ETSI TR 104 078 V1.1.1 (2025-06)

TECHNICAL REPORT

System Reference document (SRdoc);
Short Range Devices;
Radar equipment operating in 57 GHz to 64 GHz and 76 GHz to 77 GHz for applications on drones

Reference

DTR/ERM-630

Keywords

radar, short range, SRD, SRdoc

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

Uncrewed Aircraft Systems (UASs), or drones, have huge potential to transform the productivity of businesses, and to introduce an entirely new way of transporting goods, and for the delivery of services. The commercial use cases of drones, include a diverse range of industries: Utilities - for remote surveying of infrastructure; Transport and Logistics and Agriculture.

One of the greatest challenges regarding commercial or government drone operations, is that of risk-limitation in what are referred to as Very Low-Level Flying (VLLF) environments. These environments are often urban and heavily populated. Drones are required to be capable of avoiding other craft in flight, or structures on the ground including buildings, trees, wind turbines, or the landscape. This requirement is referred to as See And Avoid (SAA).

The present document concludes that different sensing requirements for SAA are needed, dependent on the drone Air Risk Category (ARC), as defined by the Joint Authorities for Rule making for Unmanned Systems (JARUS). A medium detection range of other aircraft to 2 500 m is required in ARC-d, and a shorter range 150 m requirements in ARC-a/b. JARUS rule making for UAS aviation is followed by many countries internationally, including European Union Aviation Safety Agency (EASA).

It is requested to permit the bands 76 - 77 GHz and 57 - 64 GHz for onboard UAS with the conditions in ERC/REC 70-03 [i.2] Annex 5 (band e1) and Annex 1 (band n1).

Introduction

The present document has been developed to support the co-operation between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

The band 76 - 77 GHz is already used by many applications including ground-based vehicle and TTT infrastructure systems (ERC/REC 70-03 [i.2] Annex 5), obstruction/vehicle detection via radar sensor at railway level crossings (ERC/REC 70-03 [i.2] Annex 4), obstacle detection radars for rotorcraft use (ERC/REC 70-03 [i.2] Annex 5), HD-GBSAR (ERC/REC 70-03 [i.2] Annex 6) and LPR/TLPR (ERC/REC 70-03 [i.2] Annex 6).

There therefore exists a large body of experience in manufacturing and use of radars in this band. Dedicated semiconductor devices are available from several manufacturers. Deployed equipment ranges from high value fixed installations that are professionally installed and operated to mass market, price sensitive devices.

The band 57 - 64 GHz is used for a variety of applications, and under FCC part.15 (15.255) [i.4] Field disturbance sensors/radar devices deployed on unmanned aircraft may operate within the frequency band 60 - 64 GHz, provided that the transmitter does not exceed 20 dBm peak e.i.r.p.

The present document will describe the use of 76 - 77 GHz and 57 - 64 GHz radars for additional applications such as:

- Sense and Avoid Radar sensors on uncrewed airborne systems (drones).
- Auto landing systems for drones.

1 Scope

The present document describes SRD radar equipment operating in 57 - 64 GHz and 76 - 77 GHz for applications upon drones which may require a change in the present regulatory framework for the proposed band.

It includes in particular:

- Market information.
- Technical information regarding equipment type and typical installation.
- Regulatory issues.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

[i.1] ECC Report 262: "Studies related to surveillance radar equipment operating in the 76 to 77 GHz range for fixed transport infrastructure".

[i.2] ERC/REC 70-03 (7 June 2024): "ERC Recommendation of 1997 relating to the use of Short Range Devices (SRD)".

[i.3] ETSI EN 301 091-1 (V2.1.1): "Short Range Devices; Transport and Traffic Telematics (TTT); Radar equipment operating in the 76 GHz to 77 GHz range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Part 1: Ground based vehicular radar ".

[i.4] FCC: "FCC Empowers Short-Range Radars in the 60 GHz Band", 47 CFR Part 15 (ET Docket No. 21-363; FCC 23-35; FR ID 153948).

[i.5] ETSI TR 103 137 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document (SRdoc); Surveillance Radar equipment for helicopter application operating in the 76 GHz to 79 GHz frequency range".

[i.6] ECC Report 268 (2018-02): "Technical and Regulatory Aspects and the Needs for Spectrum Regulation for Unmanned Aircraft Systems (UAS)".

[i.7] ITU-R Report M.2204 (11/2010): "Characteristics and spectrum considerations for sense and avoid systems use on unmanned aircraft systems".

[i.8] RTCA DO-366: "Minimum Operational Performance Standards (MOPS), for Air-to-Air Radar for Traffic Surveillance".

[i.9] Joint Authorities for Rule making for Unmanned Systems (JARUS) Specific Operations Risk Assessment (SORA) v2.5.

[i.10] ECC Report 222 (2014-09): "The impact of Surveillance Radar equipment operating in the 76 to 79 GHz range for helicopter application on radio systems".

[i.11] ERC/REC 74-01: "Unwanted emissions in the spurious domain".

[i.12] ETSI EN 303 360 (V1.1.1) (2017-02): "Short Range Devices; Transport and Traffic Telematics (TTT); Radar equipment operating in the 76 GHz to 77 GHz range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Obstacle Detection Radars for Use on Manned Rotorcraft".

[i.13] ECC Report 352 (2023-06): "Harmonised conditions and spectrum bands for the operation of governmental Unmanned Aircraft System".

[i.14] Arizton: "Healthcare Logistics Market Size, Share, Growth & Competitive Analysis Report By Product (Pharmaceuticals and Medical Devices), By Functionality, By End-User, By Geography - Forecast 2024-2029".

[i.15] PWC: "Skies Without Limits v2.0".

[i.16] ETSI EN 303 883-1: " Short Range Devices (SRD) and Ultra Wide Band (UWB); Part 1: Measurement techniques for transmitter requirements".

[i.17] ECC Report 176 (2012-03): "The impact of non-specific SRDs on radio services in the band 57-66 GHz".

[i.18] EASA - Easy Access Rules for Unmanned Aircraft Systems (Regulations (EU) 2019/947).

[i.19] RTCA DO-365C: "Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems".

[i.20] Top 10 reasons for drone insurance claims in 2023.

[i.21] ASTM F3442/F3442M: "Standard Specification for Detect and Avoid System Performance Requirements".

[i.22] RTCA SC-228: "Minimum Performance Standards for Uncrewed Aircraft Systems".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

governmental use: operations carried out by or on behalf of a public authority for the maintenance of law and order, protection of life and property, disaster relief and emergency response activities or services undertaken in the public interest excluding military operations/activities

NOTE: As defined in [i.13].

othership: aircraft other than the ownship (or the ego aircraft)

ownship: aircraft which should See and Avoid another ship

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	(altitude) Above Ground Level
ARC	Air Risk Category
ATAR	Air To Air Radar
BVLOS	Beyond Visual Line Of Sight
CAA	Civil Aviation Authority
dBsm	decibels per square meter
EASA	European Union Aviation Safety Agency
FMCW	Frequency Modulated Continuous Wave
FoV	Field of View
GNSS	Global Navigation Satellite System
GRC	Ground Risk Categories
JARUS	Joint Authorities for Rulemaking of Unmanned Systems
MOPS	Minimum Operational Performance Standards
NMAC	Near Mid Air Collision
PCB	Printed Circuit Board
RAS	Radio Astronomy Services
RCS	Radar Cross Section
RPAS	Remotely Piloted Aircraft Systems
RWC	Remain Well Clear
SAA	See And Avoid
SoC	System on Chip
SORA	Specific Operations Risk Assessment
SWaP-c	Size Weight and Power - low cost
SWaPc	Small Weight and Power, low cost.
TMPR	Tactical Mitigation Performance Requirement
UAS	Uncrewed Aerial System
UAV	Uncrewed Aerial Vehicle
UTM	Uncrewed Traffic Management
VLLF	Very Low-Level Flying
VTOL	Vertical Take-Off and Landing

4 Comments on the System Reference Document

No ETSI member raised any comment.

5 Presentation of the system or technology

5.1 Uncrewed aircraft systems

Uncrewed Aircraft Systems (UASs), or drones, have huge potential to transform the productivity of businesses, and to introduce an entirely new way of transporting goods, and for the delivery of services, Figure 1. During a time when organizations are under pressure to be more efficient, innovative, and ambitious in how they operate, drones offer a unique opportunity. Drones can operate autonomously and gather data quickly and accurately from hard-to-reach places. This can make a crucial difference in managing costs, controlling risks, increasing safety, and influencing outcomes.

The commercial use cases of drones, include a diverse range of industries, including utilities - for remote surveying of infrastructure -, transport and logistics and agriculture. Delivery of medicines is an area that has recently undergone massive expansion; the global healthcare logistics market alone is currently worth approximately £117 billion and is forecast to expand at a Compound Annual Growth Rate (CAGR) of 7,8 % in the period to 2026 [i.14].

Figure 1: Drone use cases, from ECC Report 268 [i.6]

The PricewaterhouseCoopers (PwC) 'Skies without Limits' study [i.15] into the impact of drones on the UK economy alone forecasts that by 2030 drones will account for a £42 billion increase in UK Gross Domestic Product (GDP). However, there is a key obstacle to this expansion. The PwC report emphasized that maximum commercial growth could only be achieved when BVLOS autonomous operations, out of sight of a ground-based operator, which cannot currently take place due to outstanding regulatory or technical issues, including obstacle detection and avoidance in flight.

5.2 Beyond Visual Line of Sight

One of the greatest challenges regarding commercial BVLOS drone operations, is that of risk-limitation in what are referred to as Very Low-Level Flying (VLLF) environments. These environments are often urban and heavily populated. Drones are required to be capable of avoiding other craft in flight, or structures on the ground including buildings, trees, wind turbines, or the landscape. Navigation is required to be resilient; satellite navigation is often occluded during VLLF and is easily interfered with. Full BVLOS operations require autonomy during take-off and landing phases as well as in flight.

BVLOS drone operations necessitate that drones can undertake several complex and inter-related tasks throughout their flight missions. They plan a route, navigate to follow that route, detect, and avoid unforeseen obstacles, take-off, and land safely, and communicate flight information into UAV Traffic Management (UTM) systems. Operations are required to be resilient to changes in weather and, with redundancy by design, to single points of failure.

Equipment will be required on-board the UAS to support safe and certified UAS flights, BVLOS. Such equipment will enable traffic-sensing, obstacle-avoidance, communication and navigation. The challenge for BVLOS is to replace the functions undertaken by a pilot during crewed flight, with on board UAV sensing, autonomy systems, and intelligence.

Pilots of conventional light aircraft, UAS, and helicopters, have identified that See And Avoid (SAA) systems are required to: provide only relevant information to pilots of obstacles that require corrective action; reliably identify the 3D location; and present prioritized information based upon time. Business requirements, to have these capabilities under the widest range of operating conditions, and aircraft requirements for low Size, Weight, Power, and low lost (SWaP-c) instrumentation, make radar systems an obvious choice. Air To Air Radar (ATAR) for collision avoidance is an important part of equipage to support BVLOS flights and has been recognized by aviation authorities and standards bodies.

5.3 See and Avoid requirement

5.3.0 General

The onboard UAS equipage requirements are dependent upon the Air Risk Category (ARC) within which the flight occurs. SORA [i.9] classifies the air risk of a UAS operation into one of four categories, from ARC-a (minimal risk) to ARC-d (high risk). The classification is based upon a flowchart which focusses primarily on encounter types, the airspace ruleset and whether the air environment is either recognized or contains known traffic. Operations in higher-risk airspace (e.g. controlled airspace with commercial aircraft) are assigned higher ARCs and require more robust See and Avoid mitigations.

5.3.1 Low air risk categories

Low air risk categories include for example airspace in the absence of manned aviation, and low altitude, Figure 2, Figure 3 and Figure 4.

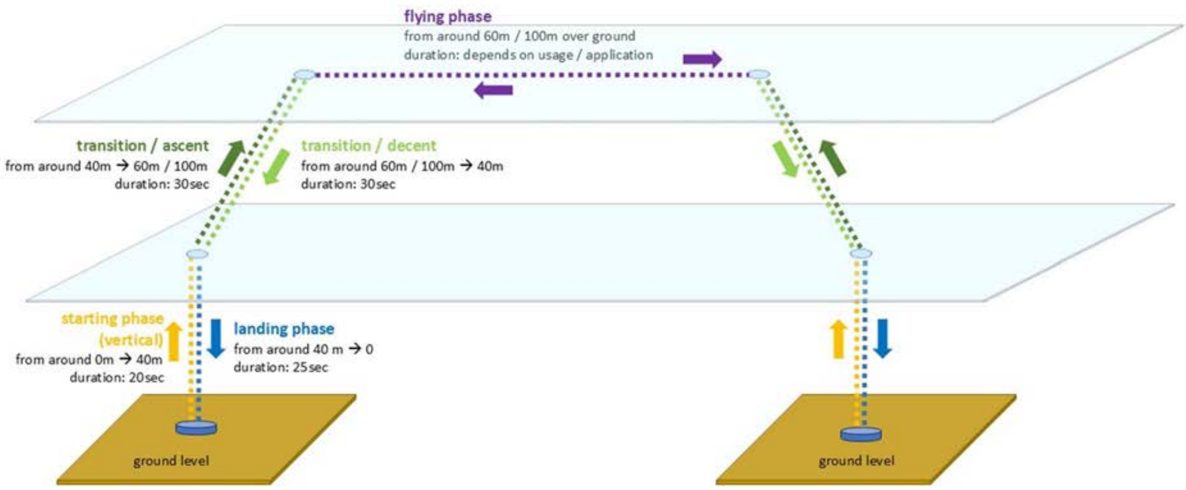

Figure 2: Typical UAS flight profile in lower air risk category: delivery from one ground installation to another (source: Robert Bosch GmbH)

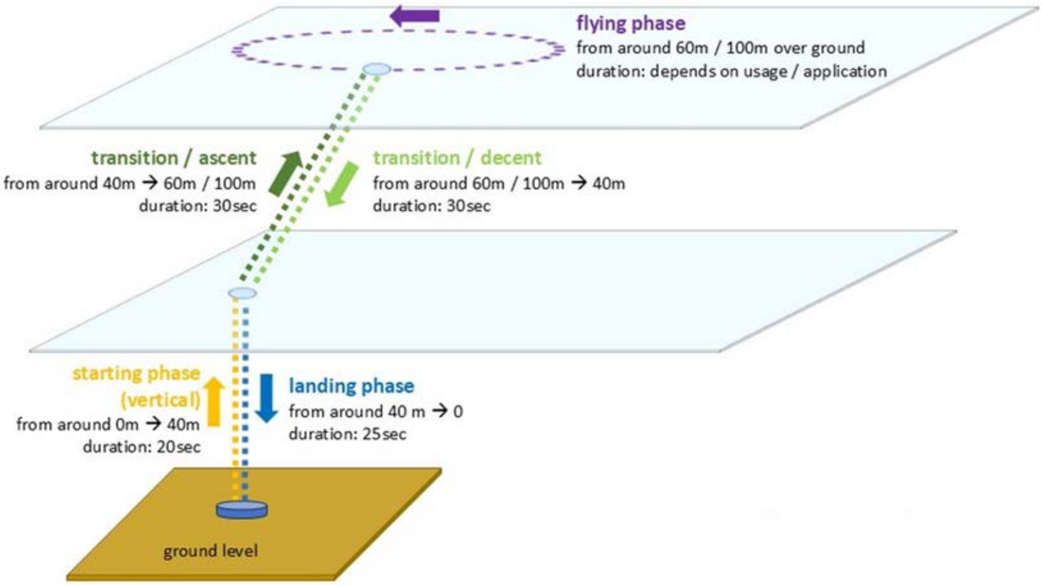

Figure 3: Typical UAS flight profile in lower air risk category: surveillance, or search (source: Robert Bosch GmbH)

UAS Flight Inspections i.e. Power Line Inspections and Railway track Surveillance  © Cambridge Sensoriis	Long linear flights such as those by drones inspecting power lines or railway track surveillance, in changeable weather, require a robust onboard sensor. Micro radar enables a drone to detect objects in the flight path, whether in the air or ground based i.e. trees, power lines, birds, or other aircraft. As well as measuring the relative position of potential obstacles, the radar also directly measures relative velocity - allowing the UAS pilot, specialized in power line or railway track inspections, to gather close-quarter data assessing for corrosion and other maintenance needs.

Figure 4: Use case: Drone linear surveys (source: ©Cambridge Sensoriis Ltd.)

This leads to a requirement for a Shorter range and low SWaP SAA radar.

In this context *short range* is for detection up to 150 m for objects that could include steel wire of diameter 2 mm and greater.

5.3.2 High air risk categories

High air risk categories include for example airspace in the vicinity of crewed and/or passenger carrying aviation, Figure 6. In these cases, airspace safety requirements provide for volumes of airspace around the ownship (that is, the ego aircraft) within which the othership (an aircraft, other than the ego aircraft) should be detected, Figure 5.

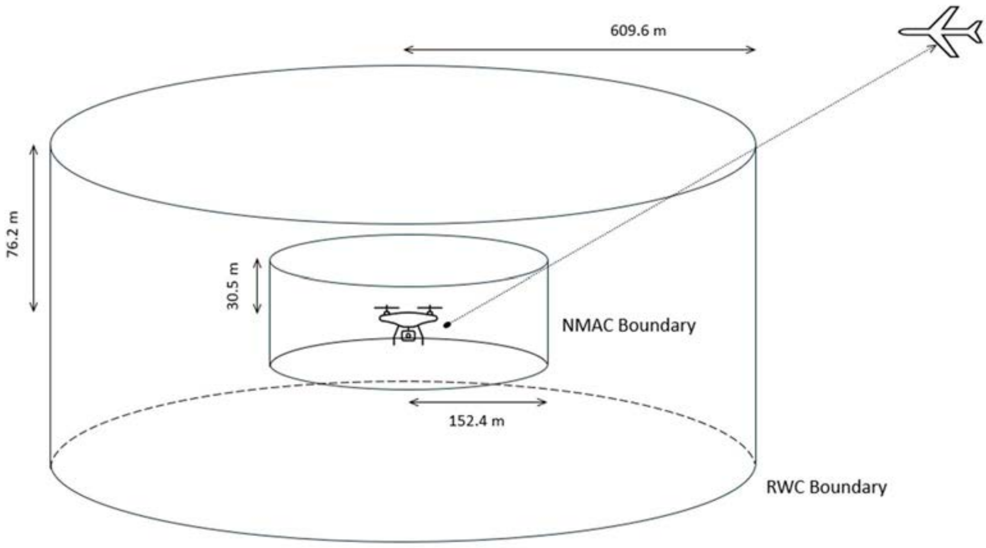

Figure 5: RWC and NMAC boundaries (source: ©Cambridge Sensoriis Ltd.)

The definitions for Remain Well Clear (RWC) and Near Mid Air Collision (NMAC) are as defined in ASTM F3442/F3442M [i.21] and are as follows:

- RWC is defined as no incursion less than 2 000 feet (609,6 m) horizontally and 250 feet (76,2 m) vertically;
- NMAC is defined as no incursion less than 500 feet (152,4 m) horizontally and 250 feet (30,5 m) vertically.

This leads to a requirement for a medium range and low SWaP SAA radar.

In this context, **longer range** ATAR are as defined in RTCA DO-366 [i.8], with radar detection range of 6,7 NM (12,4 km), for a large (circa 10 dBsm radar cross section) othership. And **medium range** is to 2 500 m for the same RCS.

Situational awareness and SAA for crewed/ uncrewed aircraft in urban environments.  © Cambridge Sensoriis	BVLOS drone operations necessitate that drones can undertake several complex and inter-related tasks throughout their flight missions. They plan a route, navigate to follow that route, See and Avoid unforeseen obstacles, take-off, and land safely, and communicate flight information into UAS Traffic Management (UTM) systems. Operations are required to be resilient to changes in weather and, with redundancy by design, to single points of failure. Micro radars will be one of the key sensors onboard the UAS in order to detect obstacles and provide situational awareness to the UAS pilot/operator, or autonomous operations.

Figure 6: Resilient drone operations (source: ©Cambridge Sensoriis Ltd.)

5.4 See and Avoid regulations for UAS

JARUS SORA [i.9] is the closest basis available to an international framework for Uncrewed Aircraft Systems (UAS) operations, and Annex D describes the 'Tactical Mitigation Performance Requirements' (TMPR) (i.e. the SAA requirements). The most difficult requirement to achieve, known as Air Risk Category (ARC), are ARC-d and ARC-c, see JARUS SORA 2.5 [i.9], Annex D, clause 5.3.2, Table 1. These require a system that meets performance standards as determined by RTCA SC-228 [i.22] or EUROCAE WG-105.

The JARUS SORA [i.9] is, with minor adjustments, the Acceptable Means of Compliance (AMC) defined by EASA and the SAA requirements are the same (Easy Access Rules for UAS Implementing Regulation (EU) 2019/947 [i.18], p. 100). These rules require that SAA radar be incorporated into UAS aircraft design, and the following standards are available:

- RTCA DO-365C [i.19] ("Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems"). (DAA in this context, is synonymous with See and Avoid for obstacles in flight - SAA.)
- RTCA DO-366 [i.8] ("Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance").

One current problem with RTCA DO-366 [i.8] is that the standard is written around large and costly UAS, which can in turn support larger radar (for ARC-d and some ARC-c). Smaller, sub 25 kg UAS aircraft cannot support either the weight or the cost of such radar. These deficiencies are being addressed with aviation regulators, see clause A.5 - Requirements for modification - and will lead to a requirement for a frequency band of operation for a low SWaP-c radar. Proposed changes to RTCA DO-366 [i.8], for smaller UAS operating at low altitude, lead to a radar detection requirement for light aircraft to 2 500 m.

One purpose of the present document is to propose radar operating in 76 - 77 GHz band for medium range SAA, on board small to medium sized UAS.

Low SWaP-c radar are typically implemented through system-on-chip devices that include radar transceiver, digital signal processing, and micro-processor(s), Figure 10. These SoCs support bandwidths of up to 4 GHz in many cases, and FMCW devices operating in the 57 - 64 GHz, and 76 - 81 GHz band are readily available. Through careful design, transmit power of a few dBm up to 20 dBm are feasible, and typical receiver noise figures of 12 dB or lower.

Such radars are often implemented with a planar phased array antenna, measuring both azimuth and elevation angles of detected objects though phase differences between receiver elements. Field of view requirements for SAA are often greater than the 120° possible from a planar antenna, and so 2 or more radar can be networked to support greater field of view.

5.5 Radar Landing systems

As well as resilient See and Avoid technologies to support BVLOS operations, the growth towards drone autonomy requires technologies to provide resilience during the landing phase of flight. Sole reliance upon a drone's GNSS, and in some cases additional camera sensing, is limiting. GNSS spoofing, or restricted visibility towards satellites in built up areas prohibits resilient autonomy for higher air risk and ground risk categories. Camera based sensing is susceptible to poor weather conditions and limiting during nighttime operations.

Several use cases require that UAS land upon moving targets, for example drones that fly from ships in support of border force operations. In these cases, GNSS based localization is overly complex, the drone should land upon a position on the ship deck, not upon a position in world coordinates as the vessel is moving. Relative positioning systems are becoming available which are active on both the drone and the ship deck (or ground-based landing pad), Figure 8 and Figure 9.

Ship-to-shore/Shore-to-ship Operations  © Cambridge Sensoriis	A UAS integrated with a cooperative radar on the landing pad of a vessel enables an automated landing upon landing platform, either on a vessel or fixed ground position. The radars on the UAS and vessel can also help provide the heading, roll, and pitch of the vessel, all vital information to help reduce workload on pilots, support the safe operation and landing of drones in dynamic and challenging conditions, and protect high-value assets.

Figure 7: Use case - autonomous drone landing (source: ©Cambridge Sensoriis Ltd.)

© Cambridge Sensoriis

Figure 8: Landing radar, supporting autonomous landing for a quadcopter (source: ©Cambridge Sensoriis Ltd.)

5.6 Other UAS Technologies

UAS are usually equipped with additional sensing and control systems to support flight. These include a flight controller; radio data link to a ground control station; GNSS system; inertial navigation system. Some drones have altimeters measuring height above ground, and Automatic Dependent Surveillance-Broadcast (ADS-B), which reports UAS location as derived from the onboard GNSS. See and Avoid systems, as described in greater detail in the present document, support the detection of objects that are not actively cooperating.

All UAS technologies are designed for low size, weight and power. All functions are powered and lifted from the onboard battery that supports the flight mission and excess weight limits flight time and/or payload carrying capacity.

6 Market information in the EU

6.1 UAS Market size for Certified and Specific drone operations

Only higher risk UAS operations are expected to require medium and long Range SAA capabilities. These include certified categories of operation, and higher risk activities in the Specific category, Figure 9.

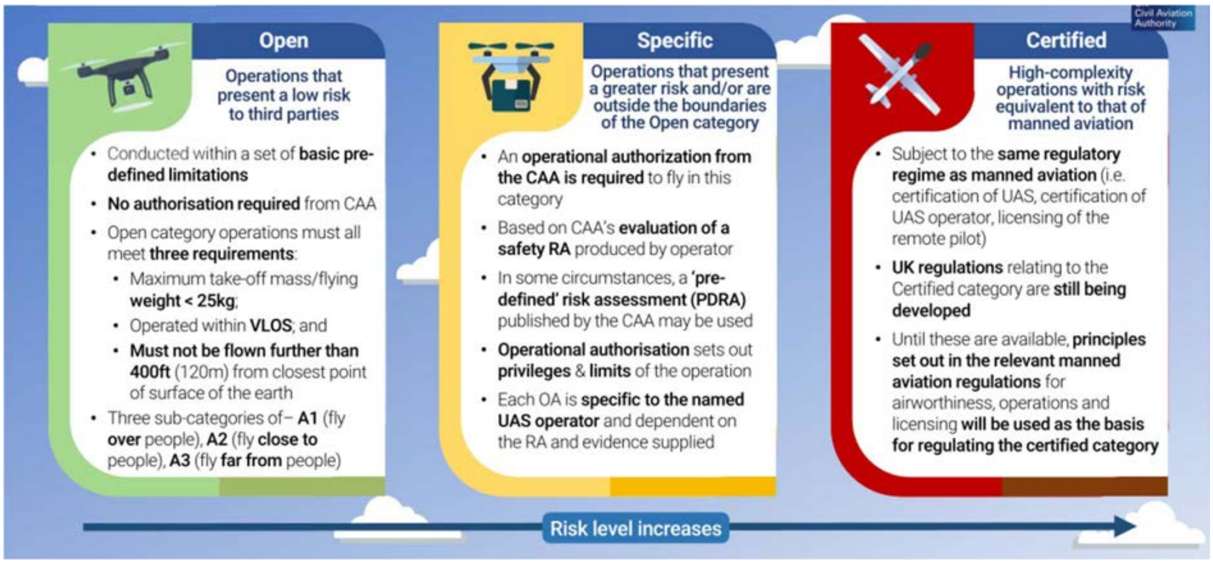

Figure 9: Operating categories of Remotely Piloted Aircraft Systems (RPAS) (source: UK Civil Aviation Authority)

Note that in this context 'Certified' refers to certification by a competent body for use in conjunction with aircraft (uncrewed or not) to support flight operations, and not certified to be compliant with a standard that relates to use of electromagnetic spectrum.

6.2 Deployed numbers

The PwC projections are for 76 000 drones in use in the UK by 2030, across all sectors. These would be used in both urban, inter-urban and rural areas. Deployed numbers per area are more difficult to estimate. In areas around drone ports serving urban areas the numbers may be greater, and much lower in rural areas. Drones have to keep a minimum safe distance of hundreds of meters between each other, in 3 dimensions, to operate safely which naturally sets a limit on deployment density. Only professionally or governmental operated UAS in ARC-D and some ARC-C will be suitable for adopting radar technologies, those whose operating time and payload are not significantly affected by the sensor. Assuming 10 % market penetration, some 7 600 UAS radar could be in use nationally (UK) by 2030 based on PwCs projections.

Deployment densities of radar on UAS can be expected to be much less than those for Advanced Driver-Assistance Systems (ADAS) radar deployed on vehicles. The projected UAS radar deployments in 2030, are < 1 % of the current number of registered cars and light goods vehicles.

ECC Report 222 from 2014 [i.10] studies the impact of Surveillance Radar equipment operating in the 76 - 79 GHz range for helicopter applications on radio systems. It makes the further points in relation to potential automotive and UAS interference:

- 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.

The same report estimates a total number of manned turbine helicopters across Europe of 4 400, and an 80 % market penetration for the collision avoidance radar for manned helicopter flights. These numbers can be expected to increase by 2030, by which time the projected 7 600 UAS borne radar systems could still be greater, but not significantly so. These crewed rotorcrafts are permitted to deploy radar for collision avoidance, and a harmonised standard exists [i.12].

6.3 Drone deployment densities

The ITU projected drone densities are modest across all drone categories and particularly for the larger drones (more likely for ARC-d and ARC-c operations), which in turn require medium range SAA. Table 1 shows the projected (by 2030) UAS density across UAS size categories.

Table 1: UAS densities vs. Size (Source: ITU [i.7])

UAS Categories	Per 10 000 kms^2
Large	0,440
Medium	1,950
Small	8,031
TOTAL	10,421

6.4 Drone insurance claims

It is also interesting to note that the within the Top 10 reasons for drone insurance claims in 2023 [i.20] (courtesy of CoverDrone Insurance), the top reason is pilot error, which accounts for over 50 % of all claims reported. Factors such as fatigue, poor communication and distraction can all increase the likelihood of a drone-related incident resulting from pilot error. The third and fourth top reason for insurance claims relate to accidental damage or loss, while the fifth top reason are bird strikes. Radar provides excellent all weather object detection performance in a low SWaPc package. Radar technology will support navigation, collision avoidance, and airspace deconfliction. By providing greater and relevant situational awareness of flying and ground-based obstructions, this reduces the workload on UAS pilots and helps to avoid or greatly reduce accidental damage or loss.

7 Technical information

7.1 Technical Description

Both the See and Avoid radar, and landing radar, are implemented using highly integrated SoC devices, including radar FMCW transmitter, receiver, mixer, associated Power amplifier and Low noise amplifiers, and digital signals processing, Figure 10. Antenna for transmitted and receive are isolated and implemented upon planar PCB to form a phased array.

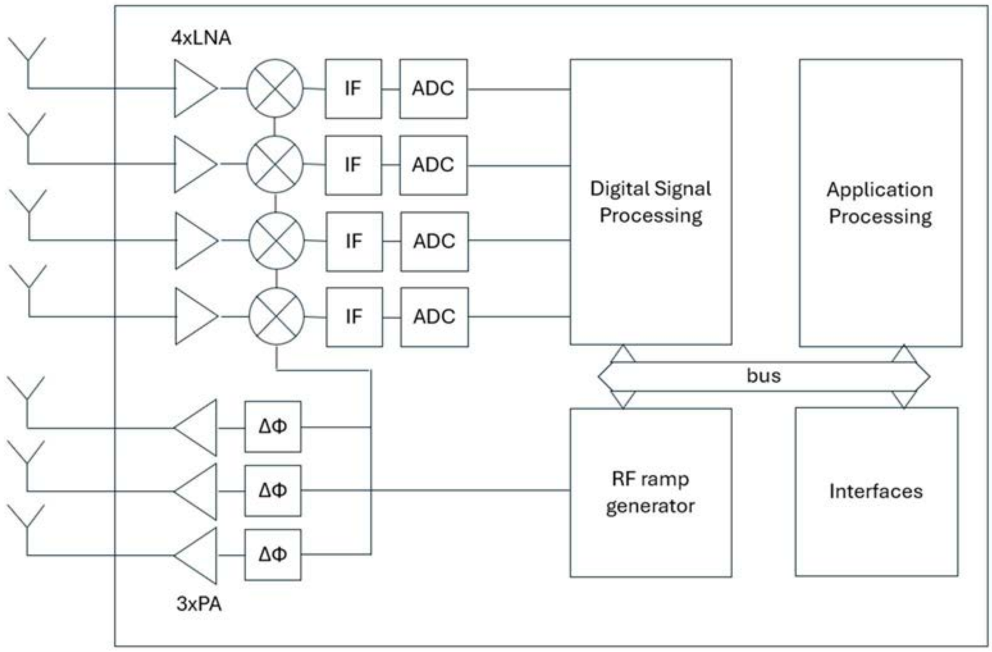

Figure 10: 76 - 81 GHz Radar SoC architecture (source: ©Cambridge Sensoriis Ltd.)

Modulation patterns for the SAA radar are software configurable, with a continuous modulation. Systems are compliant with the technical parameters of ETSI EN 301 091-1 [i.3].

Landing radar have an intermittent modulation schema, and a radar whether on the ship deck or on the UAS is typically modulated 50 % of the time.

Because modulation parameters are software configurable, whether a landing radar or a SAA radar is largely determined in firmware. The radar could step from "See and Avoid" mode (purely horizontal) into "landing" (surrounding) mode, through beam steering.

The following tables list typical parameters for a small SWaP radar for UAS applications.

It is advantageous to deliver multiple capabilities through a single radar hardware set onboard the UAS, thereby reducing UAS payload and maximizing the mission flight time.

Radar operating in 76 - 77 GHz Band, as defined in Table 2 and Table 3.

Table 2:Technical parameters of See and Avoid at medium range

Use Case	See and Avoid - Medium Range
Frequency Band	76 - 77 GHz (fmcw)
Detection Requirement	Large Other ship Aircraft, RCS 10 dBsm 2 500 m (Annex A)
Occupied Bandwidth	Configurable depending on range between 150 MHz and 1 000 MHz
FoV	120° horizontal 40° vertical (± 20°)
Instrumented Range	3 000 m
Mean Power	50 dBm eirp
Peak Power	55 dBm eirp
Receiver Noise Figure	12 dB or better
Duty Cycle	Up to 100 %
Maximum height AGL	120 m
Directionality	Forward facing, horizontal

Table 3: Technical parameters of landing and altimeter use-case

Use Case	1. Landing zone clear 2. Altimeter
Frequency Band	76 - 77 GHz
Detection Requirement	Minimum target - steel cables > 2 mm diameter Resolution in measurement distance: 50 mm
Occupied Bandwidth	1 GHz for 15 cm resolution more desirable, 5 cm and 3 GHz
FoV	90 - 120° horizontal 90 - 120° vertical
Instrumented Range	150 m
Mean Power	50 dBm
Peak Power	55 dBm eirp
Duty Cycle	Up to 100 %
Maximum height AGL	120 m
Directionality	Downward facing, vertical

Radar operating in 57 - 64 GHz Band, as defined in Table 4 and Table 5:

Table 4: Technical parameters of See and Avoid at short range

Use Case	See and Avoid - Short range
Frequency Band	57 - 64 GHz (ERC/REC 70-03 [i.2] Annex 1, Generic use)
Occupied Bandwidth	Configurable depending on range between 1 000 MHz and 2 000 MHz
FoV	90° horizontal 20° vertical
Instrumented Range	100 m For minimum target 4,29 dBsm at 64 GHz (2 mm wire radius, 1 m length, perpendicular onto target)
Mean Power	20 dBm eirp
Duty Cycle	Up to 100 %
Maximum height AGL	120 m
Directionality	Predominately forward facing (moving direction), horizontal but also, a requirement for 360° coverage around the UAS

Table 5: Technical parameters of See and Avoid during landing and take-off

Use Case	See and Avoid - Very short range Landing/take-off
Frequency Band	57 - 64 GHz
Occupied Bandwidth	Configurable depending on range. 3 - 4 GHz Resolution measuring distance: 50 mm
FoV	90° horizontal 20° vertical
Instrumented Range	20 m; (UAS speed of 5 m/s is considered)
Mean Power	20 dBm eirp
Duty Cycle	Up to 100 %
maximum height AGL	Up to 120 m
Detection requirements	Minimum target (cables): 2 mm diameter
Directionality	Forward facing (moving direction), horizontal, or downward facing, vertical

7.2 Status of technical parameters

7.2.1 Current ITU and European Common Allocations

Current allocation of the candidate bands in the CEPT (European common allocation ECA) is included in Table 6, together with actual usage within the CEPT.

Table 6: Allocations and usage within CEPT

Frequency band	Allocations - Europe (ECA)	Applications
56,9 - 57 GHz	Earth Exploration-Satellite (passive), Fixed, Inter-Satellite, Mobile, Space Research (passive)	Passive sensors (satellite), Fixed
57 - 58,2 GHz	Space Research (passive), Mobile, Inter-Satellite, Fixed, Earth Exploration-Satellite (passive)	Fixed, LPR, Passive sensors (satellite), Non-specific SRDs, TLPR, Wideband data transmission systems
58,2 - 59 GHz	Earth Exploration-Satellite (passive), Fixed, Space Research (passive), Radio Astronomy	TLPR, Non-specific SRDs, Radio astronomy, Passive sensors (satellite), LPR, Wideband data transmission systems, Fixed
59 - 59,3 GHz	Radiolocation, Space Research (passive), Inter-Satellite, Mobile, Earth Exploration-Satellite (passive), Fixed	Fixed, LPR, Passive sensors (satellite), Non-specific SRDs, TLPR, Wideband data transmission systems
59,3 - 64 GHz	Fixed, Mobile, Inter-Satellite, Radiolocation	Wideband data transmission systems, TLPR, Non-specific SRDs, LPR, ISM, ITS, Fixed
64 - 65 GHz	Mobile Except Aeronautical Mobile, Fixed, Inter-Satellite	Fixed, ITS, Radio astronomy, Wideband data transmission systems
75,5 - 76 GHz	Broadcasting, Broadcasting-Satellite, Fixed, Fixed-Satellite (Space-To-Earth), Amateur, Amateur-Satellite	Amateur, Amateur-satellite, Space research, TLPR, LPR, Fixed
76 - 77,5 GHz	Amateur-Satellite, Amateur, Radio Astronomy, Radiolocation, Space Research (Space-To-Earth)	TTT, TLPR, Railway applications, LPR, SRR, GBSAR, Amateur-satellite, Amateur, Radiolocation (civil), Radio astronomy

7.2.2 Sharing and compatibility studies already available

ECC Report 176 [i.17] from 2012 considered the impact of non-specific SRDs on radio services in the band 57 - 66 GHz. This report was the basis for the entry in Annex 1 of ERC/REC 70-03 [i.2] from 57 - 64 GHz. The potential of interference from non-specific SRDs to the Fixed Service in the frequency range 64 - 66 GHz and the lack of information relating to the deployment of Fixed Service links in this frequency range, led to the proposal not to include 64 - 66 GHz in the proposed extension of Annex 1 of ERC/REC 70-03 [i.2] for non-specific SRDs. For the protection of Fixed Service, a maximum output power limit of 10 dBm was proposed.

In 2014 ECC Report 222 [i.10] was published, following compatibility studies performed on the impact of airborne surveillance radar in the 76 - 79 GHz frequency range on radio systems and services.

This concluded that to protect the RAS stations in Europe an exclusion zone should be implemented around RAS installations operating in the 76 - 79 GHz band, and 10 European RAS sites exist. The report did not conclude on the size of the exclusion zones and provided a procedure to determine at national level the size of the exclusion zone. However, the altitude of the rotorcraft has an essential impact on the separation distance; example calculations have shown at altitude 300 m a separation distance of 98 km, and at altitude 0 m a separation distance of 29 km. Our proposed maximum operating height is 120 m.

In 2017 ECC Report 262 [i.1] was published following a co-existence study conducted with SE24. The study related to surveillance radar equipment operating in the 76 - 77 GHz range for fixed transport infrastructure.

The fixed radars considered in this study have a mounting location of approximately 5 m above the road surface and 2 - 3 m laterally from the first running lane. The executive summary states that the incident power that may be received by an automotive radar from this fixed radar installation is of the same order of magnitude than can be received from a second automotive radar. However, the reports concluded that the scanning nature of the fixed installation radar contributes to the coexistence with automotive radars, as an interference mitigation method; this has led to a regulation for fixed infrastructure radars which requires fixed transportation infrastructure radars to be of a scanning nature in order to limit the illumination time and ensure a minimum silent time to achieve coexistence with automotive radar systems.

7.2.3 Sharing and compatibility issues still to be considered

Based on the generic nature of ERC/REC 70-03 [i.2] Annex 1 band n1, airborne use is already permitted. ETSI assumes that the impact of drones on other users in the band 57 - 64 GHz need not be assessed. In the band 76 - 77 GHz the coexistence with existing and possible new applications should be considered.

7.3 Transmitter parameters

7.3.1 Transmitter output power / radiated power

Two cases are presented in the technical parameters clause above, dependent upon the operating band:

- Medium range radar, 76 - 77 GHz: peak power to 55 dBm eirp and mean power to 50 dBm.
- Short range radar, 57 - 64 GHz: mean power to 20 dBm eirp.

7.3.2 Antenna characteristics

- Medium range radar, 76 - 77 GHz: Antenna Gain typical 10 dBi to 25 dBi.
- Short range radar, 60 - 64 GHz: Antenna Gain typical 10 dBi for 20 dBm eirp.

7.3.3 Operating frequency

76 - 77 GHz for the SAA radar operating to medium range (that is 2 500 m).

Having multiple functionalities from a single onboard UAS low SWaP-s sensor is advantageous as it reduces the overall sensor payload weight and increases UAS mission time.

Radar Altimeters and Landing Radar have been implemented in the 60 - 64 GHz band, though could equally occupy 76 - 77 GHz.

57 - 64 GHz for short range SAA, or altimeters, or take-off/Landing flight support. The FCC rule making [i.6] has permitted radar devices deployed on UAS to operate within the frequency band 60 - 64 GHz, provided that the transmitter does not exceed 20 dBm peak e.i.r.p. The sum of continuous transmitter off-times, each of at least 2 ms, should equal at least 16,5 ms within any contiguous interval of 33 ms. Operation is limited to a maximum of 122 m (400 feet) AGL.

7.3.4 Bandwidth

The overall bandwidth is defined by the FM sweep pattern. This is typically in the range of 150 - 1 000 MHz for Medium or Short range SAA through 76 GHz radar, or up to 4 000 MHz from 60 - 64 GHz to support Short range SAA.

7.3.5 Unwanted emissions

Unwanted emissions would be within the limits for out of band specified by ETSI EN 303 883-1 [i.16] and spurious emissions aligned with ERC/REC 74-01 [i.11].

7.4 Receiver parameters

Common radar models include a bi-static, dual antenna configuration. The radar receiver includes an active mixer that converts the Radio Frequency signal into an Intermediate Frequency range which covers to 15 MHz. For commonly available low SWaP-c SoC devices, the receiver Noise Figure is typically 12 dBm at 1 MHz.

8 Radio spectrum request and justification

A low SWaP-c radar is required for UAS SAA in higher Air Risk Category operations, and is required by UAS regulators, under JARUS SORA [i.9]. Detection distances of up to 2 500 m for othership targets (targets other than the ego aircraft) including light aircraft will be required, as shown in Annex A. No suitable band currently exists.

In 76 - 77 GHz a 2 500 m detection range is required (see Annex A) for 10 dBsm large objects (as defined in RTCA DO-366 [i.8]), to comply with JARUS SORA [i.9] in Air Risk Categories -c and -d. In these cases, a medium range radar is required, which leads to a transmit power requirement of 55 dBm peak.

Shorter range radars are defined up to 150 m detection distances, where lower power less than 20 dBm is acceptable and operation within the 57 - 64 GHz or 60 - 64 GHz bands.

9 Regulations

9.1 Current regulations

9.1.1 ERC Recommendation 70-03

The band 76 - 77 GHz is already used by many applications including ground-based vehicle and TTT infrastructure systems (ERC/REC 70-03 [i.2] Annex 5), obstruction/vehicle detection via radar sensor at railway level crossings (ERC/REC 70-03 [i.2] Annex 4), obstacle detection radars for rotorcraft use (ERC/REC 70-03 [i.2] Annex 5), HD-GBSAR (ERC/REC 70-03 [i.2] Annex 6) and LPR/TLPR (ERC/REC 70-03 [i.2] Annex 6).

The technology that is discussed in the present document is that which is already in use in the 76 - 77 GHz band but limited to certain applications.

There therefore exists a large body of experience in manufacturing and use of radars in this band. Dedicated semiconductor devices are available from several manufacturers. Design and manufacture of antenna systems has been perfected.

In terms of technology, radars are typically FMCW with an RF power of the order of 10 - 100 mW. They all rely on digital processing, such as FFTs, to extract target information from the reflected radar signals and for post processing of this information.

In terms of systems, the main applications are TTT infrastructure (ERC/REC 70-03 [i.2] Annex 5), HD-GBSAR (ERC/REC 70-03 [i.2] Annex 6) and radar sensors at railway level crossings (ERC/REC 70-03 [i.2] Annex 4), in addition to use on Manned Rotorcraft. The main application for mass market equipment is on ground-based vehicles (ERC/REC 70-03 [i.2] Annex 5).

With the band listed in multiple Annexes in ERC/REC 70-03 [i.2], there is potential for uncertainty in exactly what applications and uses are permitted. The position with respect to uncrewed rotorcraft is also anomalous, when compared to ground vehicles. For the former, more restrictive peak and average e.i.r.p. are mandated for (manned) rotorcraft when compared with the numerous automotive radar that successfully manage mutual interference on a busy highway. Furthermore, it is, specifically, required that rotorcraft are 'manned', precluding useful deployment onto UAS systems, the uptake of which cannot have been foreseen at the time that ETSI TR 103 137 [i.5] was last updated in 2014.

9.1.2 ITU study on UAS

In November 2010, ITU-R prepared a report [i.7] that identified bands that would be useful for UAS SAA, see also [i.9]. This report was possible because of work from RTCA special committee 203 (SC-203). The bands identified for airborne SAA applications on larger UAS were:

- 4 200 - 4 400 MHz (see Table 3 of ITU Report [i.7])
- 5 350 - 5 470 MHz (see Table 3 of ITU Report [i.7])
- 8 750 - 8 850 MHz (see Table 3 of ITU Report [i.7])
- 9 300 - 9 500 MHz (see Table 3 of ITU Report [i.7])
- 13,25 - 13,40 GHz (see Table 3 of ITU Report [i.7])
- 15,40 - 15,70 GHz (see Table 5 of ITU Report [i.7])

A further 2 bands are also offered for SAA by UAS by RTCA in standard RTCA DO-366 [i.8], being bands for general radio navigation, including aeronautical, maritime, and land navigation:

- 24,24 - 24,65 GHz
- 32,3 - 33,4 GHz

A summary of the situation in these last 2 bands (as found in 2017) only follows, since the lower frequency bands are unlikely to be suitable for low SWaP-c SAA. Componentry and Antenna will be too large:

- 24,24 - 24,65 GHz available for SAA applications in Americas and Asia, but not in Europe, Africa, of Middle East. SAA would have to share spectrum with land based maritime and land-based radio navigation systems as well as inter-satellite links in the US and fixed and mobile systems in other areas of the world. Available bandwidth is insufficient for the use cases presented.
- 32,3 - 33,4 GHz available for SAA applications. SAA would have to share spectrum with land based maritime and land-based radio navigation systems as well as inter-satellite links. Available bandwidth is insufficient for the use cases presented.

RTCA DO-366 [i.8] comments that there may be additional bands at higher frequencies (with radionavigation protection); however additional international and domestic rule making would be required to use such spectrum.

9.2 Proposed regulation and justification

76 - 77 GHz:

- For medium range radars (up to 2 500 m detection distance) it is proposed that the entry e1 of ERC/REC 70-03 [i.2] Annex 5 be extended to permit use onboard UAS.
- The mean power of 50 dBm is defined over the signal repetition time.

57 - 64 GHz:

- For shorter range radar (up to 150 m detection distance), ETSI assumes that the entry n1 of ERC/REC 70-03 [i.2] Annex 1 permits use onboard UAS.

Annex A: ATAR - See and Avoid

A.1 Concept of operations

Micro-radar and sensing systems for the Uncrewed Aerial System (UAS) industry are currently in development. ATAR will provide a way to detect other aircraft and airspace users who may, or may not be, 'co-operative' i.e. detection occurs independently of any requirement upon the 'intruder's' equipage or response. It addresses only the 'detect' aspect of See And Avoid (SAA). It provides multiple simultaneous target acquisition and tracking data using a small solid state primary radar. The intention is that the detection data is subsequently processed either by a human operator, or an automated SAA system, which then performs the appropriate decision making and any avoidance functions. The mass, size and power consumption of the radar makes it possible to fit this equipment to 'small' UAS for use inflight.

NOTE: 'Small' in this context refers to sub 25 kg UAs. Examples are shown in clause A.3.

The objective of our current engagement with the Civil Aviation Authority (CAA) is to establish appropriate and proportionate criteria for:

- Minimum Operational Performance Standards (MOPS);
- Software (SW) standards; and
- Airborne Electronic Hardware (AEH) standards.

A.2 Operating environment

The intended operating environment is:

- below 500 feet Above Ground Level (AGL); and
- outside approach and departure paths for licenced airports and heliports.

Encounter aircraft, the activities they are anticipated to be performing, and their characteristic performance within the operating environment, are shown below in Table A.1.

Table A.1: Intruder characteristics

Activity	Example aircraft type	Example aircraft model	RTCA DO-366 [i.8] aircraft classification (section 2.2.7)	Performance characteristics	Maximum speed considered for operations below 500 feet AGL
Helicopter Emergency Medical Services (HEMSs) at low level due weather or on approach /departure from a non-licenced heliport	Helicopter	Airbus EC145	Large	Approach, initial climb: 65 kts Normal cruise: 128 kts	95 kts (175 km/h)
National Police Air Service (NPAS) at low level due weather, conducting search activity or on approach /departure from a non-licenced heliport	Helicopter	Airbus EC145	Large	Approach, initial climb: 65 kts Normal cruise: 128 kts	95 kts (175 km/h)
Infrastructure inspection e.g. pipeline or on approach /departure from a non-licenced heliport	Helicopter	Airbus EC135	Large	Approach, initial climb: 65 kts Normal cruise: 122 kts	95 kts (175 km/h)
GA aircraft on approach /departure from a non-licenced airstrip, or conducting practiced forced landings	Fixed wing	Cessna 172	Medium	Approach (with flaps): 70 kts Initial climb: 74 kts Emergency landing: 70 kts Normal cruise: 120 kts	75 kts (139 km/h)
GA aircraft on approach /departure from a non-licenced heliport, or conducting practiced auto-rotations	Helicopter	Robinson R44	Medium	Take-off, initial climb and landing: 60 kts Autorotation: 70 kts Normal cruise: 110 kts	75 kts (139 km/h)
Microlight aircraft on approach /departure from a non-licenced airstrip, or conducting practiced forced landings		EuroFOX	Small	Approach and initial climb: 65 kts Cruise: 80 kts	65 kts (120 km/h)
Microlight aircraft in low level cruise	Powered hang glider	Joker Trike	Small	Cruise: 48 kts	48 kts (89 km/h)
Hot air balloons in low level cruise	Balloon		Small	Maximum operating wind speed 10 kts	10 kts (19 km/h)

A.3 Ownship characteristics

The ownship to which the ATAR would be fitted are typically small UAS. These may be multi-rotor or lift-cruise UA with the ability to stop and or change direction in an agile way.

A.4 Special condition - ATAR qualification per RTCA DO-366

RTO/DO-366 [i.8] was primarily written for a specific type of UAS (large, fast moving fixed wing UAS), engaged in operations above 500 feet AGL and considering fast moving intruder aircraft. Therefore, some of the performance specifications are inappropriate for small UAS operating at very low altitudes.

A.5 Requirements for modification

The affected requirements of RTCA DO-366 [i.8] include as follows:

- 1.2.4: This requirement limits radar performance to above 500 feet.
- 1.7.2: This requirement defines an alerting time of 85 seconds.
- 2.2.3: This requirement defines the specific frequency bands for radar within the range 4 200 MHz to 33,4 GHz.
- 2.2.6-2: This requirement defines the Field of Regard and the altitude at which it is effective (> 1 000 ft).
- 2.2.7-11: This requirement defines the RDR for a small othership and an ownship UA turn rate of 3 degrees/s. This gives an RDR of 5,4 NM (10 km).
- 2.2.7-12: This requirement defines the RDR for a medium othership and an ownship UA turn rate of 3 degrees/s. This gives an RDR of 6 NM (11,1 km).
- 2.2.7-13: This requirement defines the RDR for a large othership and an ownship UA turn rate of 3 degrees/s. This gives an RDR of 6,7 NM (12,4 km).

A.6 Proposed deviations

The following are the proposed deviations to the requirements of RTCA DO-366 [i.8] listed above, along with the justification as to why the performance and safety of the system is unaffected:

- 1.2.4: This requirement limits radar performance to above 500 feet. The operational environment of the UAS the radar is designed for is between ground level and 500 feet AGL, therefore the radar performance will be designed for up to 500 feet and intruders will only be considered in this operating altitude range. This provides an equivalent level of safety to the requirements of RTCA DO-366 [i.8].
- 1.72: This requirement defines an alerting time of 85 seconds, the radar has a much lower detect time which will be used. The 85 seconds takes into multiple factors and the operational requirements of a different vehicle and type of operation which is not relevant to the smaller and more responsive UAS which would have a response time of around 3 seconds time from the track being detected to the pilot being alerted.
- 2.2.7-11: The Small Othership RDR is determined by UAS performance and the speeds at which a 'small' intruder may reasonably be anticipated to be operating at in the same low-level environment. Based on a worst-case scenario of a head-on encounter (i.e. minimum time) and no manoeuvring by the othership, a lower RDR of **1 000 m** (0,54 NM) has been selected.
- 2.2.7-12: The Medium Othership RDR is determined by UAS performance and the speeds at which a 'medium' intruder may reasonably be anticipated to be operating at in the same low-level environment. Based on a worst-case scenario of a head-on encounter (i.e. minimum time) and no manoeuvring by the othership, a lower RDR of **1 900 m** (1 NM) has been selected.
- 2.2.7-13: The Large Othership RDR is determined by UAS performance and the speeds at which a 'large' intruder may reasonably be anticipated to be operating at in the same low-level environment. Based on a worst-case scenario of a head-on encounter (i.e. minimum time) and no manoeuvring by the othership, a lower RDR of **2 500 m** (1,3 NM) has been selected.

Annex B (informative): Bibliography

- ETSI TR 103 148 (V 1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference document (SRdoc); Technical characteristics of Radio equipment to be used in the 76 GHz to 77 GHz band; Short-Range Radar to be fitted on fixed transport infrastructure".

History

Document history		
V1.1.1	June 2025	Publication