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| **US Radiocommunications Sector**  **Fact Sheet** | |
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| **Purpose/Objective:** This contribution proposes a Working document towards a Preliminary Draft Revision of Report ITU-R M.2170-0, “Compatibility analysis and results for radiolocation systems planned to operate in the 15.4 to 17.3 GHz band and aircraft landing system operating in the 15.4-15.7 GHz band as well as the radio astronomy service operating in the adjacent band 15.35-15.40 GHz, FSS systems and aeronautical radionavigation systems”. | |
| **Abstract:** ITU-R Report M.2170-0 contains the sharing studies between Radiolocation and incumbent services in the frequency bands between 15.4 and 17.3 GHz. This Recommendation was approved in 2009. During the November 2021 meeting, France raised concern on the new power of System 6. This contribution provides sharing studies between Radiolocation which has a new power and incumbent services in the frequency bands between 15.4 and 17.3 GHz. | |
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| |  | | --- | |  | | **United States of America**  Compatibility analysis and results for radiolocation systems planned to operate in the 15.4 to 17.3 GHz band and aircraft landing system operating in the 15.4-15.7 GHz band as well as the radio astronomy service operating in the adjacent band 15.35-15.40 GHz, FSS systems and aeronautical radionavigation systems |   **1 Introduction**  The United States of America would like to revise the compatibility analysis between Radiolocation and the incumbent services in the frequency band 15.4-17.3 GHz.  The United States of America proposals are in track changes.  Attachment revisions are presented for consideration. |

ATTACHMENT

REPORT ITU-R M.2170

Compatibility analysis and results for radiolocation systems planned to operate  
in the 15.4 to 17.3 GHz band and aircraft landing system operating in the  
15.4-15.7 GHz band as well as the radio astronomy service operating  
in the adjacent band 15.35-15.40 GHz, FSS systems  
and aeronautical radionavigation systems

(2009)

# 1 Introduction

WRC-07 approved WRC-12 Agenda item 1.21, “to consider a primary allocation to the radiolocation service in the band 15.4-15.7 GHz, taking into account the results of ITU-R studies, in accordance with Resolution 614 (WRC-07)”, in order to provide adequate spectrum for new advanced radar systems to function. Emerging requirements for increased image resolution and increased range accuracy necessitate wider emission bandwidths than are currently available. Allocating a primary radiolocation service in the 15.4-15.7 GHz band will provide additional spectrum for new advanced radar systems with increased image resolution and increased range accuracy that necessitate wider emission bandwidths than are currently available. Operation of radiolocation radars in this band will not adversely affect other co-primary services and should operate compatibly with the radio astronomy service in the adjacent 15.35-15.40 GHz band.

The 15.4-15.7 GHz band is allocated on a primary basis to the aeronautical radionavigation service (ARNS). There are no ICAO-standard ARNS systems that currently operate in this band although ICAO standards exist for aircraft weather radar systems. While the ARNS is recognized as a safety service as delineated in No. 4.10 of the Radio Regulations (RR), radiolocation services have demonstrated compatible operations with radionavigation radars in other bands over many years through the use of similar system characteristics such as low-duty cycle emissions and scanning beams as well as other interference reduction techniques. Studies within the ITU-R addressing compatibility between the radiolocation and radionavigation radars in other frequency bands provide reasonable evidence that sharing in the band 15.4-15.7 GHz between these services may be feasible. Recommendation ITU-R M.1730-1 contains the technical characteristics and protection criteria for radiolocation radars in the band 15.4-17.3 GHz and Recommendation ITU-R M.1372-1 identifies interference reduction techniques which enhance compatibility among radar systems.

Also, Report ITU-R M.2076 (2006) contains further mitigation factors for radiolocation interference to radionavigation radars in the 9 GHz band, many of which may apply to the band 15.4‑15.7 GHz as well. There is also limited use of the band in some countries for non-ICAO aircraft landing systems. A portion of the band is also allocated to the FSS limited to feeder links for non-GSO MSS and in both space-Earth and Earth-space directions, though there are no systems that operate in the band. The necessary compatibility studies per WRC‑12 Agenda item 1.21, Resolution 614 (WRC-07) are included in this Report.

# 2 Systems characteristics

The following sections contain the radiolocation and non-ICAO Aircraft Landing System (ALS) technical characteristics that will be used in the compatibility analysis.

## 2.1 Radiolocation system

Recommendation ITU-R M.1730-1 contains technical characteristics and protection criteria for radiolocation radars in the band 15.7-17.3 GHz only, where the band 15.7-17.3 GHz is already allocated to the radiolocation service on a primary basis. The radiolocation System‑6 is used in the compatibility analysis for this Report and the characteristics are shown in Table 1.

TABLE 1

Radiolocation systems characteristic in the 15.4-17.3 GHz band

| Characteristics | System‑6 |
| --- | --- |
| Function | Search, track and ground-mapping  (multi-function) |
| Platform type | Airborne (300 - 13700 m) |
| Tuning range (GHz) | 15.4-17.3 |
| Modulation | Linear FM chirp |
| Transmit peak power (W) | 500, 2k, 10k |
| Pulse width (μs) | 0.05-50 |
| Pulse rise/fall time (ns) | 5-100 |
| Pulse repetition rate (pps) | 200-20 000 |
| Maximum duty cycle | Up to 0.2(1) |
| Output device | Travelling wave tube |
| Antenna pattern type | Pencil (ITU-R M.1851 cosine square distribution) |
| Antenna type | Phased array |
| Antenna polarization | Linear |
| Antenna gain (dBi) | 35 |
| Antenna elevation beamwidth (degrees) | 3.2 |
| Antenna azimuthal beamwidth (degrees) | 3.2 |
| Antenna horizontal scan rate | 1-30°/s |
| Antenna horizontal scan type (continuous, random, sector, etc.) | ±45° (electronic) |
| Antenna vertical scan rate | 1, 5°/s |
| Antenna vertical scan type | +5° to −45° (electronic) |
| Antenna 1st side-lobe level | 3.5 dBi at 5.2° |
| Antenna height | Aircraft altitude |
| Receiver IF −3 dB bandwidths (MHz) | 25 |
| Receiver noise figure (dB) | 5 |
| Minimum discernible signal (dBm) | −100 |
| Chirp bandwidth (MHz) | < 1 900 |
| Transmitter RF emission bandwidth (MHz):  −3 dB  −20 dB | 1 850 1 854 |
| (1) Sharing analysis was done for 100% duty cycle. | |

## 2.2 Aircraft landing systems

The technical characteristics of ALS systems that operate in the 15.4-15.7 GHz band can be found in a working document towards a preliminary draft new Recommendations ITU-R M.[15.4-15.7\_GHZ\_ARNS]. This section provides an overview and characteristics of an ALS system that operates in the 15.4-15.7 GHz band which is implemented by some administrations. The system consists of azimuth and elevation transmitters, including separate azimuth and elevation antenna, located at the landing site. The receiver is located in the aircraft. The aircraft system receives coded transmissions on a number of selectable channels from the ground-based azimuth and elevation transmitters; it decodes the received signals for display on a cross-pointer indicator in the aircraft cockpit. A centreline display of both elevation and azimuth on the cross-pointer indicator depicts the flight path the pilot must follow to line up accurately with the runway. By consecutively scanning through azimuth and elevation, the system provides continuous measurement of the lateral and vertical deviations of the aircraft in space from the optimum approach line.

The aircraft receiver local oscillator (LO) is a crystal-controlled solid-state unit employing multipliers, amplifiers, and filters, which provide rejection of spurious signals. Filters in the detector circuit remove the IF component, so that only video is passed to the decoder.

Table 2 lists the technical characteristics of the ALS transmitter and receiver.

TABLE 2

Aircraft landing systems characteristics in the 15.4-15.7 GHz band

|  |  |  |
| --- | --- | --- |
| Characteristics | Aircraft landing system | |
| Function | Transmitter | Receiver |
| Platform type | Located at the landing site/ship | Airborne platform |
| Tuning range (GHz) | 15.4-15.7 | |
| Modulation | Pulse | N/A(1) |
| Transmit peak power (W) | 2 500 |
| Pulse width (μs) | 0.3 |
| Pulse rise/fall time (ns) | 25-50/25-200 |
| Pulse repetition rate (pps) | 15 000 |
| Maximum duty cycle | 0.001 |
| Output device | Magnetron |
| Antenna pattern type | Parabolic reflector | Horn |
| Antenna gain (dBi) | Azimuth 32 – Elevation 26 | 6 |
| Antenna elevation beamwidth (degrees) | 1.3 horizontal 6 vertical | 36 |
| Antenna azimuthal beamwidth (degrees) | 40 horizontal  2 vertical | 70 |
| Antenna horizontal scan rate | 5 Hz | N/A |
| Antenna horizontal scan type | Sector |
| Antenna vertical scan rate | 5 Hz |
| Antenna vertical scan type | Sector |

TABLE 2 (*end*)

|  |  |  |
| --- | --- | --- |
| Characteristics | Aircraft landing system | |
| Function | Transmitter | Receiver |
| Antenna 1st side-lobe level | At least 17 dB below peak | At least 17 dB below peak |
| Antenna height (m) | Land: 10  Ship: 15-24 | 2 000 (typical landing sequence initiation) |
| Receiver IF −3 dB bandwidths (MHz) |  | 12 |
| Receiver noise figure (dB) |  | 11.5 |
| Minimum discernible signal (MDS) (dBm) |  | −72 |
| (1) Not applicable.  ( | | |

# 3 ALS compatibility analysis/methodology

For this analysis, the interference to noise ratio (I/N) will be calculated, as shown in subsequent paragraphs, to assess compatibility between radiolocation systems planned to operate in the 15.4-17.3 GHz band and a typical ALS system that operates in the 15.4-15.7 GHz band.

The initial step in assessing compatibility is the determination of the noise power which is given by:

*N =* –204 dBW + 10 log(*BIF* (Hz)) + *NF* (1)

where:

*BIF*: receiver IF bandwidth (Hz);

*NF* : receiver noise figure (dB).

The following equation can be used to determine if interference to the aircraft ALS receiver from System‑6 transmissions is likely to occur and what separation distance is required to eliminate the interference:

*I* = *PTx* + *GTx* + *GRx* – *LTrans* – *FDR* (2)

where:

*I* : interference, peak power of the radar pulses at the receiver (dBW)

*PTx*: peak power of the interfering system (dBW)

*GTx* : antenna gain of the interfering transmitter in the direction of the victim receiver (dBi)

*GRx* : antenna gain of the victim receiver in the direction of the interfering transmitter (dBi)

*LTrans* : transmission loss between transmitting and receiving antennas (dB) using Recommendation ITU-R P.528-5 depending on the analysis type.

*F* : frequency (MHz)

*R* : separation distance (km)

*FDRIF* : frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB).

The *FDRIF* value can be found in working document towards a preliminary draft new Recommendations ITU-R M.[15.4-15.7\_GHZ\_ARNS]. Since the radars will operate on a co-frequency basis, only the on-tune rejection (OTR) is considered. OTR for non‑coherent chirped pulsed signals is given by:

*OTR* = 10 log (*Rx\_BW*/*Tx\_BW*) for *Rx\_BW* ≤ *Tx\_BW* (3)

Otherwise OTR = 0

where:

*Rx\_BW* : receiver bandwidth (MHz)

*Tx\_BW* : transmitter bandwidth (MHz).

The receiver sensitivity is defined as the minimum input signal level required at the antenna terminals of the receiver to produce a specified level of performance after demodulation and processing. The minimum sensitivity is derived by comparing the wanted signal to the sum of both receiver noise and received interference power in the reference receiver bandwidth.

System-6 receiver protection criterion as described in Recommendation ITU-R M.1730-1 is:

I/N −6 dB (4)

## 3.1 Compatibility analysis scenario

One compatibility analysis scenario is shown in Fig. 1.

Figure 1

Compatibility analysis scenario

![Diagram

Description automatically generated]()

## 3.2 Analysis assumptions

The analysis assumptions are:

1. Propagation loss using Recommendation ITU-R P.528-5 – A propagation prediction method for aeronautical mobile and radionavigation services using the VHF, UHF, and SHF bands. The time percentage of 5% is used.
2. The altitude of Radiolocation and the aircraft landing system (ALS) are at 2000 m above the Earth’s surface.
3. The center frequency of Radiolocation is 16.35 GHz. The center frequency of the ALS is 15.55 GHz.
4. The FDR value between Radiolocation and ALS receiver is 60 dB.
5. The ALS receiver system is randomized within a 100 km radius of an ALS transmitter system. The Radiolocation aircraft is randomized within a 100 km radius of an ALS receiver system.
6. The antenna pattern for a transmitting Radiolocation can be modeled using Recommendation ITU-R M.1851 cosine square pattern. The antenna pattern for the ALS receiver is the horn antenna pattern.
7. The pointing angle of the radiolocation transmitting antenna is randomized ±45° horizontally, and +5° to −45° vertically.
8. The ALS receiver is pointing toward the ALS transmitter.
9. The polarization loss value is 3 dB.
10. The analysis was performed with 1 million sampling points with the protection criteria is I/N of -6 dB.

## 3.3 Compatibility analysis

Figure 2 below provides the Cumulative Distribution Functions (CDFs) of I/N values for the compatibility analysis between Radiolocation and ALS. Figure 3 below provides the separation distance that are required to protect the ALS.

Figure 2

CDF Plot of I/N values for the compatibility analysis between Radiolocation and ALS

FIGURE 3

Separation distance between Radiolocation and ALS



## 3.4 Assessment of analysis results

Table 3 below provides the required separation distance between Radiolocation and ALS to protect the ALS system.TABLE 3

ALS to System-6 separation distance summary table

[TBD]



# 4 Radio astronomy service

## 4.1 RAS general characteristics

The radio astronomy service (RAS) is a service with a primary status in the band 15.35-15.4 GHz in the RR Nos. 5.340 and 5.511A. During an observation, a radio astronomy telescope points towards a celestial radio source at a specific right ascension and declination corresponding with a specific azimuth and elevation at a given moment in time, and the pointing direction of the telescope is continuously adjusted to compensate for the rotation of the Earth. Table 5 below is an extract from the WP 7D Reply Liaison Statement to WP 5B (doc. 5B/120) that shows major radio astronomy stations installed in various countries of the world, together with their location, height above mean sea level, and antenna diameter.

TABLE 5

**Typical radio telescopes for which compatibility studies might be performed**

| **Administration** | **Name** | **N. Latitude** | **E. Longitude** | **Height AMSL (m)** | **Diameter (m)** |
| --- | --- | --- | --- | --- | --- |
| Germany | Effelsberg | 50° 31' 29" | 06° 53' 03" | 369 | 100 |
| South Africa | MeerKAT | −30° 43′ 16" | 21° 24' 40" | 1 054 | 64 × 13.5 m |
| USA | Green Bank Telescope | 38° 25' 59" | −79° 50' 23" | 250 | 100 |
| USA | Jansky VLA | 33° 58' 22" to 34° 14' 56" | −107° 24' 40" to  −107° 48' 22" | 2 000 | 27 × 25 m |
| Australia | Parkes | −33º 00' 00" | 148º 15' 44" | 372 | 64 |
| China | Tianma | 31° 05′ 13" | 121° 09′ 48" | 5 | 65 |
| Japan | Nobeyama | 35º 56' 40" | 138º 28' 21" | 1 350 | 45 |
| France | Plateau de Bure | 44º 38' 02" | 05° 55' 28.5" | 2 250 | 12 × 15 m |

The peak gain of the antennas used in the radio astronomy stations presented in Table 6 below.

TABLE 6

**Peak gain and -3dB beamwidth of Radio Astronomy antennas in the frequency band 15.35-15.4 GHz**

| **Administration** | **Name** | **(m)** | **(dBi)** | **(deg)** |
| --- | --- | --- | --- | --- |
| Germany | Effelsberg | 100 | 82.6 | 0.0068 |
| South Africa | MeerKAT | 64 × 13.5 m | 84 |
| USA | Green Bank Telescope | 100 | 82.6 |
| USA | Jansky VLA | 27 × 25 m | 84 | 0.0106 |
| Australia | Parkes | 64 | 78.7 |
| China | Tianma | 65 | 78.8 | 0.0104 |
| Japan | Nobeyama | 45 | 75.6 | 0.0150 |
| France | Plateau de Bure | 12 × 15 m | 84 |







## 4.2 RAS protection criteria

The protection criteria given in Recommendation ITU-R RA.769-2 assume that the interferer is in the antenna far field of a radio telescope, and that it is received in the side lobe of the RAS antenna pattern, at a level of 0 dBi at relative angles greater than 19° from the antenna boresight (see also Recommendation ITU-R SA.509-2). It should also be noted that a radio telescope typically uses an antenna with a very high gain, on the order of 76 dB for a telescope with a diameter of 50 m, or higher. As recommended, an RAS antenna gain of 0 dBi is used in the calculation.

The sensitivity levels given in Recommendation ITU-R RA.769-2 employ values for the bandwidth and integration time for which these other factors usually are insignificant. These values are shown in Table 6.

TABLE 6

RAS protection criteria

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | System sensitivity (noise fluctuations) | | Threshold interference levels | | |
| Temperature (K) | Power spectral density (W/Hz) | Input power | Power flux-density (W/m2) | Spectral power flux-density (W/(m2 ⋅ Hz)) |
| Single dish | 0.095 m | −269 dB | −202 dBW | −156 dB | −233 dB |

## 4.3 RAS analysis assumptions and results

For this compatibility study the following assumptions are made:

1. Propagation loss using Recommendation ITU-R P.528-5 – A propagation prediction method for aeronautical mobile and radionavigation services using the VHF, UHF, and SHF bands. The time percentage of 5% is used.
2. The altitude of Radiolocation is at 8.5 km above the Earth’s surface. The altitude of the RAS is at 100 m above the Earth’s surface.
3. The center frequency of Radiolocation is 16.35 GHz. The center frequency of the RAS is 15.375 GHz.
4. The FDR value between Radiolocation and RAS receiver is 70 dB.
5. The Radiolocation aircraft is randomized within a 100 km radius of the RAS system.
6. The antenna pattern for a transmitting aircraft can be modelled using Recommendation ITU-R M.1851 cosine square pattern. The antenna for the RAS system is based on Rec ITU-R SA.509-3.
7. The pointing angle of the Radiolocation transmitting antenna is randomized ±45° horizontally, and +5° to −45° vertically.
8. The pointing angle of the RAS receiver antenna is randomized between 0° to 360° horizontally, and 0 to +90° vertically.
9. The polarization loss value is 3 dB.
10. The analysis was performed with 1 million sampling points with the protection criteria of Interference level does not exceed -202 dBW/50 MHz for less than 2% of the time.

The potential consequences of interference on a radio astronomy measurement can vary from disruption by overloading the receiver to very slight distortions of the data. Broadband interference may raise the general noise level of the radio astronomy receiver, as a result degrading the sensitivity and perhaps looking like a continuum radio source. Narrow-band interference may mimic astronomical spectral lines.

Strong interference can sometimes be tolerated if it occurs in short bursts for a small fraction of the total time. This is the case for System‑6 in our study. Weak intensity interference, near the sensitivity limit of the observation, is usually difficult to handle because it may be difficult to trace the source of the interference to remedy the situation.

Technical means of reducing interference situations include transmitter limitations, filtering, antenna design, and modulation techniques. Of these, filtering is probably the most general solution, and it is usually the most practical, at least for the short term. In some cases filtering is not desirable. Data processing can be used to remove the interference signals after they have been received.

Non-technical methods of spectrum sharing involve finding an appropriate combination of parameters in a two-dimensional (frequency, geographic area) space. Time sharing, another common dimension in spectrum management space, is usually not feasible. Geographic separation is a very common means of spectrum sharing. In the case we are studying, the locations of the radio astronomy receivers are well known, see Table 5, and are usually sited in secluded locations. Therefore, it is possible that System‑6 can avoid pointing its antenna beams in the observatory direction. It has been shown, by analysis, that only System-6 main-lobe interference can cause the protection criteria to be exceeded. In a worst-case analysis scenario, and assuming that the RAS does not use any filtering to limit and shape the received signal in the allocated band, the out of band signal received from System‑6 can be as high as to 55 dB above the protection threshold of −202 dBW at a slant distance of approximately 12 km. Using an off-frequency rejection of 70 dB, the results are shown in Figure 3.

FIGURE 3

RAS interference analysis results

[TBD]



The worst‑case results show that when System‑6 is lined up in azimuth with the RAS system, and using 100% duty, the possibility of interference exists. The probability of System-6 intentionally pointing at the RAS system; for a long time duration is very low; given that the known RAS systems shown in Table 5 have detailed location information that can be utilized by System-6 to avoid intentional interference. Adjustments in the way System-6 operate are used to reduce the interference duration or completely avoid interfering with RAS. These adjustments can include changes to the antenna beam elevation and azimuth pointing angels, increasing the aircraft speed to minimize the interference duration, changing the aircraft height to change the interference coupling geometry or a combination of all of them. Typically System-6 would point its antenna beam at or below −20°, relative to its local horizontal line.

In System-6 operational scenarios, the chirp bandwidth can vary from 1 600 MHz to less than 1 900 MHz. The use of a smaller chirp bandwidth of 1 600 MHz, with a carrier frequency of 16 350 MHz, when System-6 is within the required separation distance constraint to RAS will result in a smaller emission mask that is significant in mitigating interference and eliminating the need for additional mitigation techniques (such as a transmit filter).

# 5 Fixed-satellite service

## 5.1 Radiolocation system

The band 15.7-17.3 GHz is allocated to the radiolocation service on a primary basis, and Recommendation ITU-R M.1730-1 contains technical characteristics and protection criteria for radiolocation radars operating in this band. The characteristics for System‑6 are provided in the introduction § 2.1 Table 1.

## 5.2 FSS (Earth-to-space)











Typical characteristics of an NGSO satellite using the frequency band 15.43 – 15.63 GHz to receive signals from an Earth station are provided in Table 7 below.

TABLE 7

**Typical characteristics of FSS NGSO satellite**

**in the frequency band 15.43-15.63 GHz**

| **Characteristic** | **Notation** | **Unit** | **Value** |
| --- | --- | --- | --- |
| Platform type | - | | NGSO satellite |
| Altitude above ground level | - | km | 400 to 2,000**(1)** |
| Centre frequency | - | GHz | 15.53 |
| Carrier bandwidth | - | MHz | 200 |
| Beam characteristics | - | | Single circular beam |
| Antenna pointing | Any point at the surface of the Earth, within the footprint of the satellite**(2)** |
| Noise bandwidth |  | MHz | 1 |
| System receiver noise temperature |  | K | 600 |
| Notes:  **(1)** This is the range of values for a Low Earth Orbit (LEO) satellite.  **(2)** The footprint is assumed to be all points at the surface of the Earth that are visible from the satellite. | | | |

The antenna installed on-board the satellite is typically a parabolic reflector whose characteristics are provided in Table 8 below.

TABLE 8

**Characteristics of the FSS antenna**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Characteristic** | **Notation** | **Unit** | **Value** | | |
| Carrier | - | | 1 | 2 | 3 |
| Diameter |  | m | 1.2 | 1.8 | 2.4 |
| -3 dB bandwidth |  | deg | 1.3 | 0.75 | 0.56 |
| Aperture efficiency (note 1) |  |  | 0.6 | | |
| Operating frequency (GHz) |  | GHz | 15.53 | | |
| Peak gain (dBi) (note 2) |  | dBi | 43.6 | 47.1 | 49.6 |
| Major axis/Minor axis for the radiated beam (note 3) | - | | 1 | | |
| Near-in-side-lobe level relative to the peak gain (dB) | -25 | | |
| Far side-lobe level (dB) |  | dB | 0 | | |
| Notes:  **(1)** Typical aperture efficiency values for a parabolic antenna range from 0.55 to 0.7.  **(2)** The peak gain of a parabolic antenna is related to its diameter according to the formula (33) below.  **(3)** This ratio equals 1 because the beam is supposed circular. | | | | | |

Recommendation ITU-R S.672-4 provides a typical radiation pattern for parabolic dish antennas installed on-board GSO satellites. By extension, it is assumed usable for NGSO satellites.

## 5.3 Compatibility analysis methodology

For this analysis, the *I*/*N* ratio will be calculated, as shown in subsequent paragraphs, to assess compatibility between radiolocation systems operating in the 15.4-17.3 GHz band and the FSS system operating in the 15.4-15.7 GHz band.

The initial step in assessing compatibility is the determination of the noise power, at the satellite and earth station receivers, which is given by:

 (5)

where:

*BIF* : receiver IF bandwidth (MHz)

*Te* : receiver noise temperature (K)

*To* : 290°.

Equation (6) is used to determine the interference level from System‑6 transmissions into the satellite and earth station receivers. This equation may also be used to determine the minimum separation distance required to mitigate harmful interference:

 (6)

where:

*I* : interference, peak power of the radar pulses at the receiver (dBW)

*PTx* : peak power of the interfering system (dBW)

*GTx* : antenna gain of the interfering transmitter in the direction of the victim receiver (dBi)

*GRx* : antenna gain of the victim receiver in the direction of the interfering transmitter (dBi)

*LTrans* : transmission loss between transmitting and receiving antennas (dB) using free space loss. Free space loss = 20 log(*F*) + 20 log(*R*) + 32.44

*F* : frequency (MHz)

*R* : separation distance (km)

*FDRIF* : frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB).

FDRIF can be determined from Recommendation ITU-R SM.337-6. In this case it is computed using the simulation software.

## 5.4 Satellite compatibility scenarios and assumptions

The satellite and earth station parameters used in the analysis are found in Table 9. Missing parameter values have been assumed, as labelled in Table 9, or computed using ITU-R Recommendations as a guide.

Depictions of the potential interference scenarios used in this analysis are shown in Figs 3, and 4. Figure 3 shows the dynamic scenario of an elliptical orbiting satellite, Fig. 4 shows the static scenario where main beam antenna coupling occurs between the satellite and System‑6.

Figure 3

Scenario configuration for LEO-E elliptical orbit



Figure 4

Scenario for satellites



The analysis assumptions are:

1. Transmission loss using Recommendation ITU-R P.525 – Free Space loss, and ITU-R P.676-12 – Attenuation by atmospheric gases and related effects.
2. The altitude of Radiolocation is at 8.5 km above the Earth’s surface. The altitude of the non-GSO FSS system is 400 km above the Earth’s surface.
3. The center frequency of Radiolocation is 16.35 GHz. The center frequency of the FSS system is 15.53 GHz.
4. The FDR value between Radiolocation and FSS receiver is 60 dB.
5. The FSS system is flighting in the circular orbit with 0 degree inclination.
6. The antenna pattern for a transmitting aircraft can be modeled using Recommendation ITU-R M.1851 cosine square pattern. The antenna pattern for the non-GSO FSS is given in Rec. ITU-R S.672-4.
7. The pointing angle of the radiolocation transmitting antenna is randomized ±45° horizontally, and +5° to −45° vertically.
8. The FSS receiver is pointing toward the Earth’s station which has the altitude of 10 m.
9. The polarization loss value is 3 dB.
10. The analysis was performed with 1 million sampling points with the protection criteria is I/N of 0 dB for 99.98% and -6 dB for 99.4%.

## 5.5 Compatibility analysis scenarios

[TBD]















## 5.7 Results

The following sections contain the resulting cumulative distribution function (CDF) plots of the analysis. The FSS interference threshold lines are drawn for reference.

### 5.7.1 Circular orbit results

[TBD]

Figure 8

System‑6 and circular orbit near perigee

## 5.8 Summary of FSS compatibility results

[TBD]







## 5.9 FSS systems conclusions

The analysis carried out indicates that System-6 radar and the FSS satellites and earth stations analysed can share the 15.4 to 15.7 GHz frequency band.

# 6 Recommendation ITU-R S.1340 aeronautical radionavigation radars

A survey of ITU-R M series Recommendations (2009) revealed that currently there are no systems characteristics available for study. However Recommendation ITU-R S.1340 has aeronautical radionavigation systems in the 15.4 to 15.7 GHz band that are studied in the following sections.

## 6.1 Aeronautical radionavigation systems in the 15.4-15.7 GHz band

Aeronautical radionavigation systems obtained from Recommendation ITU-R S.1340 are analysed against System‑6 to determine separation distances for each system. The aeronautical system descriptions are copied from those recommendations and listed below for convenience. The systems studied are:

1 Surface based radar (SBR) is a land and ship based system used for the detection, location and movement of aircraft and other vehicles on the surface of airports and other aircraft landing areas.

2 Aircraft landing system (ALS) is a general purpose system used on ships, as portable or permanent land based systems and for shuttle landings. The microwave scanning beam landing system (MSBLS) is one such system. Some of the characteristics vary with the particular applications.

3 Aircraft multipurpose radar (MPR) is a radionavigation, radiolocation and weather radar.

4 Radar sensing and measurement system (RSMS) that uses radar technology at 15 GHz are particularly suited to smaller aircraft, including helicopters, offering the benefits of compact, light, equipment with good antenna directivity. This system is widely used in certain parts of the world where they make an important contribution to the safety of aircraft operation. RSMS are essentially used in low level operations up to a nominal height of around 1 500 m. An antenna mounting which transmits and receives vertically downwards would be used in the great majority of applications. Power reduction proportional to height above terrain is employed to reduce scatter and other undesirable effects.

A summary of technical characteristics of these systems are found in Table 15.

TABLE 15

Recommendation ITU-R S.1340 (1997) summary of technical characteristics

| System | Surface-based radars  (SBR) | Aircraft landing system  (ALS) | Aircraft multipurpose radars  (MPR) | Radar sensing and measurement system  (RSMS) |
| --- | --- | --- | --- | --- |
| Reference | ITU-R S.1340 Annex 1 § 1 | ITU-R S.1340 Annex 1 § 2 | ITU-R S.1340  Annex 1 § 3 | ITU-R S.1340  Annex 1 § 4 |
| Frequency range (GHz) | 15.65-16.7 | 15.4-15.7 | 15.4-15.7 | 15.63-15.65 |
| Peak power (dBW) | 43 | 38 | 40 | 0 |
| Antenna pattern | Elevation pattern § 1.1.1 Annex 1 | ITU-R S.1340 | ITU-R S.1340 (§ 3.1) | ITU-R S.1340 |
| Transmit antenna gain (dBi) | 43 | Azimuth 33° Elevation 28° | 30 | 13 |
| Receiver antenna gain (dBi) | 43 | 8 (on the landing aircraft) | 30 | 5 (back lobe) |
| Maximum side-lobe level below peak gain (dB) | 25 |  | 14 |  |

TABLE 15 (*end*)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| System | Surface-based radars  (SBR) | Aircraft landing system  (ALS) | Aircraft multipurpose radars  (MPR) | Radar sensing and measurement system  (RSMS) |
| Nominal 3 dB Receive antenna pattern beamwidth (degrees) | 3.5 | Omnidirectional | 4.5 | Omnidirectional |
| Antenna polarization | circular | horizontal and vertical | vertical | Vertical (assumed) |
| Vertical tilt range (degrees) | +1.5 | Omnidirectional | ±20 | Omnidirectional |
| Maximum horizontal scan range for receive antenna (degrees) | 360 | Omnidirectional | ±45 | Omnidirectional |
| Receiver IF bandwidth (MHz) | 25 | 3 | 0.50 | 2 |
| Noise figure (dB) | 6.5 | 8 | 8 | 6 |

## 6.2 Analysis assumptions and results for SBR, MPR and RSMS

The following section contains the analysis methodology and results for the SBR, MPR RSMS systems. For these systems the worst case *I*/*N* analysis is carried out, using equations 1, 2 and 3 from § 3, and the assumptions listed below. For each case System‑6 was set up to have a fixed height and antenna beam position angle relative to its horizontal. The victim system was set up such that the worst case interference is calculated using the parameters in Table 15. The minimum and maximum separation distances where the value of *I*/*N* = –10 dB is exceeded is shown in the results tables.

Figure 13 describes a sample analysis results case. For each case, the System-6 antenna beam pointing angel; relative to its horizontal; is unchanged. The distance between the two systems are incremented and the *I*/*N* value is calculated. The changes to *I*/*N* are caused by antenna gain coupling changes, due to changes in relative line of sight angles, and to propagation loss. The separation distance, where *I*/*N* is exceeded, is obtained for each case as shown in the tables below.

Figure 13

Description of results and typical scenario



The following analysis assumptions are made:

1 worst-case analysis for all cases;

2 victim and System‑6 are lined up in azimuth and face each other. Azimuth antennas are at peak gain;

3 System-6 duty cycle is 100%. Peak power is used;

4 free space transmission loss;

5 System-6 antenna back lobe RF energy leakage is low due to the aircraft fuselage and/or radome blockage;

6 separation distances up to 500 km;

7 the MPR and System‑6 are at the same height;

8 the SBR system is assume to be fixed. Operationally, SBR antenna rotates completing 360º every second;

9 the RSMS antenna back-lobe used is 5 dBi. This value would be significantly less due to its position on the underside of the aircraft;

10 System-6 typical operational height is 8 500 m.

TABLE 16

SBR to System-6 separation distance summary results

| System-6 beam angle relative to horizontal  (degrees) | Minimum separation distance (km)  where *I*/*N* > = –10 dB(1) | Maximum separation distance (km)  where *I*/*N >* = –10 dB(1) |
| --- | --- | --- |
| 5 | 129 | Radio horizon |
| 0 | 63 |
| –5 | 45 |
| –10 | 30 | 169 |
| –15 | 22 | 80 |
| –20 | 18 | 33 |
| –25 | 15 | 24 |
| –30 | 12 | 19 |
| –35 | 10 | 15 |
| –40 | 8 | 9 |
| –45 | 7 | 8 |
| (1) Other *I*/*N* values are lower for separation distances greater than value given below. | | |

The SBR systems have known physical locations; they are placed at few airports around the globe. During its operation, System‑6 can avoid pointing its antenna beam at these well known positions. In practical cases of System‑6 operations, interference with the SBR systems can be avoided.

TABLE 17

MPR to System-6 separation distance summary results

| System-6 beam angle relative to horizontal (degrees) | Minimum separation  distance (km)  where *I*/*N* > = –10 dB(1) | Maximum separation  distance (km)  where *I*/*N* > = –10 dB(1) |
| --- | --- | --- |
| 5 | Same as maximum separation | Radio horizon |
| 0 |
| –5 | 179 |
| –10 | 17 |
| –15 | 10 |
| –20 |
| –25 |
| –30 |
| –35 |
| –40 |
| –45 |
| (1) Other *I*/*N* values are lower for separation distances less than value given below. | | |

The MPR are placed on aircraft. While operating, these aircraft can be anywhere from sea level to several kilometres in altitude. It is difficult to predict the relative position of these systems as compared with System‑6. In a given aircraft operational volume, the probability of these systems being at the same exact height, lined up in azimuth and pointing directly at each other is very low. The results in Table 18 show that in rare cases, when everything is in the proper alignment, interference is possible. For practical operational scenarios of System‑6, the separation distances can be approximately 10 km.

In a worst-case analysis using an idealized pulse, it was found that the required separation distance is 87 km.

The RSMS are designed to measure height and ground clearance. They are placed on aircraft. While operating, these aircraft can be anywhere from sea level to 1.5 km in height above sea level. It is difficult to predict the relative position of these systems as compared with System‑6. The probability of these two radars of being lined up in azimuth and pointing directly at each other is also very low. The results in Table 18 show that in rare cases when everything is in the proper alignment, interference is possible.

In practical operational scenarios, System-6 points its antenna beam below −20º relative to horizontal. Analysing the results, shown in Table 18, we note operationally important separation distance limits where *I*/*N* threshold is exceeded. For example:

– for System-6 beam pointing angle of –45º below horizontal, *I*/*N* threshold is exceeded between distances below 6 km and above 9 km. System-6 is compatible for all other separation distances;

– for System-6 beam pointing angle of –20º below horizontal, *I*/*N* threshold is not exceeded for distances below 15 km and above 27 km. System-6 is compatible for all other separation distances.

Therefore, for practical operational scenarios and using worst‑case analysis, System-6 is compatible with RSMS.

TABLE 18

RSMS to System-6 separation distance summary results

| System-6 beam angle relative to horizontal (degrees) | Minimum separation  distance (km)  where *I*/*N* > = –10 dB(1) | Maximum separation  distance (km)  where *I*/*N* > = –10 dB(1) |
| --- | --- | --- |
| 5 | None | None |
| 0 | 84 | Radio horizon |
| –5 | 40 | 237 |
| –10 | 26 | 70 |
| –15 | 19 | 39 |
| –20 | 15 | 27 |
| –25 | 12 | 20 |
| –30 | 10 | 16 |
| –35 | 8 | 13 |
| –40 | 7 | 11 |
| –45 | 6 | 9 |
| (1) Other *I*/*N* values are lower for separation distances greater than value given below. | | |

## 6.3 Recommendation ITU-R S.1340 ALS system analysis assumptions and results

The same assumptions and analysis methodology, as carried out in § 3, are repeated for this ALS system. The relative increase in the ground based transmitter and the increase in the aircraft receiver antenna gain result in slightly better results for this case, as compared to § 3, as shown in Table 19.

TABLE 19

Recommendation ITU-R S.1340 ALS to System-6 separation distance summary table

| ALS\_Rx to ALS\_Tx distance (km) for  S/(*N* + *I*) = 20.2 dB  or greater | Ground separation distance (km) for  ALS\_Rx main lobe to System-6 main lobe ALS Tx = 2 200 W | Ground separation distance (km) for ALS\_Rx main lobe to System-6 main lobe ALS Tx = 1 100 W | Ground separation distance (km) for ALS\_Rx main lobe to System-6 side lobe ALS Tx = 1 100 W and ALS Tx = 2 200 W |
| --- | --- | --- | --- |
| 10 | 5 | 18 | Less than 1 |
| 15 | 16 | 24 |
| 20 | 24 | 35 |
| 25 | 31 | 48 |

There are two possible types of ALS systems, one is fixed in place and the other is transportable. Transportable systems are operated by a few administrations. These systems do not operate on the move, and they only operate after the landing site has been established. When the position of the ALS is known and applying both proper frequency management coordination and landing procedures, then the results of the analysis in Table 19 can be used. However, where separation distances are not possible to be put into practice using these procedures for transportable ALS stations having unknown locations alternative methods for protecting those stations need to be established.

Table 19, shows that with the proper operational procedures, System-6 even in the worst-case scenario can accommodate the ALS system and would operate as to not interfere. This would be done by keeping the proper separation distance and by proper positioning of the antenna beam.

# 7 Conclusions

The results of the analysis in this draft Report shows that based on the operational scenarios and assumptions, the radiolocation systems planned to operate in the 15.4-17.3 GHz band will be compatible with the non-ICAO ALS having known locations, RAS systems, FSS systems, and the aeronautical radionavigation systems if the separation distances identified in this report are maintained.