European Commission

JRC TECHNICAL REPORT

An experimental evaluation of the Dynamic Frequency Selection (DFS) algorithm for weather radar and WLAN/RLAN coexistence in the 5GHz band.

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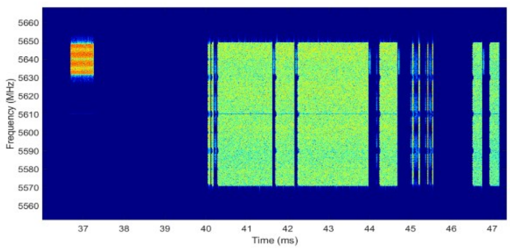
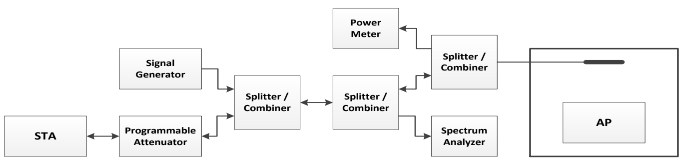
2022





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Acknowledgment

We acknowledge the contribution and feedback provided by our JRC colleagues, who supported the experimental set up and measurement campaigns performed in this study.

Abstract

The issue of interference to meteorological radars from Wireless Local Area Network (WLAN) and Radio Local Area Network (RLAN) or WAS/RLAN[1] systems operating in the 5 GHz band are on the agenda of several groups and committees since long time as initial issues of coexistence are dated more than 10 years ago. Radio Frequency Interference (RFI) is one of the main issues in weather radar community as data quality and post-processing algorithms can be negatively impacted by interferences. On the basis of the World Radiocommunications Conference in 2003, C-band radars share their operational frequency band with WLAN/RLAN and WLAN, which may lead to causing interferences in weather radar systems.

The European Commission Joint Research Centre (EC DG JRC) has started to investigate in 2020 the matter of coexistence between meteorological radars as part of the overall activity on radio frequency coexistence between wireless services. The identification of the policy options and their assessment on various dimensions was performed in a previous JRC technical report JRC125475, which also identified the need for specific experimental activities which can be conducted at the JRC. In the report JRC125475, these options were listed as options 21,23,24.

This technical report describes the experimental activities conducted in the JRC to evaluate the options identified above and the obtained results.

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[1] At ETSI level and at CEPT level, WLAN it is called WAS/RLAN (Wireless Access Systems)/ Radio Local Area Network.

Revision History

Version	Notes	Data
V1	First version with Option 21 and 24	20/01/2022
V2	Addition of the test results for Option 23	04/03/2022
V3	Revision of the draft technical report.	10/03/2022
V4	Final version before submission in PUBSY	11/03/2022

1 Introduction

The use of radio frequencies for the observation of environmental phenomena is an important part of effective early warning and emergency management system to mitigate loss of life and damage to property from natural hazards. In this context, meteorological radars or weather radars (the two terms are used with the same meaning in this report) perform precipitation and wind measurements that play a crucial role in the immediate meteorological and hydrological alert processes (ECC 2017).

In Europe, most weather radars are operating at C-band (5600-5650 MHz band), sharing the same frequency band with Radio Local Area Network (RLAN) and Wireless Local Area Network (WLAN). Since the World Radiocommunication Conference in 2003 (WRC-03), the primary allocation for Wireless Access Systems including WLAN/RLAN and WLAN, was set in the bands of 5.150–5.350 and 5.470–5.725 GHz.

Note: because different references in literature adopt the terms WLAN, RLAN and WAS with the same meaning, they are used interchangeably in this report. For example, at ETSI level and at CEPT level (CEPT2019,CEPT2020), WLAN it is called WAS/RLAN (Wireless Access Systems)/ Radio Local Area Network while in ADCO RED (ADCO 2019) or in the industry domain WLAN/RLAN is often used. Then, in this report, the term WLAN/RLAN, WLAN, RLAN and WAS have the same meaning.

On the basis of (WRC-03) weather radars[2] and WLAN/RLAN are expected to coexist in the same radio frequency bands with WLAN/RLAN following the conditions defined in ECC/DEC/(04)08 (ECC 2004), (ECC 2005) and (ETSI 2017). Then, the WLAN/RLAN, is required to implement the Dynamic Frequency Selection (DFS) to detect the radar signals and avoid the usage of the corresponding identified radars channels by WLAN/RLAN.

The JRC technical report JRC125475 already identified a number of regulatory, technical and standardization options, which were then evaluated along a number of dimensions: economic, deployment complexity and so on. Some options (options 21, 23,24 of JRC125475) required an experimental evaluation which is documented in this report.

1.1 Context of the problem

The main problem is that many cases of interference have been reported on the meteorological radars since 2006 (Saltikoff 2016),(Tristant 2017). This is due to a number of reasons which have been partially mitigated in the past through the revision of technical specifications (ETSI 2017) and other actions but cases of interference are still reported today. It is noted that CEPT provides an annual interference statistic, including interferences into Weather Radars: https://cept.org/ecc/groups/ecc/wg-fm/fm-22/client/introduction/annual-radio-interference-statistics-and-special-interference-cases (CEPT FM 2021b). Then, interferences to weather radars are a long standing problem, which is not resolved yet.

This report attempts to investigate two potential causes of the interference problem related to the Dynamic Frequency Selection (DFS) function of the WLAN/RLAN devices. This function is used to detect the weather radar signal in space so that the WLAN/RLAN device can re-allocate the transmission frequency band to another band to avoid interference to the weather radar operation.

1.2 Scope and structure of this report

The scope of this report is to report on the experimental activities related to the problem of coexistence of radar with WLAN/RLAN equipment in the 5GHz band.

[2] While this report investigates coexistence for weather radar, it is noted that various types of radars are using 5GHz bands (in particular meteorological radars transmitting at 5.6 GHz but also defense/military radars)

In particular, this report describes the experimental activities conducted for options 21,23 and 24 of JRC125475.

The description of the experimental activities is provided in this report in order the activities were executed (first option 21, then option 24 and finally option 23).

- Option 21: Assessment of the impact of activity ratio higher than 30 % on DFS efficiency. The experimental activities are described in section 2 of this report.
- Option 24: Assessment of the impact of the Application of clause 4.2.6.2.1 of standard ETSI EN 301 893. (ETSI 2017). The experimental activities are described in section 3 of this report.
- Option 23: Assessment of the impact of RLAN installation (vertical / horizontal) and its capacity to detect radar signature from the DFS (Impact of radar location/angle: vertical/horizontal on identification of the radar signature). The experimental activities are described in section 4 of this report.

Finally Section 5 of this report provides the conclusions.

2 Assessment of the impact of activity ratio higher than 30 % on DFS efficiency (Option 21)

This experimental activity is focused on the assessment of the impact (either negative or positive) on the efficiency of the Dynamic Frequency Selection (DFS) function implemented in the WLAN/RLAN to detect the weather radar signal in space.

The rationale for this test is to determine if and at which point the load rate, when exceeded by 30%, makes the DFS functionality inefficient. Several authorities have already observed this phenomenon. Based on lesson learnt from the tests, this option would be useful to identify the relevant improvement of the standard ETSI EN 301 893 (ETSI 2017) in order to reduce the risks of DFS malfunctioning. If the load rate increases, the WLAN/RLAN equipment may not be designed to implement in an efficient way the DFS. Then, this type of test can be used to evaluate if the WLAN/RLAN equipment has a margin of computing capabilities even for larger values of the load factor as described in the standard EN 301 893.

It can also improve the legal basis for market surveillance authorities to implement enforcement actions when cases of weather radar interference are reported.

2.1 Test information

Date of test:

22-23 November 2021

Normative reference

ETSI EN 301 893 V2.1.45 (Draft)

Device under test

Anonymised device name: AP-COEX42

Firmware version

V9.5.4.3

2.2 Test setup and materials (equipment)

The aim of this subsection is to the describe the overall test set-up (how the equipment is connected and operating), the materials used in the test set up (the test equipment), the configuration of the devices and the channels used (it must be a channel where the DFS is mandatory by the European regulation) and the tools used to generate traffic and to analyse traffic and signal in space

The setup used for the test is shown in Figure 2. The device under test (DUT) is a WLAN/RLAN access point (AP) with integral antennas. The AP was put in a small shielded anechoic chamber in which a probe antenna is used to connect to the test setup in conducted mode. An associated RLAN station (STA) connects to the AP through a programmable attenuator and a series of power splitter and power combiners. A signal generator is used to emulate the radar signal. A spectrum analyser monitors the spectrum and a fast power meter measures the activity factor.

2.2.1 Test setup

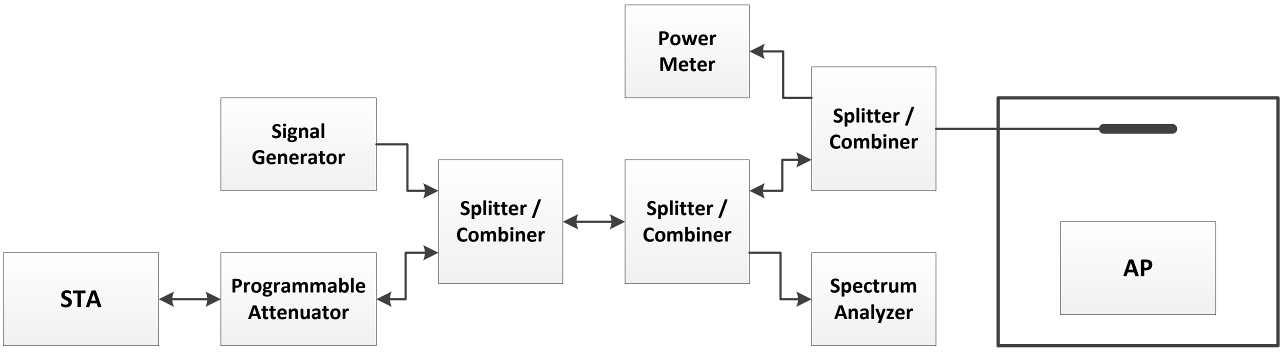


Figure 1: Test setup to evaluate the impact of activity ratio higher than 30 % on DFS efficiency.

2.2.2 List of equipment

Details on equipment used for the test are given in Table 3.

Table 1: List of equipment used for the test.

Description	Manufacturer	Model	Serial number
RLAN station (STA)	Ubit	AX200	
Programmable attenuator	Mini-Circuits	RCDAT-6000-110	11502100064
Splitter/Combiner	Narda	4456.2	06327
Splitter/Combiner	Narda	4456.2	06330
Splitter/Combiner	ATM	P213H	J664310-01
Signal generator	Keysight	PSG E8267D	MY47220082
Spectrum analyser	Keysight	PXA N9030B	MY61270177
Power meter	Dare Instruments	RPR3006W	13I00030SN055
RF diagnostic chamber	Rodhe&Schwarz	DST 200	

2.2.3 DUT configuration and operation

The Wireless settings of the AP was the following

- 2.4 GHz radio turned off
- 5 GHz radio turned on
  - Wireless Mode: 11ax
  - Channel Width: Dynamic 20 / 40 / 80 MHz
  - Guard Interval: Long-800 ns
  - Output Power: 100%
  - Channel: 128 / 5640 MHz

Traffic was forced using iperf3 tool with the following commands:

On the STA side: iperf3 –s

On the AP side to obtain 70% activity: iperf3 –c 192.168.0.21 –t 120 –b 200E6

On the AP side to obtain 33% activity: iperf3 –c 192.168.0.21 –t 120 –b 120E6

2.2.4 Radar waveform

A single waveform was used during the test. It corresponds to signal #6 in table D.4 of EN 301 893 V2.1.45 with the following parameters:

- Pulse width: 1 µs (microsecond)
- PRF1: 800.00 Hz
- PRF2: 1200.00 Hz
- Number of pulses for each PRF: 18
- Sampling frequency: 40.00 MHz

2.3 Test description

The test is an adaptation of the In-Service test described in clause 5.4.8.2.1.5 of EN 301 893 using a single radar signal. It consists in measuring the minimum power of the detected radar signal with various activity factors. The AP is configured to operate in a channel protected by DFS (ch128). A first measurement is performed without forced traffic, leading to a 0.5% activity factor, due to transmission of AP beacons. Then the measurement is repeated with forced traffic to obtain activity factors of 33% and 70%.

The following steps are performed:

a) Reset AP. After a few minutes, the AP starts broadcasting in this channel and the STA can connect to it.
b) Set the signal generator's output power such that the signal received at the location of the AP by a device with 0 dBi antenna gain is -72 dBm, i.e. 10 dB below the detection threshold.
c) Increase the signal generator power by 1 dB until the AP ceases transmitting in that channel.
d) Record the last value of signal generator power.
e) Repeat steps a) to d) for activity factors 33% and 70%.

2.4 Results

Table 4 contains the results of the test performed with three different values of activity factor (i.e. 0.5%, 33% and 70%). The signal generator level that triggers DFS is -14 dBm for all tested values of activity factor. This level leads to a received power at the DUT of -61 dBm assuming 0 dBi antenna gain. It is only 1 dB above the radar detection threshold level defined in table D.2 of EN 301 893.

Table 2: Result summary of the activity factor test.

Radar centre frequency (MHz)	**iperf client command**	**Activity factor (%)**	**Last signal generator power (dBm)**	**Received power (dBm)**
5640	none	0.5	-14	-61
5640	iperf3 -c 192.168.0.21 -t 120 -b 120E6	33	-14	-61
5640	iperf3 -c 192.168.0.21 -t 120 -b 200E6	70	-14	-61

The tested RLAN device is able to detect a typical weather radar signal when operating with an activity factor up 70%, which shows that the WLAN/RLAN device under test has a considerable margin of computing capabilities or the implementation of the DFS function is well separated from the traffic functions to support higher load factors than what specified in the standards.

3 Assessment of the impact of the application of clause 4.2.6.2.1 of standard ETSI EN 301 893 (option 24)

This experimental activity aims to assess the impact of the application of clause 4.2.6.2.1 of ETSI EN 301 893, which is defined in (ETSI 2017) by the sentence:

’The radar detection requirements specified in clause 4.2.6.2.2 to clause 4.2.6.2.4 assume that the centre frequencies of the radar signals fall within the central 80 % of the Occupied Channel Bandwidth of the WLAN/RLAN (see clause 4.2.2).’. This option will determine the DFS implementation when the figure of 80% is well achieved and to determine if the value of 80% is appropriate and especially that there is no impact on the radar when the latter's signals are lower than this 80% floor value. Based on the results obtained from the tests carried out, it will be necessary to identify the possible improvements and modifications of the standard in consequence’.

The rationale for the test is to determine that the value of 80% is appropriate and especially that there is no impact on the weather radar operation when the latter's signals are lower than this 80% floor value.

The experimental activity consists in a series of tests on WLAN/RLNA equipment where DFS is enabled to test the detection of radar signatures with radar signals falling within different percentages of central Occupied Channel Bandwidth of the RLAN.

The results of the tests can be used for direct support to the standardization process because it can be used to improve standard ETSI EN 301 893.

3.1 Test information

Date of test:

25 November 2021

Normative reference

Both ETSI EN 301 893 V2.1.1 (stable published version) and draft ETSI EN 301 893 V2.1.45.

Device under test

Anonymised device name: AP-COEX42. This is a consumer market WLAN/RLAN equipment where DFS is enabled.

Firmware version

V9.5.4.3. The device was updated to the latest software version available on the web site of the WLAN/RLAN vendor manufacturer.

3.2 Test setup and materials (equipment)

The aim of this subsection is to the describe the overall test set-up (how the equipment is connected and operating), the materials used in the test set up (the test equipment), the configuration of the devices and the channels used (it must be a channel where the DFS is mandatory by the European regulation) and the tools used to generate traffic and to analyse traffic and signal in space.

3.2.1 Test Setup

The setup used for the test is shown in Figure 2. The device under test (DUT) is an RLAN Access Point (AP) with integral antennas. The AP was put in a small shielded anechoic chamber in which a probe antenna connects to the test setup in conducted mode. An associated RLAN station (STA identified as AP-COEX42) connects to the AP through a programmable attenuator and a series of power splitter and power combiners. A signal generator is used to emulate the radar signal. A spectrum analyser monitors the spectrum and a fast power meter measures the activity factor.

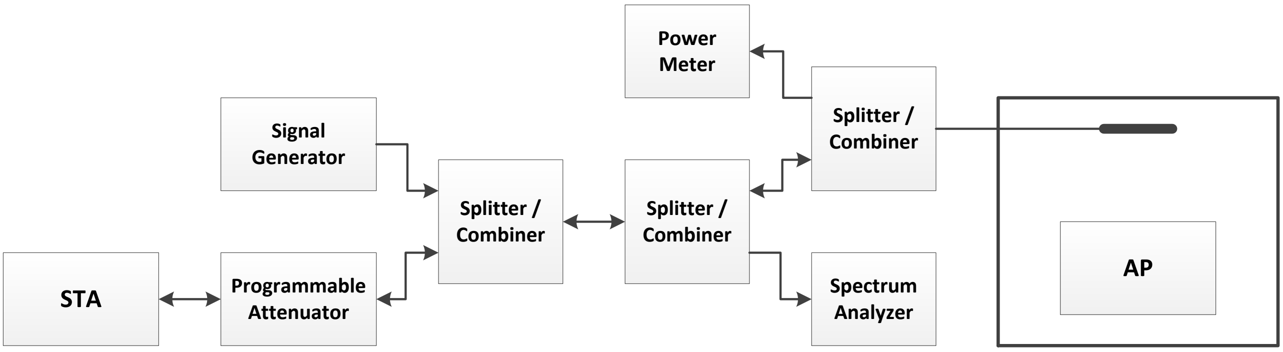


Figure 2: Test setup for the assessment of the impact of the application of clause 4.2.6.2.1 of standard ETSI EN 301 893. Option 24 of JRC Report.

3.2.2 List of equipment

Details on equipment used for the test are given in Table 3.

Table 3: List of equipment used for the test.

Description	Manufacturer	Model	Serial number
RLAN station (STA)	Ubit	AX200	
Programmable attenuator	Mini-Circuits	RCDAT-6000-110	11502100064
Splitter/Combiner	Narda	4456.2	06327
Splitter/Combiner	Narda	4456.2	06330
Splitter/Combiner	ATM	P213H	J664310-01
Signal generator	Keysight	PSG E8267D	MY47220082
Spectrum analyser	Keysight	PXA N9030B	MY61270177
Power meter	Dare Instruments	RPR3006W	13I00030SN055
RF diagnostic chamber	Rodhe&Schwarz	DST 200	

3.2.3 DUT configuration and operation

The Wireless settings of the AP was the following

- 2.4 GHz radio turned off
- 5 GHz radio turned on
  - Wireless Mode: 11ax
  - Channel Width: Dynamic 20 / 40 / 80 MHz
  - Guard Interval: Long-800 ns
  - Output Power: 100%
  - Channel: 128 / 5640 MHz

Traffic was forced using iperf3 tool with the following commands:

On the STA side: iperf3 –s

On the AP side to obtain 33% activity: iperf3 –c 192.168.0.21 –t 120 –b 120E6

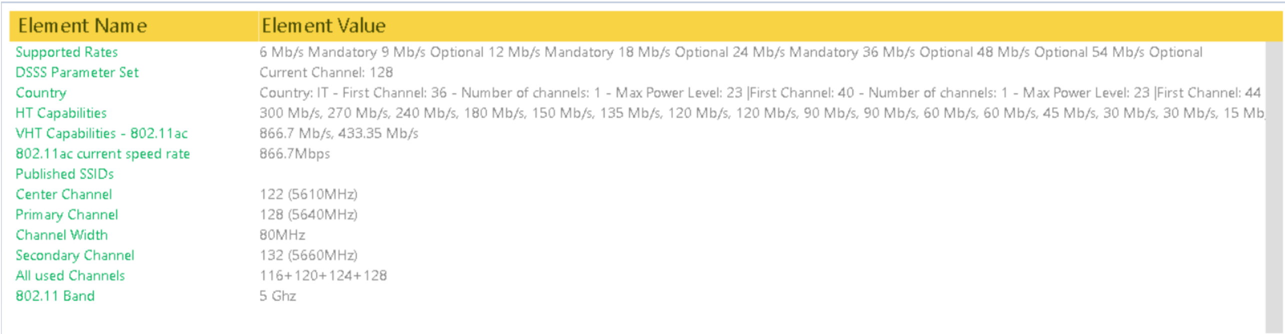
3.2.4 Channel bandwidth to consider

In clause 4.2.6.2.1 of EN 301 893, it reads that "The radar detection requirements specified in the present document assume that the centre frequencies of the radar signals fall within the central 80 % of the occupied bandwidth of the RLAN device."

Although channel 128 was selected (20 MHz channel, centre frequency 5640 MHz), the bandwidth to be considered in application of clause 4.2.6.2.1 is the total bandwidth used by the RLAN device, i.e., 80 MHz centred to 5610 MHz as it can be seen in Figure 3, a screen shot of Acrylic Wifi scanner[3].

These values of bandwidth and centre frequency are confirmed by plotting the spectrogram of an IQ capture of the Wifi signal (Figure 4). A beacon signal is transmitted at 37 ms in a 20 MHz channel with 5640MHZ centre frequency and data transmission occurs from 40 ms in an 80 MHz channel centred to 5610MHz.

[3] Acrylic Wi-Fi is a complete suite of WiFi analysis programs to perform WiFi coverage and security analysis, study WiFi communications networks in a very short time and map all devices within reach. Additional details are in https://www.acrylicwifi.com/en/wlan-wifi-wireless-network-software-tools/wlan-scanner-acrylic-wifi-free/. The Acrylic tool is used in these experimental activities to evaluate and confirm the WiFi configurations actually used in the experiment.



Element Name	Element Value
Supported Rates	6 Mb/s Mandatory 9 Mb/s Optional 12 Mb/s Mandatory 18 Mb/s Optional 24 Mb/s Mandatory 36 Mb/s Optional 48 Mb/s Optional 54 Mb/s Optional
DSSS Parameter Set	Current Channel: 128
Country	Country: IT - First Channel: 36 - Number of channels: 1 - Max Power Level: 23 |First Channel: 40 - Number of channels: 1 - Max Power Level: 23 |First Channel: 44
HT Capabilities	300 Mb/s, 270 Mb/s, 240 Mb/s, 180 Mb/s, 150 Mb/s, 135 Mb/s, 120 Mb/s, 120 Mb/s, 90 Mb/s, 90 Mb/s, 60 Mb/s, 60 Mb/s, 45 Mb/s, 30 Mb/s, 30 Mb/s, 15 Mb
VHT Capabilities - 802.11ac	866.7 Mb/s, 433.35 Mb/s
802.11ac current speed rate	866.7Mbps
Published SSIDs	
Center Channel	122 (5610MHz)
Primary Channel	128 (5640MHz)
Channel Width	80MHz
Secondary Channel	132 (5660MHz)
All used Channels	116+120+124+128
802.11 Band	5 Ghz

Figure 3: Screen shot of Acrylic Wifi scanner.

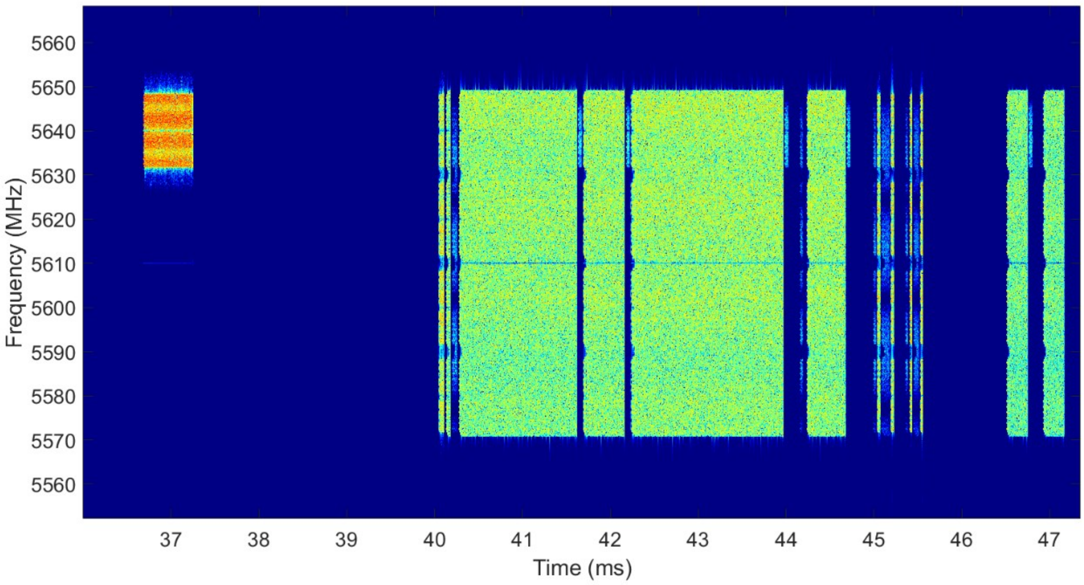


Figure 4: Spectrogram showing 20 MHz and 80 MHz channels.

3.2.5 Occupied bandwidth

The 99% occupied bandwidth (OBW) is calculated by processing with Matlab[4] the IQ capture of one data packet transmitted in an 80 MHz channel. OBW equals 77.6 MHZ as shown in Figure 5 and the central 80% of occupied bandwidth is the frequency interval [5579;5641] MHz.

[4] MATLAB is a scientific programming language. Additional details are at https://www.mathworks.com.

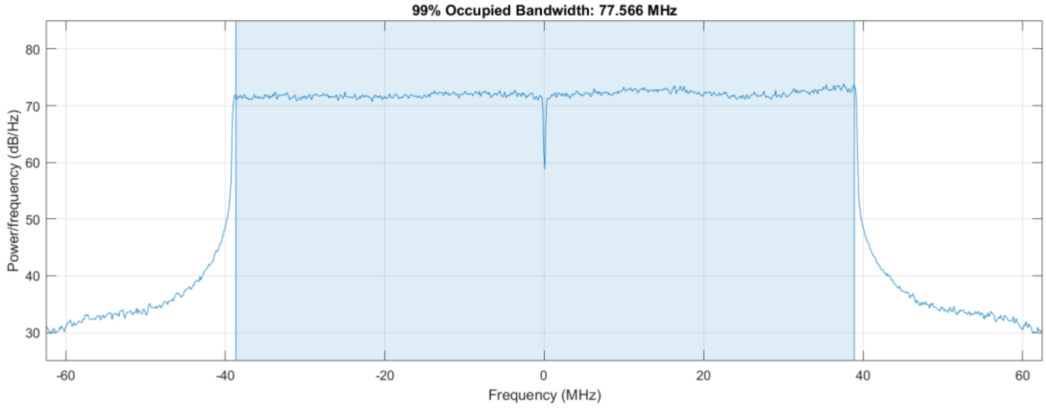


Figure 5: Calculation of occupied bandwidth.

3.2.6 Radar waveform

A single waveform was used during the test. It corresponds to signal #6 in table D.4 of EN 301 893 V2.1.45 with the following parameters:

- Pulse width: 1 µs (microsecond)
- PRF1: 800.00 Hz
- PRF2: 1200.00 Hz
- Number of pulses for each PRF: 18
- Sampling frequency: 40.00 MHz

3.3 Test description

The test is an adaptation of the In-Service test described in clause 5.4.8.2.1.5 of EN 301 893 (ETSI 2017) using a single radar signal. It consists in measuring the minimum power of the detected radar signal with various values of centre frequency of the simulated radar signal (outside the identified 80% limit).

The rational for the test is that different values of the centre frequency may impact negatively the DFS function of the WLAN/RLAN equipment because the amount of weather radar signal energy collected by the DFS function may not be optimal in comparison to the technical specification defined in (ETSI 2017) Then, it is interesting to evaluate the robustness of the DFS function implemented in a 'real' (not simulated) WLAN/RLAN equipment

The following steps are performed:

a) Reset AP. After a few minutes, the AP starts broadcasting in this channel and the STA can connect to it.
b) Set the center frequency of the signal generator to the first value.
c) Set the signal generator's output power such that the signal received at the location of the AP by a device with 0 dBi antenna gain is -72 dBm, i.e. 10 dB below the detection threshold.
d) Increase the signal generator power by 1 dB until the AP ceases transmitting in that channel.
e) Record the last value of signal generator power.
f) Repeat steps a) to d) for other of centre frequencies of the generated signal.

3.4 Results

Table 4 contains the results of the test performed with four different values of centre frequencies of the radar signal. The signal generator level that triggered DFS ranges between -15 to -13 dBm corresponding to a received power at the DUT between -62 to -60 dBm so very close to -62 dBm, the radar detection threshold level defined in table D.2 of EN 301 893.

Table 4: Result summary of the test with various radar centre frequencies.

Radar centre frequency (MHz)	**Radar signal centre frequency in comparison to RLAN occupied bandwidth (OBW)**	**Activity factor (%)**	**Last signal generator power (dBm)**	**Received power (dBm)**
5579	Lower edge of 80% OBW	33	-14	-61
5675	Lower edge of 90% OBW	33	-15	-62
5645	Upper edge of 90% OBW	33	-13	-60
5648.8	Upper edge of OBW	33	-13	-60

The conclusion of the test activity is that tested RLAN device is able to detect a typical weather radar signal whose centre frequency falls at the edge of the frequency band defined in clause 4.2.6.2.1 of EN 301 893 and also outside this frequency band and up to the upper edge of the RLAN occupied bandwidth.

4 Assessment of impact of the RLAN installation (vertical / horizontal) and its capacity to detect radar signature from the DFS (Impact of radar location/angle : vertical/horizontal on identification of the radar signature) (Option 23).

This section aims to describe the experimental campaigns conducted in the JRC facilities to evaluate the technical option 23 described in JRC125475. This is a technical option, where it is envisaged to carry out a series of tests on different WLAN/RLAN equipment devices to verify the impact of the WLAN/RLAN installation position (vertical / horizontal) on the DFS efficiency. This option will determine the capacity of the WLAN/RLAN to detect the radar signature and the impact of the installation position on the DFS implementation. Some authorities have been informed by WiFi manufacturers that this position (i.e., the position of the WiFi device) had an influence on the accuracy of the execution of DFS. Based on the results obtained from the tests carried out, it is necessary to identify the possible improvements and modifications of the harmonised standard in consequence.

Due to lack of equipment, we conducted the test on a single WLAN/RLAN equipment device even if it is quite recent (i.e., the device was purchased in 2021).

4.1 Test information

Date of test:

08 -16 February 2022

Normative reference

ETSI EN 301 893 V2.1.45 (Draft) [1]

Device under test

Anonymised device name: AP-COEX42

Firmware version

V9.5.4.3

4.2 Test setup

Experiments were carried out in the JRC's Shielded Anechoic Chamber (SAC). The device under test (DUT) was an RLAN access point with integral antennas, placed in the quiet zone of the chamber on a two-axis positioner as shown in Figure 6. On the left in the foreground, appears a double-ridged horn antenna used to measure the radiation emitted by the DUT and to transmit a test radar signal. A log-periodic antenna can be seen in the back right corner. It was connected to a spectrum analyser to collect and monitor the Radio Frequency spectrum.

Figure 6: Orientation test in the Shielded Anechoic Chamber.

A schematic of the test setup is shown in Figure 7. A circulator was used to isolate the transmit and receive paths. A low noise amplifier (LNA) and 10 dB attenuator allowed optimising the dynamic range of the power meter.

The distance between the aperture of the horn antenna and the Device Under Test (DUT) was set to 3 meters.

A server instance of iperf3[5] was started on a smart phone wirelessly connected to the DUT while a client instance of iperf3 was running on a computer associated with the DUT.

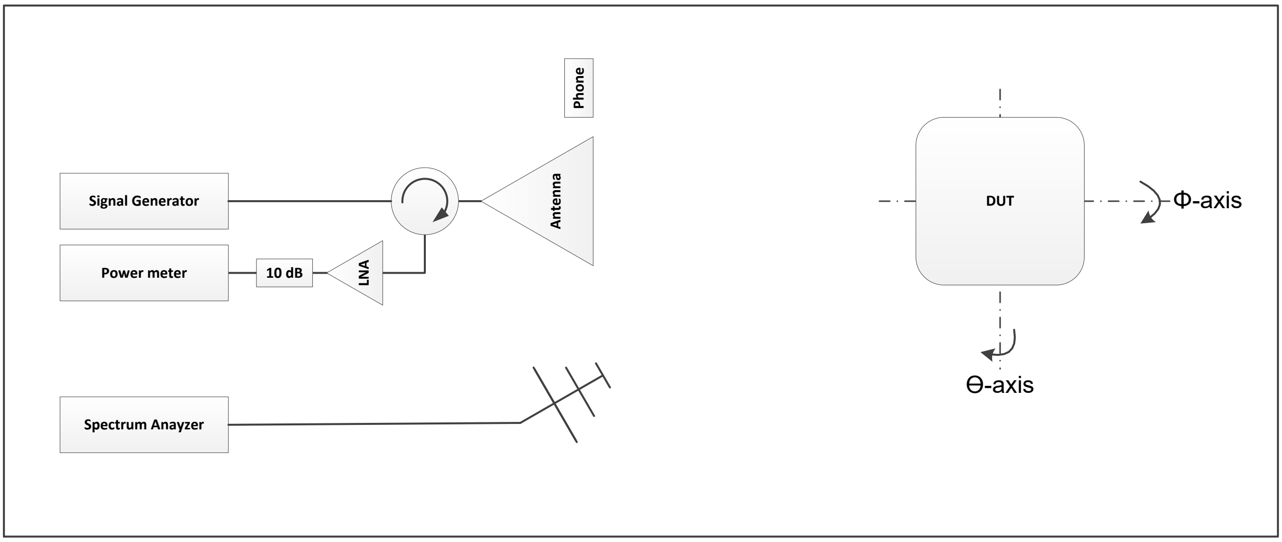


Figure 7: Orientation test setup.

[5] iPerf3 is a tool for active measurements of the maximum achievable bandwidth on IP networks. Additional details are provided in https://iperf.fr/.

4.2.1 Referential for reporting orientation test results

The terminology and coordinate systems are taken from the CTIA Test Plan for Wireless Devise Over-the-Air Performance (CTIA 2019). A spherical coordinate system is linked to the DUT as shown in Figure 8. The phi (ϕ) axis is defined as being along the Z-axis. As the phi axis rotates, the orientation of the theta axis varies with respect to the DUT. The green arrow identifies the direction to the measuring antenna (Horn antenna).

The two polarizations of the measured electric field are defined in terms of the two rotation axes:

- Phi polarization is along the direction of motion when the phi axis rotates.
- Theta polarization is along the direction of motion when the theta axis rotates.

In the same manner as the combined-axes system shown in Appendix A of the CTIA test plan and reproduced in Figure 9, our Z-axis is in fact the horizontal axis. Therefore, the phi polarisation is measured when the polarisation of horn antenna is orientated vertically. The horn antenna was rotated by 90° to measure the theta polarisation.

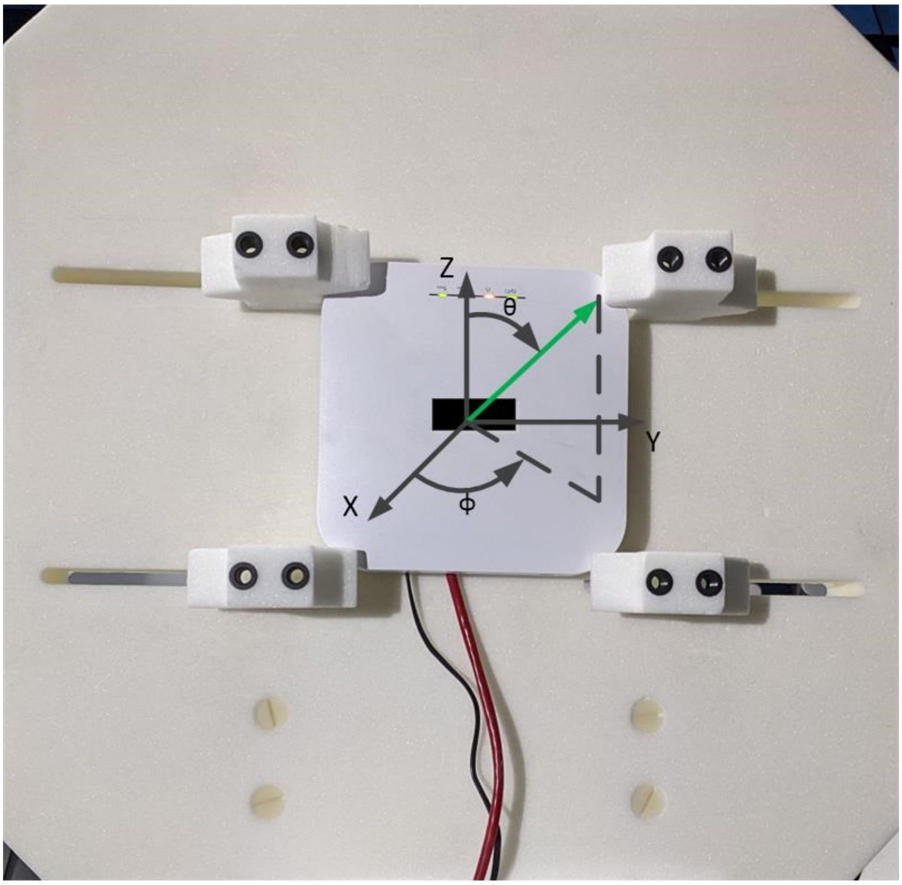


Figure 8: Coordinate system associated with the DUT.

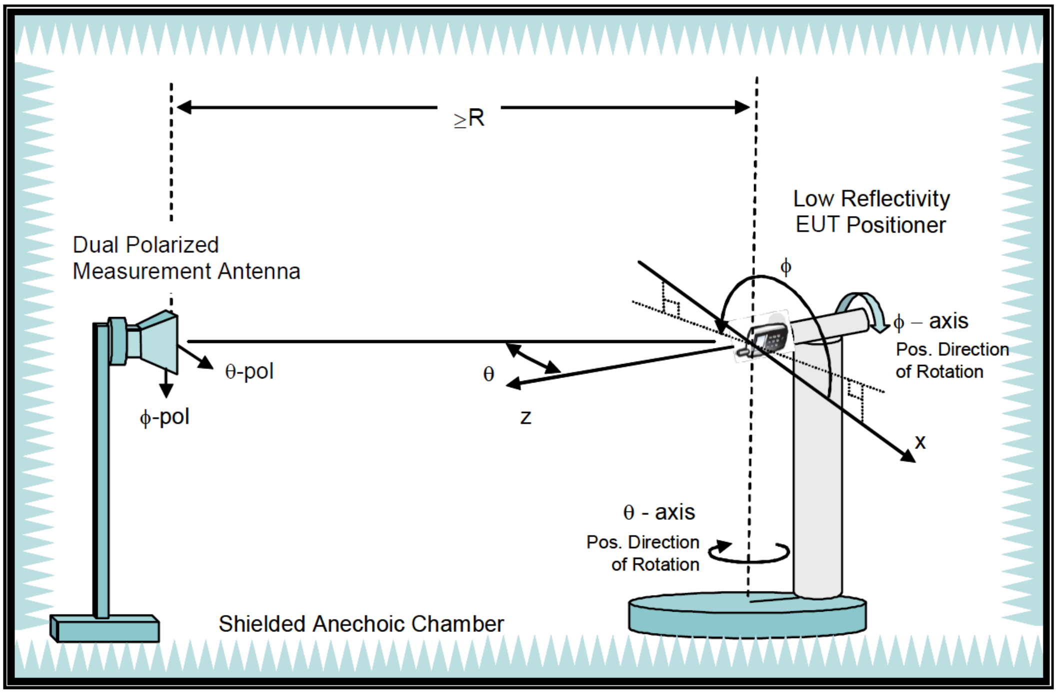


Figure 9: Typical setup for a combined-axes system as shown in Appendix A of the CTIA test plan (CTIA 2019).

4.2.2 List of equipment

Details on equipment used for the test are listed in Table 5.

Table 5: List of equipment used for the test.

Description	Manufacturer	Model	Serial number
RLAN station (STA)	One Plus	8T	40db0bf7
Signal generator	Keysight	PSG E8267D	MY47220082
Spectrum analyser	Rohde & Schwarz	FSV7	101503
Power meter	Dare Instruments	RPR3006W	13I00030SN055
Shielded Anechoic Chamber	Global EMC	dimensions 7m x 3.5m x 3m	
Standard Horn Antenna	Schwarzbeck	BBHA 9120D	732
Log Per Antenna	Schwarzbeck	ESLP9145	245
Low Noise Amplifier	B&Z Tecnololies	BZR-02001800-382034-202525	10829
Circulator	Narda-ATM	ATc3-6	J664010-01

4.2.3 DUT configuration and operation

The Wireless settings of the Access Point (AP) was the following:

- 2.4 GHz radio turned off
- 5 GHz radio turned on
- Wireless Mode: 11ax
- Channel Width: 80 MHz
- Guard Interval: Long-800 ns
- Output Power: 100%
- Channel: 128 / 5640 MHz

Traffic was forced using iperf3 tool with the following commands:

On the STA side: `iperf3 –s`

On the AP side: iperf3 -c 192.168.0.10 -p 5201 -u -b 120M -t inf

4.2.4 Radar waveform

A single waveform was used during the test. It corresponds to signal #6 in table D.4 of EN 301 893 V2.1.45 with the following parameters:

- Pulse width: 1 µs (microsecond).
- PRF1: 800.00 Hz (PRF is the pulse repetition frequency).
- PRF2: 1200.00 Hz.
- Number of pulses for each PRF: 18.
- Sampling frequency: 40.00 MHz.

4.2.5 Test description

The test consisted first in the measurement of the 3D radiation pattern of DUT to identify directions with high, low and moderate radiation powers.

In a second step, measurements of the DFS sensitivity were performed for different orientations of the DUT.

4.3 Results

4.3.1 Radiation patterns

Radiation patterns were measured for 18 values of theta angle ranging from 5° to 175° in 10° steps and 37 values of phi angle ranging from 0° to 360° in 10° steps.

For each angular position, the power and duration of each transmit packet (RF burst) were recorded for a period of one second. Then the average power was calculated from the burst power expressed in milliwatt as follows:

$$AveragePower(mW) = \frac{\sum BurstPower(i) * BurstDuration(i)}{\sum BurstDuration(i)}$$

Then the EIRP (Effective Isotropic Radiated Power) was calculated in the following way:

$$EIRP(dBm) = AveragePower(dBm) - CalFactor + FSPL - G_A$$

With

- *CalFactor:* a calibration factor including LNA gain, attenuator and cable losses
- *FSPL:* the Free Space Path Loss (FSPL) for d=3 m and f=5640 MHz
- G_{A}: the horn antenna gain

Finally, the results of the radiation pattern measurements are displayed either in the form of theta cuts like in Figure 10 or 3D plots like in Figure 11 and Figure 12.

Each subplot of Figure 10 displays, in polar coordinates, the levels of radiated power relative to the maximum measured EIRP versus phi angle for a given theta angle.

Although both polarisations were measured, only the phi polarisation (i.e. vertical polarisation) is considered in the following analysis. This is because the test radar signal was also transmitted in the vertical polarisation.

The following observations are made:

- The maximum EIRP is +23.1 dBm in the direction theta=35° and phi=110°.
- The minimum EIRP is +4.8 dBm in the direction theta=135° and phi=180°.
- The Total Radiation Power (TRP) is +17.7 dBm.

Figure 11 is a 3D plot showing the upper part of the radiation pattern. It shows that the device radiates more power from its upper right part.

Figure 12 is a 3D plot showing the reduced radiation coming from the back of the device and particularly in the lower part.

Even if the results in Figure 11 and Figure 12 are not surprising considering the shape of the DUT and the operating conditions, it is interesting to evaluate if the DFS is affected by the position of the DUT considering the significant difference in the radiated power for different angles in both Figure 11 and Figure 12.

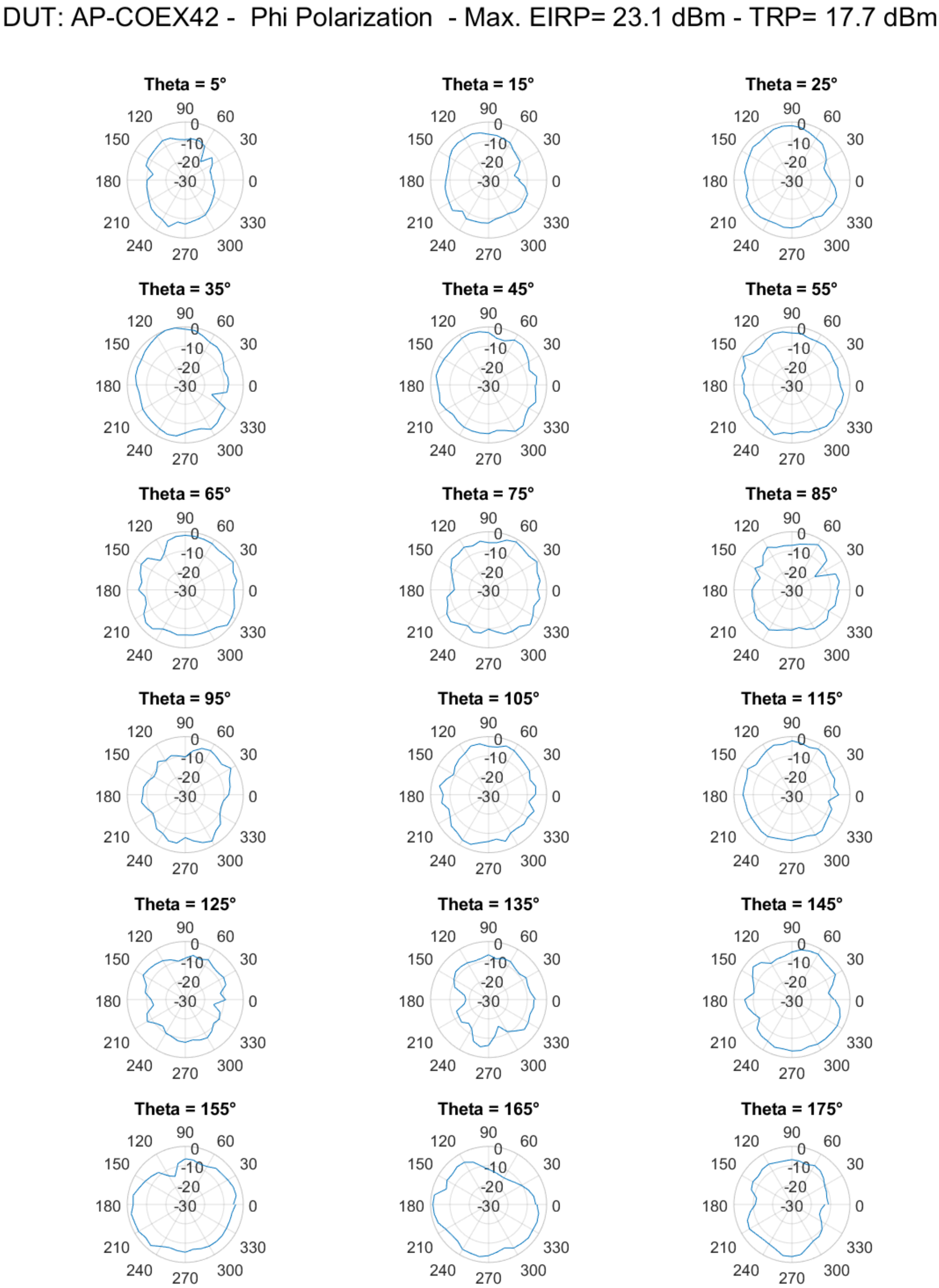


Figure 10: Polar plots of the radiation pattern of the phi polarisation.

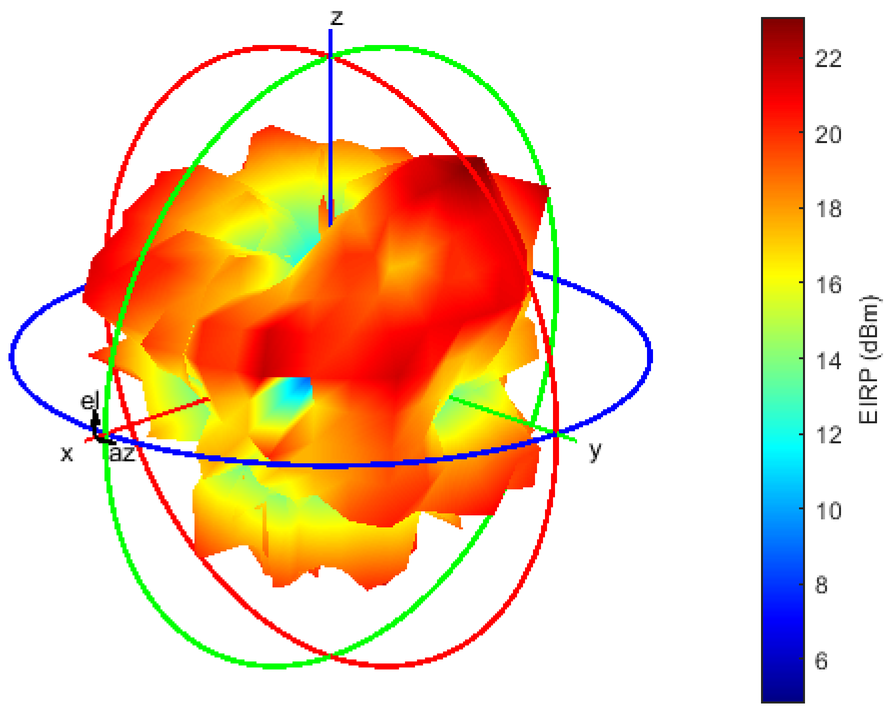


Figure 11: 3D plot of the radiation pattern of the phi polarisation showing maximum EIRP.

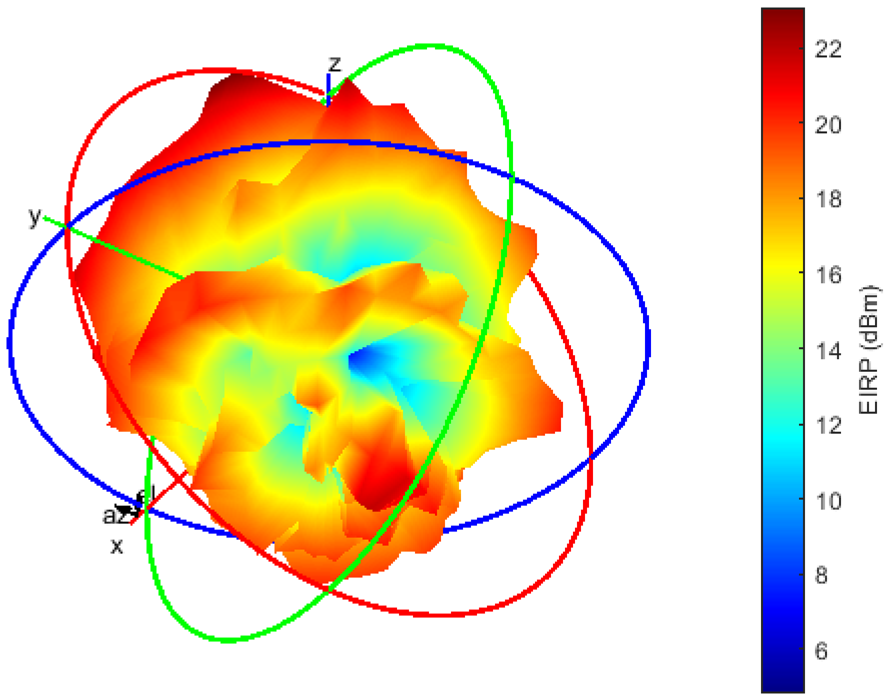


Figure 12: 3D plot of the radiation pattern of the phi polarisation showing minimum EIRP.

4.3.2 DFS orientation test

The DFS orientation test consists in measuring the minimum power of the radar signal that triggers DFS for various orientations of the DUT.

Results are summarised in Table 6. The first and second column contain the orientation angles used for the test. The third column reports the power radiated by the DUT in the direction of the horn antenna. The fourth column contains the output power of the signal generator that trigged DFS. The last column contains power levels of the radar signal that would receive a device with 0 dBi antenna gain at the location of the DUT. These last values are calculated from the radar signal levels at the input of the horn antenna taking into account the antenna gain and free space path loss, and are called "DFS sensitivity" in the following.

Table 6: Results of the DFS orientation test

Theta (deg)	Phi (deg)	DUT EIRP (dBm)	Signal Generator power (dBm)	Power at antenna input (dBm)	DFS Sensitivity (dBm)
35	110	23.1	-19	-24.9	-68.9
135	180	4.8	1	-4.9	-48.9
95	0	15.6	-13	-18.9	-62.9
165	60	8.9	-2	-7.9	-51.9
5	240	16.8	-6	-11.9	-55.9
65	90	21.2	-15	-20.9	-64.9
95	150	11.7	-8	-13.9	-57.9
165	210	18.7	-1	-6.9	-50.9
155	230	19.8	-21	-26.9	-70.9
95	50	18.8	-22	-27.9	-71.9

DFS sensitivity can be directly compared to the radar detection threshold level of -62 dBm as defined in Table D.2 of EN 301 893. This radar detection threshold level is called "DFS limit" and it is reported below in Figure 13. Because the test was not done on a slave device only the Note 1 from Table D.2 is applicable to this experimental activity.

Table D.2: Radar Detection Threshold Levels

e.i.r.p. Spectral Density (dBm/MHz)	Value (see note 1 and note 2)
10	-62 dBm
NOTE 1:	This is the level at the input of the receiver of an RLAN device with a maximum e.i.r.p. density of 10 dBm/MHz and assuming a 0 dBi receive antenna. For devices employing different e.i.r.p. spectral density and/or a different receive antenna gain G (dBi) the Radar Detection Threshold Level at the receiver input follows the following relationship: DFS Detection Threshold (dBm) = -62 + 10 - e.i.r.p. Spectral Density (dBm/MHz) + G (dBi); however the Radar Detection Threshold Level shall not be less than -64 dBm assuming a 0 dBi receive antenna gain.
NOTE 2:	Slave devices with a maximum e.i.r.p. of less than 23 dBm do not have to implement radar detection unless these devices are used in fixed outdoor point to point or fixed outdoor point to multipoint applications (see clause 4.2.6.1.3).

Figure 13 Radar Detection Threshold Levels taken from ETSI 301 893 (ETSI 2017).

The procedure to evaluate the DFS limit is described in the following paragraphs.

The test started with the orientation corresponding to the maximum radiated power. A DFS sensitivity of -68.9 dBm was measured which is 6.9 dB below the DFS limit. Therefore, the DUT meets the DFS requirement when tested in the direction of its maximum transmit power. Since this is the defined procedure for compliance assessment of the WLAN/RLAN devices in ETSI 301 893 (ETSI 2017) (sections 4.2.3.2.2, 4.2.7.3, 5.4.4.2). this device would have passed the test.

The second measurement was performed for the orientation corresponding to the minimum radiated power where a DFS sensitivity of -48.9 dBm was measured. It is 13.1 dB above the required detection threshold level. The DUT does NOT meet DFS requirement when tested in the direction of its minimum transmit power.

Additional orientations with intermediate values of RLAN radiation power levels were tested and are reported in the subsequent lines of Table 6. It follows that the DUT is able to detect the test radar signal below the threshold most of the time but there are cases when the WLAN/RLAN signal is detected above the threshold, which may cause problems of interference. We have to take in consideration that for the reciprocity theorem, the transmitted power by the WLAN/RLAN may also be lower than the maximum. Then, the level of interference may be still accepted overall, even if the DFS failed to detect the signal of the correct DFS level.

A graphical representation of the DFS sensitivity versus RLAN radiated power is show in Figure 14. The general tendency is that the DUT detects lower radar signal levels in the direction of the higher radiation power.

Note: each point is actually the average (i.e., mean) of the measurements repeated for 5 times.

It contains a straight line which represents the DFS detection threshold. The authors have used the equation in Note 1 of table D.2 from ETSI 301 893 (ETSI 2017), which is represented in Figure 13:

$$\text{DFS Detection Threshold (dBm)} = -62 + 10 - \text{e.i.r.p. Spectral Density (dBm/MHz)} + \text{G (dBi)}$$

The value of G=0 dBi was used because it is the value used to calculate the Radar Power at the DUT.

To estimate the e.i.r.p. Spectral Density, the authors have considered the spectral density of the beacons transmitted in a 20 MHz channel because it is higher than the spectral density of the RF burst with 80 MHz bandwidth. The occupied bandwidth in a 20 MHz channel is 16.5 MHz, therefore the spectral density is estimated from the measured EIRP as e.i.r.p. Spectral Density (dBm/MHz)= EIRP (dBm) – 10*log10(16.5).

Then, we can see in Figure 14 that that only two points are above the limit among them one being close to the limit.

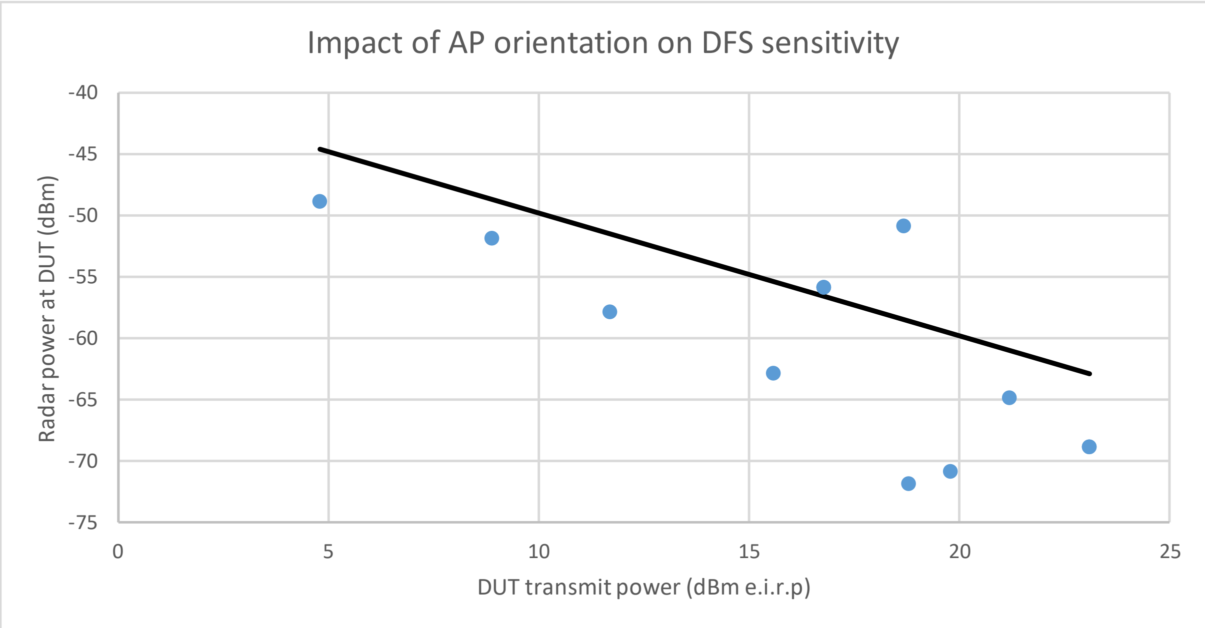


Figure 14 Graphical representation of DFS sensitivity versus DUT transmit power.

We note from Figure 14 that many points are about 3-4 dB below the line. This is not surprising since manufacturers always add implementation margin.

5 Conclusions

This report provides the results of the experimental activities conducted by the JRC to investigate specific aspects related to the potential problems of weather radar interference by WLAN/RLAN which may share the radio frequency spectrum in the 5GHz band following the spectrum regulations defined in WRC 2003.

This report is a follow up of the JRC125475, who investigated problem of interference along different dimensions including organizational, economic and technical aspects. JRC125475 identified a number of key options to mitigate or resolve the interference issues including the need to conduct experimental activities. The options identified as Option 21, 23 and 24 in JRC125475 were investigated in detail by the JRC personnel and the results of such investigation are reported in this technical report.

The results of the empirical evaluation have shown that:

- Option 21. The tested RLAN device is able to detect a typical weather radar signal when operating with an activity factor up 70%, which shows that the WLAN/RLAN device under test has a considerable margin of computing capabilities or the implementation of the DFS function is well separated from the traffic functions to support higher load factors than what specified in the standards
- Option 23. The tested RLAN device is compliant for the implementation of the DFS according to the standard ETSI 301 893 (ETSI 2017) where the direction of its maximum transmit power must be used. On the other side, the experimental results show that for some directions (i.e., the ones with weak power in the DUT radiation pattern), the device fails to detect the weather radar signal at the threshold indicated in ETSI 301 893 (ETSI 2017). This issue may be compensated by the reciprocity theorem because the RLAN device would transmit with less power.
- Option 24. The conclusion of the test activity is that tested RLAN device is able to detect a typical weather radar signal whose centre frequency falls at the edge of the frequency band defined in clause 4.2.6.2.1 of ETSI 301 893 (ETSI 2017). and also outside this frequency band and up to the upper edge of the RLAN occupied bandwidth.

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List of abbreviations and definitions

Abbreviation	Definition
ADCO RED	Administrative Co-operation group under the Radio Equipment Directive
ANFR	Agence Nationale des Frequences
BFWA	Broadband Fixed Wireless Access
CEPT	European Conference of Postal and Telecommunications Administrations
CNECT	DG Directorate-General for Communications Networks, Content of EC
dB	Decibel
dBm	decibel-milliwatts
DFS	Dynamic Frequency Selection
DG	Directorate General
DUT	Device Under Test
E.I.R.P.	Equivalent Isotropically Radiated Power
EC	European Commission
ECC	Electronic Communications Committee
ECO	European Communications Office
ESOs	European Standards Organizations
ETSI	European Telecommunications Standards Institute
EU	European Union
EUMETNET	European Meteorological Network
FM	Frequency Management
FSPL	Free Space Path Loss
GROW	DG Internal Market, Industry, Entrepreneurship & SMEs
HIPERLAN	High Performance Radio
HS	Harmonized Standard
HUI	Human User Interface

IEEE	Institute for Electrical and Electronics Engineers
IoT	Internet of Things
ITU	International Telecommunication Union
JRC	DG Joint Research Centre of EC
MAC	Medium Access Control
MINECO	Ministerio de Economía y Competitividad
MS	Member State
NRA	National Regulatory Authorities
NWP	Numerical Weather Prediction
OoB	Out Of Band
p-to-mpt	Point to MultiPoint
p-to-p	Point to Point
PRF	Pulse Repetition Frequency
RED	Radio Equipment Directive
RF	Radio Frequency
RFI	Radio Frequency Interference
RLAN	Radio Local Area Networks
RoP	Rules of Procedure
RSC	Radio Spectrum Committee
RSPG	Radio Spectrum Policy Group
Rx	Receiver
S/N	Serial Number
SSID	Service Set IDentifier
TCAM	Telecommunication Conformity Assessment and Market Surveillance Committee
TDWR	Terminal Doppler Weather Radars
TPC	Transmit Power Control
TRP	Total Radiated Power

Tx	Transmitter
WAS	Wireless Access Systems
WGFM	Working Group Frequency Management
WiFi	Wireless Fidelity ISO/IEC local area network standard (IEEE 802.11 family)
WLAN	Wireless Local Area Network (in this report WLAN/RLAN is considered a synonym of RLAN)
WM	Working Methods
WMO	World Meteorological Organisation
WRC	World Radio Conference

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