted at Universiti Teknologi Malaysia Kuala Lumpur, Malaysia

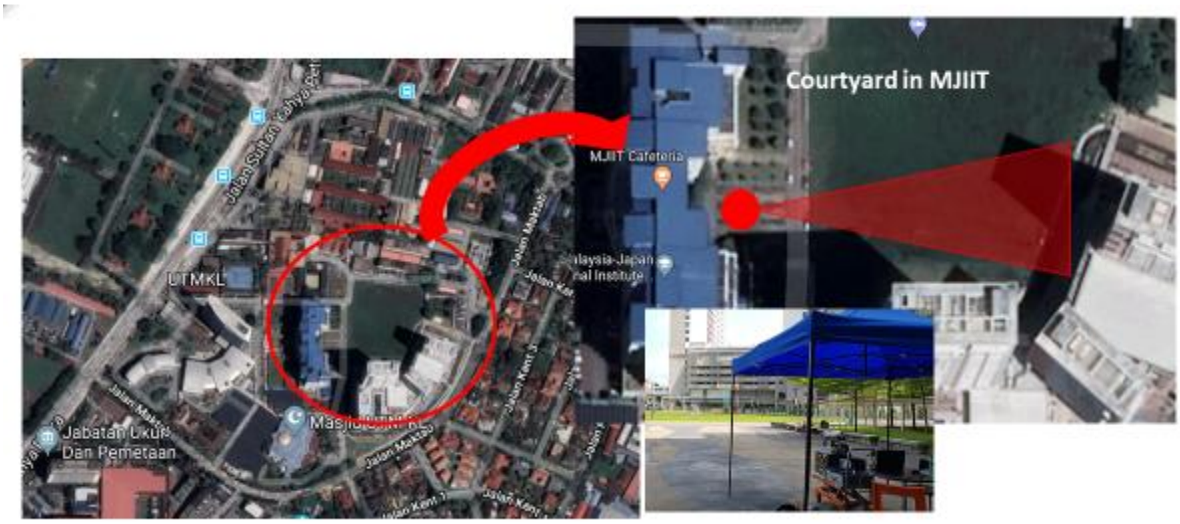


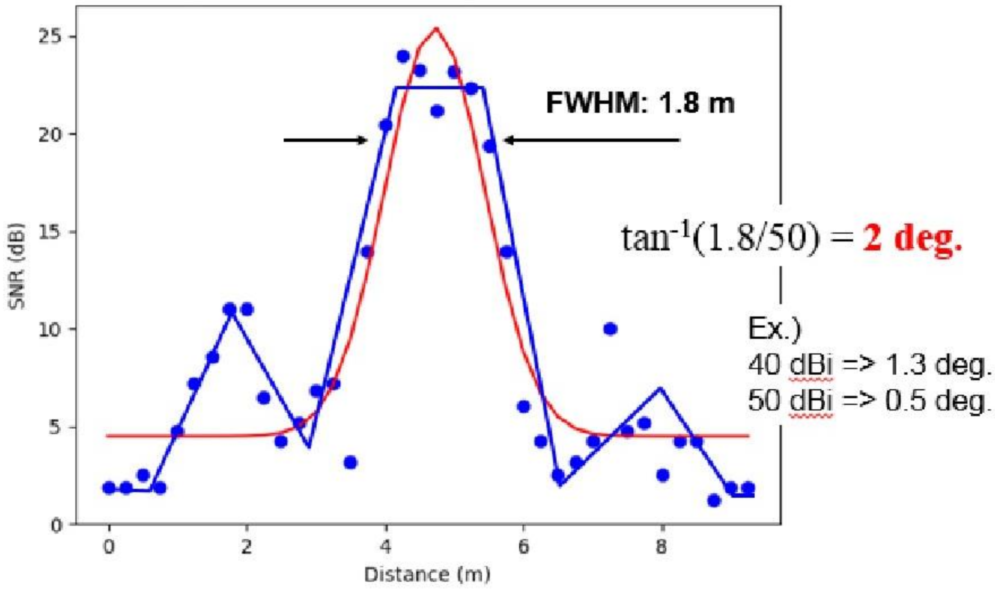
FIGURE 16

Plan position indicator images under polarization of transmitter and receiver set (top) as parallel and (bottom) as perpendicular. Photo of the barrier wall is also shown. The measurement was conducted at Universiti Teknologi Malaysia Kuala Lumpur, Malaysia

There are four parameters that need to be considered when computing the radar detection area, namely the antenna beamwidth, elevation angle (θ), antenna height (h) and distance (R). The elevation angle can be varied accordingly for adjusting the length of the detection area. R corresponds to the distance to the point on the radar detection area that is projected at the elevation angle, where $R = \frac{h}{\tan\theta}$. Using a 7.6 cm cylinder 50 m away from the remote antenna unit (RAU), the measured beamwidth of the Cassegrain antenna is 2 degrees, as shown in Fig. 17. The value of the beamwidth is important for determining the diameter of the radar detection area, where the diameter of the radar detection area will increase as the beamwidth is increased. The range resolution of the tested RAU is approximately between 15 to 20 cm for two 5 dBsm reflectors that are placed apart. The received power was measured when the two reflectors are separated by various separation distance from the centre of the antenna beamwidth.

FIGURE 17

Measured remote antenna unit beamwidth



b. Experimental Work at Kuala Lumpur International Airport

To evaluate this radar system in airport conditions, we tested the radar system at an apron area in the Kuala Lumpur International Airport as shown in Fig. 18. Since the surface of the apron area is flattened and covered by concrete, as compared to the UTM KL field, the clutter signal from the grass and ground might be significantly smaller. Figure 19 shows observed IF spectra of received signals with two FODs: 7.6 cm cylinder at a distance of 55 m and a −10-dBsm reflector set at a distance of 105 m. Small fluctuation of noise floor directly reflects the flatness of the airport surface. When a height of the radar head (antenna position) is set 0.8 m, the reflected power from the cylinder is approximately −70 dBm. On the other hand, the signal from the reflector becomes large at the height of 1.4 m although the signal from the cylinder is degraded. This shows the surface has a concave structure with some gradient, which cannot be felt by the eye. The top of the concave blocks the signal to the reflector when the antenna height is short.

The antenna height increases the reflection strength from the reflector; however, the signal from the cylinder decreases because the small beam divergence (approximately 1 degree with 35-dBi antenna gain) may not reach near target. This result indicates that the antenna height in the airport situation is a key to detect small FODs. In airport condition, the maximum range R of the 1 mW prototype RAU is more than 200 m, as shown in Fig. 20, for a 7.6 cm cylinder. This can further be extended by having a higher gain antenna or reducing the noise floor. 1mW-output system limits the maximum range of the radar, however, optimization of antenna/amplifier will realize the coverage of more than 300 m. The prototype RAU was able to detect FOD samples of various sizes, shapes and material, as illustrated in Fig. 8, where the reflected power of the various FOD samples are normalized by a 1” c cylinder with radar cross section of −20 dBsm at 95 GHz. Under 20 mm/h rainfall, it was observed that some scattering appears in the reading due to rain puddles around the sample FOD, as shown in Fig. 20.

FIGURE 18

Location for foreign object debris detection systems measurement conducted at Kuala Lumpur International Airport, Malaysia

FIGURE 19

Obtained IF spectra in radar height at (left) 0.8 m and (right) 1.4 m.
Schematic of targets and radar position in the concave apron structure is also shown in the bottom.
The measurement was conducted at Kuala Lumpur international airport, Malaysia

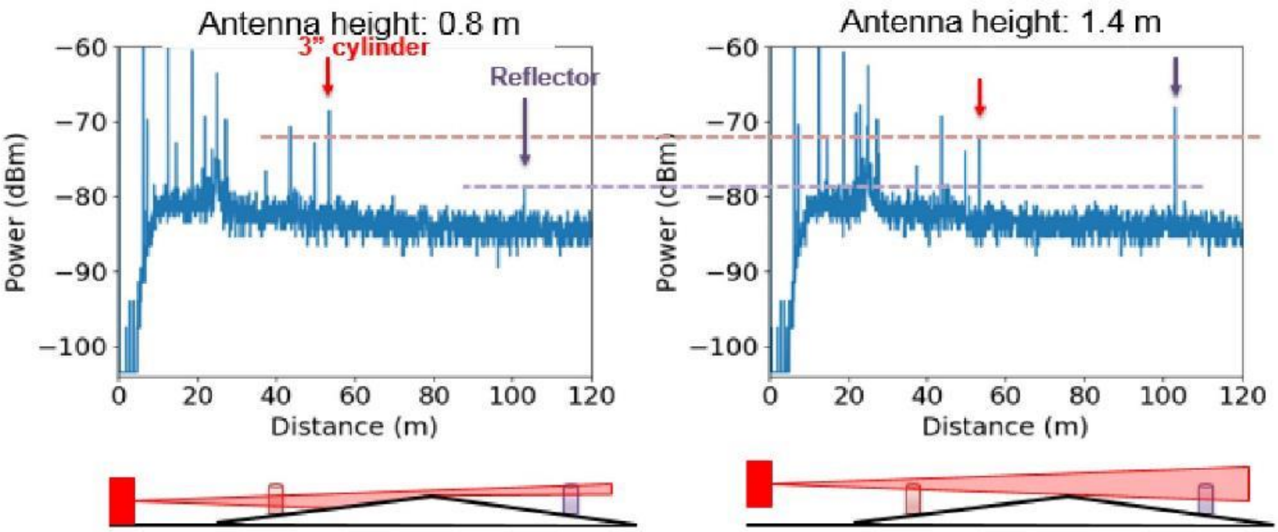


FIGURE 20

Measured remote antenna unit range

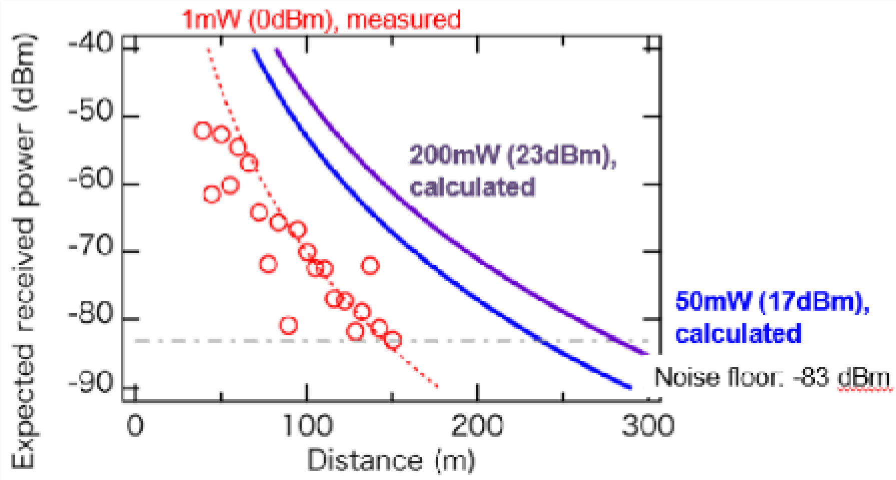
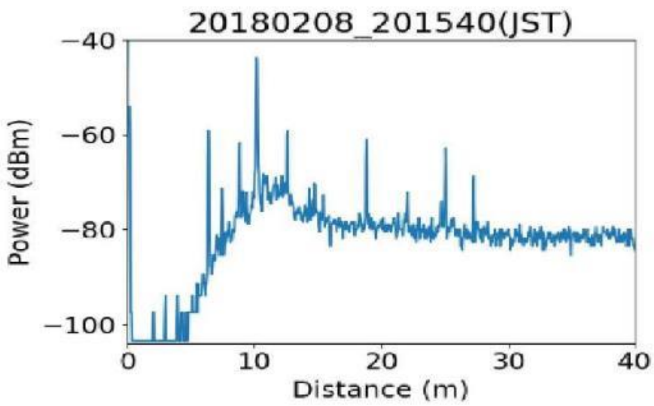


FIGURE 21

Rain scattering effect



c. Field Trial at Kuala Lumpur International Airport Runway 2

Figure 22 illustrates the concept of the FOD detection system for the Kuala Lumpur International Airport (KLIA) that consists of the airport operation centre and FOD radars. The FOD radars along the runway are connected to the airport operation centre through the optical fibre cables. The optical frequency modulated continuous wave signals are generated by the optical source and electrical signals at the control centre and are optically amplified and distributed via the optical divider to FOD radars. The control centre receives the signals from each FOD radar, and these signals are processed, displayed and stored in the server at monitoring centre.

The runway layout and FOD detection system installed in KLIA at runway 2 with designation 14R/32L are depicted in Fig. 23, where the layout has taken into consideration the most optimum possible detection areas that adhere to Annex 14 of the International Civil Aviation Organization Convention and the Civil Aviation Authority Malaysia requirements. The shortest and longest distance of radar poles from the runway centre line are 177 m and 260 m with the high are 5 m from the runway ground level respectively.

FIGURE 22

System Block Diagram of foreign object debris detection system in Kuala Lumpur International Airport

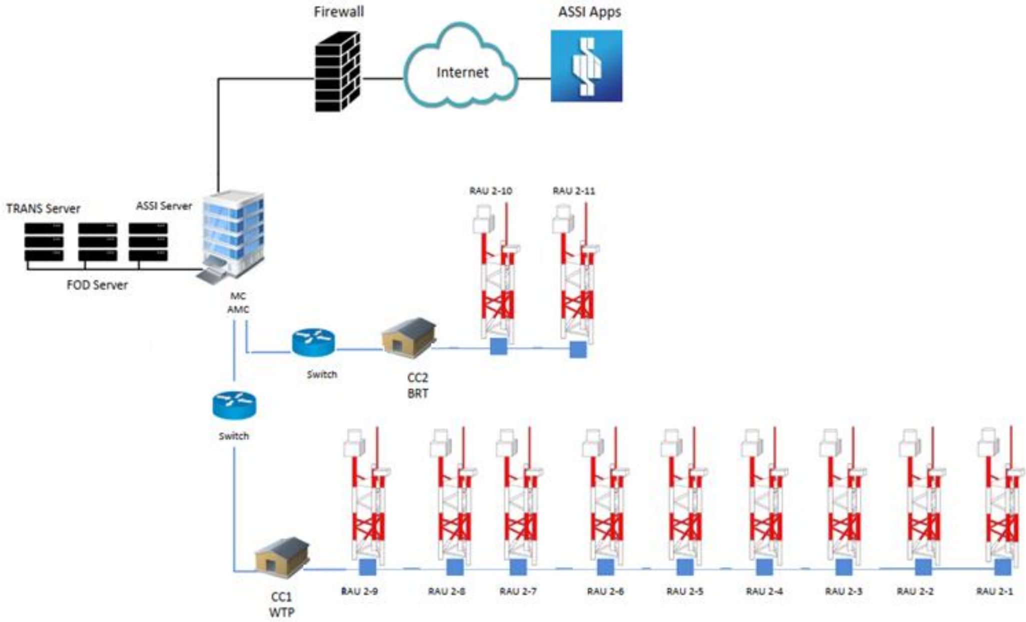


FIGURE 23

Illustration of foreign object debris detection system schematic layout in Kuala Lumpur International Airport runway 14L/32R

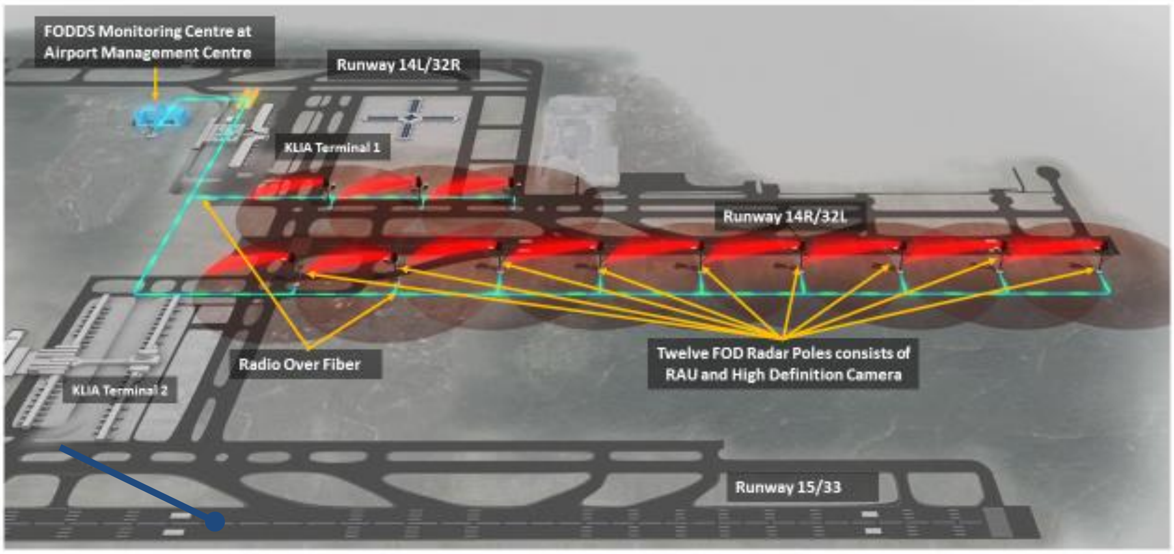
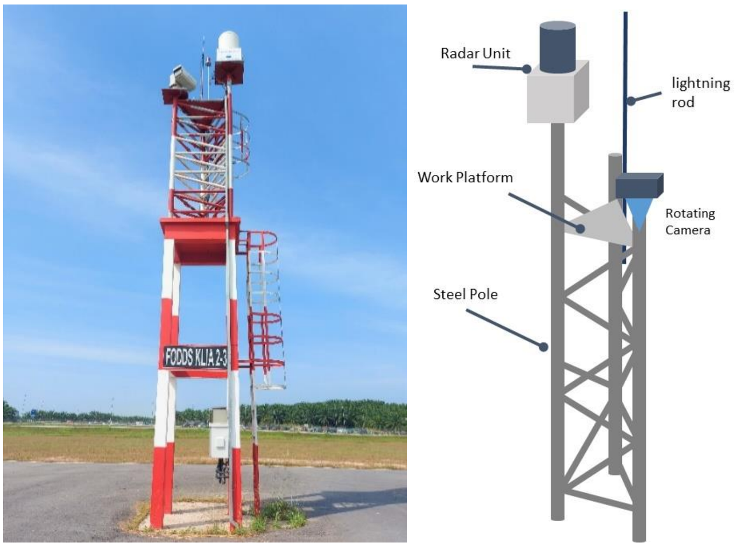


Figure 24 shows the FOD radar poles constructed in KLIA, the three legged design pole improved single FOD radar pole performance installed in Narita International Airport in term of less lateral wind load as well as reduced vertical and lateral vibration which is may significant if the tower near to aircraft touch down area.

FIGURE 24

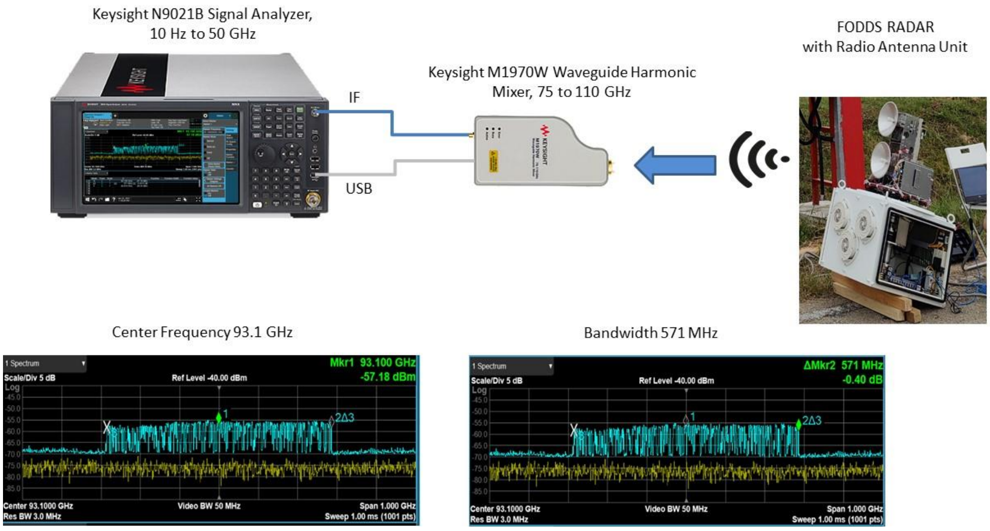
Schematic design and photo of three legged FOD radar pole in Kuala Lumpur International Airport



Prior to the radar installation, the signal transmission was tested and measured for radar spectrum verification by Malaysian Communication and Multimedia Commission, the regulatory body for spectrum licencing. The spectrum inspection and measurement were conducted using Keysight N9021B signal analyser up converted by M1970W waveguide harmonic mixer at 75 GHz to 110 GHz as shown in Fig. 25, where 93.1 GHz centre frequency and 571 MHz bandwidth was measured respectively.

FIGURE 25

Radar signal transmission measurement set up using millimetre wave spectrum analyser and external harmonic mixer



The FOD radar was able to detect FOD samples of various sizes, shapes and material, as shown in Fig. 26, where the reflected power of the various FOD samples was normalized by a 1″ cylinder with radar cross section of −20 dBsm at 95 GHz. Through the field trial work, the FOD radar was able to detect a 3 cm metal cylinder FOD up to 500 m range from radar head during clear sky and 200 m under 20 mm/h rainfall. Some of the small FOD detected during the field trial are 1 cm asphalt and 4 cm bird carcass with 39.75 dBsm and −41.56 dBsm measured RCS value respectively as shown in Fig. 27.

FIGURE 26

Various foreign object debris samples used for field trial at Kuala Lumpur International Airport with estimated radar cross-section value

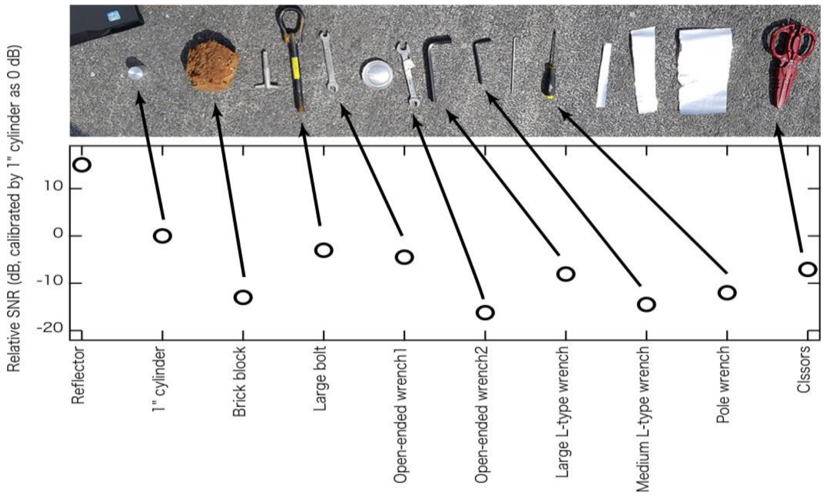
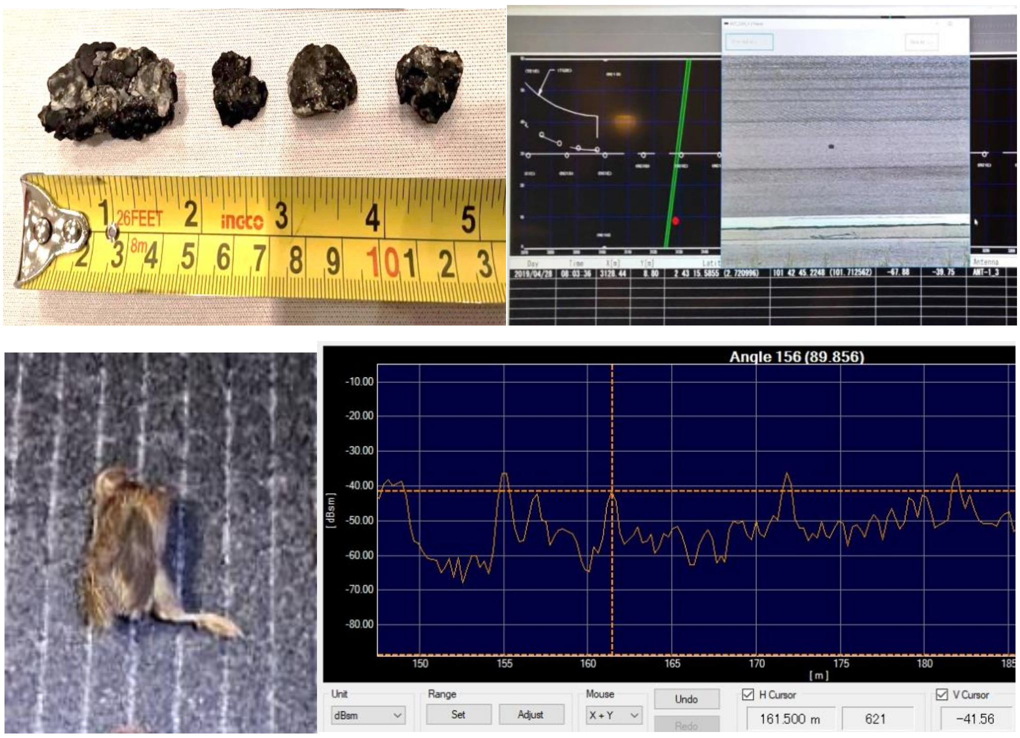


FIGURE 27

Several asphalt foreign object debris were detected, and the smallest is 1 cm with −39.75 dBsm radar cross-section value (above) and 4cm bird carcass with −41.56 dBsm (below)



The 'Minimum Aviation System Performance Specification (MASPS) for Foreign Object Debris Detection System' ED-235 established by The European Organisation for Civil Aviation Equipment L'Organisation Européenne pour l'Equipement de l'Aviation Civile (EUROCAE) was adopted for system performance evaluation methodology. Two measurements were conducted at two designated areas, perpendicular and 30 degrees from the radar pole as depicted in Fig. 28. Measurements are performed by using various types of FOD according to MASPS. The nine identical FODs under test are placed at nine locations in the range of 10 m between FODs sample, which FODs in P4, P5 and P6 placed at the centre of the runway. The FODs are turned in every 30 degrees clockwise to obtain 12 directions and left at the measurement area for 5 minutes to obtain detection probability. There are 52 samples of FOD were measured in this evaluation exercises. For example, Fig. 29 shows PPI image of the nine runway edge lights (right) as the FOD under test. The green line displayed FFT status of the specified angle (above) to obtain single line RCS graph (below) for three FOD under test. The RCS value −15.41 dBsm was recorded for the FOD under test located at 172.25 m from radar.

FIGURE 28

Illustration of Minimum aviation system performance specification measurement setup (above) and nine foreign object debris samples arrangement and direction (below)

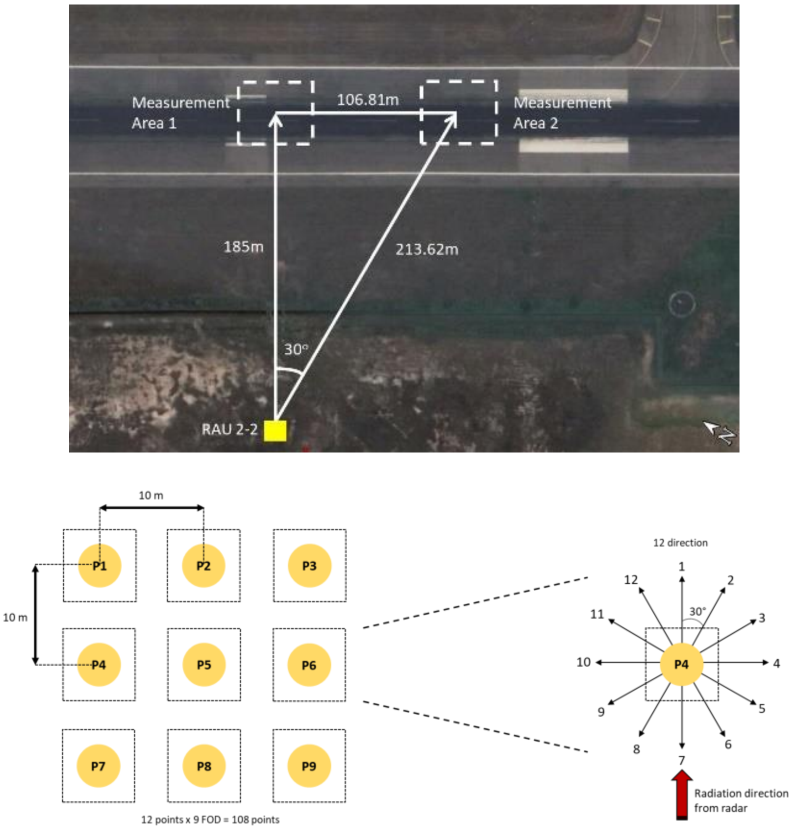


FIGURE 29

Plan position indicator images under polarization of transmitter and receiver (top) and measured radar cross-section value for three edge light foreign object debris (bottom) indicated