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| U.S. Radiocommunications Sector  Fact Sheet | |
| **Working Party:** ITU-R WP-5B | **Document No:** USWP5B31-14-FS |
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| **Document Title:** PRELIMINARY DRAFT NEW RECOMMENDATION ITU-R M.[24.45-24.65\_GHz\_ARNS] - Characteristics of and protection criteria for radars operating in the aeronautical radionavigation service in the frequency band 24.45-24.65 GHz | |
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| **Purpose/Objective:** The purpose of this contribution is to develop a new recommendation for aeronautical radionavigation systems, including unmanned aircraft systems (UAS) Detect and Avoid (DAA) radar systems, in the 24.45-24.65 GHz band. | |
| **Abstract:** This contribution will continue the process of developing a new recommendation for systems that operate in the 24.45-24.65 GHz Aeronautical Radionavigation Service allocation including UAS DAA systems. This contribution will address comments received from other administrations during the previous ITU-R WP-5B meeting. Due to the stability of the technical characteristics data for the airborne and ground based DAA system this contribution proposes to upgrade the Working Document into Preliminary Draft New Recommendation. This contribution will be an update to the new report found in Annex 13 of the Chairman’s Report of the 21 December 2022 Document 5B/731-E hybrid meeting. | |

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| **Radiocommunication Study Groups** |  |
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| **XX July 2023** |
| **English only** |

Introduction

This document proposes new Recommendation with characteristics and protection criteria for aeronautical radionavigation systems, including unmanned aircraft (UA) detect and avoid (DAA) radar system operating in the aeronautical radionavigation service (ARNS) in the frequency band 24.45-24.65 GHz. These technical and operational characteristics are to be used as a guideline in analyzing compatibility between radars operating in the aeronautical radionavigation service and systems in other services within this band.

Proposal

The United States proposes that ITU-R Working Party (WP) 5B consider the updates to the working document towards a preliminary draft New Recommendation [ITU-R M.[24.45-24.65\_GHz\_ARNS]](https://www.itu.int/dms_ties/itu-r/md/19/wp5b/c/R19-WP5B-C-0731!N13!MSW-E.docx) attached to the Chairman’s Report. The proposed updates seek to address the editor’s notes and square brackets in this document.

The United States proposals are highlighted in yellow. It is also proposed to elevate the status of this document to Preliminary Draft New Recommendation. It should be noted that in certain instances the United States has provided USA notes in response to the editor’s notes for clarification. These notes are not intended to be retained for the final output of this document.

**Attachment:** 1

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| Annex 13 to Working Party 5B Chairman’s Report |
| PRELIMINARY DRAFT NEW  RECOMMENDATION ITU-R M.[24.45-24.65\_GHZ\_ARNS] |
| Characteristics of and protection criteria for radars operating in the  aeronautical radionavigation service in the frequency  band 24.45-24.65 GHz |

(202X)

[Editor’s note: During the July 2022 WP 5B meeting, it was agreed that further work was required to fully develop this document. This additional work needs to include a more robust description of the Detect and Avoid (DAA) radar systems similar to what is found in Section 5 of Annex 1 in Recommendation ITU-R M.1796-2. The work also needs to improve the protection criteria section of this recommendation to include protection information for pulsed interferes and continuous noise-like interferes as well as the aggregate impact of interference from multiple sources of interference and multiple types of interference (see Annex 2 of Recommendation ITU-R M.1796-2). In addition, information on the relationship between the DAA radars in this Recommendation and DAA radars in other Recommendations such as ITU-R M.1796-2 would be helpful. Finally, the relationship and compatibility requirements for airborne and ground based DAA radars that are proposed for this band.]

[*USA Note: The current draft has already been update to separate the airborne DAA radar from the ground based DAA radar in Section 2 of the Annex and expands the protection criteria in Section 4 as well taking into account Annex 2 of Recommendation ITU-R M.1796-2.*]

Scope

This document specifies the characteristics and protection criteria of radars operating in the aeronautical radionavigation service (ARNS) in the frequency band 24.45-24.65 GHz. The technical and operational characteristics should be used in analysing compatibility between radars operating in the aeronautical radionavigation service and systems in other services.

Keywords

24.45-24.65 GHz, radar, characteristics, protection.

Abbreviations/Glossary

ABDAA: Airborne detect and avoid

ARNS: Aeronautical radionavigation service

CDMA: Code-division multiple access

DAA: Detect and avoid

e.i.r.p.: Effective isotropically radiated power

ESA: Electronically scanned array

FDMA: Frequency division multiple access

FMCW: Frequency-modulated continuous wave

GBDAA: Ground based detect and avoid

LFM: Linear frequency modulation

PSD: Power spectral density

RCS Radar cross-section

RR: Radio Regulation

SNR Signal-to-noise power ratio

TDMA: Time-division multiple access

UA: Unmanned aircraft

UAS: Unmanned aircraft system

Related ITU Recommendations, Reports

Recommendations

ITU-R [M.1372](https://www.itu.int/rec/R-REC-M.1372/en) Efficient use of the radio spectrum by radar stations in the radiodetermination service

Report

ITU-R [M.2204](https://www.itu.int/pub/R-REP-M.2204) Characteristics and spectrum considerations for sense and avoid systems use on Unmanned Aircraft Systems (UAS)

The ITU Radiocommunication Assembly,

considering

*a)* that antenna, signal propagation, target detection, and wide necessary bandwidth of radar required to achieve their functions are optimum in certain frequency bands;

*b)* that the technical characteristics of radars operating in the aeronautical radionavigation service (ARNS) are determined by the mission of the system and vary widely even within a frequency band;

*c)* that the performance characteristics of receivers should be adequate to ensure that they do not suffer from interference due to transmitters situated at a reasonable distance and which operate in accordance with the Radio Regulations,

recognizing

*a)* that the frequency band 24.45-24.65 GHz is allocated on a primary basis to the radionavigation (including aeronautical radionavigation), fixed, mobile except aeronautical mobile, and inter-satellite services in ITU‑R Region 2;

*b)* that the frequency band 24.45-24.65 GHz is allocated on a primary basis to the radionavigation (including aeronautical radionavigation), inter-satellite, fixed, and mobile services in ITU-R Region 3;

*c)* that numerous features of radiodetermination radars can be expected to help suppress low-duty cycle (less than 5%) pulsed interference, especially from a few isolated sources and techniques for suppression of low-duty cycle pulsed interference between two or more pulsed system are contained in Recommendation ITU-R M.1372 – Efficient use of the radio spectrum by radar stations in the radiodetermination service;

*d)* that the inter-satellite service operating in the frequency band 24.45-24.65 GHz shall not claim protection from harmful interference from airport surface detection equipment stations of the radionavigation service,

recommends

**1** that the technical and operational characteristics of the ARNS radars operating in the ARNS described in the Annex should be considered representative of those operating in the frequency band 24.45-24.65 GHz and used in studies of compatibility with systems in other services;

**2** that, in the absence of performance requirements, the criterion of interfering signal power to radar receiver noise power level (*I*/*N)* of −6 dB, should be used as the required protection level for the aeronautical radionavigation radars, and that this represents the aggregate protection level if multiple interferers are present;

3 that compatibility assessments should recognize the safety of flight function of the ARNS radar and include an appropriate aviation safety margin;

4 that, in the case of pulsed interference, additional analysis should consider the undesired transmitter pulse train characteristics and the receiver signal processing to the extent possible in Recommendation ITU-R M.1372 as specified in *recognizing c)*.

Annex  
  
Technical and operational characteristics of radars operating in the  
aeronautical radionavigation service in the  
frequency band 24.45-24.65 GHz

# 1 Introduction

ARNS system operates in Regions 2 and 3 on a primary basis in the frequency band 24.45‑24.65 GHz. This Annex presents the technical and operational characteristics of representative ARNS radars operating in this frequency band.

ARNS systems are installed in unmanned aircraft (UA) or on the ground to detect non-cooperative aircraft as a component of an UA Detect and Avoid (DAA) system. These radars are used for collision avoidance on-board UA and can be used as a part of the integration of unmanned aircraft system (UAS).

# 2 Description of the detect and avoid radar system characteristics

*[Editor’s note: The description of the DAA radar systems below is needs to include the types of UAS systems that employ the DAA radars identified in Table 1, representative operational scenarios, scanning strategies, operations in and around airports, and interference detection capabilities for each type of system. These descriptions should also indicate whether the DAA is used throughout the entire flight or if its use is limited to certain segments of the flight. A discussion on the range of operation is determined would also be helpful. Also ensure that the text on DAA radar systems is consistent with the DAA descriptions in the Handbook on DAA systems that is currently under development.]*

[*USA Note: Many of the comments in Editor’s note above has been addressed in the description below as well in section 2.1 and 2.2.*]

The safe flight operation of UA in non-segregated airspace necessitates advanced techniques to detect and track nearby aircraft, terrain, remain well clear of obstacles, and properly act and respond to certain weather conditions. UA must avoid these objects in the same manner as manned aircraft. Two primary sensor systems are operational to allow a UAS to meet this requirement. The first class comprises sensor(s) or electronic system(s) on the air vehicle and is called airborne detect and avoid (ABDAA). The second class involves sensor(s) or electronic system(s) monitoring the air space from the ground and is refer to as ground based DAA (GBDAA).

**2.1 Airborne detect-and-avoid radar**

ABDAA radars are being developed for the purpose of enhancing flight safety by providing warnings of potential collisions or conflicts with non-cooperative aircraft [[1]](#footnote-1). The mission of this class of airborne radars encompasses several partially-overlapping functions referred to as collision avoidance, conflict avoidance, self-separation, safe separation, sense-and-avoid and due regard. This class of radars is of particular interest in unmanned aircraft (UA) applications where there is no onboard pilot to provide the safety-of-flight function visually. Unmanned aircraft are powered, aircraft that do not carry a human pilot, use aerodynamic forces to provide vehicle lift, and may fly semi-autonomously or autonomously, or be piloted remotely.

Detect-and-avoid radars must track all potentially threatening aircraft (called ‘intruders’) in their field of regard while simultaneously searching for new threats. Since more than one intruder will frequently be in the radar’s field of regard, a multi-target tracker is required. This requires either fairly rapid track-while-scan operation, or alternatively, interleaved search and track functions in a mode called ‘search while track’ in which the track updates are scheduled as they are required. This type of operation requires beam agility beyond the capability of a mechanically scanned antenna. For this reason, airborne DAA radars typically use either electronically scanned antennas or beamforming techniques to provide the required search and track functions.

The range required for detection and tracking depends on the amount of warning time required. This in turn depends on the speed of the host platform (called the ‘ownship’), the speed of intruder aircraft, the ownship’s manoeuvring capability, the type of avoidance manoeuvre (e.g. lateral vs vertical) and delays in initiating and executing the avoidance manoeuvre. A relatively fast UA with limited manoeuvrability would require a sensor with a greater range than a slower, more manoeuvrable UA.

The goal of airspace access for appropriately equipped UA systems is to achieve a level of safety equal to that of an aircraft with a pilot in the cockpit. The remote pilot will need to be aware of the environment within which the aircraft is operating, be able to identify the potential threats to the continued safe operation of the aircraft and take the appropriate action. In order for UAS to operate in non-segregated civil airspace, they must be integrated safely and adhere to current operational rules that provide an acceptable level of safety similar to that of a conventional manned aircraft. The DAA radar is part of an unmanned aircraft collision avoidance system whose primary function is to provide the capability to detect, track and report non-cooperative air traffic information to the remote pilot in order to maintain adequate separation from intruder aircraft. The system utilizes a “Pilot-in-the-Loop” approach in which the ground-based UA pilot will have final authority regarding UAS manoeuvres to avoid other aircraft (manned or unmanned).

**2.2 Ground based detect-and-avoid radar**

GBDAA is used for air traffic surveillance in support of DAA operations for unmanned aircraft. GBDAA detects and generate tracks within its declaration volume of airborne traffics. Unlike primary radars, DAA radars detect aircraft that flies at relatively low altitudes with smaller radar cross-sections.

As with the ABDAA, GBDAA compliments other surveillance sensors by providing detection of non-cooperative traffic (i.e., those without operating transponders or ADS-B Out capabilities). Aircraft tracks are established at sufficient range and accuracy to enable an UA flying within GBDAA operational volume to remain well clear of other aircraft.

FIGURE 1

Ground-based detect and avoid

Diagram, map

Description automatically generated

Presently, in the frequency band 24.45-24.65 GHz, there are no significant differences between the GBDAA and ABDAA systems. The requirements is simply to support the safety case, whether that’s achieved with airborne sensors, ground-based sensors, or both. However, it should be noted that the capability of ground-based vs airborne radar is different. A GBDAA radar looking up can see both in front, behind and aircraft of interest, whereas an ABDAA radar onboard the aircraft is generally pointed in the direction of flight and can only detect objects across a field of view in the direction it’s pointed. Additionally, smaller UAS are limited in the size and power of radar they can carry, whereas ground based radar has less limitation with regards to size or weight. There are also different technical challenges; for example, with GBDAA where line-of-sight over hills and buildings will need to be considered during implementation whereas with ABDAA implementation may require careful consideration of ground clutter (and returns from objects on the ground more generally) at low altitudes.

GBDAA systems use ground based sensor as the surveillance sensor and may have multiple GBDAA sensors to cover the necessary surveillance volume. The GBDAA can be utilized to enable transit operations, or operations at lower altitudes in area near airports as well as to enable extended operations.

**3 Characteristics of aeronautical radionavigation detect and avoid radar**

The technical parameters are provided in Table 1.

TABLE 1

Technical parameters of detect and avoid radar

| Parameter | Units | Radar 1 (Note 1) | Radar 2 (Note 1) |
| --- | --- | --- | --- |
| Platform |  | Airborne | Airborne |
| Platform height | km | Up to 20 | Up to 20 |
|  |  |  |  |
| Radar type |  | FMCW | FMCW |
| Range class |  | Short range | Medium range |
| Operating range | km | 3 | 8 |
| Maximum number of drones within the same operating area |  | 3 to 8 | 3 to 10 |
| Ground speed | km/h | <430 | <430 |
| Target speeds (max) | m/s | <200 | <200 |
| Frequency tuning range  (Note 2) | GHz | 24.45-24.65 | 24.45-24.65 |
| Channelization methods |  | FDMA: 3 ch 45 MHz  CDMA: 4 ch  TDMA: 4 ch  LFM-dir: up/down | FDMA: 3 to 6 ch  CDMA: 4 ch  TDMA: 4 ch  LFM-dir: up/down |
| Channel selection method between radars  (Note 3) |  | SW selectable | SW selectable |
| Emission type |  | FXN | FXN |
| Radar Modulation |  | LFM | LFM |
| Modulation bandwidth | MHz | 45 | 10 to 50 (Note 4) |
| Pulse width | μs | 200 | 50 to 200 (Note 4) |
| Pulse rise and fall times | μs | < 1 | < 1 |
| RF emission bandwidth at   −3 dBc  −20 dBc  −40 dBc | MHz | <48  <54  <60 | 110% BWchirp 120% BWchirp 130% BWchirp |
| Pulse repetition frequency | kHz | 4.7 | 2 to 10 |
| Average transmitter power | W | 2 | 12 |
| Out-of-band emission characteristics | dBc | < -75  (through 3rd harmonic) | < -75  (through 3rd harmonic) |
| Spurious emission characteristics | dBuV/m in 1MHz BW | < 83 | < 83 |
| Receiver IF bandwidth  −3 dB  −20 dB  −60 dB | MHz | < 10  < 20  < 70 | <10  < 30  < 40 |
| Sensitivity (MDS) (at RX input. SNR = 12 dB) | dBm | −119 | −122 |
| Receiver noise figure | dB | 6 | 3 |
| Calculated Rx noise power (Note 4) | dBW | −131 | −134 |
| Saturation level | dBm | −40 | −40 |
| Antenna type |  | ESA (Note 6) | ESA (Note 6) |
| Antenna placement |  | Fixed (internally sealed package) | Fixed (internally sealed package) |
| Antenna gain | dBi | 21 | 27 |
| First antenna sidelobe | dBi | < −16 | < −16 |
| Horizontal beamwidth (2-way at 0,0) | degrees | 2 | 2 |
| Vertical beamwidth (2-way at 0,0) | degrees | 6 | 2 |
| Polarization |  | Horizontal | Horizontal |
| Horizontal antenna scan (from boresight) | degrees | ±60 | ±60 |
| Vertical antenna scan (from boresight) | degrees | ±40 | ±40 |
| Protection Criteria  (aggregate) I/N | dB | -6 | -6 |
| Notes:  1 In some cases a UAS is unable to equip with airborne DAA. These radars can also be deployed on the ground in order to provide the intended DAA functions.  2 Utilized bandwidth - Inclusive of frequency-channel guard-bands.  3 Channel selection is purely SW-defined and can be on-the-fly dynamic. Some settings may allow radar to self-configure based on detected spectrum-conflict.  4 Waveform is software-defined on a CPI-by-CPI basis, and optimized for targets, and spectral environments.  5 Compressed bandwidth before processing gain.  6 High T/R ESA RF beamforming on both transmit and receive. | | | |

# 4 Protection criteria

## 4.1 Continuous noise-like interference

Radars are affected in fundamentally different ways by unwanted signals of different forms, and an especially sharp difference prevails between the effects of continuous noise-like energy and those of pulses. Continuous-wave interference of a noise-like type inflicts a desensitizing effect on radiodetermination radars, and that effect is predictably related to its intensity. The desensitizing effect on radars from other services of a continuous-wave or noise-like type modulation is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density (PSD) can, to within a reasonable approximation, simply be added to the PSD of the radar receiver thermal noise. If PSD of radar‑receiver noise in the absence of interference is denoted by *N*0 and that of noise-like interference by *I*0, the resultant effective noise PSD becomes simply *I*0 + *N*0.

Given that, the radar protection criteria traditionally established within ITU-R are based on the penalties incurred to maintain the target-return signal-to-noise ratio in the presence of the interference, requiring that the target-return power be raised in proportion to the increase of noise power from *N*0 to *I*0 + *N*0. That can only be done by accepting shorter maximum ranges on given targets, sacrificing observation of small targets, or modifying the radar to give it a higher transmitter power or power-aperture product.

These penalties vary depending on the radar’s function and the nature of its targets. For most radars, an increase in the effective noise level of about 1 dB would inflict the maximum tolerable degradation on performance. In the case of a discrete target having a given average or median Radar cross-section (RCS), that increase would reduce the detection range by about 6% regardless of any RCS fluctuation characteristics that target might have. This effect results from the fact that the achievable free-space range is proportional to the 4th root of the resultant signal-to-noise power ratio (SNR), from the most familiar form of the radar range equation. A 1 dB increase of effective noise power is a factor of 1.26 in power, so it would, if uncompensated, require the free-space range from a given discrete target to be reduced by a factor of 1/(1.261/4), or 1/1.06; i.e. a range capability reduction of about 6%. In the range equation, the SNR is also directly proportional to transmitter power, to power-aperture product (for a surveillance radar), and to target radar cross section. Alternatively, therefore, the 1 dB increase of effective noise power could be compensated by forgoing detection of targets except those having an average radar cross section 1.26 times as large as the minimum-size target that could be detected in the interference-free regime or by increasing the radar transmitter power or its power-aperture product by 26%. Any of these alternatives is at the limit of acceptability in most radar missions, and the system modifications would be costly, impractical, or impossible, especially in mobile radars. For discrete targets, those performance penalties hold for any given probability of detection and false‑alarm rate and any target fluctuation characteristics.

### 4.1.1 Aggregation of interference contributions

The 1 dB increase referred to throughout the above discussions corresponds to an (*I + N*)/*N* ratio of 1.26, or an *I/N* of about −6 dB. This represents the tolerable aggregate effect of all interferers. It applies for reception via the radar’s main beam as well as for simultaneous reception via side lobes. The tolerable *I/N* for an individual noise-like interferer therefore depends on the number of interferers and their geometry and should be assessed in the analysis of a given scenario. This is a consequence of the fact that almost all the radars in this band serve event-driven missions, observe non-cooperative targets, and do not have the benefit of redundancy, including the re-transmission of packets that is becoming used more and more in communications technologies. Basically, sensing, including radar, is a fundamentally different use of the RF spectrum than is communications, and the same interference-protection rules are not appropriate for both.

## 4.2 Pulsed interference

The effect of pulsed interference is more difficult to quantify and is strongly dependent on receiver/processor design and mode of operation. In particular, the differential processing gains for valid-target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. Several different forms of performance degradation can be inflicted by such desensitization. Assessing it will be an objective for analyses of interactions between specific radar types. Assessing it will be an objective for analysis of interactions between specific pulsed radar types.

In general, numerous features of radiodetermination radars can be expected to help suppress low-duty cycle pulsed interference, especially from a few isolated sources. Techniques for suppression of low‑duty cycle pulsed interference are contained in Recommendation ITU-R M.1372. When multiple interferers are present, the recommended *I/N* protection criteria remains unchanged. The total interference level actually arriving at the radar receiver depends on the number of interferers, their spatial distribution and their signal structure and needs to be assessed in the course of an aggregation analysis of a given scenario. If interference were received from several azimuth directions, an aggregation analysis has to cumulate simultaneous contributions from all these directions, being received via the radar antenna’s main beam and/or side-lobes, in order to assess compatibility.

For typical radars an increase of about 1 dB would constitute significant degradation, equivalent to a detection-range reduction of about 6%. Therefore, the criterion of interfering signal power to radar receiver noise power level (*I*/*N)* of −6 dB should be used as the required protection level for the aeronautical radionavigation radars provided that this represents the aggregate protection level if multiple interferers are present. The compatibility assessments should also recognize the safety of flight function of the ARNS radar and include an appropriate aviation safety margin.

These protection criteria represent the aggregate effects of multiple interferers, when present; the allowable *I*/*N* ratio for an individual interferer depends on the number of interferers and their geometry and needs to be assessed in the course of analysis of a given scenario. The aggregation factor can be very substantial in the case of certain communication systems in which a great number of stations can be deployed.

1. Aircraft that are not equipped with an air traffic control radar beacon system transponder, automatic dependent surveillance-broadcast system, traffic alert and collision avoidance system or airborne collision avoidance system]. [↑](#footnote-ref-1)