CEPT ECC
Electronic Communications Committee

ECC Report 222

The impact of Surveillance Radar equipment operating in the 76 to 79 GHz range for helicopter application on radio systems

Approved September 2014

0 EXECUTIVE SUMMARY

This report presents the results of the compatibility studies performed on the impact of airborne surveillance radar in the 76 to 79 GHz frequency range on radio systems and services.

The airborne surveillance application is described in more detail in the ETSI report ETSI TR 103 137 V1.1.1 (2014-01) ”Surveillance Radar equipment for helicopter application operating in the 76 GHz to 79 GHz frequency range” [1]. In the ETSI Report two different radar modes are presented; a short range mode operating in the 76 to 77 GHz band and a long range mode operating in the 76 to 79 GHz band. These modes use different radar characteristics and are treated separately in this report.

This report only considers the effect of the airborne use of the proposed technology on the following services:

- Radio Astronomy Service (RAS);
- Radio Amateur and Amateur Satellite Services (AS);
- Automotive radar application;
- Fixed transport infrastructure radar.

The impact of this airborne use on systems in the Fixed Service operating in the adjacent band 71-76 GHz has not been studied in this Report. Neither the effect of the aforementioned services on the airborne application is considered as the latter is expected to operate on a non-interference non-protected basis.

Radioastronomy (co-channel)

Separation distances between 47 km and 98 km are required under worst case assumptions (see section 4.2.2) to protect the RAS stations in Europe (see ANNEX 2:). The difference between the near field and medium range obstacle detection system is small (near field system 47-98 km, medium range system 57-98 km). The altitude of the helicopter has an essential impact on the separation distance (altitude 300m: separation distance 98 km, altitude 0 m: separation distance 29 km. The above mentioned distances are derived for an effective antenna height on the radio astronomy site of 50 m. The effect of the terrain can increase the size of the separation distances (e.g. 98 km could increase to 115 km) in case of RAS located in elevated positions (or when the helicopter would fly at greater altitudes) or reduce it when the terrain offer shielding to the radio astronomy site. As an example the impact of the terrain at the RAS station Plateau du Bure is shown in ANNEX 6:. It will be left to Administrations to identify, where necessary, the size and shape of the exclusion zone to protect radio astronomy sites, by using appropriate digital terrain models.

The occurrence probability has also been analysed in this report. As a limit the data loss value of 2% from [4] maybe applicable as the percentage of lost observation packets each 2000 s period over one day.

The simplest interpretation would to restrict the helicopter radar activity around the RAS station to fulfil the 2 % per day. This would mean a maximum on-time of 28.8 minutes a day, or about six Take-Offs and Landings per day (assuming 5 minutes transmitter on-time each landing and take-off).

More detailed occurrence probability calculations are provided in addition considering assumptions on helicopter deployment. As a result the occurrence probability shows a huge variance. The following Table summarises the situation.

Table 1: summary of results

	Scenario A	Scenario B
Description	Used for 25% of missions and only for take-off and landing (10% of flight hours)	Used for 100% of missions and for 50% of flight hours
Example 1: 98 km separation distance with 300 m altitude, atmospheric loss 0.15 dB/km, 650 MHz RAS bandwidth	Occurrence probability 2.7% Radius of exclusion zone 48.9 km	Occurrence probability 53.2% Radius of exclusion zone 96.1 km
Example 2: 47 km separation distance with 300 m altitude, atmospheric loss 0.35 dB/km, 8 GHz RAS bandwidth, near field obstacle detection system	Occurrence probability 0.6% Radius of exclusion zone 0 km	Occurrence probability 12.2% Radius of exclusion zone 43 km

It was not possible in this report to determine a representative result for the occurrence probability and exclusion zone.

Therefore, administrations should decide on a national level on the need for and the size of an exclusion zone.

The procedure in Annex 10 is one example of an assessment method that might be used on a national level.

No differentiation has been made between rescue (which is only a fraction of all operations, see chapter 2.4) and non-rescue helicopter missions in the above calculations, because this is seen as outside the scope of this report.

This report does not consider military helicopters because the information about military use was not available. It is expected that military helicopters equipped with the radar systems will increase the interference probability. Administrations are urged to consider the actual deployment of military helicopters when establishing coordination zones.

Radiostronomy (unwanted emission 89 GHz)

An adjacent band compatibility study is provided for 89 GHz as this is a passive band[1]. One may expect similar results for all RAS bands adjacent to the helicopter radar band (e.g. 79-86 GHz, 92-94 GHz and 94.1-116 GHz).

The equivalent maximum unwanted emission e.i.r.p are dependent on the assumed separation distance. The calculated unwanted emissions limits under the assumption of a uniform flat distribution of the spurious limit over 6 GHz bandwidth are:

- with 200m assumed separation distance about -70 dBm/MHz;
- with 1 km assumed separation distance -57 dBm/MHz;
- with 10-25km assumed separation distance -30 dBm/MHz.

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[1] ITU Radio regulations Footnote 5.340

Amateur Service

MCL calculations in this report concluded that the only critical scenario would be a helicopter transmitting into the mainbeam of an amateur station. The likelihood of that situation is estimated to be well below 0.1%. Good compatibility is therefore likely for both helicopter and portable/directional terrestrial amateur stations, even allowing for uncertainty/growth in both uses over the coming years.

Radio Location

Information from NATO are mentioned in ECC Report 056 [10] and ECC/DEC/(04)03 [12] that there are currently no radiolocation systems operational in the band and there are no plans to introduce such systems. No studies were conduct since no other information was received.

Vehicular radars

The only critical situation is when the helicopter is coming to the mainbeam of the vehicular radar. However, this situation is not expected to cause a problem because

- This happens only when the helicopter is flying at very low altitudes below 30m close to a highway and when the helicopter is landing on a highway;
- For a helicopter assisting in a road accident the traffic is considered to be stopped, rerouted or be moving slowly. Traffic will be kept at a safe distance from the landing helicopter. The helicopter is also not necessarily landing on the road;
- Because of the relatively low number of helicopter and because only a small percentage of helicopter operations is performed close to road traffic (only emergency missions) the probability of interference is considered to be low;
- Both radar types (vehicular and helicopter radar) are likely to use FMCW modulation that mitigates the mutual interference. Here it should be considered that the distance between interferer and victim is assumed to be much larger than in the inter-vehicle situation;
- The beam and frequency scanning capabilities of both radar types can reduce the intercept probability even further.

Fixed radars

In similar manner to the discussion regarding vehicle radars, a helicopter borne radar would only be expected to cause a problem to a fixed radar if the helicopter was landing in the field of observation of the fixed radar, and then only in that particular direction. A fixed infrastructure radar is expected to operate in the presence of other radars, including vehicle radars.

One of the main applications of fixed radars is for traffic management and automated incident detection. If a helicopter were attending a traffic incident, then a temporary interruption to automated incident detection surveillance would be acceptable.

Limitation of helicopter radars

The following table provides the limits used in the studies in this report. They were derived from the technology specific limits from the ETSI SRdoc [1].

Table 2: possible limitation

	Low power system	Medium power system
Frequency band	76 to 79 GHz	76 to 79 GHz
Peak power e.i.r.p. Note 2	26 dBm	33 dBm
Mean average power density e.i.r.p. Note1, Note 2	0 dBm/MHz	10 dBm/MHz
Mitigations	DC 20%/s (7 dB)	DC 40%/s (4dB) 25% (6 dB) mainbeam occurrence probability each 10°

1. This is the mean power during RF transmitter ON- time and measured with 1 ms dwell time per 1 MHz.
2 These are typical values at standard ambient conditions

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
AMSL	Above Mean Sea Level
AS	Radio Amateur and amateur satellite Services
BW	Bandwidth
CEPT	European Conference of Postal and Telecommunications Administrations
CW	Continuous Wave
DC	Duty Cycle
EASA	European Aviation Safety Agency
ECC	Electronic Communications Committee
EHEST	European Helicopter Safety Team
e.i.r.p.	equivalent isotropically radiated power
EME	Earth-Moon-Earth
ETSI ERM	European Telecommunications Standards Institute - Electromagnetic compatibility and Radio spectrum Matters
FMCW	Frequency Modulated Continuous Wave
FPGA	Field Programmable Gate Array
Grx	Receive antenna gain
Gtx	Transmit antenna gain
HC	Helicopter
HEMS	Helicopter Emergency Medical Service
IF	Intermediate Frequency
ITU	International Telecommunication Union
ITU-R	Radiocommunication Sector of ITU
LEO	Low Earth Orbit
LPR	Industrial Level Probing Radar
MCL	Minimum Coupling Loss
RAS	Radio Astronomy Service
RCS	Radar Cross Section
RF	Radio Frequency
RTTT	Road Transport and Traffic Telematics
SN	Signal/Noise
SRD	Short Range Device
SRR	Short Range Radar
TLPR	Tank Level Probing Radar
TL	Transmission Loss
TR	Technical Report
VIP	Very Important Person
VHF	Very High Frequency
VLBI	Very Long Baseline Interferometer
WRC	World Radiocommunication Conference

1 INTRODUCTION

This report presents the results of the compatibility studies performed on the impact of airborne surveillance radar in the 76 to 79 GHz frequency range on radio systems and services.

The application of mm-wave radar technology for the airborne application is described in more detail in the ETSI report ETSI TR 103 137 V1.1.1 (2014-01) ”Surveillance Radar equipment for helicopter application operating in the 76 GHz to 79 GHz frequency range”[1].

In the ETSI Report two different radar modes are presented; a short range mode operating in the 76 to 77 GHz band and a long range mode operating in the 76 to 79 GHz band. These modes use different radar characteristics and are treated separately in this report.

This study only considers the effect of the airborne use of the proposed technology on the following services:

- Radio Astronomy Service (RAS);
- Radio Amateur and Amateur Satellite Services (AS);
- Automotive radar application;
- Fixed transport infrastructure radar.

The effect of the aforementioned services on the airborne application is not considered as the latter is expected to operate on a non-interference non-protected basis.

2 HELIBORNE SURVEILLANCE RADARS

The proposed system concept consists of possibly multiple radar sensors distributed around the helicopter fuselage to detect obstacles entering a certain protective volume around the helicopter. This heliborne obstacle warning system will aid the crew in the obstacle detection task while manoeuvring at low airspeeds typically close to the ground. The system reduces the risk of collision with objects by an early detection of obstacles and will therefore improve safety for aircrew, passengers and persons on the ground.

The mature and readily available radar technology in the band 76 GHz to 79 GHz provides appropriate sensor performance combined with values of low sensor size, weight, power consumption and cost that make it ideally suited for this airborne application.

Radar characteristics are derived from the required detection capability to also detect those obstacles that are most difficult to be visually identified by the flight crew (e.g. power lines, poles, masts etc.).The effective detection range of the sensors is prescribed by the velocity at which the helicopter approaches the environment as well as the minimum warning time needed for the pilot to assess the situation and initiate evasive manoeuvres.

Note: The term ‘altitude’ in regard to helicopters refers to the height of the helicopter above the local ground level

2.1 SYSTEM IMPLEMENTATION ON HELICOPTER

The intended function of the Obstacle Detection System is to detect and inform the flight crew of obstacles in a protective volume around the helicopter. The operational benefit of this system is in the initial or final phases of flight, as well as during hovering phases, in which the helicopter manoeuvers in ground vicinity at low airspeeds. It is in those flight phases in which there is an increased risk of collision with all kinds of obstacles. To cover all degrees of freedom of the helicopter in approach, landing, hovering and take-off, the envelope to be covered is ideally the lower hemisphere around the helicopter (Figure 1).

The coverage in an actual realization of the system is a trade-off between required functionality, integration complexity and affordability. In an example implementation the sensors are integrated below the main rotor head in a distributed manner such as to cover a protective volume around the main and tail rotor area (Figure 2). In this realization the obstacle detection system provides a main and tail rotor strike alerting functionality. Typical use cases therefore involve hovering flight as well as manoeuvring at low airspeeds. For a small helicopter type as depicted in Figure 2, typically 4 sensors need to be integrated to cover the full 360° horizontal field-of-view. For various use cases, the number of sensors can be increased to extend coverage in the lower hemisphere of the helicopter (Figure 1).

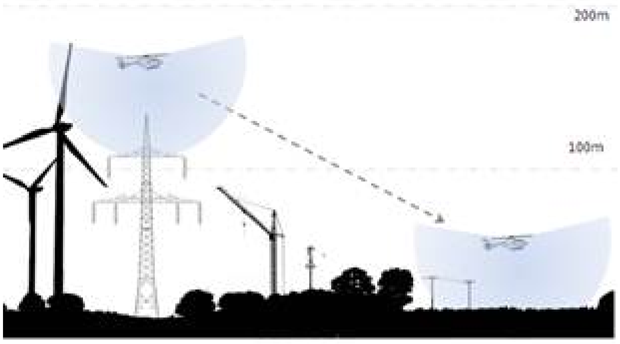

Figure 1: Coverage lower hemisphere, landing in confined area (e.g. System 2 in section 2.5.2)

Figure 2: Example of 360° coverage using 4 sensors (e.g. System 1 in section 2.5.1)

The system will be used in an environment with obstacles in the vicinity of the helicopter, only. It will be switched off if the helicopter leaves this environment. This will be defined in the flight manual. The system will therefore typically be used at low altitudes (typically between 0 and 300m height above ground level) but shall not be limited to that. In all cases, helicopter operators have to follow the minimum safe altitude regulation provided by the national aviation authority (see section 2.3).

The effective detection range of the sensor system is prescribed by the velocity at which the helicopter approaches the environment as well as the minimum warning time needed for the pilot to assess the situation and initiate evasive manoeuvres. When considering only hovering and low-airspeed manoeuvring phases of flight (e.g. landing, hoisting operations, taxiing), the required detection range is limited to 40 m for the Near Field Obstacle Detection system or 250 m for the Medium Field Obstacle Detection System.

2.2 OPERATIONAL PROFILE EXAMPLE

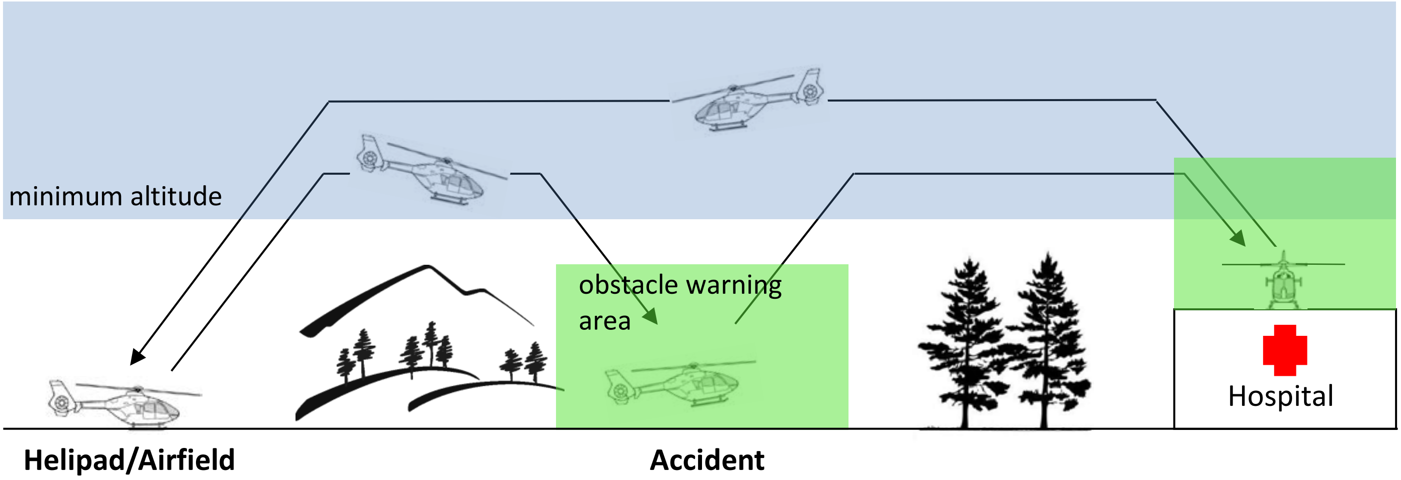

Figure 3: Typical operational profile for helicopter emergency medical service for primary rescue mission

Figure 3 shows a typical HEMS (helicopter emergency medical service) mission. The helicopter takes off from the helipad/airfield in a known and obstacle free environment and therefore there is no need to enable the obstacle warning system. After arriving at the accident site, the helicopter descends to the landing zone and picks up the person injured. During landing, hover and take-off, the obstacle warning system is operative and informs the flight crew of obstacles in the direct vicinity of the helicopter environment in case of unknown and/or complex obstacle environment. The helicopter flies in cruise altitude to the hospital. Emission of radar energy is deactivated in this phase. During landing and take-off at the hospital, the flight crew again is informed of obstacle by the obstacle warning system in case of unknown and/or complex obstacle environment. The emission of radar energy will be deactivated during cruise flight back to the helicopters air base. As the helipad/airfield is a known and obstacle free environment there is no need to enable the obstacle warning system during the landing phase.

Minimum flying altitudes and off-field landing are regulated for each state (see the following section).

2.3 CIVIL AVIATION REGULATIONS

The European Aviation Safety Agency (EASA) is a European Union agency building the centrepiece of the European Union’s strategy for aviation safety.

EASA issues the “Implementing Rules for Air Operations of Community Operators” which state that “An aircraft shall not be flown below minimum altitudes established by the State overflown”.

As an example the regulation in Germany [18] is summarised below:

a) Landing outside of airfield (off-airfield landing) is only allowed after permission from the competent authority of the federal state.

   Exceptions are e.g. emergency landing and helicopter emergency medical service (§25 Abs. 1 LuftVO);

b) Minimum safe altitude is 300 meter (1 000 feet) above residential area, production plants, gatherings and accident sites above the highest obstacle in an area of 600 meter. For all other areas it is 150 m (500 feet) above ground and water;

c) For cross-country flights, a minimum altitude of 600 meter (2 000 feet) is applicable;

d) In German aviation regulations the Public Services (law enforcement, military etc.) can deviate from these regulations in exceptional cases if mandatory to perform their sovereign duty, thereby always respecting public order and safety.

2.4 STATISTICS FOR HELICOPTER OPERATIONS

Information available from [9]:

- For 2008, it was estimated that approximately 6800 helicopters were registered in Europe for civil use.
- No reliable flight hour data is available for all registered helicopters across Europe. However, for the year 2008 a total of 1.7 million flight hours and 4.7 million landings was estimated for turbine powered helicopter, involved in civil use, registered in Europe.

Assumptions on helicopter types:

- In Germany, 756 helicopters have been registered at the Federal Office of Civil Aeronautics (Luftfahrtbundesamt) at 28.02.2014. Out of these 756 helicopters, 272 (or 36%) are powered with piston engine and 484 (or 64%) are powered with turbine engine. Piston engines helicopters are not considered to use the described system for the following reasons:
  a) Due to the different technology of piston engine compared to turbine engine, piston engine helicopter have significantly reduced ratio of power to weight. Therefore the possibility to install auxiliary avionic (increasing weight and power consumption) is very limited;
  b) Piston engine helicopters have mainly a maximum Take-Off weight below 2000 kg. Therefore these helicopters have limited usability for HEMS (no capacity to install medical equipment and winch);
  c) Commercial aspect: ratio system price to helicopter price is too high.
- Assuming a turbine engine percentage of 64% across Europe (taken from the percentage in Germany), a total turbine engine helicopter number of 4400 can be used (= 6800 x 64%).

Considerations on airborne radar use:

- Turbine helicopters are being used for a variety of missions by a variety of operators (HEMS, Police, Utility, Off-Shore, VIP transport etc.);
- Radar system only used during take-off and landings (as many take-offs as landings);
- System is considered to be operative for 5 min per landing/take-off (worst case);
- System only used when operating in an unknown and/or complex obstacle environment (e.g. outdoor landing for HEMS operators, inadvertently flight in degraded visual environment, pilot not familiar with landing area);
- The following calculations have been based on the statistic of 4.7 million landings for turbine helicopters in 2008;
- Considering modest growth in helicopter operations for the next year, a total number of 10 million take-off/landings is assumed;
- It can be considered that the number of take-offs, hover and landings in which the airborne radar system will be in use is 25% of all take-offs and landings for all turbine equipped HCs:
  a) 15% are estimated as primary rescue missions like HEMS and police rescue missions. (HEMS missions are distinguished between primary rescue missions in which the radar system can be assumed to be used and secondary missions, e.g. inter hospital flights in which the system is rarely used);
  b) 10% are estimated as non-rescue missions like Utility-, Off-Shore-, VIP transport-missions:
    - The main part of these missions contains Off-Shore operations which is transport of person to and from oil rigs and wind park maintenance;
    - < 5% of these missions are estimated to be operated onshore;
  c) Hover missions are included in these numbers;
- Not all turbine equipped helicopters will perform operations in complex obstacle area;
- 80% market penetration after 10 years of market entry.

Table 3: Consideration of Helicopter Operations

	Scenario	A	B	C	D
Number of Flight Hours per Year	hours	1700000	1700000		
Number of Landings and Take-Offs per Year				10000000	10000000
Area of Europe	km²	4400000	4400000		
Time of System operation per landing/take-off	min			5	5
Number of operations where the system is used	%	25%	100%	25%	100%
system on time per flight hour	%	10%	50%		
market penetration	%	80%	80%	80%	80%
Calculation					
Number of flight hours per area	hr/km²	0,4	0,4		
Number of landings/take-off per area	km²			1,8	1,8
System on time per area per year	min/km²	0,5	9,3	2,3	9,1
System on time per area per day	sec/day/km²	0,08	1,52	0,37	1,49

Note: This report does not consider military helicopters because the information about military use was not available. It is expected that military helicopters equipped with the radar systems will increase the interference probability. Administrations are urged to consider the actual deployment of military helicopters when establishing coordination zones.

Both scenarios A and B are based on an assumed ON-time per flight hour in %:

- Scenario A: Assumes a system ON-time of 10% per flight hour and the assumption is made that the system is used for 25 % of all take-off and landing manoeuvres.
- Scenario B: Assumes a system ON-time of 50% per flight hour (worst case). In addition, the assumption is made that the system is used in every take-off and landing manoeuvre (worst case).

Both scenarios C and D are based on an assumed ON-time per take-off and landing in minutes.

- Scenario C: Assumes a system ON-time of 5min per take-off and landing and the assumption is made that the system is used for 25 % of all take-off and landing manoeuvres.
- Scenario D: Assumes a system ON-time of 5min per take-off and landing. In addition, the assumption is made that the system is used in every take-off and landing manoeuvre (worst case).

Scenarios B and D consider 100 % use of the system which is unrealistic due to the high number of routine flights where the system is not expected to be used.

2.5 TECHNICAL CHARACTERISTICS

Technical characteristics and justification for spectrum requirements for the airborne application are detailed in ETSI TR 103 137 V1.1.1 (2014-01) ”Surveillance Radar equipment for helicopter application operating in the 76 GHz to 79 GHz frequency range” [1].

The sensor unit consists for example, of an RF-Frontend with typically two transmitters and a 16 channel receiver with integrated baseband-signal conditioning.

The Transmitter consists of a highly integrated 77 GHz SiGe- MMIC with signal-generator and up to 4 transmit-amplifiers. The signal generator creates a fast ramp FMCW signal which will be sent sequentially by one of the two transmitters. On the receiver site, each channel is connected to a single antenna-column with a wide horizontal and a narrow vertical beam. The signals of the receivers are sampled and pre-processed using the massive parallel signal processing capability of an FPGA. The signal processing is providing information about range and velocity of the detected objects. In the horizontal plane, the output of the receivers is combined using digital beam forming techniques.

The technical details of two possible radar systems are given in sections 2.5.1 and 2.5.2 based on the obstacle detection requirements and operational use cases. Parameters to be used in the studies are given in section 2.5.3.

2.5.1 Near Field Obstacle Detection System (System 1)

This radar system is used for detection of obstacles in the direct vicinity of the helicopter. This mode is supporting hover and slow moving operations for approach, landing and take-off. This mode uses wideband signals to provide a precise range information of objects with a high range separation in the order of centimetres. The detection range does not need to be more than 40 m. This mode operates in the 76 GHz to 77 GHz band with a bandwidth of typically 800 MHz. System parameters are given in the below Table 4.

Table 4: Main RF parameters for Near Field Obstacle Detection System (System 1)

Frequency range of operation	76 to 77 GHz
Mean power (e.i.r.p.)	20 dBm over 800 MHz bandwidth (Note 1, Note 3)
Mean power (e.i.r.p) dBm/MHz	-4 dBm/MHz (Note 2, Note 3)
RF power duty cycle per s	20%
Peak power (e.i.r.p.)	26 dBm over 800 MHz bandwidth (Note 3)
Bandwidth (3dB)	800 MHz

Transmitter antenna gain	13 dBi (details see in ANNEX 3:)
Receiver antenna gain	22 dBi
Coverage	Typically 360 ° coverage of main and tail rotor area with 4 sensors (see Figure 2) – can be increased with additional sensors for coverage in the lower hemisphere

Note 1: This is a calculated value from the measured peak power and the measured DC value
Note 2: This is the mean power during RF transmitter ON-time and measured with 1 ms dwell time per 1 MHz.
Note 3: These are typical values at standard ambient conditions

Detailed measurements can be found in ANNEX 7:.

The system parameter are complying with the limits for automotive radars in the band 76 to 77 GHz as given in the ETSI standard EN 301 091-1 [6].

2.5.2 Medium Range Obstacle Detection System (System 2)

Another radar system may be used for detecting obstacles during approach, landing and take-off. In these flight phases the detection range needs to be higher to ensure an appropriate warning time when flying at higher speeds. The detection range does not need to be more than 250m. This mode operates in the 76 to 79 GHz band. The sensor is modulated with a bandwidth of typically 130 MHz at three different centre frequencies. The different centre-frequencies are necessary to provide additional electronically beam steering in vertical direction. Due to helicopter limitations electronic beam steering is used as a practical solution. This system is making a 3D-Observation. This means, that beside horizontal beamsteering, also a vertical beamsteering is necessary. The change of the centre-frequency from approx. 76 to 79 GHz results in a capability of 7.5° vertical beamsteering. A reduction to the 76-77 GHz band would reduce this capability by a factor of 3 to 2.5°, which is not enough for good operation.

The system parameter (see Table 5) are complying with the limits for automotive radars in the band 76 to 77 GHz as given in the ETSI standard EN 301 091-01 [6], but are above the limits for short range vehicular radars in the band 77 to 79 GHz as given in the standards EN 302 264-01 [7].

Table 5: Main RF parameters for Medium Range Obstacle Detection System (System 2)

Parameters	Values
Frequency range of operation	76 to 79 GHz
Mean power (e.i.r.p.)	29 dBm over 130 MHz bandwidth (Note 1, Note 3)
Mean power spectral density (e.i.r.p)	8 dBm/MHz (Note 2, Note 3)
RF power duty cycle per s	34%
Peak power (e.i.r.p.)	33 dBm over 130 MHz bandwidth (Note 3)
Bandwidth (3dB)	130 MHz at typically three center frequencies
Transmitter antenna gain	13 dBi (details see ANNEX 3:)
Receiver antenna gain	22 dBi
Coverage	lower hemisphere (see Figure 1)

Note 1: This is a calculated value from the measured peak power and the measured DC value
Note 2: This is the mean power during RF transmitter ON- time and measured with 1 ms dwell time per 1 MHz.
Note 3: These are typical values at standard ambient conditions

Detailed measurements can be found in ANNEX 7:.

In a typical implementation a number of surveillance sensors are integrated in a distributed manner around the helicopter to cover the complete lower hemisphere.

Medium Range Obstacle Detection System (System 2) operates with vertical Field of View scan in 4 cycles (see also ANNEX 3:) which leads to additional mitigation factor of about 6 dB.

2.5.3 Technical Parameters used in this report

The following table provides a comparison of the existing limits for vehicular radars with the parameters for the above two helicopter radar systems and derives two sets of limit to be used in the studies in this report.

Table 6: comparison of technical parameters

	ERC/REC 70-03 Annex 4 and 5	ECC/DEC/ (04)03	Helicopter radar System 1	Helicopter radar System 2	Low power system	Medium power system
Frequency band	76-77 GHz	77-81 GHz	76-77 GHz	76-79 GHz	76-79 GHz	76-79 GHz
Peak power e.i.r.p. Note 3	55 dBm / 1 GHz	55 dBm / 4 GHz	26 dBm / 800 MHz	33 dBm / 130 MHz	26 dBm	33 dBm
Mean/average power e.i.r.p. Note 3	50 dBm average power or 23.5 dBm average power for pulse radar only	Not specified (would be with 4 GHz bandwidth 33 dBm)	20 dBm / 800 MHz	29 dBm / 130 MHz	20 dBm Note 1	30 dBm Note 1
Mean average power density e.i.r.p. Note 3	Not specified (would be 20 or -6.5 dBm/MHz for 1 GHz bandwidth)	-3 dBm/MHz / -9 dBm/MHz outside a vehicle	-4 dBm/MHz	8 dBm/MHz	0 dBm/MHz Note 2	10 dBm/MHz Note 2
Mitigations			DC 20 %/s	DC 34%/s	DC 20% (7 dB)	DC 40%/s (4dB) 25% (6 dB) mainbeam occurrence probability each 10°
				Mean e.i.r.p. density including mitigations	-7 dBm/MHz	0 dBm/MHz

Note 1: This is a calculated value from the measured peak power and the measured DC value
Note 2: This is the mean power during RF transmitter ON- time and measured with 1 ms dwell time per 1 MHz.
Note 3: These are typical values at standard ambient conditions

ANNEX 1: contains some calculations to validate the power and bandwidth requirements of those radars.

3 RADIO SERVICES AND SYSTEMS

Current allocation of the candidate bands are summarized in Table 7, together with actual usage within the CEPT.

Table 7: ITU Allocations and actual usage in CEPT

Frequency Band	ITU Allocations in Region 1	Actual usage of the band at national level within CEPT	Actual usage of adjacent bands at national level within CEPT
76 to 77.5 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur-Satellite Amateur Space Research (space-to-Earth)	Amateur, Amateur-satellite, SRR, Radiolocation (civil) Radiodetermination applications (Within the band 75-85 GHz for TLPR and LPR applications) Railway applications (Obstruction/vehicle detection at level crossings) Radio astronomy (primary service) (Continuum and spectral line observations) RTTT (Within the band 76-77 GHz Radar. Road Transport and Traffic Telematic) (SRD application)	Amateur, Fixed, Space research (VLBI), Amateur-satellite, Radiodetermination applications (Within the band 75-85 GHz for TLPR and LPR applications)
77.5 to 78 GHz	AMATEUR-SATELLITE AMATEUR Radio Astronomy Space Research (space-to-Earth)	SRR Radio astronomy (Continuum and spectral line observations) Radiodetermination applications (Within the band 75-85 GHz for TLPR and LPR applications)	
78 to 79 GHz	RADIOLOCATION Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth)	SRR Radio astronomy (Continuum and spectral line observations) Radiodetermination applications (Within the band 75-85 GHz for TLPR and LPR applications) Defence systems Radiolocation (civil)	SRR Radio astronomy (Continuum and spectral line observations) Radiodetermination applications (Within the band 75-85 GHz for TLPR and LPR applications) Defence systems Radiolocation (civil)

From RR Footnote 5.149: In making assignments to stations of other services to which the band 76 to 86 GHz is allocated, Administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see RR Nos. 4.5 and 4.6 and Article 29).

3.1 RADIO ASTRONOMY SERVICE (RAS)

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 certain moment in time. During this observation the pointing direction of the telescope is continuously adjusted to compensate for the rotation of the Earth. It is assumed that interference from a terrestrial transmitter is generally received through the side lobes of the RAS antenna.

The ITU-R Recommendations taken as a basis for the compatibility study carried out are the following:

- Recommendation ITU-R RA.769-2: “Protection Criteria used for Radioastronomical Measurements” [2];
- Recommendation ITU-R RA.1513-1: “Levels of data loss to RAS observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the RAS on a primary basis” [4];
- Recommendation ITU-R P.452-14: “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz*” [3];
- Recommendation ITU-R P.676-5: “Attenuation by atmospheric Gases” [5].

Recommendation ITU-R RA.769 [2] assumes that the interference is received in a side lobe of the antenna pattern, i.e. at a level of 0 dBi at ≥19º from bore sight. It should be noted that a radio telescope is an antenna with a very high main beam gain, typically of the order of 70 dB. If interference is likely to be received via the main lobe of the antenna pattern, this high gain should also be taken into account. However, Recommendation ITU-R RA.769 [2] assumes that the chance that the interference is received by the main lobe of the antenna is low, and therefore uses the level of 0 dBi in the calculation of the levels of detrimental interference given in this Recommendation.

It is considered that the interference received at the radio telescope antenna shall not exceed the levels of detrimental interference given in Recommendation ITU-R RA.769. For the frequencies between 76 and 84 GHz, RAS observing programs are dedicated to spectral line and continuum observations, which have different protection requirements. In this report only the continuum observations is considered.

Since the band 76 to 79 GHz is not listed in Recommendation ITU-R RA.769, the limits needs to be interpolated from the listed bands 43 GHz and 89 GHz.

A list of RAS stations operating in the range 76 to 79 GHz within CEPT is available in ANNEX 2:.

Detailed information on the scientific importance of the 4mm Band (76 to 79 GHz) for the RAS in given in ANNEX 4:.

3.2 AMATEUR AND AMATEUR SATELLITE SERVICE

The amateur and amateur-satellite services have harmonised allocations in all three ITU Regions in the frequency range 76 to 81 GHz range as follows:

Table 8: Allocations for Amateur Services

Frequency	Services
76.0 to 77.5 GHz	Amateur & Amateur Satellite
77.5 to 78.0 GHz	AMATEUR & AMATEUR SATELLITE
78.0 to 81.0 GHz	Amateur & Amateur Satellite

The European Table of Frequency Allocations (ERC Report 25 [17]) also includes footnote EU35, which allocates 75.5 to 76 GHz to the Amateur and Amateur Satellite services due to previous compatibility concerns with wideband 79 GHz short-range automotive radar in ECC Report 056 [10].

The operational characteristics of amateur stations and amateur-satellite stations vary significantly. Whilst overall numbers are relatively small compared to lower frequency bands, operation has matured as equipment has become increasing available. Based on the IARU Region-1 VHF Managers Handbook [19] they can be categorised in this frequency range as:

- Weak-signal reception of Narrowband Terrestrial operation in harmonised sub-bands centred at 76032, and 77501 MHz (and at 75976 MHz, where EU35 is implemented);
- These narrowband amateur stations are generally portable low-power directional systems focussed on long-range communications from hilltop portable stations (where they can achieve line-of-sight contacts up to 100-200km).

In addition there are:-

- A small number of fixed stations with larger antennas/power undertaking technology development and trials for Earth-Moon-Earth (EME) communications (also called 'Moonbounce'), using narrowband modulation in the 77.1 to 78.2 GHz range;
- A small number of shorter range wider bandwidth data/multimedia links and omnidirectional propagation beacons;
- Plans for experimental beacons on small satellites.

3.2.1 Characteristics for the Amateur Service

Recommendation ITU-R M.1732-1 [11] provides characteristics of stations operating in the amateur service for use in sharing studies. However this is not very specific for the 77 GHz bands. In 2004 more specific data for amateur systems was used for ECC Report 056 [10]. Since that report, technology has developed further and more recent ITU-R SG5 studies for WRC15 account for this (such as the wider availability of PAs and low noise preamps) This enables the following table to be used as the basis of sharing studies for the more typical amateur stations.

Table 9: Examples of Amateur Service characteristics in the band 76-79 GHz

Parameter	CW-Morse	SSB Voice	NBFM Voice
Transmitter Power(1) (dBm)	0 – 20 (typically: 13)	0 – 20 (typically: 13)	3 – 20 (typically: 13)
Typical Feeder Loss (dB)	1	1	1
Antenna gain (dBi)	36 – 42 (typically: 40)	36 – 42 (typically: 40)	36 – 42 (typically: 40)
Typical e.i.r.p.(dBW)	22	22	22
Antenna polarisation	Horizontal, Vertical,	Horizontal, Vertical	Horizontal, Vertical
Receiver IF bandwidth (kHz)	0.5	2.7	15
Receiver Noise Figure(2) (dB)	3 – 7 (typically 4)	3 – 7 (typically 4)	3 – 7 (typically 4)

(1) Maximum powers are determined by each administration.
(2) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

For studies in the 77.5-78 GHz amateur Primary allocation, ITU WP5 has adopted a –6dB I/N interference ratio. For the purpose of this study, higher power EME experiments, which are fairly rare, have been ignored.

3.2.2 Characteristics for the Amateur-Satellite Service

Most current amateur satellites are typically nano or picosats (also called ‘cubesats’) that occupy slightly elliptical Sun-Synchronous low earth orbits (LEO) of 600-800km altitude. These smaller satellites have relatively low power and antenna gain.

In 2012 studies by ITU Working Party 5A for WRC-15 AI-1.18 were unable to identify current in-orbit use of the 77.5-78 GHz frequency band in the amateur-satellite service. However this should not preclude future usage, including plans for transmission beacons on-board amateur satellites for attitude determination and atmospheric propagation research for reception by amateur ground stations. If implemented the satellite beacon frequencies would be most likely aligned with the terrestrial narrowband amateur stations

A practical issue arises due to significant Doppler shift in low earth orbit at these frequencies. Therefore, many amateurs would in practice utilise at least the same if not greater bandwidth than for terrestrial usage and the most likely situation would be sidelobe rather than main beam compatibility. Therefore further considerations are confined to amateur service only.

4 COMPATIBILITY STUDIES

4.1 RESULTS FROM ECC REPORT 056

The following 3 primary radiocommunication services have been considered in ECC Report 056 [10]:

- Radiolocation Service;
- Radio Astronomy Service;
- Radio Amateur and Amateur Satellite Services.

ECC Report 056 [10] did not address the impact of radiocommunication services on SRR receivers, as the latter are expected to operate on a non-interference non-protected basis.

Technical SRR parameters from ECC Report 056:

Table 10: Main RF parameters for 79 GHz SRR

Frequency	Services
Mean PSD (e.i.r.p)	– 3 dBm/MHz
Mean Power (e.i.r.p)	24 dBm
Peak Power (e.i.r.p)	55 dBm
Bumper attenuation	6 dB

4.1.1 Radiolocation Service

NATO informed CEPT at the time ECC Report 056 was prepared that there are no radiolocation systems operational in the 79 GHz frequency range and that there are currently no plans to introduce such systems. No compatibility studies were therefore conducted with radiolocation systems in this frequency range. Further details are provided in Annex B of ECC Report 056 [10].

In addition, ECC/DEC/(04)03 [12] mentions in considering i) “that information has been received from NATO that there are currently no radiolocation systems operational in the band and there are no plans to introduce such systems”.

Consequences for this report: No need to conduct studies as there is no other information available.

4.1.2 Radio Astronomy Service

The compatibility of SRR systems with the Radio Astronomy Service (RAS) around 79 GHz was studied on the assumption of a mean e.i.r.p. per SRR device of –3 dBm/MHz. The analysis shows that coexistence is dependent on the aggregated impact of SRR devices transmitting in the direction of a RAS station.

A detailed compatibility study with the Radio Astronomy Service is provided in Annex C of ECC Report 056.

It is concluded in ECC Report 056 [10] that regulatory measures (e.g. automatic deactivation mechanism close to RAS observatory stations) are necessary to enable the coexistence between SRR and the RAS.

Consequences for this report: Studies with different power values, deployment scenarios and propagation ranges are provided in section 4.2 of this report.

4.1.3 Radio Amateur and Amateur Satellite Services

Without consideration of mitigation factors ECC Report 056 [10] obtained separation distances under worst case conditions in the order of 2 km in the main lobe to main lobe case for 79 GHz SRR systems.

ECC Report 056 considered in additions that the probability of interference as a result of SRR radiating through its antenna main lobe into the AS station antenna main lobe would however be very low. The occurrence of the main beam to side lobe interference scenario would still be expected to be low. When considering the side lobe to side lobe case, the protection distance would be around 80 m.

Furthermore it is mentioned in ECC Report 056 that there are currently only some hundreds of active AS stations inside CEPT (e.g. around 50 in Germany). In the future a greater number of AS stations could be expected (e.g. for linked stations).

A detailed compatibility study with the Amateur and Amateur Satellite Services is presented in Annex D of ECC Report 056 [10].

Consequences for this report: The updated separation distances for the requested power levels and an estimate on the occurrence probability are provided in section 4.3 of this report.

4.2 STUDIES WITH RADIOASTRONOMY

4.2.1 Choice of the propagation model for sharing studies with the radioastronomy service

For sharing studies between automotive SRR and RAS in the 78 GHz band, Report ITU-R SM.2057 used Recommendation ITU-R P.452. However, it has to be highlighted that Recommendation ITU-R P.452-14 is in principle validated up to 50 GHz (see paragraph 1 of Annex 1: “The prediction procedure is appropriate to radio stations operating in the frequency range of about 0.7 GHz to 50 GHz”). Recommendation ITU-R P.620-6, applicable up to 110 GHz, could be used here. The main difference to P.452 seems to be the term

$$E(p_1, d) = 2.6\left[1 - \exp\left(\frac{-d}{10}\right)\right] \log\left(\frac{p_1}{50}\right),$$

which models signal enhancements for low percentages of time.

The following Figure shows *E(p₁,d)*.

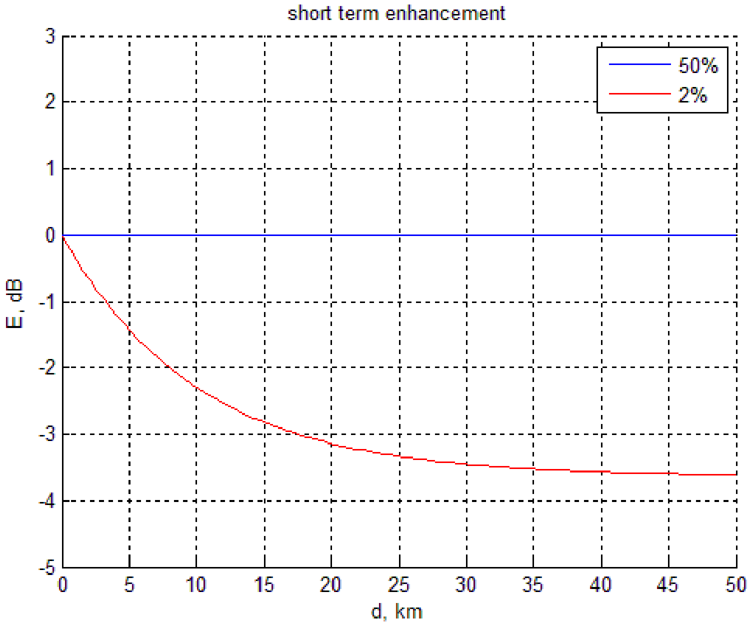

Figure 4: Signal enhancements at low percentage of time

The impact of the above considerations is assumed to be only marginal and therefore the following calculations are using Recommendation ITU-R P.452 [3] with 50% time percentage.

4.2.2 Separation distances for RAS stations (co-channel single entry)

Input parameters:

- Operating altitude of air-borne radar: 100m and 300m;
- Helicopter radar mean e.i.r.p.. $P_{e.i.r.p.}$: 20 dBm (-10 dBW) and 24dBm (-6 dBW); mitigation factors are already considered in those values (see section 2.5.3);
- Operating band width radar: smaller than RAS bandwidth;
- Effective height of RAS antenna: 50m;
- Operating frequency of radar and radio observatory: 77.75 GHz;
- Antenna gain RAS Ge: 0dBi;
- Operating band width radio observatory:
  - $\Delta\nu$= 0.65 GHz;
  - $\Delta\nu$= 8 GHz (wide bandwidth continuum observations);
- Path loss model: the propagation calculations using Recommendation ITU-R P.452-14 include line of sight up to the radio horizon, diffraction over spherical earth and troposcatter with atmospheric absorption; time percentage 50%;
- Atmospheric absorption: 0.15 dB/km (as common for RAS observing sites and good observing conditions) and 0.35 dB/km for the standard atmosphere from [5];
- Recommendation ITU-R RA. 769 threshold ΔP_H for 77 GHz: -194.8 dBW and -188 dBW (Integration time tint=2000s, reference bandwidth 650 MHz and 8 GHz, nearest values for T_a = 12 K and T_r = 30 K from 89 GHz table entries), calculated according to the following formula:

$$\Delta P_H = 10 \cdot \log_{10}\left(\frac{0.1 \cdot k_B \cdot (T_a + T_r)}{\sqrt{\Delta\nu \cdot t_{\text{int}}}}\right) + 10 \cdot \log_{10}(\Delta\nu) \qquad \text{[dBW]}$$

with bandwidth $\Delta\nu$ in Hz, t_{int} in seconds and the Boltzmann constant $k_B=1.381 \cdot 10^{-23}$ W/Hz.

The required coupling loss due to path loss between RAS station and helicopter radar is calculated according to MCL = $P_{e.i.r.p.}+G_e-\Delta P_H$.

Figure 5 shows the path loss according to P.452.

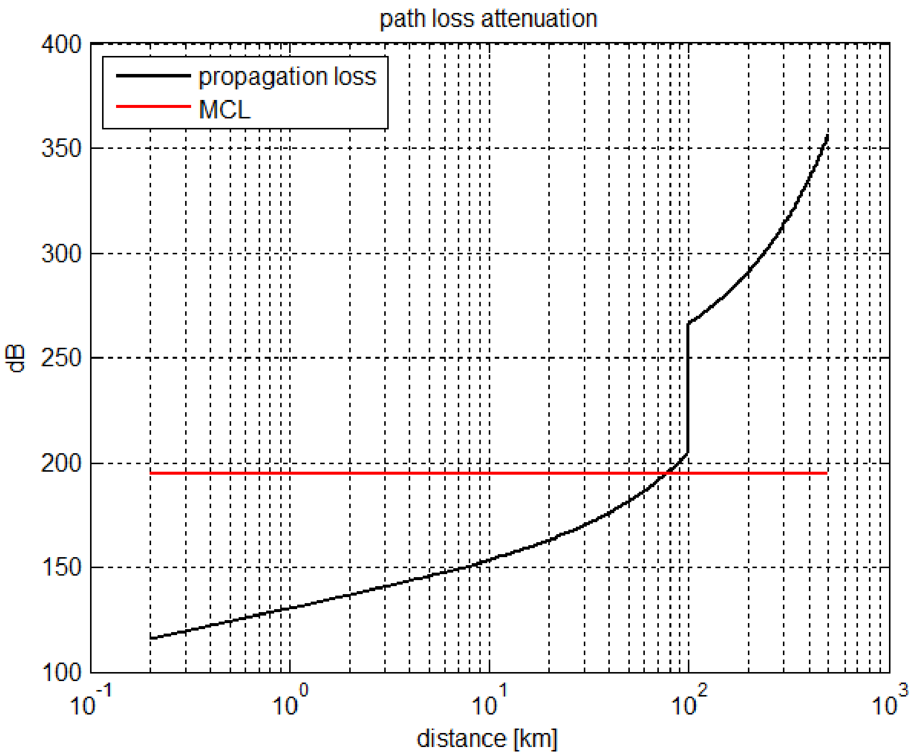

Figure 5: Propagation losses for 77.75 GHz for a 50 m high telescope and 300m altitude of the transmitter according to ITU-R P. 452-14 (atmospherical loss 0.35 dB/km, MCL line at 194.8 dB)

From Figure 5 we note that we are at the edge of the diffraction regime for the required MCL.

Results for the different assumptions are summarized in Table 11.

Table 11: Summary of the required distances to protect RAS stations

Operating band width radio observatory		650 MHz Note	650 MHz Note	8 GHz	8 GHz
ITU-R RA. 769 threshold ΔP_H		-194.8 dBW	-194.8 dBW	-189.4 dBW	-189.4 dBW
Helicopter radar mean e.i.r.p. $P_{e.i.r.p.}$		-6 dBW	-10 dBW	-6 dBW	-10 dBW
MCL dB		188.8	184.8	183.4	178.4
atmospheric loss	Helicopter altitude	minimum separation distances			
0.15 dB/km	300 m	98 km	98 km	93 km	78 km
0.35 dB/km	300 m	68 km	57 km	57 km	47 km
0.15 dB/km	100 m	69 km	68 km	68 km	68 km
0.35 dB/km	100 m	68 km	57 km	57 km	47 km

Note: 650 MHz bandwidth is only an example of a smaller radio astronomy bandwidth

4.2.3 The radio horizon

The above calculation assumed a flat terrain and therefore LOS to the radio horizon. The radio horizon with the according LOS path loss values are calculated in Table 12.

Table 12: calculation of the radio horizon

Height helicopter above ground (m)	Height RAS (m)	Radio horizon (km)	Path loss LOS+0.35dB/km	Path loss LOS+0.15dB/km
300	1000	201	246,5	206,4
300	500	163	231,4	198,9
2000	50	212	251,1	208,6
1000	50	159	229,8	198,0
300	50	100	205.2	185.2
200	50	87	199.5	182.1
100	50	70	191.6	177.6
50	50	58	185.8	174.2
30	50	51	182.5	172.2
20	50	47	180.3	170.8
10	50	42	177.4	169
0	50	29	169.6	163.8

In the following figure the path loss values are shows over distance together with the required MCL values from Table 11 above. It can be seen from there that a separation distance of more than 115 km could not be possible with the worst case MCL values from Table 11 (188.8 dB) and the atmospheric loss of 0.15 dB/km although the radio horizon can much larger (e.g. up to 212 km).

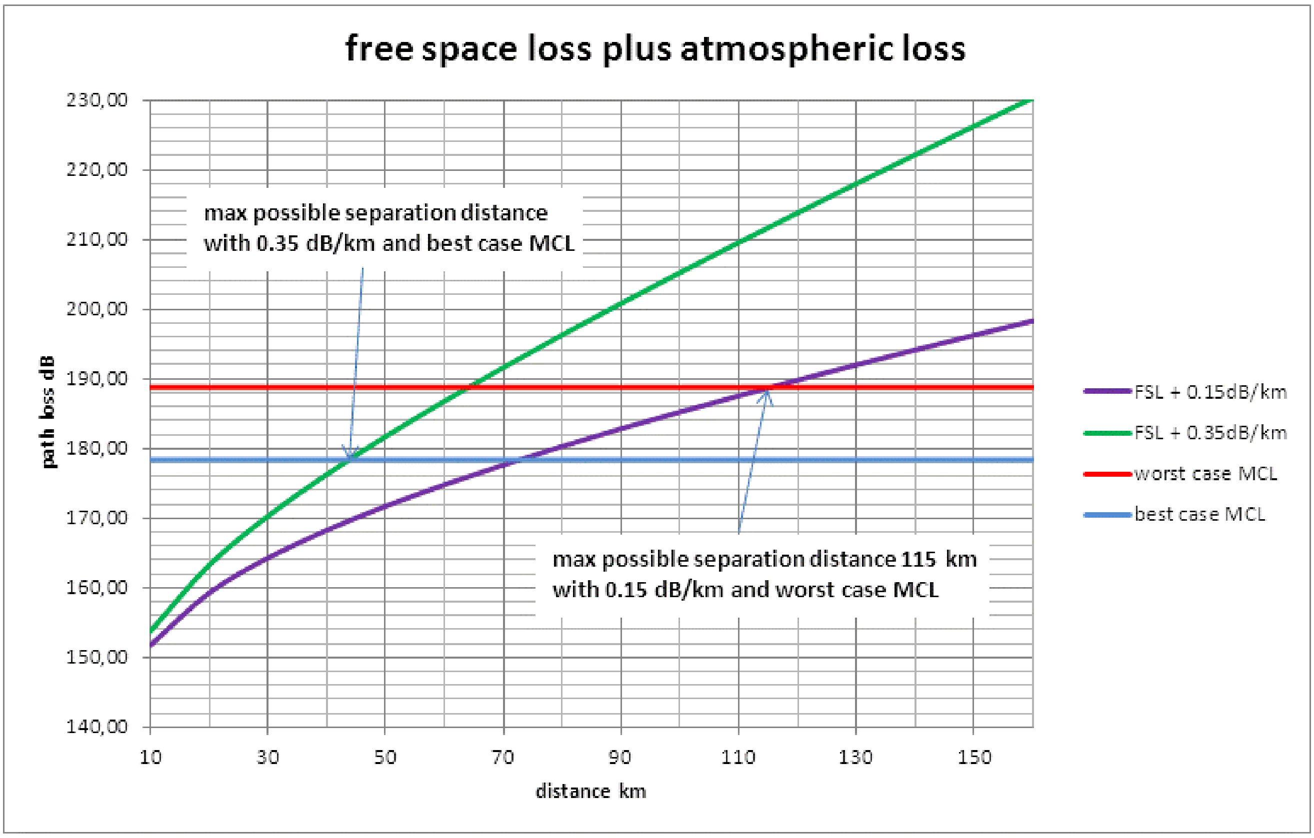

Figure 6: derivation of max required separation distance

For the example of a MCL of 178 dB for continuum observation (see previous section) the required separation distances are for 0.15dB/km atmospheric loss about 70 km and for 0.35 dB/km about 42 km:

- 300m altitude, radio horizon 100km: the LOS path loss is between 7 dB and 27 dB above the required decoupling, that means 100km separation distance not required;
- 100m altitude, radio horizon 70km: the LOS path loss of 192 dB is 14 dB above the required decoupling;
- 10m altitude, radio horizon 42 km: the LOS path loss of 178 dB just sufficient to deliver the required decoupling.

This exercise is in line with the calculations in the previous sections and shows that the propagation model from Recommendation ITU-R P.452 results in free space loss plus atmospherically losses up to the radio horizon, without any consideration of clutter or other losses.

4.2.4 Consideration of the terrain

In some cases an exclusion zone could be derived from the particular topography of the region. This exclusion zone is height dependent and requires automated system control.

ANNEX 6: illustrates an example of the radio astronomy station Plateau de Bure and the areas in which helicopter activity with an active 77 GHz radar can cause interference to a radio observatory.

4.2.5 Probability of interference

In this section the occurrence probability of interference from helicopter radars into the RAS is assessed.

Some consideration on acceptable data loss to Radio Astronomy is given in [4]. It is recommended there:

1. that, for evaluation of interference, a criterion of 5% be used for the aggregate data loss to the RAS due to interference from all networks, in any frequency band allocated to the RAS on a primary basis, noting that further studies of the apportionment between different networks are required;

2. that, for evaluation of interference, a criterion of 2% be used for data loss to the RAS due to interference from any one network, in any frequency band which is allocated to the RAS on a primary basis;

   and

3. that the percentage of data loss, in frequency bands allocated to the RAS on a primary basis, be determined as the percentage of integration periods of 2 000 s in which the average spectral power flux-density (pfd) at the radio telescope exceeds the levels defined (assuming 0 dBi antenna gain) in [2]. The effect of interference that is periodic on time scales of the order of seconds or less, such as radar pulses, requires further study.

The 2% from [4] maybe applicable for this study as the percentage of lost observation packets each 2000 s period over one day.

The simplest interpretation would to restrict the helicopter radar activity around the RAS station to fulfil the 2 % per day. This would mean a maximum on-time of 28.8 minutes a day, or about six Take-Offs and Landings per day (assuming 5 minutes transmitter on-time each landing and take-off).

More detailed calculations are provided below to derive results on the occurrence probability with real helicopter deployment values.

The following provides a calculation for the probability of system ON time per day for helicopters in areas around a RAS station. It assumes a homogenous geographical distribution of helicopter landings/take-offs and uses the system ON-time per day per HC calculated before in section 2.4.

The term “critical range” will be used in this report as range where the RAS protection objective from ITU-R RA.769 is exceeded. The occurrence probability will be calculated assuming helicopter deployment only in that “critical range” around the RAS. Although the value is equal to the “separation distances” derived from section 4.2.2, the differentiation has been made here to avoid confusions with the occurrence probability calculations in this section.

The separation distances from MCL calculations are used as critical ranges to calculate the occurrence probability within that radius around the RAS stations. For a helicopter altitude of 300m and an atmospheric loss of 0.15 dB/km they vary between 78 and 98 km (for an atmospheric loss of 0.35 dB/km between 47 and 68 km). In the following the results are given for three values between 47 and 98 km (47, 68 and 98 km) to give an indication of the range of results.

Table 13 shows in lines 2, 4 and 6 the occurrence probability for the critical ranges of 98 km, 68 km and 47 km around the RAS station without any protection zone. In addition, Figure 7 gives a continuous curve with the occurrence probability as function of critical range and scenario.

Table 13: Occurrence probability for all helicopter missions per day and exclusion zone calculation

	Critical range km	Scenario A	Scenario B	Scenario C	Scenario D
1: System on time per area per year, min/km²		0.5	9.3	1.8	7.3
2: Occurrence probability without exclusion zone	98	2.7%	53.2%	13.0%	52.2%
3: 2% achieved for exclusion zone with the radius of, km	98	48.9	96.1	90.2	96.1
4: Occurrence probability without exclusion zone	68	1.3%	25.6%	6.3%	25.1%
5: 2% achieved for exclusion zone with the radius of, km	68	0.0	65.3	56.1	65.2
6: Occurrence probability without exclusion zone	47	0.6%	12.2%	3.0%	12,0%
7: 2% achieved for exclusion zone with the radius of, km	47	0.0	43.0	27.1	42.9

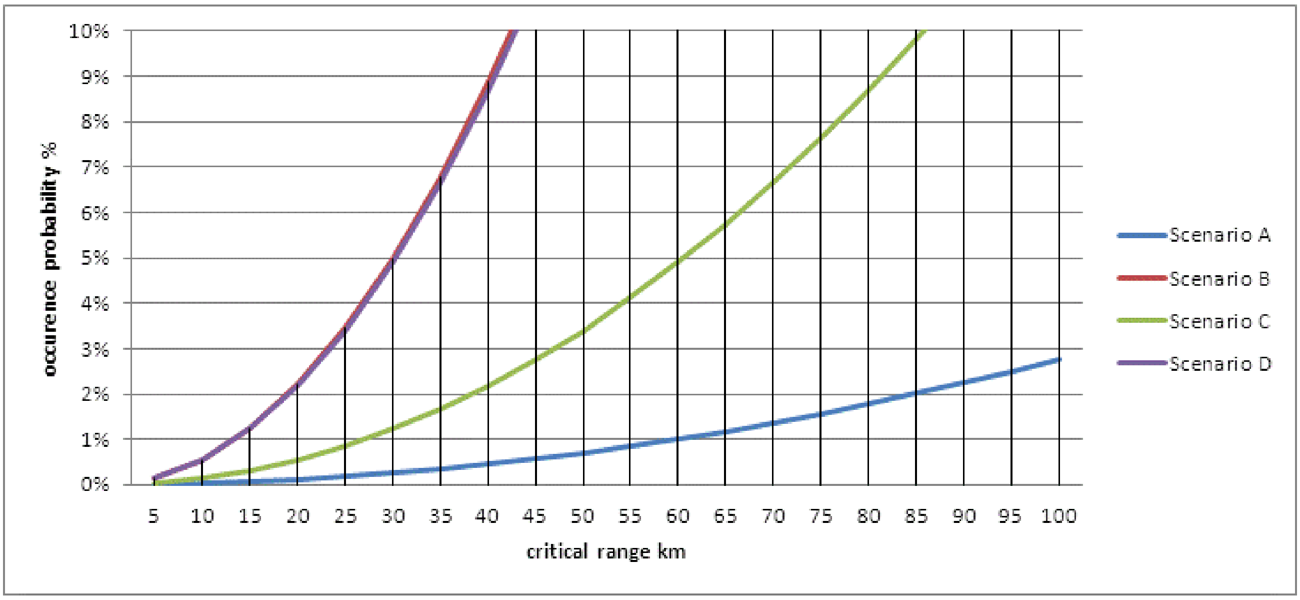

Figure 7: Occurrence probability as function of critical range and scenario

It can be seen that for the worst case critical range of 98 km even for scenario A the occurrence probability of helicopter radar transmitter on time is 2.8% per day which is in excess of the acceptable data loss value of 2 %. That means with a critical range of 98 km a data loss value of 2% can only be achieved with a certain exclusion zone. The radius of the exclusion zone can be calculated assuming a circular area around the RAS with the formula $R{=}Rx{*}\sqrt{(1{-}2\%/Px)}$, where R is the radius of the exclusion zone, Rx the critical range from MCL calculations (section 4.2.2) and Px the occurrence probability within Rx. Line 3, 5 and 7 in Table 13 are showing the radius of the exclusion zone to achieve the 2 %, which is 49 km for the worst case distance from section 4.2.2 and scenario A helicopter deployment (see ANNEX 9: with some illustrations).

Exclusion zones may not be required for the case that smaller critical ranges as the 98 km from the MCL calculations maybe sufficient. For example with 68 km critical range the occurrence probability is for scenario A 1.3% and thus below the acceptable data loss value of 2 %.

The above calculations are only examples and can be used as guidance. Administrations should decide on a national level on the need for and the size of an exclusion zone. The procedure provided in Annex 10 is one example of an assessment method that might be used on a national level.

The above calculation assumes homogenous distribution of helicopters in the area of Europe. Helicopters operate around airfields and dedicated helicopter bases and the majority of take-offs/landings especially for rescue missions will be concentrated at these locations. These locations also tend to be close to populated areas as the number of rescue missions is correlated to the population density, which is not expected for the RAS locations. Therefore a further calculation is provided in ANNEX 5: for the RAS station Pico de Veleta, where the helicopter activity per area has not been derived from the European average but from the population density. Assuming one take-off and landing per 1000 inhabitants the results indicate that for a critical range of 62 km the 2% would be achieved.

No differentiation has been made between rescue (which is only a fraction of all operations, see section 2.4) and non-rescue helicopter missions in the above calculations, because this is seen as outside the scope of this report.

The following mitigations were not considered in this section:

- helicopter continuously changes height during operation
- topology at the RAS location (see previous section).

4.2.6 Adjacent band compatibility (unwanted emissions)

An adjacent band compatibility study is provided for 89 GHz as this is a passive band[2]. One may expect similar results for all RAS bands adjacent to the helicopter radar band (e.g. 79-86 GHz, 92-94 GHz and 94.1-116 GHz).

Input parameters:

- Operating altitude of air-borne radar: 100m and 300m;
- Effective height of RAS antenna: 50m;
- Operating frequency of radar (unwanted) and radio observatory: 89 GHz;
- Antenna gain RAS $G_{e:}$ 0dBi;
    - Operating band width radio observatory: $\Delta\nu$= 6 GHz;
- Path loss model: the propagation calculations using ITU-R P.452-14 include line of sight up to the radio horizon, diffraction over spherical earth and troposcatter with atmospheric absorption; time percentage 50%;
- Atmospheric absorption: 0.15 dB/km (as common for RAS observing sites and good observing conditions) and 0.36 dB/km for the standard atmosphere from [5];
- ITU-R RA. 769 threshold ΔP_H -190 dBW (reference bandwidth 6 GHz, nearest values for T_a = 12 K and T_r = 30 K from 89 GHz table entries).

The 89 GHz band is protected by ITU Radio Regulations Footnote 5.340 (passive band, no emissions permitted).

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[2] ITU Radio regulations Footnote 5.340

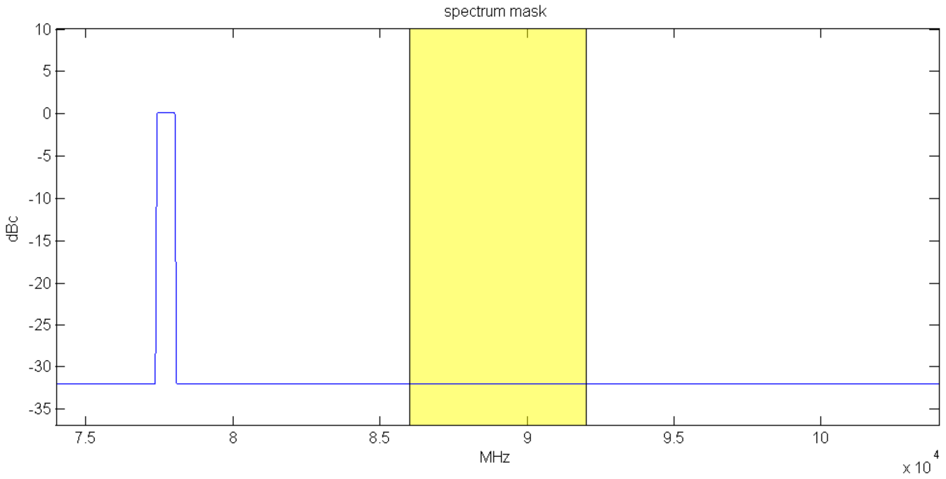

Figure 8: Spectrum mask, the astronomical band is shaded yellow

The below Figure 9 shows the required separation distance as function of the required spurious emission (flat distributed over 6 GHz), the atmospheric loss and time percentage.

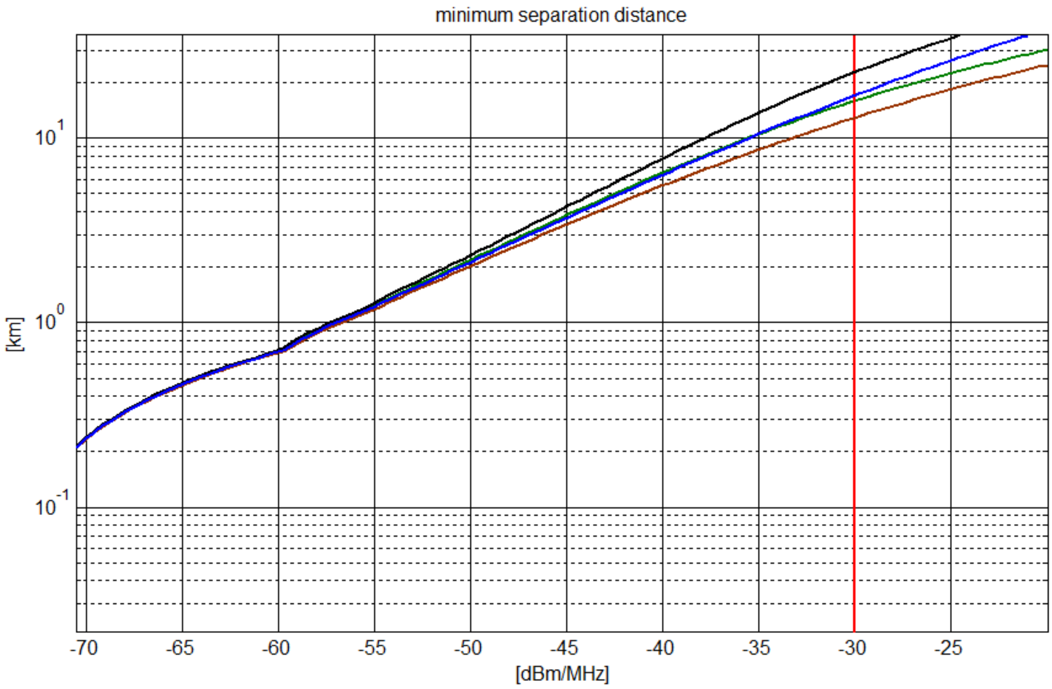

Figure 9: separation distance as a function of emitted p.s.d. (blue: γ=0.15 dB/km, p=50%, black: γ=0.15 dB/km, p=2%, brown: γ=0.36 dB/km, p=50%, green: γ=0.36 dB/km, p=2%)

The equivalent maximum unwanted emission e.i.r.p is dependent on the assumed separation distance. The calculated unwanted emissions limits under the assumption of a uniform flat distribution of the spurious limit over 6 GHz bandwidth are:

- with 200m assumed separation distance about -70 dBm/MHz;
- with 1 km assumed separation distance -57 dBm/MHz;
- with 10-25km assumed separation distance -30 dBm/MHz.

4.2.7 Summary of the studies with RAS

Separation distances between 47 km and 98 km are required under worst case assumptions (see section 4.2.2) to protect the RAS stations in Europe (see ANNEX 2:). The difference between the near field and medium range obstacle detection system is small (near field system 47-98 km, medium range system 57-98 km). The altitude of the helicopter has an essential impact on the separation distance (altitude 300m: separation distance 98 km, altitude 0 m: separation distance 29 km. The above mentioned distances are derived for an effective antenna height on the radio astronomy site of 50 m. The effect of the terrain can increase the size of the separation distances (e.g. 98 km could increase to 115 km) in case of RAS located in elevated positions (or when the helicopter would fly at greater altitudes) or reduce it when the terrain offer shielding to the radio astronomy site. As an example the impact of the terrain at the RAS station Plateau du Bure is shown in ANNEX 6:. It will be left to Administrations to identify, where necessary, the size and shape of the exclusion zone to protect radio astronomy sites, by using appropriate digital terrain models.

The occurrence probability has also been analysed in this report. As a limit the data loss value of 2% from [4] maybe applicable as the percentage of lost observation packets each 2000 s period over one day.

The simplest interpretation would to restrict the helicopter radar activity around the RAS station to fulfil the 2 % per day. This would mean a maximum on-time of 28.8 minutes a day, or about six Take-Offs and Landings per day (assuming 5 minutes transmitter on-time each landing and take-off).

More detailed occurrence probability calculations are provided in addition considering assumptions on helicopter deployment. As a result the occurrence probability shows a huge variance. The following Table summarises the situation.

Table 14: summary of results

	Scenario A	Scenario B
Description	Used for 25% of missions and only for take-off and landing (10% of flight hours)	Used for 100% of missions and for 50% of flight hours
Example 1: 98 km separation distance with 300 m altitude, atmospheric loss 0.15 dB/km, 650 MHz RAS bandwidth	Occurrence probability 2.7% Radius of exclusion zone 48.9 km	Occurrence probability 53.2% Radius of exclusion zone 96.1 km
Example 2: 47 km separation distance with 300 m altitude, atmospheric loss 0.35 dB/km, 8 GHz RAS bandwidth, near field obstacle detection system	Occurrence probability 0.6% Radius of exclusion zone 0 km	Occurrence probability 12.2% Radius of exclusion zone 43 km

It was not possible in this report to determine a representative result for the occurrence probability and exclusion zone.

Therefore, administrations should decide on a national level on the need for and the size of an exclusion zone.

The procedure in Annex 10 is one example of an assessment method that might be used on a national level.

No differentiation has been made between rescue (which is only a fraction of all operations, see chapter 2.4) and non-rescue helicopter missions in the above calculations, because this is seen as outside the scope of this report.

This report does not consider military helicopters because the information about military use was not available. It is expected that military helicopters equipped with the radar systems will increase the interference probability. Administrations are urged to consider the actual deployment of military helicopters when establishing coordination zones.

Radioastronomy (unwanted emission 89 GHz)

An adjacent band compatibility study is provided for 89 GHz as this is a passive band[3]. One may expect similar results for all RAS bands adjacent to the helicopter radar band (e.g. 79-86 GHz, 92-94 GHz and 94.1-116 GHz).

The equivalent maximum unwanted emission e.i.r.p are dependent on the assumed separation distance. The calculated unwanted emissions limits under the assumption of a uniform flat distribution of the spurious limit over 6 GHz bandwidth are:

- with 200m assumed separation distance about -70 dBm/MHz;
- with 1 km assumed separation distance -57 dBm/MHz;
- with 10-25km assumed separation distance -30 dBm/MHz.

4.3 AMATEUR AND AMATEUR-SATELLITE SERVICES (AS)

In 2004 ECC Report 056 [10] considered compatibility between automotive wideband 79 GHz SRR and incumbent services. At the time ECC Report 056 assumed a very low number of amateurs and large separation distances helped by amateurs on hilltops versus car radar at road level – assisted by directional amateur antenna beams, as well as relatively high noise figure receivers.

Since that time, equipment and activity has evolved (including the use of pre-amps) so amateur hill-top line of site contact distances of 100-200km are regularly achievable using high gain directional antennas.

Unlike the automotive case, a helicopter at altitude is far less likely to be obscured by ground clutter and thus there is an increased concern regarding main beam line of sight cases.

Rather than a highly mathematical analysis, it is reasonable to in the first instance to examine this new situation using a simple qualitative assessment. This is based on the helicopter radars and most Amateur systems having relatively similar low power transmitters. The main difference is in their antenna systems, bandwidths, duty cycles and operating characteristics.

4.3.1 MCL calculations

In this section the separation distances are derived for the two helicopter systems for amateur mainbeam and sidelobe cases based on LOS conditions.

Table 15: MCL calculations with the two system approaches

	Heliradar system 1 Amateur	Heliradar system 1 Amateur	Heliradar system 2 Amateur	Heliradar system 2 Amateur
f/GHz	77	77	77	77
noise figure	4	4	4	4
BW/MHz	0.0027	0.0027	0.0027	0.0027
kTBF	-135.69	-135.69	-135.69	-135.69
additional loss dB	0	0	0	0
I/N dB	-6	-6	-6	-6
Ge dBi	40	0	40	0
Imax dBm/BW	-141.69	-141.69	-141.69	-141.69
propagation exp	2	2	2	2
Tx power dBm/BW2 Note	-7	-7	0	0

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[3] ITU Radio regulations Footnote 5.340

	Heliradar system 1 Amateur	Heliradar system 1 Amateur	Heliradar system 2 Amateur	Heliradar system 2 Amateur
Tx power dBm/MHz	-7.00	-7.00	0.00	0.00
Tx power/BW1	-32.69	-32.69	-25.69	-25.69
distance km	8.68	0.09	19.43	0.19

1. mitigation factors have been included (see section 2.5)

It can be concluded that the only critical scenario would be an helicopter transmitting into the mainbeam of an amateur station. Therefore, the next section will deal with the likelihood of that situation.

4.3.2 Compatibility for the Amateur Service

The principle concern is the likelihood of a Helicopter and amateur station in proximity and in the main beam. The ETSI system reference document for the Helicopter system (ETSI TR 103 137 v1.1.1[1]) provides a useful amount of information on market size etc. in the European Union. This is complemented by assuming a modest growth in the number of amateurs since ECC Report 056 [10] was issued in 2004.

The below table considers the radar on time per day from section 2.4 and calculates the occurrence probability of main beam coupling.

Table 16: Occurrence probability of mainbeam coupling

	Scenario A	Scenario B	Scenario C	Scenario D
System on time per area per seconds per day [sec/day/km²]	0.08	1.52	0.37	1.49
beam width [°]	1.8			
worst case separation distance km	19.43			
area of vulnerability [km²]	5.93			
system on time within an amateur main beam per seconds per day	0.5	9.0	2.2	8.9
percentage of system on time within an amateur main beam per day	0.001%	0.010%	0.003%	0.010%

The likelihood of main beam coupling problem is well below 0.1%.

For the relatively rare cases where main beam coupling may occur, consideration of the two classes of helicopter radar and amateur activity may provide additional mitigation:-

- Amateurs generally operate on a Listen-Before-Transmit (LBT) basis and are largely portable stations. Currently there are very few fixed links or omni- directional propagation beacon/repeater systems;
- In the 76-77 GHz range the most sensitive amateur operations tend to be at the lower band edge as described in Section 3.2;
- In the wider 76-79 GHz range, the beam and frequency scanning for the long range radar variant can reduce the intercept probability even further.

Good compatibility is therefore likely for both helicopter and portable/directional terrestrial amateur stations, even allowing for uncertainty/growth in both uses over the coming years.

Note: Should the number of fixed or higher power amateur stations grow in future - a more rigorous treatment might be required, but that does not seem necessary at this time.

4.3.3 Compatibility for the Amateur-Satellite Service

Should Amateur Satellites start to use the band the most likely scenario is a nano or picosat (also called ‘cubesat’) would carry a low power beacon in a low earth orbit (LEO) of 600-800km altitude in the amateur Primary allocation at 77.5-78 GHz. Ground stations would probably use a steerable high gain antenna and a frequency tracking receiver that can account for Doppler shift etc. The following may provide some future guidance:

Amateur Satellite to Helicopter

The Helicopter radar system reference document (ETSI TR103 137, [1]) indicates that the vertical half power beamwidths are either 6° degrees (Long Range Radar) or 10° degrees (for Short Range Radar) and nominally horizontal elevation looking at the horizon. Therefore the helicopter receiver is unlikely to see any increase in noise floor due to an overhead low-power downlink (which may only be present for about 10 minutes as the satellite transits the sky).

Helicopter to Amateur Ground Station

As the amateur ground station would be tracking the satellite position with an elevated high gain antenna above the horizon, the most likely sharing situation would be sidelobe (0dBi gain) rather than main beam compatibility.

In both the above cases co-existence would be expected and the result is good compatibility with the Amateur Satellite Service.

4.4 VEHICULAR RADARS

The band 76-79 GHz is also used by vehicular radars using similar technology to the airborne surveillance radar application. Recommendation ITU-R M.2057-0 [14] gives systems characteristics and protection criteria of automotive radars operating in the frequency band 76 to 81 GHz for intelligent transport systems applications.

Figure 10 shows the scenario with typical antenna characteristics of both systems.

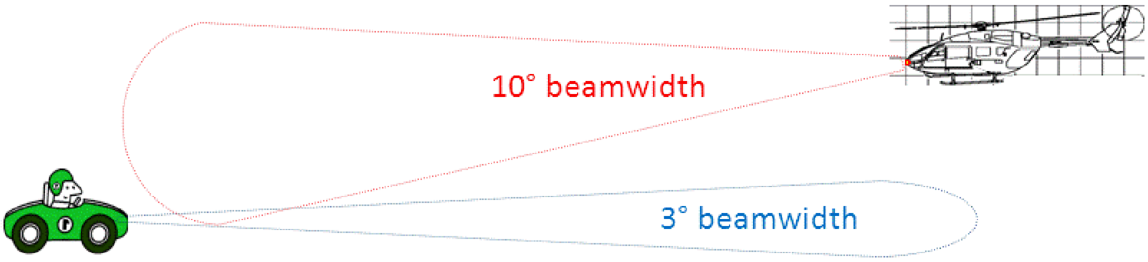

Figure 10: Scenario vehicular radar vs helicopter

Table 17 gives the parameters used for the vehicular radar in this section.

Table 17: Vehicular radar system parameters

Parameter	Value
f/GHz	76-81 GHz
Ps dBm/BW1	10
BW1 MHz	1
Gs dBi	30
noise figure dB	15
Noise floor dBm	-99,00
Protection criterion INR dB	-6
Antenna beamwidth	3°

The interference to noise ratio (INR) at the vehicular radar receiver is first calculated based on free space loss (see Figure 11).

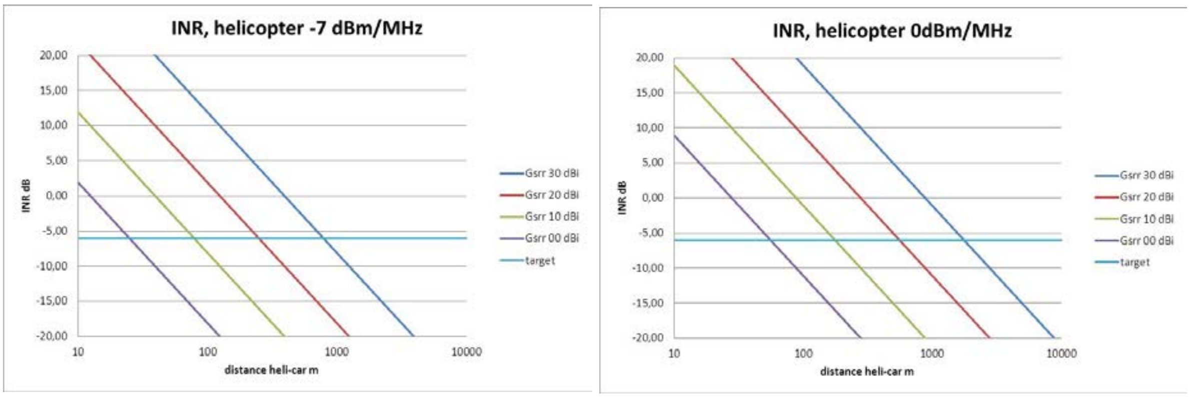

Figure 11: INR calculations

The impact is analysed further considering the wanted received signal level at the vehicular radar. Similar to the approach taken in ECC Report 137 [15] the received wanted power p_e at the vehicular radar can be derived using the radar equation:

$$p_e = \frac{p_{srr}.g_{srr}}{\left(4\pi R^2\right)^2}.\sigma.\frac{g_{srr}\lambda^2}{4\pi} = p_{srr}.\left(g_{srr}\right)^2.\underbrace{\frac{4\pi\sigma}{\lambda^2}}_{ts}.\left(\underbrace{\left(\frac{\lambda}{4\pi R}\right)^2}_{1/pl}\right)^2$$

Translated in dB, this leads to the following formula:

$$P_e = P_{srr} + 2G_{srr} + TS - 2PL$$

with:

TS : Vehicle Target Strength, defined as

$$TS = \text{RCS} + 10Log\left(\frac{4\pi}{\lambda^2}\right)$$

RCS : Radar cross section =10log(σ)

P_{srr} : SRR power

PL : Free space propagation loss (equal to $20*\log(4\pi R/\lambda)$)

G_{srr} : SRR antenna gain

Table 18 summarises typical RCS values.

Table 18: RCS assumptions

Parameter	Unit	Value
frequency	Hz	7,60E+10
lambda	m	0,003947368
Radius sphere	m	1
RCS conductive sphere	m^2	3.1
	dB	5
average RCS car	m^2	100
	dB	20
corner reflector dimension	m	0.6
RCS corner reflector	m^2	8710
	dB	39.4
flat conductive plate Area	m^2	1
RCS flat conductive plate	m^2	806481.7
	dB	59.1

Annex 3 of ECC Report 137 [15] provides more information on RCS values.

Figure 12 and Figure 13 are providing the resulting C/(I+N) at the vehicular radar receiver for both helicopter radar systems and a typical radar cross section of a car of 100 m^2. Free space loss is also assumed here.

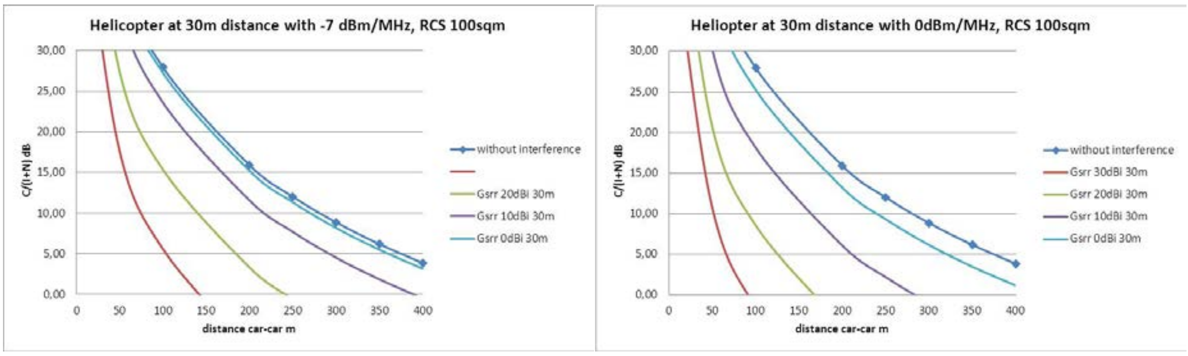

Figure 12: C/(I+N) for the helicopter at 30m from the vehicular radar with variable gain of the vehicular radar seen be the helicopter (left figure low power helicopter radar, right figure higher power helicopter radar)

It can be seen from the curve without interference that the max target distance for the chosen RCS is about 300m for a signal to noise ratio of about 8 dB. The degradation due to interference in Figure 12 is shown at an exemplary distance between helicopter and vehicular radar of 30m. The following figure gives the results for a distance between 15 and 40 m.

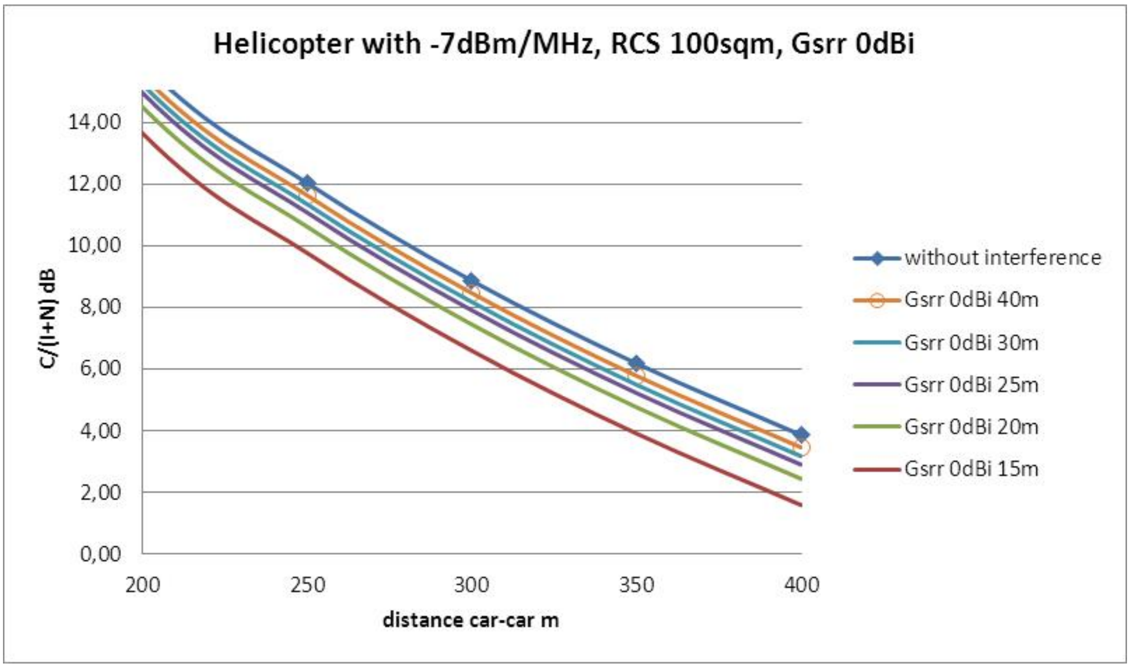

Figure 13: C/(I+N) for the helicopter between 15 and 40m from the vehicular radar seen under 0dBi by the helicopter

The required altitude of the helicopter to be in the mainbeam of the very narrow vehicular radar antenna is shown in Figure 14 (3° beamwidth, Horizontal pointing).

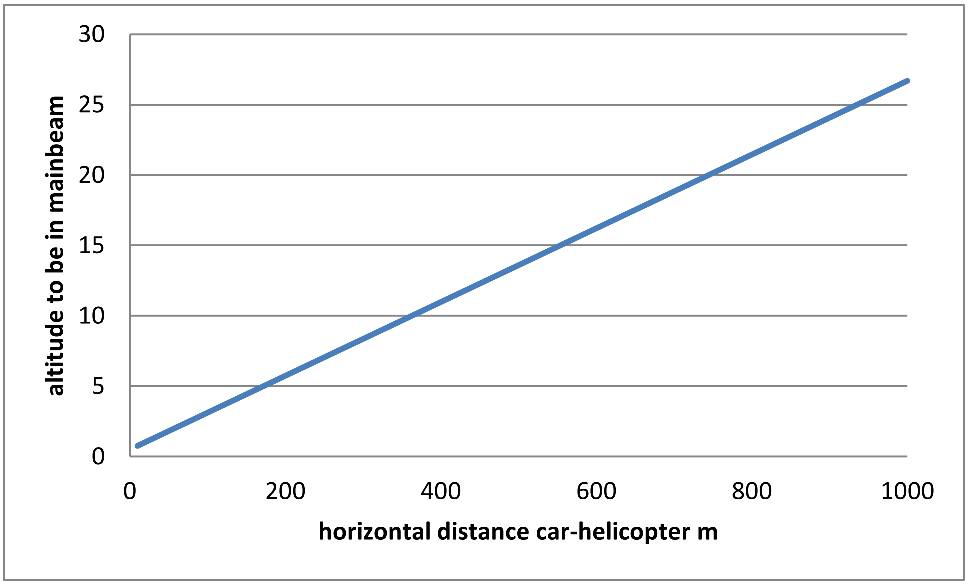

Figure 14: max helicopter altitude to be in the mainbeam of the vehicular radar

That means the helicopter is only in the mainbeam of the vehicular radar at very low altitudes when the helicopter is expected to approach for landing.

Summary:

The INR protection criterion of -6dB can be reached in the sidelobe of the vehicular radar (0dBi) with a separation distance of about 50m for the low power helicopter radar and 170m for the higher power helicopter radar. The SNR calculations with a radar cross section of a typical target show similar results with slightly smaller distances (30m for the low power system). From this it can be concluded that no problem is expected for usual flying altitudes of a helicopter above 200m and cases where the helicopter is in the sidelobe of the vehicular radar. In the mainbeam much higher separation distances are required. Therefore the only critical situation is when the helicopter is coming to the mainbeam of the vehicular radar. However, this situation is not expected to cause a problem because

- This happens only when the helicopter is flying at very low altitudes below 30m close to a highway and when the helicopter is landing on a highway;
- For a helicopter assisting in a road accident the traffic is considered to be stopped, rerouted or be moving slowly. Traffic will be kept at a safe distance from the landing helicopter. The helicopter is also not necessarily landing on the road;
- Considering the scenario of a helicopter landing in a road traffic environment (e.g. to assist during an accident) the interferer and victim radar systems will be operating at different altitudes and orientations. It is considered unlikely that any interference is received through the main beam;
- Because of the relatively low number of helicopter and because only a small percentage of helicopter operations is performed close to road traffic (only emergency missions) the probability of interference is considered to be low;
- Both radar types (vehicular and helicopter radar) are likely to use FMCW modulation that mitigates the mutual interference. Here it should be considered that the distance between interferer and victim is assumed to be much larger than in the inter-vehicle situation;
- The beam and frequency scanning capabilities of both radar types can reduce the intercept probability even further.

4.5 FIXED RADARS

The band 76 to 77 GHz is also used by fixed infrastructure radars. These use similar technology to vehicle radars but with the following differences.

- Antennas can be slightly larger than those on vehicles, and therefore are narrower beamwidth and higher gain;
- They are generally mounted at heights of 3 to 5 m and with the antenna pointed slightly downwards from the horizontal;
- A typical fixed radar has an antenna that scans in azimuth;
- The observation range is greater than for vehicle radars, e.g. 1000 m.

A fixed infrastructure radar is expected to operate in the presence of other radars, including vehicle radars.

In similar manner to the discussion regarding vehicle radars, a helicopter borne radar would only be expected to cause a problem to a fixed radar if the helicopter was landing in the field of observation of the fixed radar, and then only in that particular direction.

One of the main applications of fixed radars is for traffic management and automated incident detection. If a helicopter were attending a traffic incident, then a temporary interruption to automated incident detection surveillance would be acceptable.

5 CONCLUSIONS

Radioastronomy (co-channel)

Separation distances between 47 km and 98 km are required under worst case assumptions (see section 4.2.2) to protect the RAS stations in Europe (see ANNEX 2:). The difference between the near field and medium range obstacle detection system is small (near field system 47-98 km, medium range system 57-98 km). The altitude of the helicopter has an essential impact on the separation distance (altitude 300m: separation distance 98 km, altitude 0 m: separation distance 29 km. The above mentioned distances are derived for an effective antenna height on the radio astronomy site of 50 m. The effect of the terrain can increase the size of the separation distances (e.g. 98 km could increase to 115 km) in case of RAS located in elevated positions (or when the helicopter would fly at greater altitudes) or reduce it when the terrain offer shielding to the radio astronomy site. As an example the impact of the terrain at the RAS station Plateau du Bure is shown in ANNEX 6:. It will be left to Administrations to identify, where necessary, the size and shape of the exclusion zone to protect radio astronomy sites, by using appropriate digital terrain models.

The occurrence probability has also been analysed in this report. As a limit the data loss value of 2% from [4] maybe applicable as the percentage of lost observation packets each 2000 s period over one day.

The simplest interpretation would to restrict the helicopter radar activity around the RAS station to fulfil the 2 % per day. This would mean a maximum on-time of 28.8 minutes a day, or about six Take-Offs and Landings per day (assuming 5 minutes transmitter on-time each landing and take-off).

More detailed occurrence probability calculations are provided in addition considering assumptions on helicopter deployment. As a result the occurrence probability shows a huge variance. The following Table summarises the situation.

Table 19: summary of results

	Scenario A	Scenario B
Description	Used for 25% of missions and only for take-off and landing (10% of flight hours)	Used for 100% of missions and for 50% of flight hours
Example 1: 98 km separation distance with 300 m altitude, atmospheric loss 0.15 dB/km, 650 MHz RAS bandwidth	Occurrence probability 2.7% Radius of exclusion zone 48.9 km	Occurrence probability 53.2% Radius of exclusion zone 96.1 km
Example 2: 47 km separation distance with 300 m altitude, atmospheric loss 0.35 dB/km, 8 GHz RAS bandwidth, near field obstacle detection system	Occurrence probability 0.6% Radius of exclusion zone 0 km	Occurrence probability 12.2% Radius of exclusion zone 43 km

It was not possible in this report to determine a representative result for the occurrence probability and exclusion zone.

Therefore, administrations should decide on a national level on the need for and the size of an exclusion zone.

The procedure in Annex 10 is one example of an assessment method that might be used on a national level.

No differentiation has been made between rescue (which is only a fraction of all operations, see chapter 2.4) and non-rescue helicopter missions in the above calculations, because this is seen as outside the scope of this report.

This report does not consider military helicopters because the information about military use was not available. It is expected that military helicopters equipped with the radar systems will increase the interference probability. Administrations are urged to consider the actual deployment of military helicopters when establishing coordination zones.

Radiostronomy (unwanted emission 89 GHz)

An adjacent band compatibility study is provided for 89 GHz as this is a passive band[4]. One may expect similar results for all RAS bands adjacent to the helicopter radar band (e.g. 79-86 GHz, 92-94 GHz and 94.1-116 GHz).

The equivalent maximum unwanted emission e.i.r.p are dependent on the assumed separation distance. The calculated unwanted emissions limits under the assumption of a uniform flat distribution of the spurious limit over 6 GHz bandwidth are:

- with 200m assumed separation distance about -70 dBm/MHz;
- with 1 km assumed separation distance -57 dBm/MHz;
- with 10-25km assumed separation distance -30 dBm/MHz.

Amateur Service

MCL calculations in this report concluded that the only critical scenario would be a helicopter transmitting into the mainbeam of an amateur station. The likelihood of that situation is estimated to be well below 0.1%. Good compatibility is therefore likely for both helicopter and portable/directional terrestrial amateur stations, even allowing for uncertainty/growth in both uses over the coming years.

Radio Location

Information from NATO are mentioned in ECC Report 056 [10] and ECC/DEC/(04)03 [12] that there are currently no radiolocation systems operational in the band and there are no plans to introduce such systems. No studies were conduct since no other information was received.

Vehicular radars

The only critical situation is when the helicopter is coming to the mainbeam of the vehicular radar. However, this situation is not expected to cause a problem because

- This happens only when the helicopter is flying at very low altitudes below 30m close to a highway and when the helicopter is landing on a highway;
- For a helicopter assisting in a road accident the traffic is considered to be stopped, rerouted or be moving slowly. Traffic will be kept at a safe distance from the landing helicopter. The helicopter is also not necessarily landing on the road;
- Because of the relatively low number of helicopter and because only a small percentage of helicopter operations is performed close to road traffic (only emergency missions) the probability of interference is considered to be low;
- Both radar types (vehicular and helicopter radar) are likely to use FMCW modulation that mitigates the mutual interference. Here it should be considered that the distance between interferer and victim is assumed to be much larger than in the inter-vehicle situation;
- The beam and frequency scanning capabilities of both radar types can reduce the intercept probability even further.

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[4] ITU Radio regulations Footnote 5.340

Fixed radars

In similar manner to the discussion regarding vehicle radars, a helicopter borne radar would only be expected to cause a problem to a fixed radar if the helicopter was landing in the field of observation of the fixed radar, and then only in that particular direction. A fixed infrastructure radar is expected to operate in the presence of other radars, including vehicle radars.

One of the main applications of fixed radars is for traffic management and automated incident detection. If a helicopter were attending a traffic incident, then a temporary interruption to automated incident detection surveillance would be acceptable.

Limitation of helicopter radars

The following table provides the limits used in the studies in this report. They were derived from the technology specific limits from the ETSI SRdoc [1].

Table 20: possible limitation

	Low power system	Medium power system
Frequency band	76 to 79 GHz	76 to 79 GHz
Peak power e.i.r.p. Note 2	26 dBm	33 dBm
Mean average power density e.i.r.p. Note1, Note 2	0 dBm/MHz	10 dBm/MHz
Mitigations	DC 20%/s (7 dB)	DC 40%/s (4dB) 25% (6 dB) mainbeam occurrence probability each 10°

1. This is the mean power during RF transmitter ON- time and measured with 1 ms dwell time per 1 MHz.
2 These are typical values at standard ambient conditions

ANNEX 1: GENERIC POWER AND BANDWIDTH REQUIREMENTS OF HELICOPTER OBSTACLE DETECTION RADARS

A1.1 THEORETICAL ASSUMPTIONS

Detection Task:

A reflecting obstacle with a cross-section of $\sigma := 1\cdot\mathrm{cm}^2$ should be detected within $\tau_{rx} := 0.1\cdot\mathrm{s}$ from a minimum distance of d =40 m with an accuracy of $\Delta x := 20\cdot\mathrm{cm}$.

Bandwidth requirement:

The detection error is inversely proportional to the modulation bandwidth of the radar signal:

$\Delta\nu_{tx} := \frac{c}{2\cdot\Delta x}$, in this case yielding a minimum

$$\Delta\nu_{tx} = 749.481\cdot\mathrm{MHz}$$

Radar link loss:

The operating frequency shall be $\nu_o = 77\cdot\mathrm{GHz}$ for which the effective radar cross-section $RCS := \frac{4\cdot\pi\cdot\sigma^2\cdot\nu_o^2}{3\cdot c^2}$

of the obstacle is $RCS = 2.763\cdot 10^{-3}\cdot\mathrm{m}^2$ = - 25 dBsm

The radar equation $P_r = \frac{P_{tx}\cdot 10^{\frac{G_{tx}}{10}}\cdot A_{rec}\cdot RCS}{\left(4\cdot\pi\cdot d^2\right)^2}$

is used to calculate the power P_r reflected from an obstacle with reflection cross-section RCS at a distance d for a receiving antenna of effective area A_{rec} and a transmitted power P_{tx} (W) being emitted using an antenna with a gain G_{tx} (dBi). The ratio

$$A_{refl}\left(G_{tx}, A_{rec}, RCS, d\right) := 10\cdot\log\left[\frac{10^{\frac{G_{tx}}{10}}\cdot A_{rec}\cdot RCS}{\left(4\cdot\pi\cdot d^2\right)^2}\right]$$

maybe termed the radar coupling loss.

Assuming that the transmitter antenna gain is e.g. $G_{tx} := 18$ dBi and the effective area of the receiving antenna is $A_{rec} := 0.05\cdot\mathrm{m}^2$, then the link loss amounts to

$$A_{refl}\left(G_{tx}, A_{rec}, RCS, d\right) = -106.663 \quad \mathrm{dB}$$

Typical receiver characteristics:

The received bandwidth may be split into (overlapping) channels each having an assumed bandwidth of $\Delta\nu_{chan} := 10\cdot\mathrm{MHz}$ and a noise level of 15 dB.

with $T_{noise}(dB) := 290\cdot\left(10^{\frac{dB}{10}} - 1\right)\cdot K$ we obtain the receiver noise level of

$$N_{rx} := 10 \cdot \log\left(\frac{k \cdot T_{noise}(15) \cdot \Delta\nu_{chan}}{mW}\right)$$ or $N_{rx} = -89.115$ dBm.

Being able to integrate the received signal during processing of the individual channels for a maximum time given by the reaction time of the system, $\tau_{rx} := 0.1 \cdot s$ we obtain a channel system sensitivity (S/N=1) of $N_{sys} := N_{rx} - 5 \cdot \log\left(\tau_{rx} \cdot \Delta\nu_{chan}\right)$ or $N_{sys} = -119.115$ dBm.

Required Transmitter Power:

Assuming that a link margin of additional $SN := 10$ dB is needed for reliable detection under difficult conditions, then the required transmitter input power is given by

$$P_{in} := N_{sys} - A_{refl}\left(G_{tx}, A_{rec}, RCS, d\right) + SN$$

yielding $P_{in} = -2.452 \frac{dBm}{\Delta\nu_{chan}}$

corresponding to a total emitted in-band power of $P_{tot} := P_{in} + 10 \cdot \log\left(\frac{\Delta\nu_{tx}}{\Delta\nu_{chan}}\right)$ or

$$P_{tot} = 16.296 \quad \text{dBm}$$

adding the antenna gain yields an in-band e.i.r.p. of at least

e.i.r.p. = $P_{tot} + G_{tx} = 34.296$ dBm

That means a peak power of about 34 dBm within 800 MHz would be required.

A1.2 EXISTING SYSTEM

Detection Task:

A high tension wire with a radar cross-section of $\sigma t = -25\ dBsm$ (31 cm²) should be detected within

Trx = 3.5 msec with an update rate of 30 Hz from a minimum distance of d =40 m with an accuracy of 25 cm

Bandwidth requirement:

The detection error is inversely proportional to the modulation bandwidth of the radar signal:

$\Delta\nu_{tx} := \frac{c}{2 \cdot \Delta x}$, in this case yielding a minimum bandwidth of Δvtx = 600 MHz.

The radar sensor uses a fast ramp linear frequency modulation. To stabilize the waveform, the oscillator needs some additional bandwidth. In practice, a total Bandwidth of Δvtx = 650 MHz is used.

Radar link loss:

The operating frequency shall be $\nu_0 = 77 \cdot GHz$ for which the effective radar cross-section

of the obstacle is RCS = - 25 dBsm or 0.0031 m² (31 cm²)

The radar equation $$P_r = \frac{P_{tx} \cdot 10^{\frac{G_{tx}}{10}} \cdot A_{rec} \cdot RCS}{\left(4 \cdot \pi \cdot d^2\right)^2}$$

is used to calculate the power P_r reflected from an obstacle with radar cross-section RCS at a distance d for a receiving antenna of effective area A_{rec} and a transmitted power P_{tx} (W) being emitted using an antenna with a gain G_{tx} (dBi). The ratio

$$A_{refl}\left(G_{tx}, A_{rec}, RCS, d\right) := 10 \cdot \log\left[\frac{10^{\frac{G_{tx}}{10}} \cdot A_{rec} \cdot RCS}{\left(4 \cdot \pi \cdot d^2\right)^2}\right]$$

is termed the radar coupling loss.

The transmitter antenna has a gain of Gtx=13 dBi.

The receiver array has a gain of lGrx = 22 dBi

The effective area of the receiver antenna array can be calculated as follows:

$$Arec := \frac{10^{\frac{lGrx}{10}} \cdot \lambda^2}{4 \cdot \pi}$$

This results in an effective area of the receiving antenna

$$Arec = 1.912 \times 10^{-4} m^2$$

Then the link loss amounts to

Arefl = -135 dB

Typical receiver characteristics:

The received bandwidth is split into (overlapping) channels each having a bandwidth of

$$\Delta \nu chan := 0.047 \cdot MHz$$

and a noise level of 15 dB

with $T_{noise}(dB) := 290 \cdot \left(10^{\frac{dB}{10}} - 1\right) \cdot K$ we obtain the receiver noise level of

$$N_{rx} := 10 \cdot \log\left(\frac{k \cdot T_{noise}(15) \cdot \Delta\nu_{chan}}{mW}\right) = -112 \text{ dBm}$$

Being able to integrate coherently the received signal during processing of the individual channels for a maximum time given by the reaction time of the system,

$$\tau rx := 3.5 \cdot ms$$

a channel system sensitivity (S/N=1) of

$$Nsys := Nrx - 10 \cdot \log(\tau rx \cdot \Delta \nu chan) \qquad = -134.6 \text{ dBm}$$

is obtained.

Required Transmitter Power:

Assuming that a link margin of additional $SN := 10$ dB is needed for reliable detection under difficult conditions, then the required transmitter input power is given by

$$P_{in} := N_{sys} - A_{refl}\left(G_{tx}, A_{rec}, RCS, d\right) + SN$$

yielding for Pin = 10.7 dBm.

Adding the antenna gain yields an in-band e.i.r.p. of at least

e.i.r.p. = 10.7 dBm + Gtx = 23.7 dBm

Using state of the art technology, the measured e.i.r.p. at room temperature is 26 dBm (with a measurement bandwidth of > 50 MHz). This increases the link margin to 12 dB.

Furthermore, the transmit power may increase at low temperature by 4 dB.

ANNEX 2: RADIOASTRONOMY STATIONS IN CEPT

The following table lists the RAS stations in ITU region 1 operating in the range 76 to 79 GHz.

Table 21: Use or potentially use of RAS in the 76 to 79 GHz frequency band within CEPT

Observatory Name	Administration	Longitude (E), Latitude (N)	Elevation (m AMSL)	Geographical Characteristics
Plateau de Bure, 12 x 15 m Array, IRAM,	France	05° 54’ 28.5” 44° 38’ 02”	2250	Isolated high mountaintop in line-of-sight to various public facilities
Maido (la Réunion) Horns 0.25 x 0.36 m, 0.70 x 0.48 m Note 2	France	55°23’01” -21°04’46”	2200	Mountain top
Effelsberg, 100m, Note 1	Germany	06° 53’00” 50° 31’32”	369	Broad flat plain exposed to nearby roads
Pico de Veleta, 30 m IRAM	Spain	–03° 23’ 34” 37° 03’ 58”	2850	Mountainside overlooking nearby ski resort, line of sight to city of Granada
Yebes 40m Yebes 14m	Spain	–03° 05’22” 40° 31’27”	981	Broad flat plain exposed to roads
Sardinia Radio Telescope 64 m	Italy	09° 14’40” 39° 29’50”	650	High exposed plain
Onsala 20 m	Sweden	11° 55’35” 57° 23’45”	23	Waterside, forested, relatively isolated
Metsahovi 14m	Finland	24° 23'37" 60° 13'04"	61	
Noto 32 m Note 2	Italy	14°59′20.51″ 36°52′33.78″		Flat exposed plain VLBI
Cambridge 32m Note 2	UK	0°2′13.4″ 52°10′1.2″		Flat terrain

Note 1: at the time of the preparation of this report this station was not able to make measurements in the band 76-79 GHz;
Note 2: those stations are not listed in ECC/DEC/(11)02 [20]

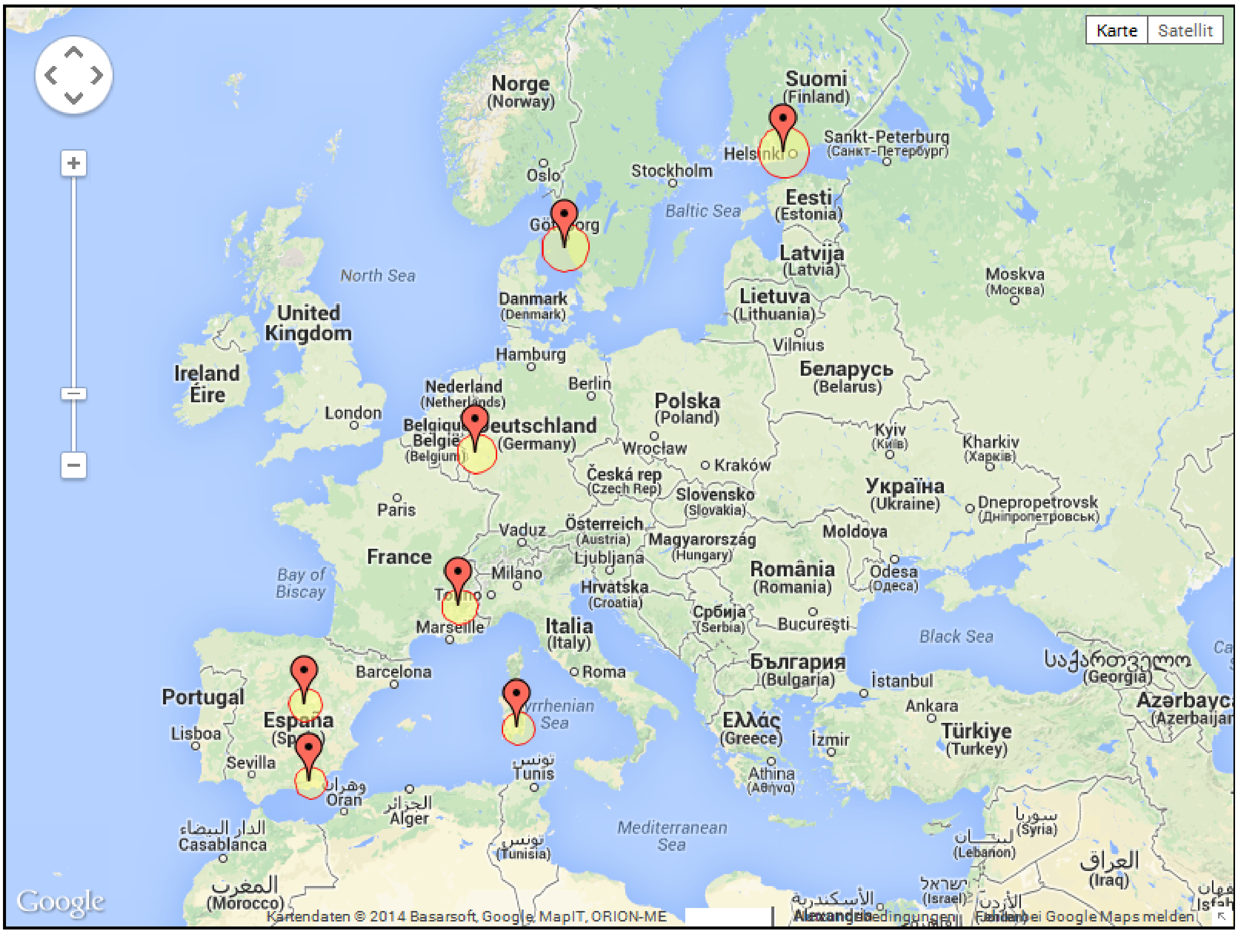


Figure 15: map of Europe considering as an example 80 km radius protection area around Radio Astronomy Stations

ANNEX 3: ANTENNA PARAMETERS

A3.1 ANTENNA GAIN OF NEARFIELD OBSTACLE DETECTION SYSTEM (SYSTEM 1)

The antenna has a gain of typically 13 dBi.

The polarization is linear vertical.

A typical horizontal antenna diagram is shown in Figure 16. The vertical diagram is shown in Figure 17.

The horizontal half power beamwidth is typically 70 degree, without sidelobes as shown in Figure 16.

The vertical half power beamwidth is typically 10 degree with sidelobes below -15 dBc as shown in Figure 17.

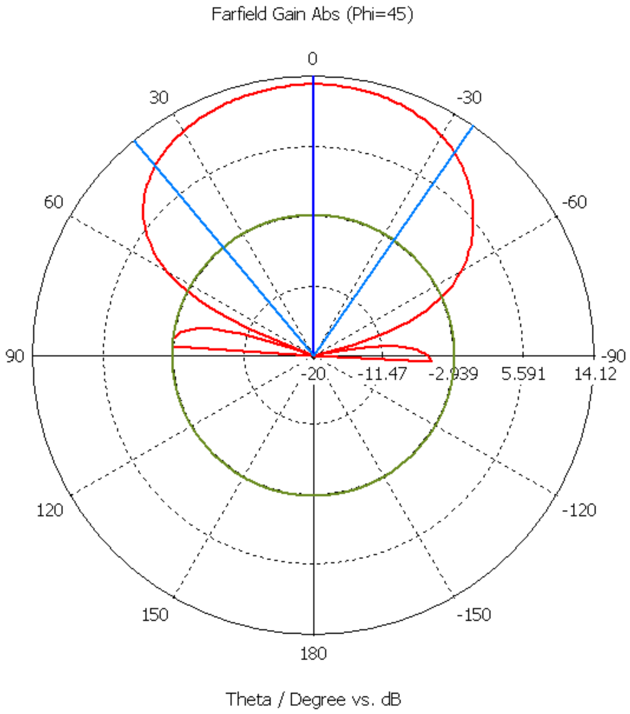


Figure 16: Typical horizontal antenna diagram of the transmit-antenna and of a single receive-antenna

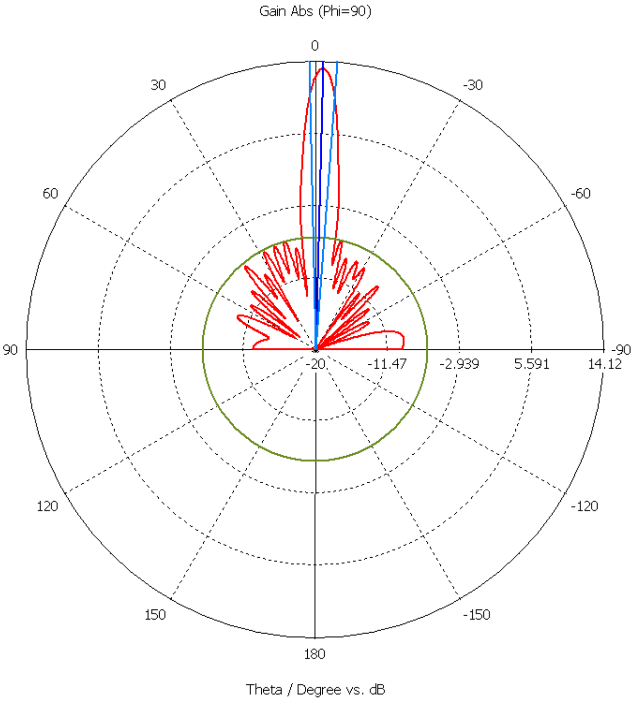


Figure 17: Typical vertical Antenna diagram of the transmit-antenna and the receive-antenna

A3.2 ANTENNA GAIN OF MEDIUM RANGE OBSTACLE DETECTION SYSTEM (SYSTEM 2)

The antenna has a gain of typically 13 dBi. The polarization is linear 45°.

A typical 3D- antenna diagram is shown in Figure 18. The vertical diagram for two different mainlobe-directions is shown in Figure 19.

The horizontal half power beamwidth is typically 70 degree, without sidelobes as shown in Figure 18.

The vertical half power beamwidth is typically 6 degree with sidelobes below -15 dBc as shown in Figure 19.

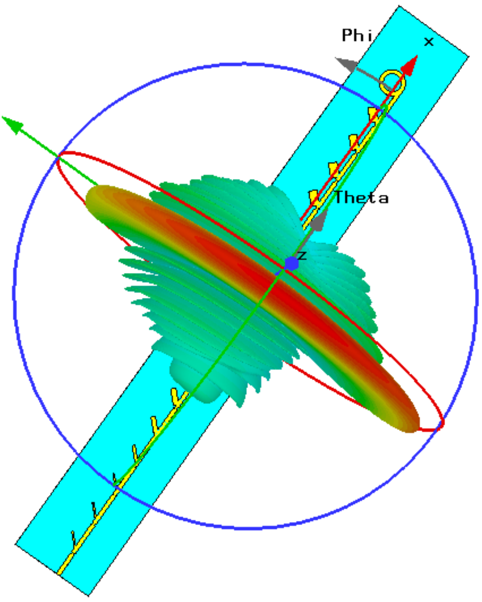


Figure 18: Typical 3D-antenna diagram of the transmit-antenna

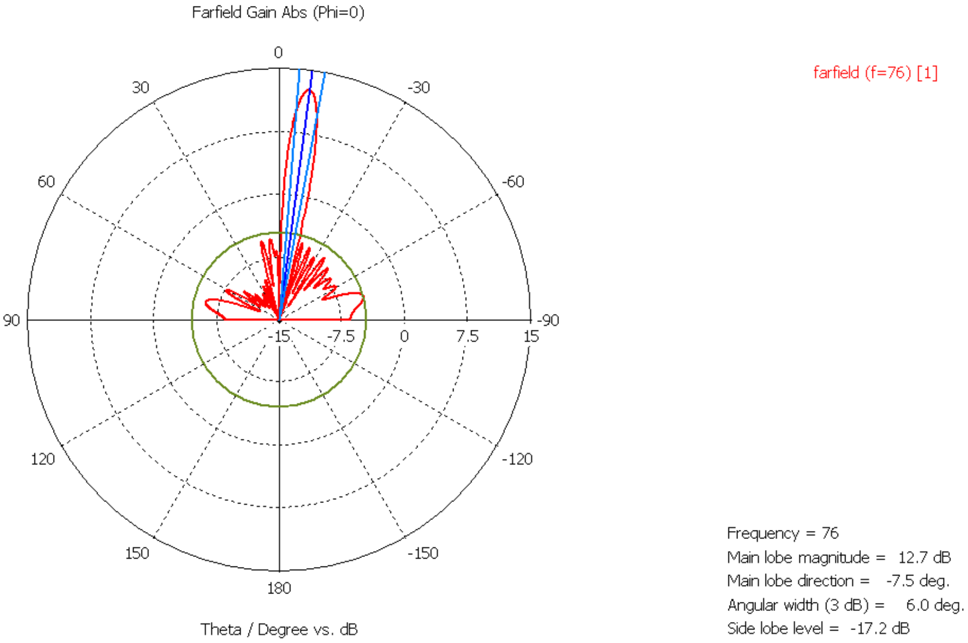


Figure 19: Typical vertical Antenna diagram of the transmit-antenna

Example for the field of view covered by 3 x 3 sensors:

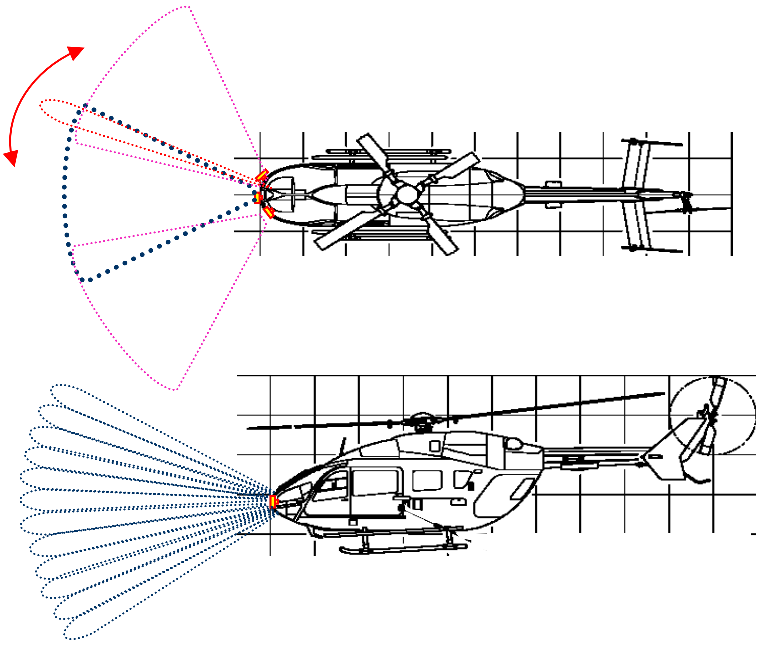


Figure 20: example of antenna steering

The vertical field of view is scanned in 4 cycles. At each cycle 3 antenna beams are active (see Figure below). Within each cycle, the transmitter is powered on for a time of 7 msec. and powered off for a time of 45 msec.; the complete field of view is scanned in 4 x 52 msec = 208 msec.

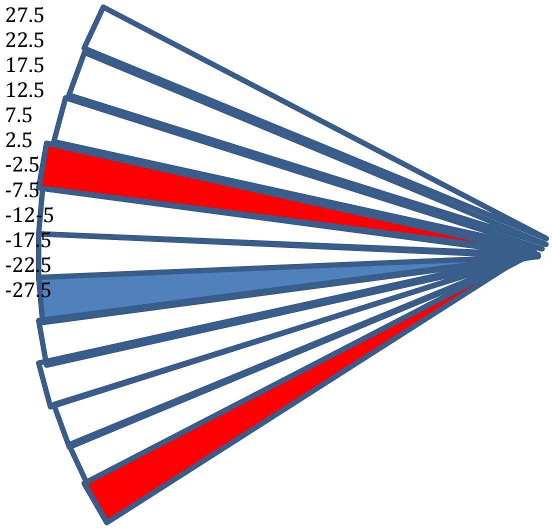


Figure 21: Active antennas at cycle 1

ANNEX 4: RADIO ASTRONOMY AT MILLIMETRE FREQUENCIES

Millimetre radio astronomy is now one of the most dynamic fields of astronomy with major recent achievements in cosmology, extragalactic astronomy and in understanding the processes within star-formation regions. As we move to higher frequency, shorter wavelength observations we are increasingly dominated by considerations of the opacity of the atmosphere. This is highest at the transitions of oxygen at about 60 GHz, 120 GHz, etc. These specific frequencies are effectively impossible to observe from the ground and divide the millimetre spectrum into a series of ‘windows’ in which ground based astronomical observations are possible. Within these windows the effects of atmospheric water vapour give rise to continuous absorption rising rapidly at higher frequencies. Consequently, millimetre wavelength observatories are generally located at high altitude sites (often on mountain tops) to reduce as far as possible the quantity of water vapour lying above them. This has the disadvantage that such observatories often have line of sight paths extending hundreds of kilometres so that they are susceptible to terrestrial interference from a very large area.

In Europe there are single dish millimetre radio telescopes in Finland, Sweden, Turkey, Russia, France, Spain, Italy and a millimetre interferometer array is operating in southern France on the Plateau de Bure (see Annex 2). One of the significant bands in the millimetre regime is at 77 GHz, usually referred to in radio astronomy as the ‘4mm band’.

Scientific Importance of the 4mm Band (76 to 79 GHz)

This wavelength range is remarkably rich in low-lying transitions of important interstellar and circumstellar molecules, especially ‘deuterated’ forms (a form in which some or all of the ’normal’ hydrogen atoms have been replaced by deuterium atoms) of several of the most common types. There is a need for extensive surveys of the most common deuterium-bearing molecules in a large sample of molecular clouds of all variants. The study of molecular deuteration is essential to get insight into the molecular processes that are at work in the interstellar medium. N2D+ is one example molecule that is very useful in this respect, and its 1-0 transition is extremely important for cold environments like prestellar cores.

There are several important spectral lines in the band and examples are listed in Table 22.

Table 22: Molecular transitions in and adjacent to the band 76 to 79 GHz

Molecule	Transition	Frequency (MHz)
DC3N	9-8	75987
DNC	1-0	76306
AlO	N=2-1	76560
N2D+	1-0	77110
C3HD	212-101	78912
CH3NC	4-3	80422

The ALMA interferometer in Chile (in which several astronomical institutes in Europe have a stake) envisages operations on that band as illustrated by Figure 22 (from http://www.alma.ac.uk/other/alma-band-2-workshop/Band2_Capabilities.pdf).

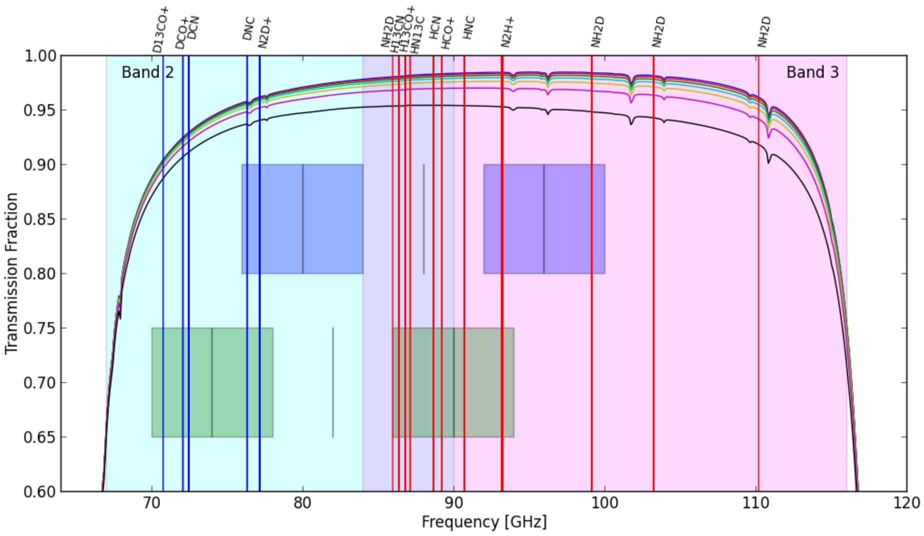


Figure 22: Potential Future ALMA capabilities: ~16 GHz total bandwidth, 4 x 4 GHz basebands assuming a combined Band 2 & 3 receiver. Setup 1 (green): LO freq. 82.0 GHz covering D13CO+, DCO+, DCN, DNC, N2D+, NH2D, H13CN, H13CO+, HN13C, HCN, HCO+, HNC, N2H+ Setup 2 (blue): LO freq. 88.0 GHz covering DNC, N2D+, N2H+ and NH2D

As ALMA is restricted to observing the southern sky, radio astronomy needs similar capabilities on the northern hemisphere, a role filled by the observatories listed in ANNEX 2:.

Another area of considerable interest concerns the potential temporal and spatial variations of ‘constants’ of nature. Small variations of the ratio of masses of electron and proton with cosmic time are predicted in some theories of particle physics and cosmology. Variations of these constants can be measured by comparing frequencies of spectral lines that depend differently on the constants. By observing selected molecular lines in a source at high redshift, one can compare the frequencies as they were in the early universe with the corresponding frequencies ‘now’ in the laboratory. Systematic errors are reduced considerably if all lines can be observed with the same telescope. This is possible for example with the Onsala 20m telescope (Sweden) where observations can be done in the ranges 18 to 50 GHz and 70 to 116 GHz.

A more speculative area of research, but certainly a very challenging and important topic of contemporary astronomy is the search for signals from the cosmic dark ages. Spectral lines from atoms and molecules in primordial perturbations at high redshifts can give information about the conditions in the early universe before and during the formation of the first stars; detection here would be extremely important. Several international groups around the world are now preparing future strategies and observations to search for signals from this epoch. The predicted redshifts for the first star formation imply that the redshifted frequencies from this epoch of the lowest transitions from several important primordial species will fall into the 4 mm band.

ANNEX 5: CONSIDERATION OF DEMOGRAPHICAL ASPECTS

In Germany, 78.500 primary HEMS missions have been performed in 2011 (see [16]). This result in a possible number of 157.000 landings / take-offs for this mission. Related to the population of 80 million people in Germany, 1 take-off and landing can be assumed per 1000 persons. As the level of public service provided and therefore also the number helicopters used for HEMS, law enforcement, firefighting etc. also correlate to a country's GDP (Gross Domestic Product), the number of HC operations in Germany are thought to be among the highest in Europe.

For the example of Pico de Veleta (where a RAS station is located, see Figure 23 below and ANNEX 2:) the occurrence probability is now analysed based on the number of 1 take-off and landing per 1000 inhabitants (derived above from Germany).

Population:

- Province of Granada: 920 000
- City of Granada: 240 000
- Province of Málaga: 1 640 000
- City of Málaga: 570 000
- Province of Jáen: 670 000
- City of Jáen: 120 000
- Province of Almería 640 000
- City of Almería 190 000

100 km range covers Province of Granada, City of Málaga, 1/3 of Province of Málaga, City of Jáen, 1/3 of Province of Jáen, City of Almería, ½ of Province of Almería (inhabitants 920 000, 570 000, 390 000, 120 000, 170 000, 190 000, 230 000):

- 2 590 000 inhabitants ≈ 5 000 take-off and landings per year ≈ 13.7 per day (≈ 5% time of a day assuming 5 minutes per take-off/landing)

50 km range covers 2/3 of Province of Granada including City of Granada (450 000, 240 000):

- 690 000 inhabitants ≈ 1 400 take-off and landings per year ≈ 3,8 per day (≈ 1.3% of a day);
- For 62 km radius the 2% value would be reached.

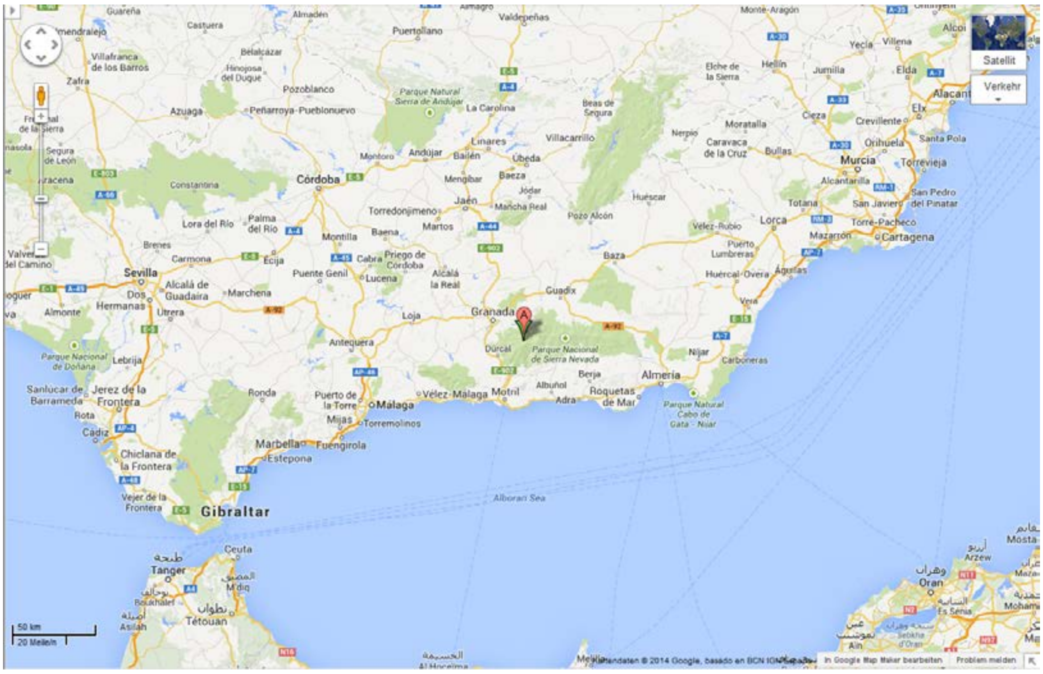
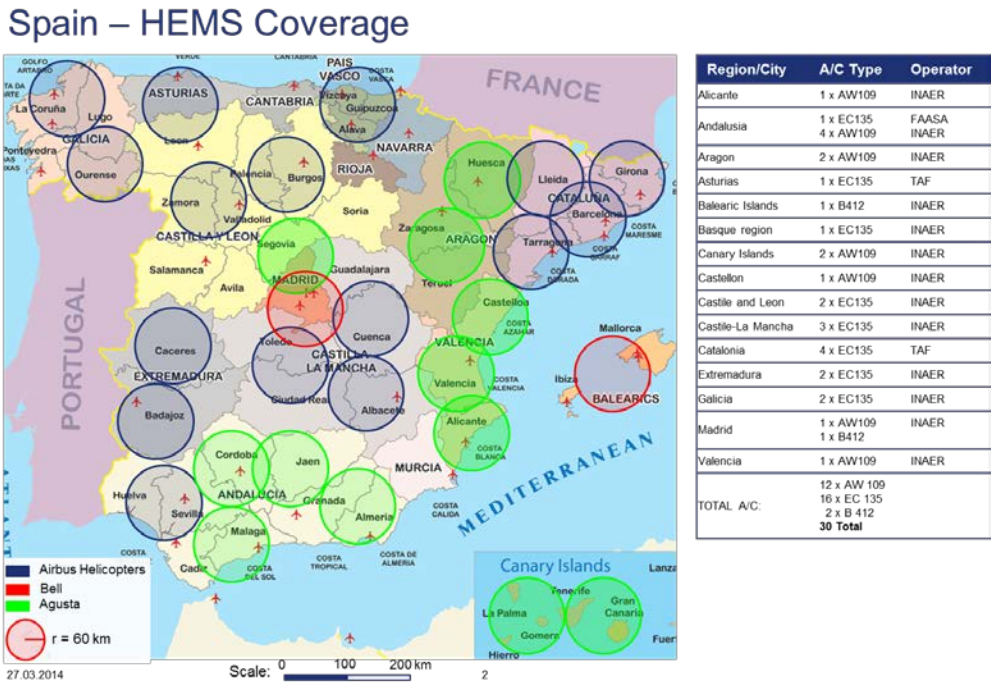


Figure 23: area around Radio Astronomy Station Pico de Veleta, Spain

A5.1 CURRENT COVERAGE OF HEMS HELICOPTERS IN SPAIN

The following figure shows the current coverage of HEMS helicopters across the territory of Spain. The circle represents the operating range of each helicopter. Assuming 50km radius only one helicopter is based in the area of RAS Pico de Veleta.


Spain – HEMS Coverage

Region/City	A/C Type	Operator
Alicante	1 x AW109	INAER
Andalusia	1 x EC135 4 x AW109	FAASA INAER
Aragon	2 x AW109	INAER
Asturias	1 x EC135	TAF
Balearic Islands	1 x B412	INAER
Basque region	1 x EC135	INAER
Canary Islands	2 x AW109	INAER
Castellon	1 x AW109	INAER
Castile and Leon	2 x EC135	INAER
Castile-La Mancha	3 x EC135	INAER
Catalonia	4 x EC135	TAF
Extremadura	2 x EC135	INAER
Galicia	2 x EC135	INAER
Madrid	1 x AW109 1 x B412	INAER
Valencia	1 x AW109	INAER
TOTAL A/C:	12 x AW 109 16 x EC 135 2 x B 412 **30 Total**	

Figure 24: HEMS coverage Spain

ANNEX 6: PROTECTION ZONE FOR THE SITE PLATEAU DU BURE

In the following figures, the antenna height of the radio astronomy site is 15m above ground level. The calculations are performed using a digital terrain model with resolution 50 m.

Figure 25 shows the area in line of sight from the radio astronomy site of Plateau du Bure, from a hypothetical helicopter flying at 30 m above ground.

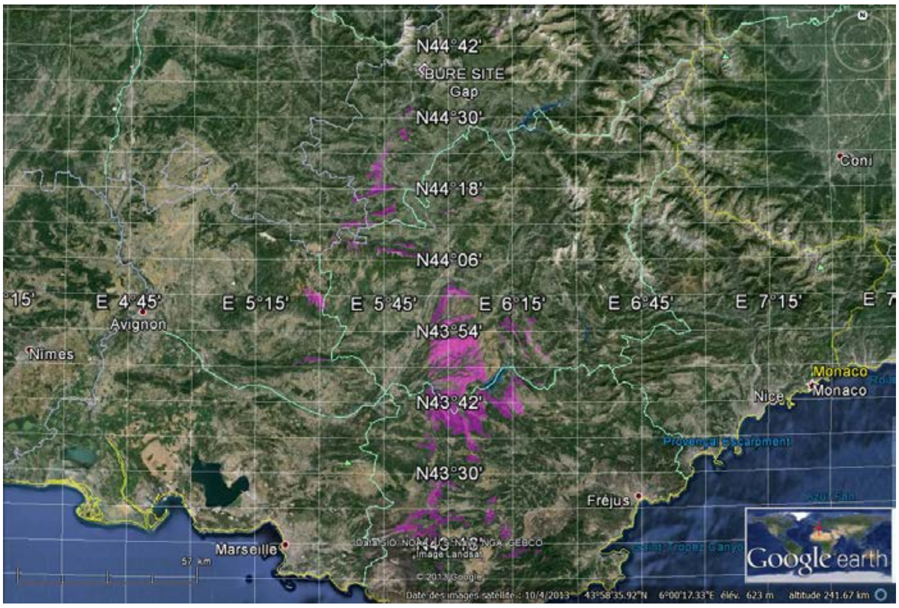


Figure 25: Line of sight zone. Helicopter flying at 30 m above ground

Figure 26 shows the area in line of sight from the radio astronomy site of Plateau du Bure, from a hypothetical helicopter flying at 150 m above ground.

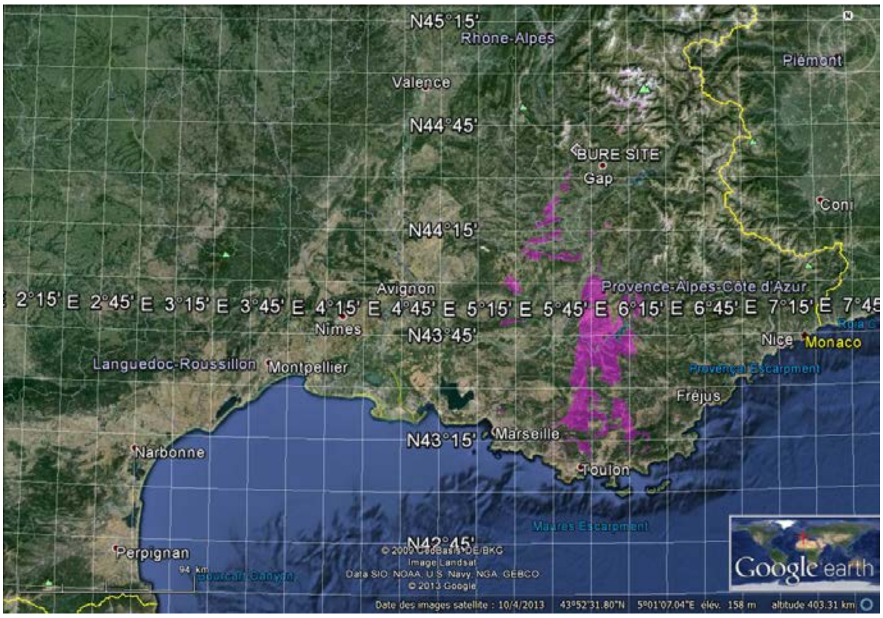


Figure 26: Line of sight zone. Helicopter flying at 150 m above ground

Figure 27 shows the area in line of sight from the radio astronomy site of Plateau du Bure, from a hypothetical helicopter flying at 300 m above ground.

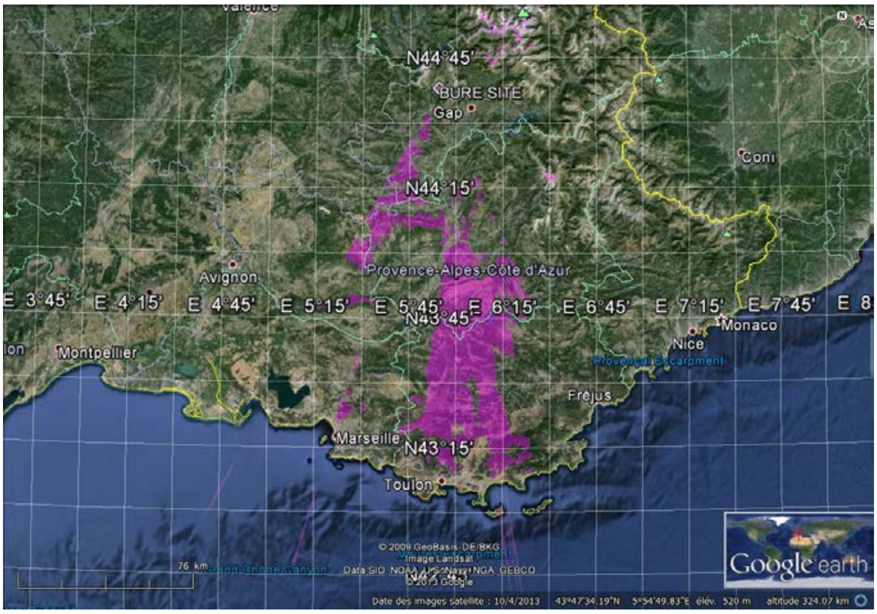


Figure 27: Helicopter flying at 300 m above ground

ANNEX 7: MEASUREMENT EXAMPLES ON HELICOPTER RADAR

Test setup:

The Device under Test (DUT) is mounted on a turntable in an anechoic chamber.
The receiver is placed at a distance of 6.1 m in the farfield of the transmit-antenna.
The calculation of the effective isotropic radiated power (e.i.r.p.) is done with the follwing formula:

$$\mathrm{EIRP} := \mathrm{Pe}\cdot\frac{(4\cdot\pi\cdot R)^2}{\mathrm{Ge}\cdot\lambda^2}$$

with:

- R = 6.1m, λ = 3.9 mm;
- Pe = measured power level;
- Ge = Antenna Gain of the receiver horn-antenna = 22.5 dB.

The e.i.r.p. can be calculated as follows: e.i.r.p. (dBm) = Pe(dBm) + 63 dB.

Spectral measurements:

The receiver block diagram is shown in Figure 28. The use of a fundamental mixer with local oscillator (LO) is recommended due to the broad frequency sweep of 800 MHz from System 1.The LO frequency is set to 75.5 GHz. The RF-Frequency of 76 GHz is converted to 500 MHz.

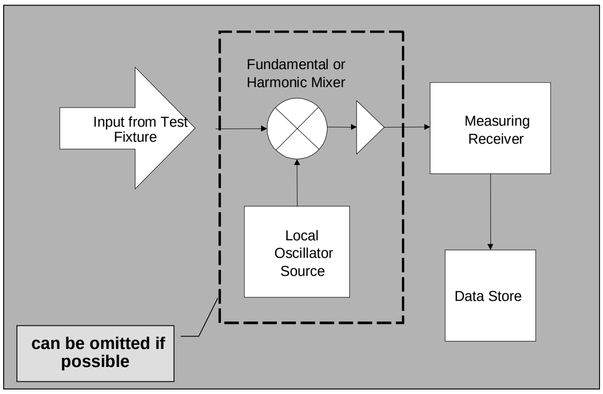


Figure 28: Receiver block diagram

Based on measured values on component levels (antenna and transmitter chip) as well as a timing measurement, a calculation has been made for peak power e.i.r.p. , mean power and mean power density. The measured results from the spectrum-analyser combined with a duty-cycle measurement are compared with those values. The measurement should show good agreement with the calculated values.

Timing Measurements:

The power-on/off time is measured with an oscilloscope and a detector-diode connected to the IF-output of the fundamental mixer.

Measurements on System 1 (near field obstacle detection):

The measured DUT is an engineering sample with 4 dB less output-power compared to the serial product. Figure 29 shows the modulation form. During a timeframe of 4.1 msec. The frequency is sweeped 128 times over a bandwidth of 800 MHz. Following this timeframe, the rf-power is switched off, because no transmission is required during the signal processing time for the rest of the operational cycle. The system has an update-rate of 1/20.4 msec.

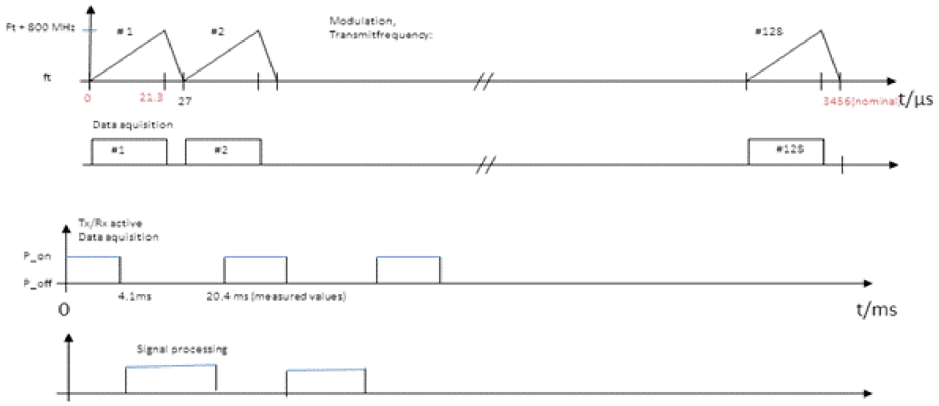


Figure 29: Modulation Scheme & Timing:

System-Calculation, Radar System 1:

- FM-Sweep: 800 MHz;
- Antenna Gain: Gtx=13 dBm;
- Transmit-Power: Pt=13 dBm (at standard ambient conditions);
- Peak power (e.i.r.p.)= Pt + Gtx = 26 dBm;
- Power-On Time: 4.1 msec / Repetition Time: 20.4 msec;
- Duty-Cylce: DC = 20%;
- Mitigation factor in dB: Mitigation = -10*log(DC) = 7 dB;
- Mean power = peak power – mitigation = 19 dBm;
- Mean power density in dBm/MHz (e.i.r.p.) = Mean power – 10log(800) = 19 dBm – 29 dB = -10 dBm/MHz.

Mean power measurements:

Signal source analyzer setup for spectral measurement:

- Resolution bandwidth (RBW) = 1 MHz.;
- Video bandwidth (VBW) = 3 MHz;
- Detector mode: r.m.s.;
- With a span of 1 GHz and 1000 points there is one sample point per MHz or one sample point per RBW;
- Trace: max hold.

Sweep Time 1.00 s

PNO: Fast
IFGain:Low

Trig: Free Run
Atten: 6 dB

Avg Type: RMS
Avg|Hold: 42/100

Mkr1 961 MHz
-71.688 dBm

5 dB/div Ref -40.00 dBm

Start 400.0 MHz
#Res BW 1.0 MHz
#VBW 3.0 MHz*
Stop 1.4000 GHz
#Sweep 1.000 s (1001 pts)

Figure 30: Sweeptime 1 sec, maxhold

e.i.r.p. (DUT,on) = Measured value + 63 dB = -71 dBm/MHz + 63 dB = -8 dBm/MHz
e.i.r.p. (System 1,on) = e.i.r.p.(DUT,on) + 4 dB = -4 dBm/MHz

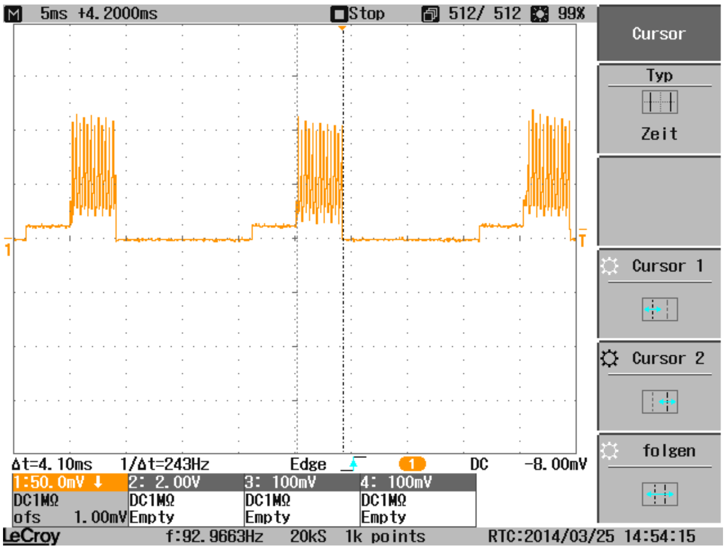
The measured value is considered to be the mean power during the rf -transmitter active time (max hold function).

Taking into account the RF power duty cylce of 20% (- 7 dB mitigation, see Figure 31 and Figure 32) the meanpower is e.i.r.p. (System 1) = e.i.r.p. (System 1, on) – 7 dB = - 10 dBm/MHz.

This value agrees with the calculated mean power density.

Note: The DUT signal contains short-term cw-signal parts, which will lead to peaks in the spectrum. These peaks will be removed for the serial product.

Supplementary Duty-Cycle measurement:



5ms +4.2000ms Stop 512/ 512 99%

Δt=4.10ms 1/Δt=243Hz Edge DC -8.00mV

1:50.0mV DC1MΩ ofs 1.00mV
2: 2.00V DC1MΩ Empty
3: 100mV DC1MΩ Empty
4: 100mV DC1MΩ Empty

f:92.9663Hz 20kS 1k points RTC:2014/03/25 14:54:15

Figure 31: Power_on-time= 4.1 msec

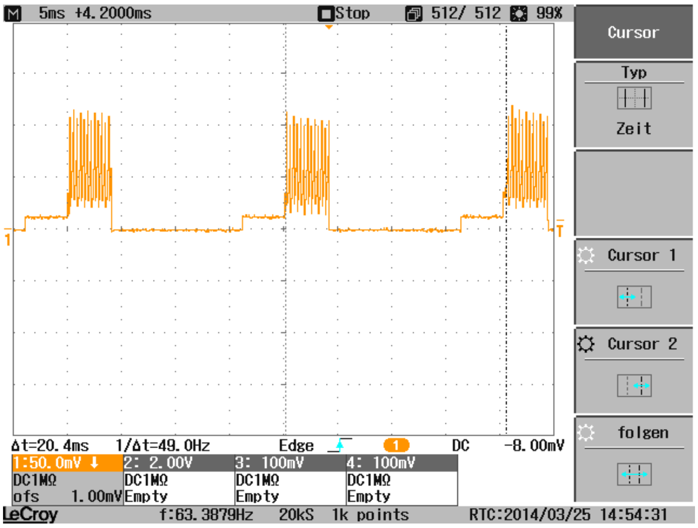


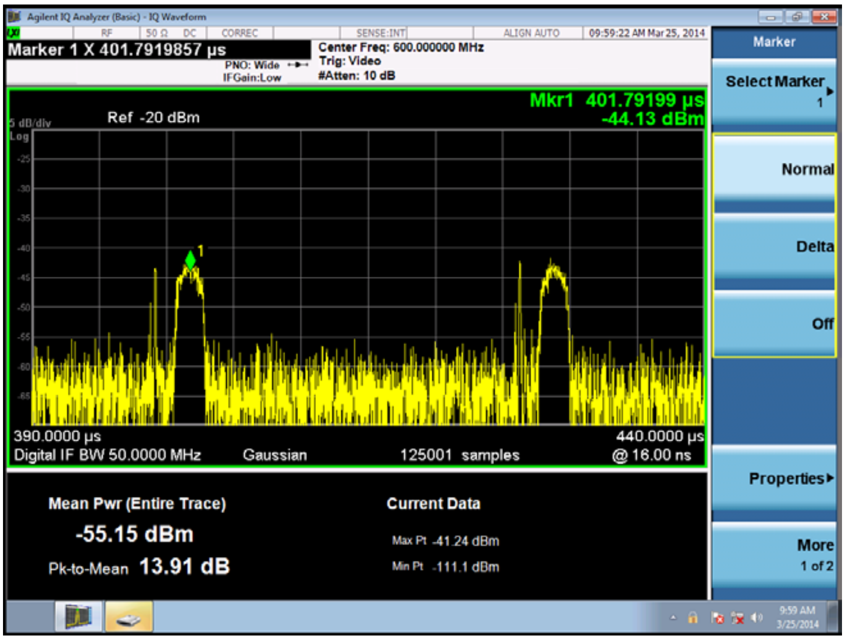
Figure 32: Repetion time= 20.4 msec

➔ Duty cycle = 20 % -> mitigation factor = 10*log(Duty cycle) = - 7 dB

Peak power measurements

Signal source analyser setup:

- IQ-Mode, Output-Power vs. Time, Bandwidth = 50 MHz;
- One 50 MHz-Sample from each frequency ramp at 76.1 GHz (IF = 600 MHz).



Marker 1 X 401.7919857 µs

PNO: Wide

IFGain:Low

Center Freq: 600.000000 MHz

Trig: Video

#Atten: 10 dB

Ref -20 dBm

Mkr1 401.79199 µs -44.13 dBm

390.0000 µs

440.0000 µs

Digital IF BW 50.0000 MHz Gaussian 125001 samples @ 16.00 ns

Mean Pwr (Entire Trace) -55.15 dBm

Pk-to-Mean 13.91 dB

Current Data

Max Pt -41.24 dBm

Min Pt -111.1 dBm

Figure 33: Peak power measurement with 50 MHz Bandwidth

DUT_Peak power (e.i.r.p.) / 50 MHz = measured value (Max Pt) + 63 dB = -41.2 dBm/50 MHz + 63 dB = 21.8 dBm/50 MHz

e.i.r.p. (System 1) = DUT_Peak power (e.i.r.p.) / 50 MHz + 4 dB = 25.8 dBm/50 MHz

(calculated value: 26 dBm)

Comment: The display shows rf-power vs. time. At a selected frequency point, the RF-Power is measured with a bandwidth of 50 MHz. The time between the two peaks corresponds to the time between two frequency ramps (approx. 27 µsec.)

ANNEX 8: POSSIBLE OPERATIONAL RESTRICTIONS

- The system is expected to be used only when operating in a complex and or unknown environment. The pilot is expected to operate the system only when needed. System command and control (ON/OFF) can be exerted manually by the pilot;

- For the operational usage of the system, an automatic mode is necessary, activating the system when the airspeed of the helicopter falls below a predefined value. A manual action by the pilot would increase the workload in a demanding flight phase like approach, take-off or emergency landing;

- The system provides sufficient pre-warning time only when manoeuvring at low-speeds. When the system is switched on, an automatic mode shall inhibit sensor transmission when the airspeed exceeds a predefined value (cruise flight phase). The operational use of the system is not limited by height above ground. An automated control by height is problematic because it is sometimes required to operate near rock face or detect obstacles such as wind turbines or radio masts.

ANNEX 9: ILLUSTRATION OF DISTANCES AND DATA LOSS VALUES

An illustration of the distances and data loss values for the occurrence probability calculations on RAS in section 4.2.5 is given below for the example of 98 km critical range around a RAS and scenario A helicopter deployment.

The 98 km critical range would be applicable under the following assumptions:

- a flat terrain around the RAS station (and thus line of sight up to 100km);
- 50m RAS antenna height;
- a helicopter flying at 300m altitude;
- atmospheric losses of 0.15 dB/km.

Under these assumptions the occurrence probability of helicopter radar transmitter on time within this 98 km radius is 2.8% per day and is in excess of the acceptable data loss value of 2 %.

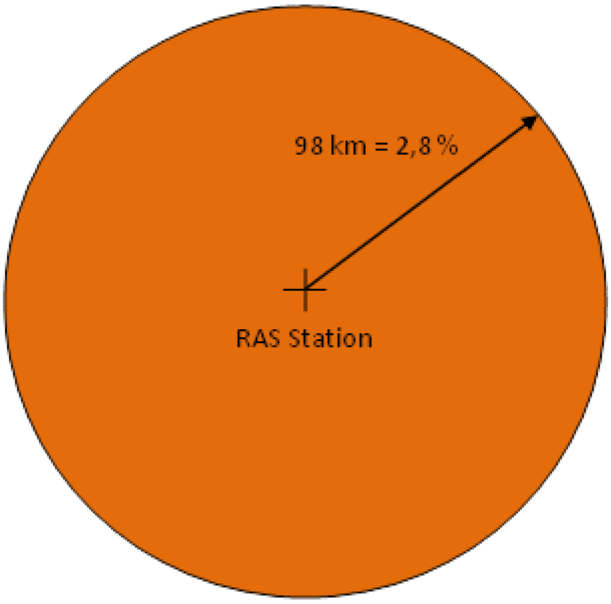


Figure 34: occurrence probability for 98 km without exclusion zone

To reduce the occurrence probability to an acceptable value of 2% an exclusions zone would needs to be installed. The radius of the exclusion zone can be calculated with the formula $R = Rx * \sqrt{(1 - 2\% / Px)}$, where R is the radius of the exclusion zone, Rx the critical range from MCL calculations and Px the occurrence probability within Rx. For the example of Rx=100 km, Px 2.8% the exclusion zone radius R would be 49 km. Figure 35 is illustrating the situation for that example.

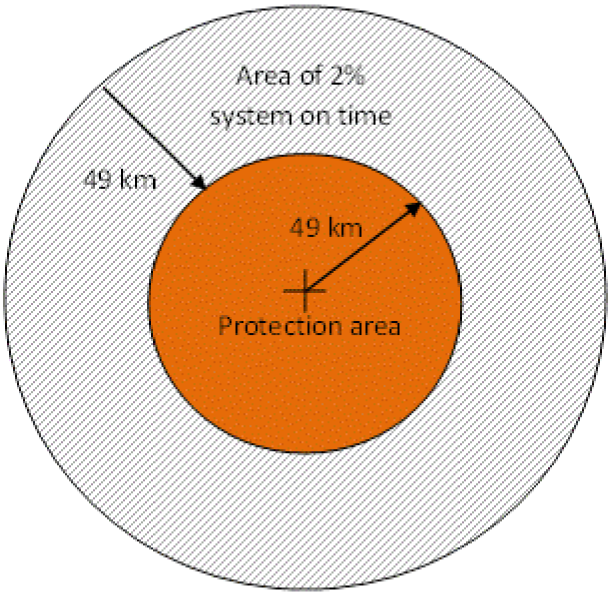


Figure 35: protection area when considering 2% acceptable data loss

ANNEX 10: PROCEDURE TO DECIDE ON A NATIONAL LEVEL ON THE NEED FOR AND THE SIZE OF AN EXCLUSION ZONE

It was not possible in this report to agree on one representative result for the occurrence probability and exclusion zone. Therefore, administrations should decide on a national level on the need for and the size of an exclusion zone.

The following procedure is one example of an assessment method that might be used on a national level.

1. What is the critical range Rx around the RAS station (information from sections 4.2.2, 4.2.3 and 4.2.4);
2. What is the relevant helicopter deployment model (Scenario A, B, C or D in section 2.4). Two options are possible here:
   - Option 1: Without constraining the use of the helicopter radar system to particular flight levels or types of engines
     - Worst case deployment assumptions from scenario B or D should be considered
   - Option 2: The following restrictions could ensure the applicability of the assumptions for the deployment scenarios A and C:
     (a) restricted to turbine engines
     (b) with automatic control to avoid the radar activation at altitudes above 300m
     - ANNEX 8: considers some possible operational restrictions to reduce the radar system on time and thus to reduce the relevance of the above worst case scenarios B and D;
3. Derive from Figure 7 in section 4.2.5 with the results from the first 2 bullets above (critical range and scenario) the occurrence probability Px/%;
4. If Px from the previous bullet 3 gives a value of below 2 %, then no need for an exclusion zone. If Px is above 2 % then calculate with the following formula the radius of the required exclusion zone: $R=Rx*\sqrt{(1-2\%/Px)}$, with where R is the radius of the exclusion zone, Rx the critical range from MCL calculations (section 4.2.2) and Px the occurrence probability within Rx.

ANNEX 11: LIST OF REFERENCE

[1] ETSI TR 103 137 V1.1.1 (2014-01) ”Surveillance Radar equipment for helicopter application operating in the 76 GHz to 79 GHz frequency range”

[2] Recommendation ITU-R RA.769: Protection criteria used for radio astronomical measurements

[3] Recommendation ITU-R P.452-14: “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”

[4] Recommendation ITU-R RA.1513-1: “Levels of data loss to RAS observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the RAS on a primary basis”.

[5] Recommendation ITU-R P.676-8: “Attenuation by atmospheric Gases”

[6] ETSI EN 301 091-1 Radar equipment operating in the 76 GHz to 77 GHz range; Part 1: Technical characteristics and test methods for radar equipment operating in the 76 GHz to 77 GHz range

[7] ETSI EN 302 264-1 Short Range Radar equipment operating in the 77 GHz to 81 GHz band; Part 1: Technical requirements and methods of measurement

[8] European Aviation Safety Agency Annual Safety Review 2011

[9] EHEST Analysis of 2000 – 2005 European Helicopter Accidents

[10] ECC Report 056: Compatibility of Automotive Collision Warning Short Range Radar Operating at 79 GHz With Radiocommuncation Services

[11] Recommendation ITU-R M.1732-1: Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies

[12] ECC Decision (04)03 on the frequency band 77 - 81 GHz to be designated for the use of Automotive Short Range Radars

[13] ERC Recommendation 70-03, Relating to the use of Short Range Devices (SRD)

[14] Recommendation ITU-R M.2057-0 (02/2014) Systems characteristics of automotive radars operating in the frequency band 76 81 GHz for intelligent transport systems applications

[15] ECC Report 137: analysis of potential impact of mobile vehicle radars on radar speed meters operating at 24 GHz

[16] Air rescue statistics on Germany 2011: http://www.adac.de/_mmm/pdf/Einsatzstatistik%20Dt.%20Luftrettung%202011_127053.pdf

[17] ERC Report 25: European Common Allocations

[18] LuftVO §6 Sicherheitsmindesthöhe (minimum safe altitude), Mindesthöhe bei Überlandflügen nach Sichtflugregeln / Militärisches Luftfahrthandbuch 3.3, http://www.gesetze-im-internet.de/luftvo/BJNR006520963.html

[19] IARU Region-1 VHF Managers Handbook

[20] ECC/DEC/(11)02 on industrial Level Probing Radars (LPR) operating in frequency bands 6 - 8.5 GHz, 24.05 - 26.5 GHz, 57 - 64 GHz and 75 - 85 GHz

[21] Recommendation ITU-R P.620-6: Propagation data required for the evaluation of coordination distances in the frequency range 100 MHz to 105 GHz