International Telecommunication Union

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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

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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 (typical operational height = 8 500 m)
Tuning range (GHz)	15.4-17.3
Modulation	Linear FM chirp
Transmit peak power (W)	500
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
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
1st/2nd 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 are not found in ITU Recommendations or Reports (2009). 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	Airborne platform
Tuning range (GHz)	15.4-15.7	
Modulation	Pulse	N/A[(1)]
Transmit peak power (W)	2 200	
Pulse width (μs)	0.3	
Pulse rise/fall time (ns)	100/100	
Pulse repetition rate (pps)	3 334	
Maximum duty cycle	0.001	
Output device	Magnetron	
Antenna pattern type	Beam	Beam (assumed)
Antenna gain (dBi)	Azimuth 31º – Elevation 26º	4
Antenna elevation beamwidth (degrees)[(2)]	±20 horizontal 1.25 vertical	30
Antenna azimuthal beamwidth (degrees)[(2)]	Azimuth 2 horizontal 6 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	20 dB down from the main lobe peak	20 dB minimum (assumed)(3)
Antenna height (m)	Ground level	1 000 (typical landing sequence initiation)
1st/2nd receiver IF −3 dB bandwidths (MHz)		15
Receiver noise figure (dB)		10
Minimum discernible signal (MDS) (dBm)		−72

(1) Not applicable.

(2) There are two antenna systems one for azimuth and one for elevation.

(3) The receiver antenna 1st side-lobe level needs to be verified.

3 ALS compatibility analysis/methodology

For this analysis, the signal to noise plus interference ($S/(N+I)$) 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 because:

a) there is no known ITU protection criteria for this type of ALS receiver;

b) the required receiver sensitivity value for the system performance is known.

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

$$N = -204 \text{ dBW} + 10 \log(B_{IF} \text{ (Hz)}) + NF \qquad (1)$$

where:

B_{IF}: 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:

$$I = P_{Tx} + G_{Tx} + G_{Rx} - L_{Trans} - FDR \qquad (2)$$

where:

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

P_{Tx}: peak power of the interfering system (dBW)

G_{Tx}: antenna gain of the interfering transmitter in the direction of the victim receiver (dBi)

G_{Rx}: antenna gain of the victim receiver in the direction of the interfering transmitter (dBi)

L_{Trans} : transmission loss between transmitting and receiving antennas (dB) using free space loss or Recommendation ITU-R P.528-2 depending on the analysis type. Free space loss = 20 log(F) + 20 log(R) + 32.44

F : frequency (MHz)

R : separation distance (km)

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

The FDR_{IF} value can be determined from Recommendation ITU-R SM.337-6. 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:

$$OTR = 10 \log (Rx\_BW/Tx\_BW) \qquad \text{for } Rx\_BW \leq Tx\_BW \tag{3}$$

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.

The receiver sensitivity may be defined by the formula:

$$Sensitivity \text{ (dBW)} = (S/(N+I))_{min} + 10 \log (kT_oB) + (NF) \tag{4}$$

where:

$(S/(N+I))_{min}$: minimum input signal-to-noise plus interference power ratio needed to process a signal at the required level of performance (dB)

k : Boltzmann's constant, 1.38×10^{-23} (J/K)

T_o : absolute temperature of the receiver input (Kelvin = 290°)

B : receiver 3 dB IF bandwidth (Hz), value used is 15 MHz

NF : receiver noise figure (dB), value used is 10 dB.

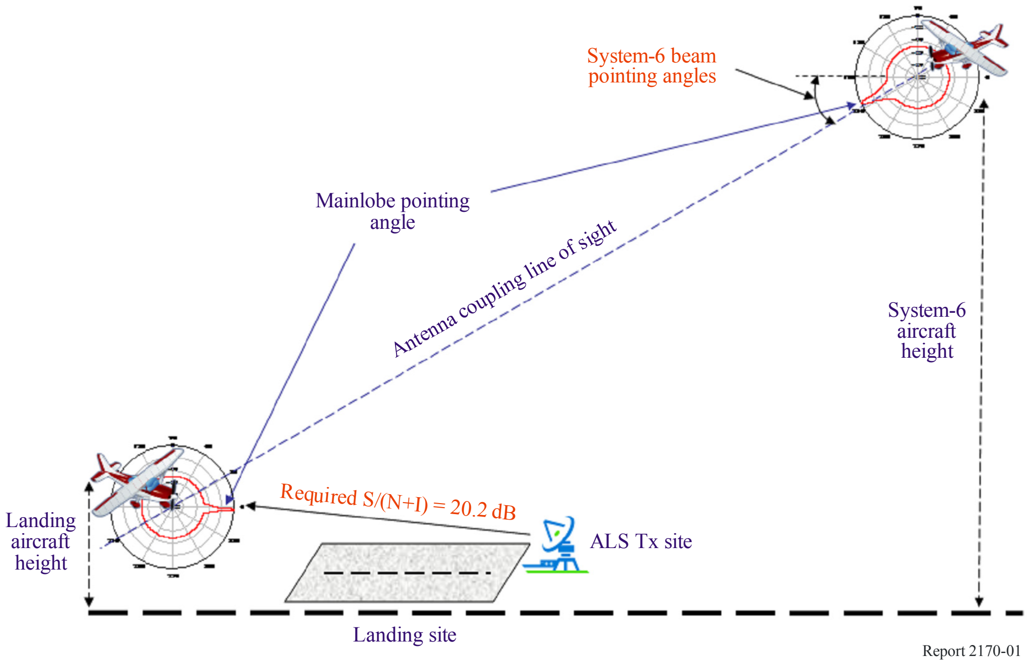
For this analysis the receiver sensitivity value is −72 dBm or −102 dBW. Using equation (4), the resulting minimum signal-to-noise $(S/(N+I))_{min}$ is 20.2 dB. This signal level ensures good receiver performance in the presence of potential interference.

3.1 Compatibility analysis scenario

One compatibility analysis scenario is shown in Fig. 1.

FIGURE 1

Compatibility analysis scenario



3.2 Analysis assumptions

The analysis assumptions are:

1 Worst-case analysis.

2 System-6 duty cycle is 100%, normally this value is 20%. When landing, the ALS transmitter and ALS aircraft receivers are always in the active state.

3 Main lobe-to-main lobe antenna coupling between ALS receiver and System-6 (if the ground transmitter is narrow-beam sector scanning, there will be cases where there will not be main lobe-to-main lobe coupling, in which case the pilot would have to readjust his position to land. During acquisition the aircraft may not be lined up with the ground transmitter location).

4 Transmission loss using Recommendation ITU-R P.528-2 – Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands, using Figs 6a and 6c.

5 Half and full power ALS transmitter.

6 If the ALS receiver is in the nose of the aircraft, susceptibility to interference entering the victim aircraft antenna back lobes maybe low due to the aircraft fuselage radio-frequency (RF) blockage.

7 System-6 antenna back lobes RF energy leakage can be very low due to the aircraft fuselage and/or radome blockage.

8 Aircraft landing sequence, for this analysis, starts at a marshalling point that is 1 000 m above the landing site and 25 km distance to ALS transmitters (10 km distance is a typical value, 25 km is used as worst-case analysis).

9 System-6 typical operational height is 5 000 to 10 000 m. The typical operational height value of 8 500 m is used.

10 Since there is no known interference criteria for the landing system receiver portion on the aircraft, it is assumed that if the signal-to-noise plus interference, at the victim aircraft receiver, is equal to or greater than 20.2 dB (using a –102 dBW ALS receiver minimum sensitivity value), then the radar and aircraft ALS landing system receiver are considered compatible for the applicable distance separations analysed.

3.3 Compatibility analysis

Signal-to-interference plus noise levels are calculated for several cases. These are:

1 Separation distances between ALS landing aircraft and ALS transmitters are set to 10, 15, 20 and 25 km. Separation distances between System-6 and the ALS landing aircraft are set between 1 and 100 km to determine the minimum separation.

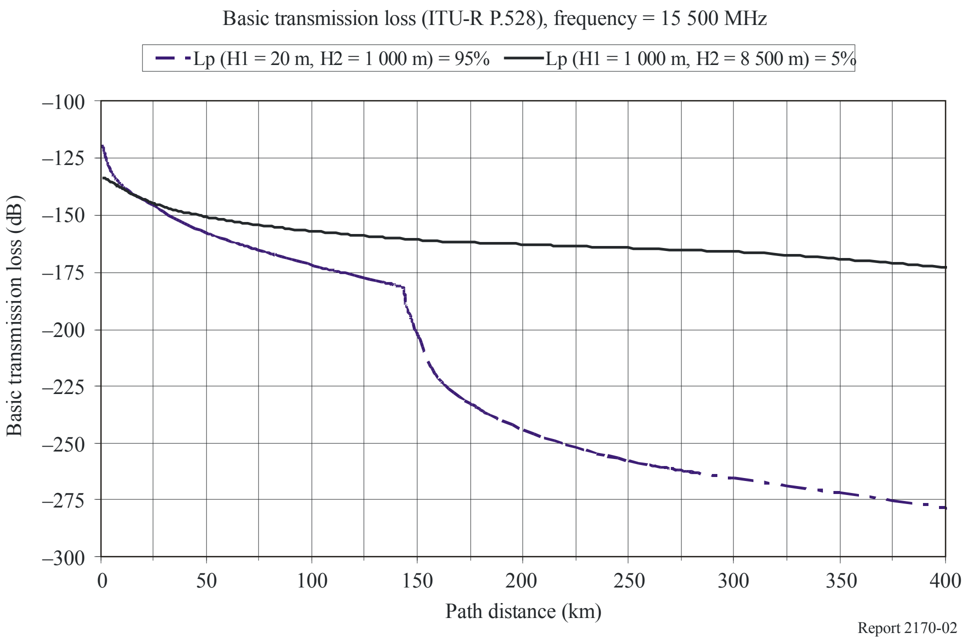
2 For each distance combination the signal to noise plus interference is computed for:

a) System-6 antenna main lobe to ALS aircraft antenna main lobe gains;

b) System-6 antenna side lobe to ALS aircraft antenna main lobe gains.

Recommendation ITU-R P.528-2 is used to calculate the basic transmission loss, where, the basic transmission loss, $L_b(0.05)$ is used to estimate L_b values for an unwanted interfering signal, System-6, that is exceeded during 95% (100% – 5%) of the time, and $L_b(0.95)$ curve is used to estimate the service range for a wanted signal, ALS transmitter to ALS receiver, at which service would be available for 95% of the time in the absence of interference. A plot of the basic transmission loss curves is shown in Fig. 2. Analysis using Recommendation ITU-R P.528-2, Annex 1 equations (1), (2) and (3) revealed that due to the small distance used the results are exactly the same as those that have been obtained in this analysis.

FIGURE 2



Sample calculation for the main-lobe to main-lobe antenna coupling case is provided in Table 3:

TABLE 3

Sample calculation for main-lobe to main-lobe antenna coupling

Link budget	Wanted ALS Tx	Wanted ALS Rx	System-6 Tx
Frequency (MHz)	15 500.0		16 350.0
Peak transmit power (W)	2 200.0		500.0
Peak transmit power (dBW)	33.4		27.0
Pulse bandwidth (chirp maximum value is 1 900 MHz) (MHz)			1 600.0
Polarization type	Circular		Linear
Polarization loss (dB)		0.00	
Receiver IF bandwidth (MHz)		15.00	
Receiver noise figure (assumed) (dB)		10.00	
Minimum discernible signal (MDS) (dBm)		−72.00	
Minimum discernible signal (MDS) (dBW)		−102.00	
Minimum signal-to-noise ratio (dB)		13.00	
Calculated receiver noise power/Hz (dBW/Hz)		−194.00	
Calculated receiver noise power (dBW)		−122.24	
Minimum signal-to-noise + interference (dB)		20.24	
Interference threshold value (dBW)		−142.48	
Bandwidth correction factor (OTR) ratio (Ratio)			106.67
Bandwidth correction factor (OTR) (dB)			20.28
Peak antenna gain (dBi)	26	4.00	35.00
Received signal power excluding propagation loss (dBW)	63.42	63.42	45.71
Antenna height (km)	0.02	1.00	8.50
Ground distance − wanted and unwanted systems (km)			41
Ground distance ILS Rx to ILS Tx (km)	25		
Slant range (km)		25.02	41.70
Calculated transmission loss from Recommendation ITU-R P.528-2. Similar to Figs 6a and 6c (dB)		−146	−149
Peak received power including propagation loss (dBW)		−82.08	−103.29
Interference or signal-to-noise ratio (*I*/*N* or *S*/*N*) (dB)		40.2	18.9
Signal-to-interference plus noise *S*/(*I* + *N*) (dB)			21.16

3.4 Assessment of analysis results

The results from the worst-case analysis are summarized in Table 4. The assessment can be made regarding the separation distances that are required to ensure electromagnetic compatibility between the radiolocation system and the ALS system. For cases of far antenna side lobe to far antenna side lobe coupling analysis, no separation distances are required. Normal ALS full transmit power, 2 200 W, and half power of 1 100 W are used in the calculations.

TABLE 4

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	11	20	Less than 1
15	24	31	
20	31	44	
25	41	55	

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. A brief survey found the following RAS system that may use the 15.35-15.4 GHz band. See Table 5 for details.

TABLE 5

Brief RAS survey results for the 15.35 to 15.4 GHz band

Location	Geographic longitude	Geographic latitude	Altitude above sea level (m)	Diameter telescope (m)	Minimum elevation (degrees)	Reference
Effelsberg, Germany	06° 53′ 00″	50° 31′ 32″	369	100	7	1
Medicina, Italy	11° 38′ 49″	44° 31′ 14″	28	32	5	1 and 2
Sardinia, Italy	09° 14′ 40″	39° 29′ 50″	650	64	5	1
Badari, Russia	102° 13′ 16″	51° 45′ 27″	832	32	−5	1
Kalyazin, Russia	37° 54′ 01″	57° 13′ 22″	195	64	0	1
Pushchino, Russia	37° 40′ 00″	54° 49′ 00″	200	22	6	1
Svetloe, Russia	29° 46′ 54″	61° 05′	80	32	−5	1
Zelenchukskaya, Russia	41° 35′ 32″	43° 49′ 53″	1 000	32	−5	1 and 2
Onsala, Sweden	11° 55′ 35″	57° 23′ 45″	10	25	0	1
Cambridge, UK	00° 02′ 20″	52° 09′ 59″	24	13	0	1
National Radio Astronomy Observatory − Green Bank, W VA, United States of America	−79° 50′ 23″	38° 25′ 59″	807	105	0	3
National Radio Astronomy Observatory − VLA, San Agustin, NM, United States of America	−107° 37′ 06″	34° 04′ 44″	2115	27 antennas 25 m (each antenna)	0	3
National Radio Astronomy Observatory − VLBA				25 m (each)	0	3
Pie Town, NM, United States of America	−108° 07′ 09″	34° 18′ 04″	2 371			
Kitt Peak, AZ, United States of America	−111° 36′ 45″	31° 57′ 23″	1 916			
Los Alamos, NM, United States of America	−106° 14′ 44″	35° 46′ 30″	1 967			
Fort Davis, TX, United States of America	−103° 56′ 41″	30° 38′ 06″	1 615			
North Liberty, IA, United States of America	−91° 34′ 27″	41° 46′ 17″	241			
Brewster, WA, United States of America	−119° 41′ 00″	48° 07′ 52″	255			
Owens Valley, CA, United States of America	−118° 16′ 37″	37° 13′ 54″	1 207			
St. Croix, VI, United States of America	−64° 35′ 01″	17° 45′ 24″	16			
Mauna Kea, HI, United States of America	−155° 27′ 20″	19° 48′ 05″	3 725			
Hancock, NH, United States of America	−71° 59′ 12″	42° 56′ 01″	309			

TABLE 5 (*end*)

Location	Geographic longitude	Geographic latitude	Altitude above sea level (m)	Diameter telescope (m)	Minimum elevation (degrees)	Reference
Parkes, Australia	148° 15′ 494″	–33° 00′ 00″	400	64	2	3
MIYUN50, China	116° 58′	40° 33′	No data	50	No data	3
Nobeyama, Japan	138° 28′ 32″	35° 56′ 29″	No data	45	10	4
Kashima, Japan	140° 39′ 58″	35° 57′ 03″	No data	34	No data	4
K-SRBL, Korea	127.37°	36.40°	No data	2	No data	3
KVN-Yonsei, Korea	126° 56′ 35″	37° 33′ 44″	No data	20	No data	3
KVN-Ulsan, Korea	129° 15′ 04″	35° 32′ 33″	No data	20	No data	3
KVN-Tamna, Korea	126° 27′ 43″	33° 17′ 18″	No data	20	No data	3

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/m^2)**	**Spectral power flux-density ($W/(m^2 \cdot Hz)$)**
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 a radio telescope can point to all directions in the sky, i.e. its azimuth can vary between 0º and 360º and its elevation can vary between 0º and 90º;

2 the interference scenario assumes antenna coupling of System-6 main lobe and side lobes to RAS side lobe; systems are lined up in azimuth;

3 the RAS side lobe antenna gain is 0 dBi;

4 main lobe to main lobe antenna coupling is rare;

5 main lobe to main lobe interference duration is brief. Typically the aircraft is moving at speeds of 1 000 km/h (about 278 m/s) or more;

6 System-6 duty cycle is 100%. The maximum expected duty is 20%.

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 for several System-6 beam angles are shown in Table 7. For each analysis scenario, the System-6 antenna beam position is fixed and the separation distance between System-6 and the RAS are incremented, causing changes in the relative geometry and thereby resulting in different interference levels.

TABLE 7

RAS interference analysis results

System-6 beam angle	**0°**	**−5°**	**−10°**	**−15°**	**−20°**	**−25°**	**−30°**	**−35°**	**−40°**	**−45°**
Worst received power (dBW)	−173	−163	−158	−154	−153	−150	−166	−150	−153	−147
Closest separation distance where −202 dBW threshold is exceeded, in km	95	45	32	25	20	20	15	13	12	11
Farthest separation distance to where −202 dBW threshold is exceeded, in km	421	290	90	50	38	28	25	20	20	15
Range extent where −202 dBW threshold is exceeded, in km	326	245	58	25	18	8	10	7	8	4
Duration of interference that exceeds threshold for aircraft speed of 500 km/hr, in seconds	2 347	1 764	418	180	130	58	72	50	58	29
Duration of interference that exceeds threshold for aircraft speed of 900 km/hr, in seconds	1 304	980	232	100	72	32	40	28	32	16

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 thirty 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

The technical characteristics of FSS systems that operate uplinks and downlinks in the 15.4-15.7 GHz band were found in Recommendation ITU-R S.1328-3. Table 8 provides characteristics and includes some added technical assumptions that are required to perform the simulation.

TABLE 8

FSS systems characteristic in the 15.4-15.7 GHz band

Parameters	**Rec. ITU-R S.1328-3 Annex 1 Table 1 non-GSO MSS LEO-E**	**Rec. ITU-R S.1328-3 Annex 1 Table 1 LEO-N feeder link**	**Rec. ITU-R S.1328-3 Annex 6 Table 11 FL MSS**	**Rec. ITU-R S.1328-3 Annex 14 Table 32 non-GSO/FSS N-SAT-HEO1**
1 Orbital parameters				
Shape of orbit	Elliptical	Circular		Elliptical
Height (km)	7 846 × 520	700	1 500	44 641 × 26 932
Inclination angle (degrees)	116.6	82	74	42.5
Coherence (track repeat)	3 h	46 h		23 h 56 min
Number of satellites per plane	5	13	12	1
Number of orbital planes	2	7	4	3-5
Satellite separation within plane (degrees)	72	27.7	30	–
Satellite phasing between planes (degrees)	36	25.7	90	Variable

TABLE 8 (*continued*)

Parameters	Rec. ITU-R S.1328-3 Annex 1 Table 1 non-GSO MSS LEO-E	Rec. ITU-R S.1328-3 Annex 1 Table 1 LEO-N feeder link	Rec. ITU-R S.1328-3 Annex 6 Table 11 FL MSS	Rec. ITU-R S.1328-3 Annex 14 Table 32 non-GSO/FSS N-SAT-HEO1
2 Targeted frequency range and polarization				
Uplink frequency (GHz)	15.45-15.65	19.3-19.6		17.7-18.1
Uplink polarization	–	Circular	LHCP	Circular
Downlink frequency (GHz)	6.875-7.075	15.43-15.63	15.45-15.65	15.43-15.63
Downlink polarization	–	Circular	RHCP	Circular
3 Spectrum required in each direction (MHz)	200	300(1)/200(2)	200	400(1)/200(2)
4 Carrier transmission parameters				
Modulation type	QPSK	TDMA/QPSK		CDM, TDM, CDM/FDM (QPSK)
Number of service link beams	61	–		1
Number of feeder-link segments/polarization	31	1		–
Segment bandwidth (MHz)	12	–		–
Receiver bandwidth (kHz)	3 000/7 000	20 000(1); 20 000(2)	48 000	2 500, 6 000, N/A, N/A
Transmission bandwidth (kHz)	3 000/7 000	20 000(1); 20 000(2)	48 000	15 000, 700, 17 800, 6 000
Overall (C/N_0) per user (dB/Hz) or (C/N) (dB)	–	6.5 dB (E_b/N_0)	46	8, 8 6, 6
Uplink e.i.r.p./carrier (dBW) Maximum Minimum	50	67.2	67 29.6	74.4, 46.9, 74.8, 77.3
Downlink e.i.r.p./carrier (dBW) Maximum Minimum	–	15.8	24.9 –3.8	48.5, 52.2, N/A, N/A
Type of satellite transponder	Transparent	Processing		Transparent
5 Satellite antenna parameters				
Tx maximum gain (dBi)	11	5.2	22	41.9
Rx maximum gain (dBi)	11	5.2	22	44.5
Main lobes	–	–		–
Side lobes (dB)	–16	–		–
Back lobes (dB)	–38	–		–
Steerable antenna or not	No		Yes	Steerable
Receiver noise temperature (K) (assumed)	520			
Antenna pattern for analysis (assumed)	Rec. ITU-R S.672-4 −20 dB side lobe			

TABLE 8 (*end*)

6 **Earth station antenna parameters**				
Peak Tx gain (dBi)	55.3	48.4	49	62.4
Peak Rx gain (dBi)	48.2	48.4	49	60.5
Radiation pattern	–	Rec. ITU-R S.465-5	Rec. ITU-R S.465-5 (assumed)	Rec. ITU-R S.580-6
Antenna noise temperature from Rec. ITU-R SF.1006 (1993) (K) (assumed)		300		
Minimum operating elevation angle (degrees)	5	10		70
Steerable antenna				
7 **Number of earth stations and distribution**	20-40	Up to several dozens	6 or more	Up to 100
8 **Earth station switching strategy**	Highest and 2^{nd} highest elevation angle	Maximum duration of communication session	Minimum elevation angle	Minimum operating elevation angle

ARC: automatic range compensation.

LHCP: left-hand circular polarization.

RHCP: right-hand circular polarization.

(1) Uplink.

(2) Downlink.

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:

$$N = -144 \text{ dBW} + 10 \times \log(B_{IF}) + 10 \times \log\left(1 + \frac{T_e}{T_o}\right) \tag{5}$$

where:

B_{IF}: receiver IF bandwidth (MHz)

T_e: receiver noise temperature (K)

T_o: 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:

$$I = P_{Tx} + G_{Tx} + G_{Rx} - L_{Trans} - FDR \tag{6}$$

where:

- I : interference, peak power of the radar pulses at the receiver (dBW)
- P_{Tx} : peak power of the interfering system (dBW)
- G_{Tx} : antenna gain of the interfering transmitter in the direction of the victim receiver (dBi)
- G_{Rx} : antenna gain of the victim receiver in the direction of the interfering transmitter (dBi)
- L_{Trans} : transmission loss between transmitting and receiving antennas (dB) using free space loss or Recommendation ITU-R P.528-2 depending on the analysis type. Free space loss = 20 log(F) + 20 log(R) + 32.44
- F : frequency (MHz)
- R : separation distance (km)
- FDR_{IF} : frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB).

FDR_{IF} 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, 4, and 5. 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 and Fig. 5 shows the static scenario where main beam antenna coupling occurs between the earth stations and System-6.

FIGURE 3

Scenario configuration for LEO-E elliptical orbit

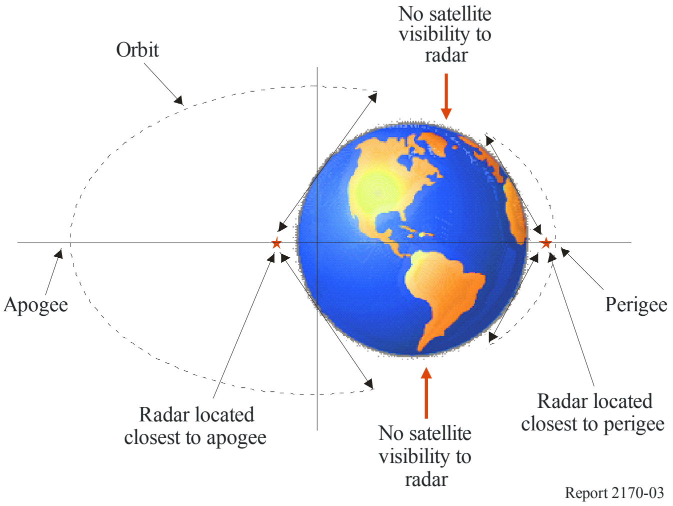


FIGURE 4

Scenario for satellites

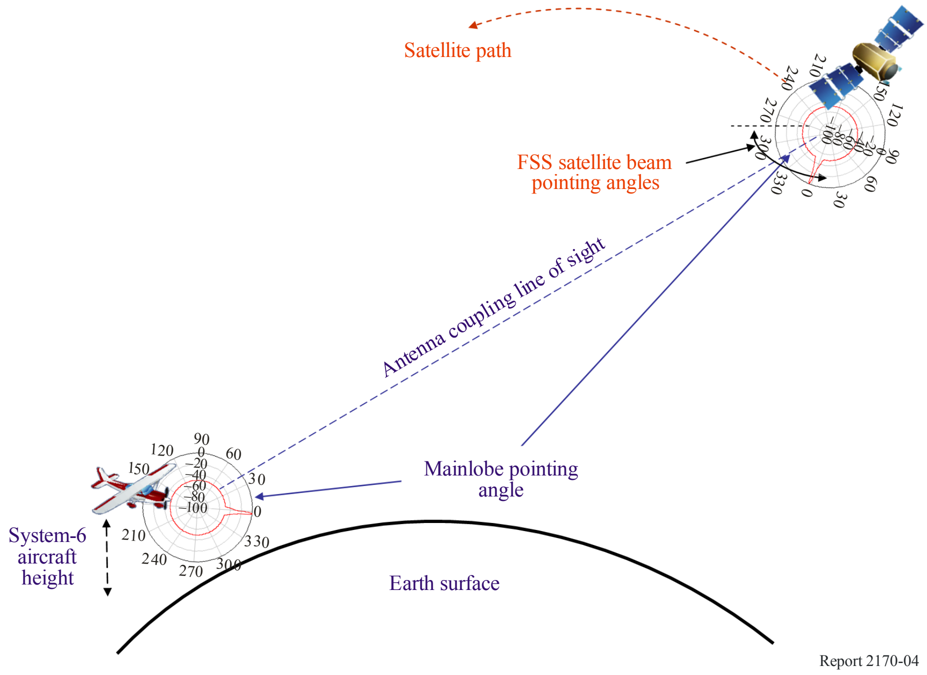
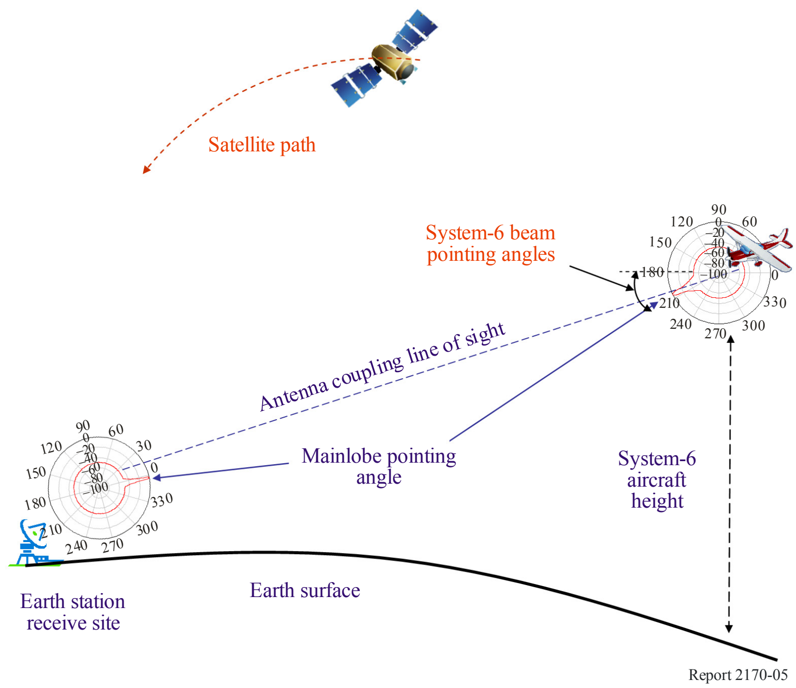


FIGURE 5

Scenario for earth stations



The analysis assumptions are:

1 Worst-case orbits for interference are used. Orbits are positioned such that they will always pass overhead of the interferer. In reality, due to System-6 aircraft motion, and the fact that the satellite inclination will be such that the satellite will drift relative to the Earth's rotation, main beam antenna coupling between the System-6 radar and the satellite is very infrequent.

2 Signal attenuation due to terrain is not considered, resulting in a worst-case scenario with regards to interference levels.

3 Polarization mismatch loss between circular and linear antenna polarizations is 3.0 dB.

4 Propagation loss is calculated using Recommendations ITU-R P.452-13 and ITU-R P.525-2, as recommended by Recommendation ITU-R SF.1006.

5 The satellite antenna points downward towards Earth.

6 Recommendation ITU-R M.1851 is used for a System-6 radar antenna pattern.

7 Recommendations ITU-R S.465-5 and ITU-R S.580-6 are used for the FSS earth station antenna pattern.

8 Recommendation ITU-R S.672-4 with a –20 dB side lobe is used for the FSS satellite antenna pattern.

9 The System-6 operational height range is 5 000 to 10 000 m. The operational height used in this analysis is 8 500 m.

10 The FSS earth station height is 20 m above sea level.

11 The FSS protection criterion is taken from Recommendation ITU-R S.1432-1. It stipulates a long-term protection criterion *I*/*N* of 6% for other systems having a co-primary status.

12 Recommendation ITU-R SF.1006 is used to obtain the earth stations short- and long-term protection criteria.

For the elliptical orbit, the radar closest to the apogee side (satellite height at 7 846 km) is where the interference into the satellite may be important. It is not expected that the perigee side (satellite height at 520 km) for this specific orbit would be used to secure the customer data and therefore interference may not be significant.

5.5 Compatibility analysis scenarios

The analysis was performed using a software tool. Two types of analysis are conducted, one for assessing interference into the satellite receiver and the other to assess interference into the earth station. The analysis types for each case are summarized in Table 9.

TABLE 9

Analysis types

Reference	**Rec. ITU-R S.1328-3 Annex 1 Table 1 non-GSO MSS LEO-E elliptical orbit**	**Rec. ITU-R S.1328-3 Annex 1 Table 1 LEO-N feeder link**	**Rec. ITU-R S.1328-3 Annex 6 Table 11 FL MSS**	**Rec. ITU-R S.1328-3 Annex 14 Table 32 non-GSO/FSS N-SAT-HEO1**
Analysis type	Radar interference into satellite	Radar interference into earth station		

5.5.1 Software simulation parameters

Dynamic simulations were performed using a software analysis tool to determine statistics of the interference levels from a System-6 radar into an FSS system operating in the same band. The analysis scenarios for determining the potential interference from System-6 into the satellite receiver and the earth station receiver are shown in Figs 6 and 7. Figure 6 shows the satellite path over a defined analysis cube.

The analysis cube, which has a width of 1 000 km, a length of 1 000 km and a height of 10 km, is an assumed volume of space where systems characteristics vary randomly over a specified range of values inside that volume. It is defined for two cases. The first case is where the interference is from System-6 into the satellite receiver. In this case the analysis cube is centred on a point on the ground and System-6 is allowed to be located within a portion of that volume. System-6 height varies randomly between a minimum height of 5 km and a maximum height of 10 km. Also other characteristics vary randomly as shown in Fig. 7 and Table 10. In the second simulation case, System-6 interference is into the earth stations, where the cube is centred on each earth station.

The random variable ranges of the parameters simulated in the software as shown in Table 10.

FIGURE 6

Satellite path over analysis cube

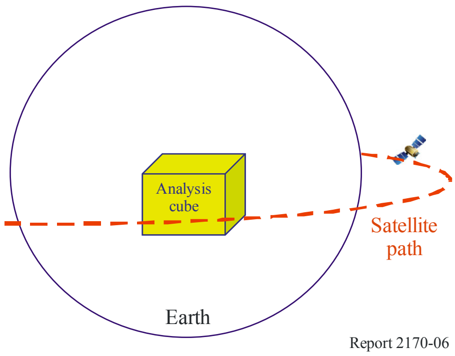


FIGURE 7

Variable parameters in the analysis cube

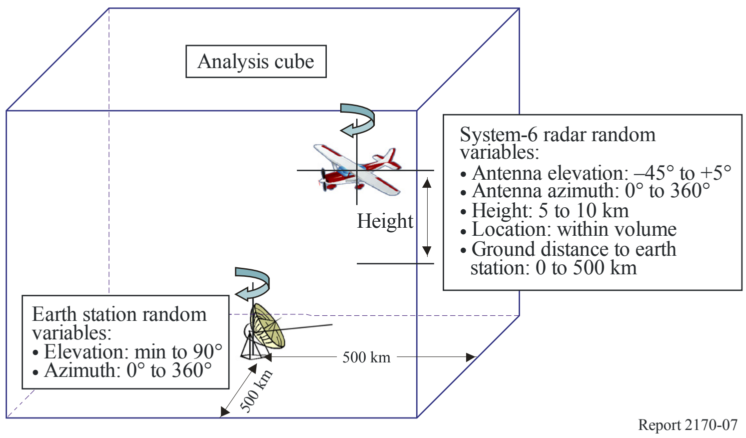


Table 10 shows the range of values simulated.

TABLE 10

Simulation analysis random values range

Parameter	Minimum value	Maximum value	Notes
Simulation			
Terrain data			Terrain data is not used
Number of samples			The number of samples for each analysis is approximately 2.3 million samples at a delta time of 5 ms
System-6 parameters			
Distance to interference	Centre of analysis cube	Radius is 500 km	Range is less than radar horizon distance
Antenna height above terrain (km)	5	10	Typical operational height is 8.5 km
Antenna elevation angle (Degrees)	–45	+5	Normal SAR operation is between −20 to –45°
Antenna azimuth angle (Degrees)	0	360	
Antenna pattern			Rec. ITU-R M.1851 with cosine cubed pattern
Centre frequency (GHz)	16.2	16.5	This allows for co-frequency and adjacent frequency analysis. It should note that minimum centre frequency (16.2 GHz) minus 1/2 the chirp (800 MHz) equals 15.4 GHz, which is the low end of frequency of interest
Pulse LFM chirp (MHz)	1 600	1 600	
Polarization mismatch (dB)	–3.0	–3.0	Typical value used in many ITU Recommendations
Non-GSO MSS LEO-E elliptical orbits			
Distance to interferer (km)			Determined by the elliptical path geometry
Antenna (degrees)			Points towards System-6 when in sight
Orbit			Fixed around the equator
Antenna pattern			Assumed Rec. ITU-R S.672-4 with a near-in-side-lobe level in dB relative to the peak gain of −20 dB
Analysis path			Minimum two complete paths
Earth station parameters			
Antenna elevation angle (degrees)	10 10 70	90 90 90	For LEO-N For FL-MSS For N-SAT-HEO1
Antenna azimuth angle (degrees)	0	360	
Antenna height (m)	20	20	Nominal value for antenna height is 20 m
Antenna patterns			Rec. ITU-R S.465-5 for LEO-N Rec. ITU-R S.465-5 for FL-MSS (assumed) Rec. ITU-R S.580-6 for N-SAT-HEO1
Analysis volume			A 500 km radius in a cube volume centred on the earth station. The analysis volume is 10 million km^3

5.6 Interference criteria

The interference protection criteria for the FSS satellite and earth station are defined below.

5.6.1 Interference criteria for satellite station

The interference protection criteria for the satellite is obtained using Fig. 1 of Recommendation ITU-R S.1432-1 – Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz. Interference allowance, in terms of percentage of system noise power, can be converted into corresponding values of *I*/*N* ratios. For the satellite receiver case, a 6.0% increase in the receiver noise, due to interference from other systems having a co-primary status; like, potentially, System-6 in this case, yields *I*/*N* of –12.2 dB for 100% of the time of any month. Therefore, the interference protection value of –12.2 dB is used to assess the interference.

5.6.2 Interference criteria for earth station

To develop short-term and long-term interference criteria for the earth stations, the method in Recommendation ITU-R SF.1006 described by equations (3) and (4) in Annex 1 is used for this analysis. Using the receiver noise temperature of 300°K, a reference bandwidth as shown in Table 10, a fade margin of 2 dB, a link noise contribution N_L of 1 dB and a ratio of incremental thermal noise power to interference power of 0 dB, in the reference bandwidth, and with a value of n_2 equal to 1 corresponding to a single entry of interference, the short-term interference criteria is derived. Using equation (3) of Recommendation ITU-R SF.1006, the long-term interference is also derived. Table 11 shows the calculated values for short- and long-term interference.

TABLE 11

Values of parameters from Table 1 of Annex 1 of Recommendation ITU-R SF.1006 for the 15-40 GHz band

Selected values from Recommendation ITU-R SF.1006 (Table 1)	Units	Value
Frequency range	(GHz)	15-40
Service of interfering system		Fixed
Wanted system	Service	Fixed-satellite
	Station type	Earth station
	Modulation	Digital
p_1, percentages of the time during which the interference from all sources may exceed the permissible level; p_1 represents long-term ($p_1 \geq 1\%$)	(%)	20
p_2, percentages of the time during which the interference from all sources may exceed the permissible level; p_2 short-term conditions ($p_2 \leq 1\%$)	(%)	0.003
n_2, effective number of expected non-simultaneous equal-level and equal-percentage-of-time, interference contributions, associated with p_2	number	2
B reference bandwidth	(Hz)	10^6
J, ratio of the permissible long-term (20% of the time) interfering power from any one interfering source to the thermal noise power in the receiving system	(dB)	−7
W a thermal noise equivalence factor for interfering emissions in the reference bandwidth. It is positive when the interfering noise would cause more degradation than thermal noise	(dB)	0
T_r, noise temperature of receiving system (for earth stations under clear-sky conditions)	(K)	300
M_s fade margin of link	(dB)	6
N_L link noise contribution	(dB)	1

The interference criteria calculation results for the earth stations are in Table 12.

TABLE 12

Interference criteria used for earth stations in the analysis

Earth station	Unwanted interference power into earth station receiver Pr(p) in reference bandwidth (dBW)		
	LEO-N earth station	**FL MSS earth station**	**N-SAT HEO1 earth station**
Reference earth station IF bandwidth (MHz)	20	48	6
Long-term interference criteria (Rec. ITU-R SF.1006) percentage of time *p* for which *Pr*(*p*) may be exceeded = 20.0%	−137.8	−134.0	−143.0
Short term interference criteria (Rec. ITU-R SF.1006) percentage of time *p* for which *Pr*(*p*) may be exceeded = 0.003%	−125.1	−121.3	−130.3

5.7 Results

The following sections contain the resulting cumulative distribution function (CDF) plots of the analysis. The FSS interference threshold line at −12.2 dB is drawn for reference.

5.7.1 Elliptical orbit results

Referencing Figs 3 and 5, the two cases studied for the elliptical orbit are one where System-6 is positioned closest to the satellite perigee in the first case and closest to the apogee in the second case. The *I*/*N* ratio versus the percentage time that *I*/*N* value is exceeded is shown in Fig. 8 for the perigee case and Fig. 9 for the apogee case.

FIGURE 8

System-6 and elliptical orbit near perigee

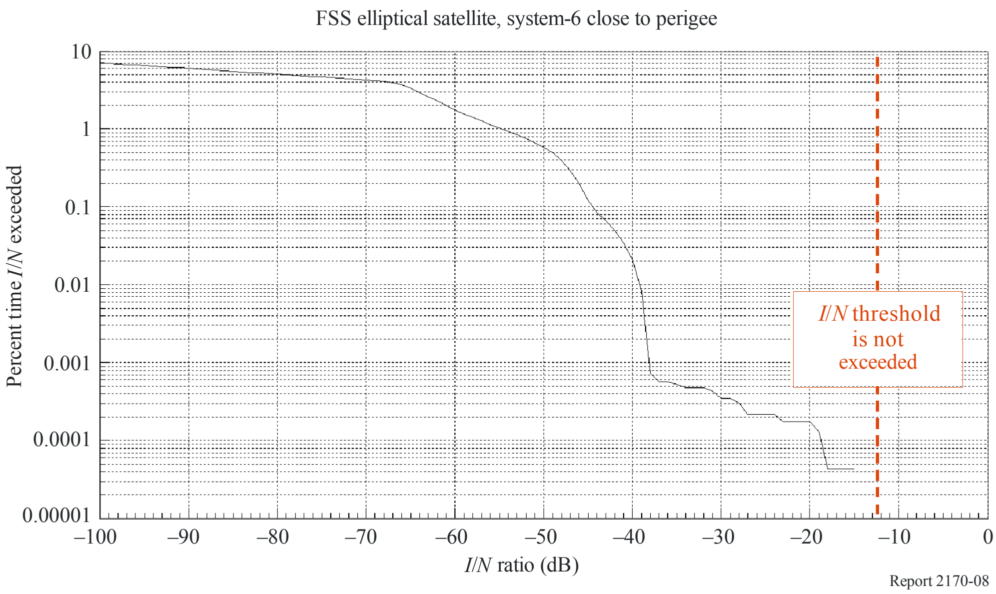
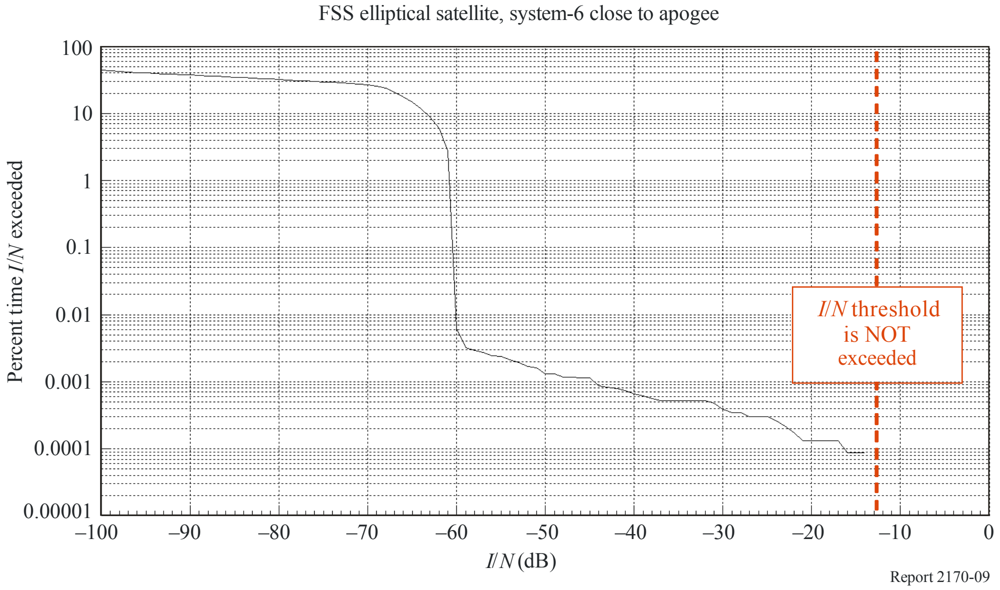


FIGURE 9

System-6 and elliptical orbit near apogee



5.7.2 Earth station results

Three cases of earth stations are studied. The three cases are for LEO-N, FL-MSS, and for N-SAT-HEO1 as described in Table 9 and Figs 5 and 7. The results of interference versus the percentage time that value is exceeded are shown in Figs 10, 11 and 12 with the reference threshold for each case.

FIGURE 10

System-6 and LEO-N earth station

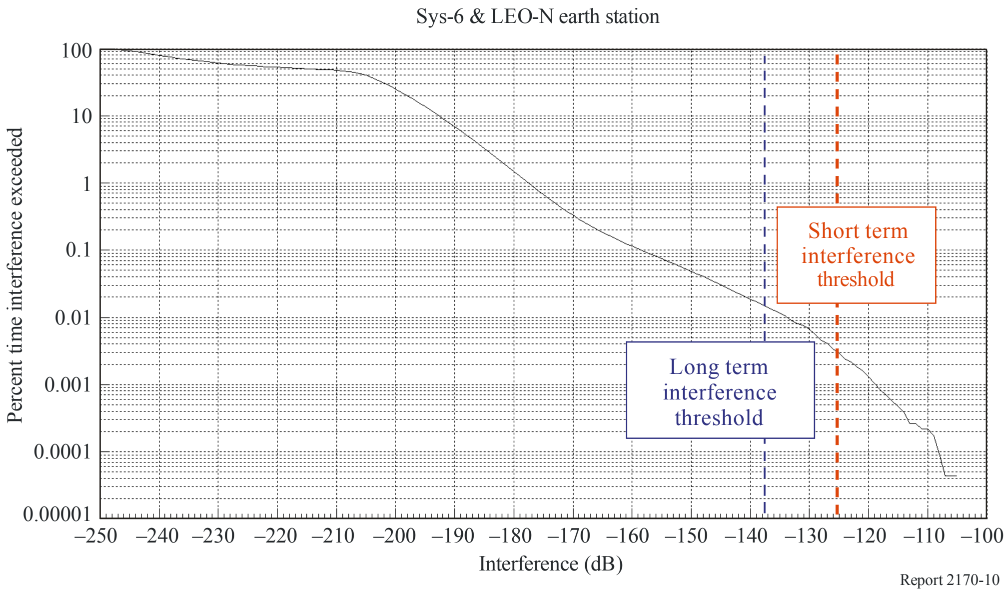


FIGURE 11

System-6 and FL-MSS earth station

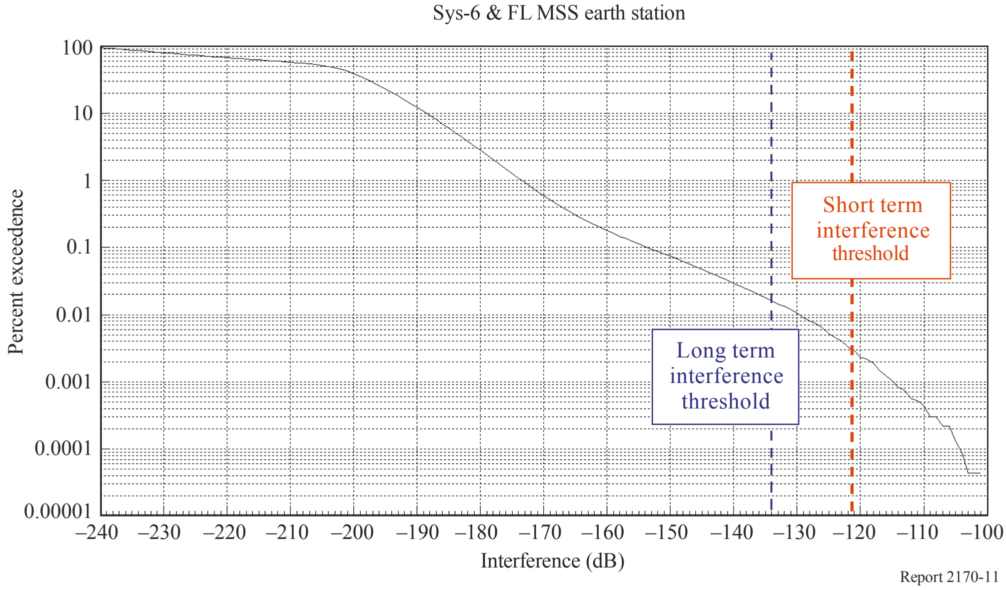


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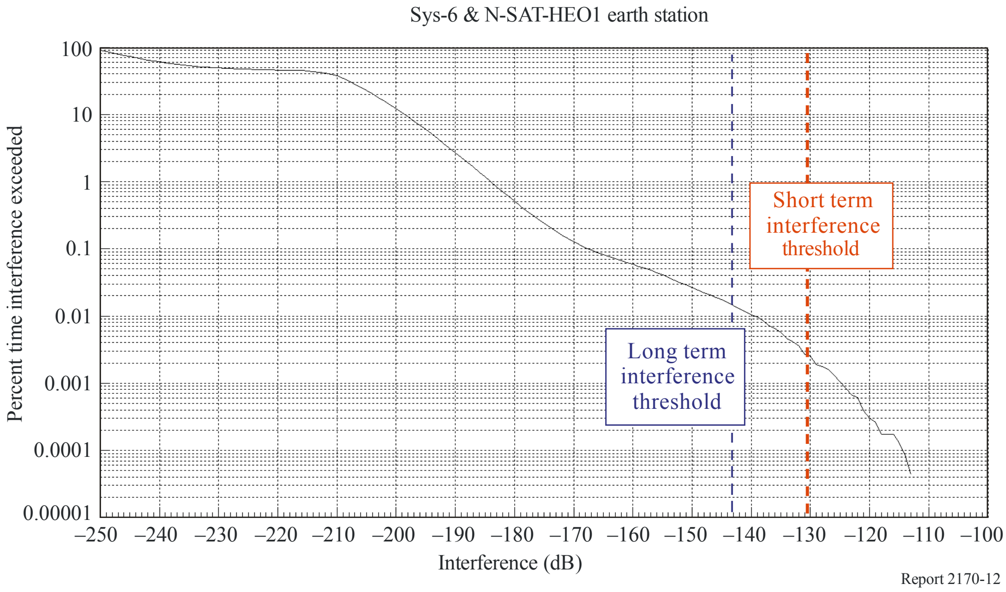
FIGURE 12

System-6 and N-SAT-HEO1 earth station



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5.8 Summary of FSS compatibility results

The results from the compatibility analysis are summarized in Tables 13 and 14. In all cases the interference from System-6 is below the FSS interference criteria.

TABLE 13

Simulation results summary for the satellite cases

Analysis case	Required *I*/*N* interference criteria (dB)	Required percentage of time threshold not exceeded	Comments
Non-GSO MSS LEO-E elliptical orbit for two cases with first case of System-6 close to perigee and second case of System-6 close to apogee, as shown in Figs 3 and 4 and Table 10	–12.2	100%	System-6 meets the *I*/*N* protection criteria in both the apogee and perigee simulation cases

TABLE 14

Simulation results summary for the earth station cases

Analysis case	Short-term interference criteria percentage of time associated with short-term interference is 0.003%	Short-term interference results	Long-term interference criteria percentage of time associated with short-term interference is 20.0%	Long-term interference results
LEO-N feeder link as shown in Figs. 5 and 7 and Table 10	–125.1	–125.2 dB System-6 meets interference protection criteria	–137.8	–198.3 dB System-6 meets interference protection criteria
FL MSS as shown in Figs. 5 and 7 and Table 10	–121.3	–121.4 dB System-6 meets interference protection criteria	–134.0	–194 dB System-6 meets interference protection criteria
N-SAT-HEO1 as shown in Figs 5 and 7 and Table 10	–130.3	–131.4 dB System-6 meets interference protection criteria	–143.0	–204.0 dB System-6 meets interference protection criteria

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

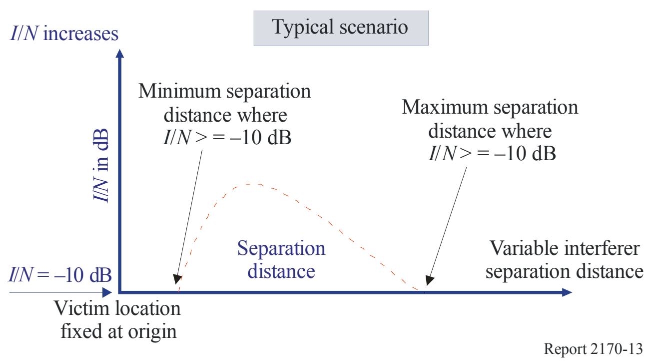
6.2 Analysis assumptions and results for SBR, MPR and RSMS

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

<table>
<tr><th>System-6 beam angle relative to horizontal (degrees)</th><th>Minimum separation distance (km) where I/N > = –10 dB[(1)]</th><th>Maximum separation distance (km) where I/N > = –10 dB[(1)]</th></tr>
<tr><td>5</td><td rowspan="11">Same as maximum separation</td><td rowspan="2">Radio horizon</td></tr>
<tr><td>0</td></tr>
<tr><td>–5</td><td>179</td></tr>
<tr><td>–10</td><td>17</td></tr>
<tr><td>–15</td><td rowspan="7">10</td></tr>
<tr><td>–20</td></tr>
<tr><td>–25</td></tr>
<tr><td>–30</td></tr>
<tr><td>–35</td></tr>
<tr><td>–40</td></tr>
<tr><td>–45</td></tr>
</table>

(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.