



Report ITU-R M.2170
(12/2009)

**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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***Note:** This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2010

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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 1 st side-lobe level	3.5 dBi at 5.2°
Antenna height	Aircraft altitude
1 st /2 nd 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	1 850
-20 dB	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 31° – Elevation 26°	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	
	Transmitter	Receiver
Antenna 1 st 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)
1 st /2 nd 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:

- there is no known ITU protection criteria for this type of ALS receiver;
- 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:

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

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:

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

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:

$$OTR = 10 \log (Rx_BW/Tx_BW) \quad \text{for } Rx_BW \leq Tx_BW \quad (3)$$

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:

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

where:

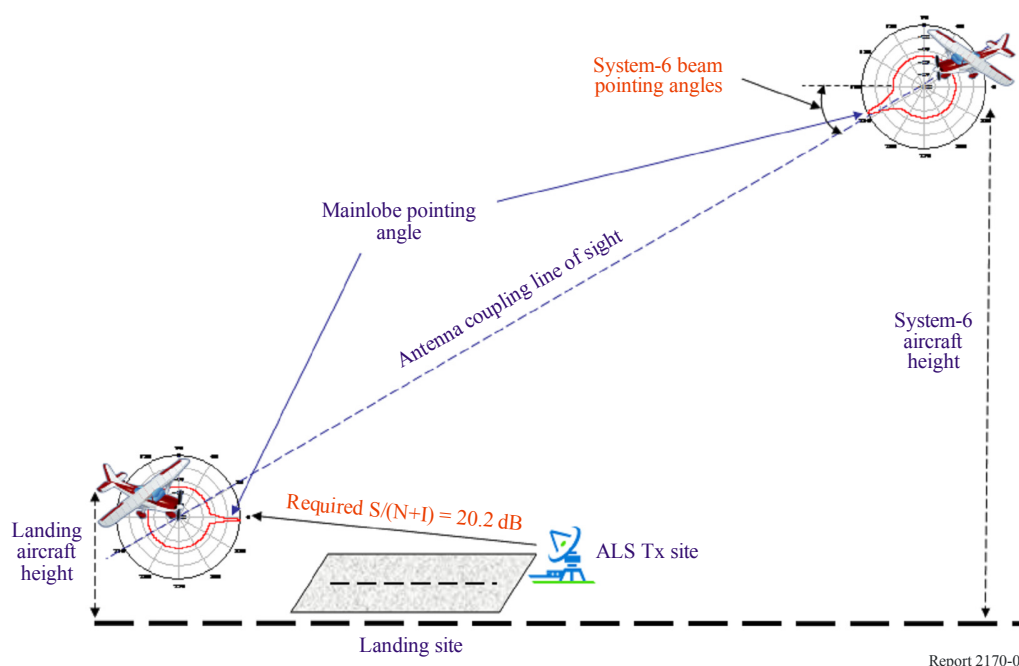
- $(S/(N + I))_{min}$: minimum input signal-to-noise plus interference power ratio needed to process a signal at the required level of performance (dB)
- k : Boltzmann's constant, 1.38×10^{-23} (J/K)
- T_o : absolute temperature of the receiver input (Kelvin = 290°)
- B : receiver 3 dB IF bandwidth (Hz), 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.

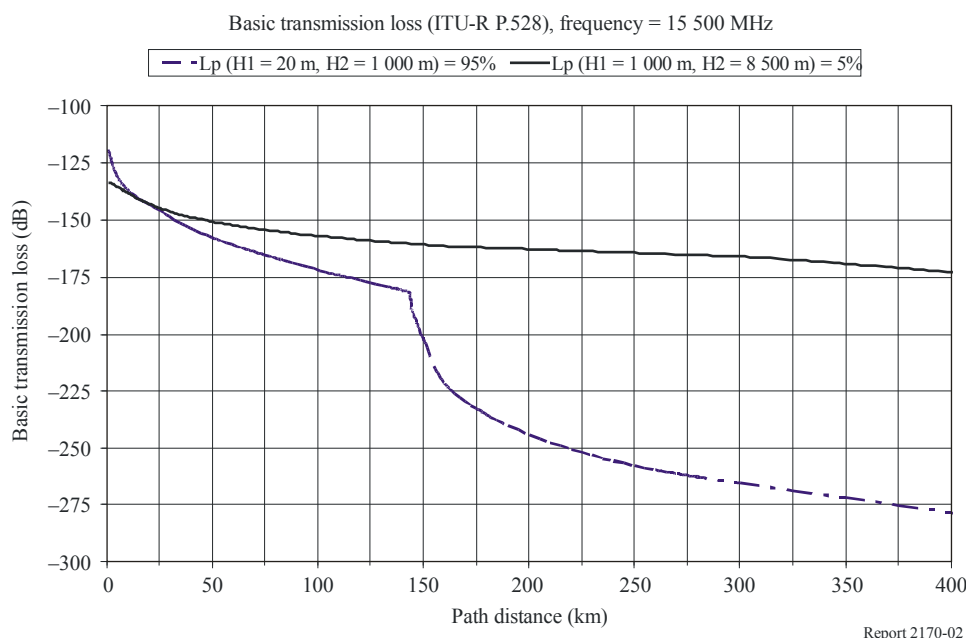
3.3 Compatibility analysis

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.