TEST REPORT

Test Report No. : UL-RPT-RP14705831-1216C

Customer	:	Raspberry Pi LTD
Model No. / HVIN	:	V2.0
PMN	:	Raspberry Pi 5
FCC ID	:	2ABCB-RPI5
ISED Certification No.	:	IC: 20953-RPI5
Technology	:	WLAN
Test Standard(s)	:	FCC Part 15.407(h)(2) Innovation, Science and Economic Development Canada RSS-247 6.3.2(c), 6.3.2(d) & 6.3.2(e)

1. This test report shall not be reproduced except in full, without the written approval of UL International (UK) Ltd.
2. The results in this report apply only to the sample(s) tested.
3. The sample tested is in compliance with the above standard(s).
4. The test results in this report are traceable to the national or international standards.
5. Version 3.0 supersedes all previous versions.

Date of Issue: 17 October 2023

Checked by:

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Customer Information

Company Name:	Raspberry Pi LTD
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Report Revision History

Version Number	Issue Date	Revision Details	Revised By
1.0	13/09/2023	Initial Version	Ben Mercer
2.0	13/10/2023	Admin update	Ben Mercer
3.0	17/10/2023	FVIN removed	Ben Mercer

Table of Contents

1 Attestation of Test Results

1.1 Description of EUT

The equipment under test was a single board computer with *Bluetooth*, 2.4 GHz WLAN and 5 GHz WLAN transceivers.

1.2 General Information

Specification Reference:	47CFR15.407
Specification Title:	Code of Federal Regulations Volume 47 (Telecommunications): Part 15 Subpart E (Unlicensed National Information Infrastructure Devices) - Section 15.407
Specification Reference:	RSS-247 Issue 2 February 2017
Specification Title:	Digital Transmission Systems (DTSs), Frequency Hopping Systems (FHSs) and Licence-Exempt Local Area Network (LE-LAN) Devices
FCC Lab. Designation No.:	UK2011
ISEDC CABID:	UK0001
Location of Testing:	Unit 3 Horizon, Wade Road, Kingsland Business Park, Basingstoke, Hampshire, G24 8AH, United Kingdom
Test Date:	02 June 2023

1.3 Summary of Test Results

FCC Reference (47CFR)	ISED Canada Reference	Measurement	Note	Result
Part 15.407(h)(2)(iii)	RSS-247 6.3.2(c) & 6.3.2(d)	Channel Closing Transmission Time and Channel Move Time	-	✓
Part 15.407(h)(2)(iv)	RSS-247 6.3.2(e)	Non-Occupancy Period	2	✓
Key to Results ✓ = Complied ✗ = Did not comply				

Note(s):

1. The manufacturer confirms that the information regarding the parameters of the radar waveforms is not available to the end user.
2. This test is not required for a client without radar detection according to Tables 1 and 2 of KDB 905462 D02, however it was performed to show compliance with KDB 905462 D02 5.1.2 e) and KDB 905462 D03, section (b)(5) and (b)(6).

1.4 Deviations from the Test Specification

For the measurements contained within this test report, there were no deviations from, additions to, or exclusions from the test specification identified above.

2 Summary of Testing

2.1 Facilities and Accreditation

The test site and measurement facilities used to collect data are located at Unit 3 Horizon, Wade Road, Kingsland Business Park, Basingstoke, Hampshire, RG24 8AH, United Kingdom.

UL International (UK) Ltd is accredited by the United Kingdom Accreditation Service (UKAS). UKAS is one of the signatories to the International Laboratory Accreditation Co-operation (ILAC) Arrangement for the mutual recognition of test reports. The tests reported herein have been performed in accordance with its terms of accreditation.

2.2 Methods and Procedures

Reference:	FCC KDB 905462 D02 UNII DFS Compliance Procedures New Rules v02 (April 08, 2016)
Title:	Compliance Measurement Procedures for Unlicensed-National Information Infrastructure Devices Operating in the 5250-5350 MHz and 5470-5725 MHz Bands Incorporating Dynamic Frequency Selection

2.3 Calibration and Uncertainty

Measuring Instrument Calibration

In accordance with UKAS requirements all the measurement equipment is on a calibration schedule. All equipment was within the calibration period on the date of testing.

Measurement Uncertainty & Decision Rule

Overview

No measurement or test can ever be perfect and the imperfections give rise to error of measurement in the results. Consequently the result of a measurement is only an approximation to the value of the measurand (the specific quantity subject to measurement) and is only complete when accompanied by a statement of the uncertainty of the approximation.

The expression of uncertainty of a measurement result allows realistic comparison of results with reference values and limits given in specifications and standards.

Decision Rule

Measurement system instrumentation shall be used with an accuracy specification meeting the accuracy specification limits according to IEC/IECEE OD-5014.

As applicable, unless specified otherwise in the quotation, the compliance “Decision Rule” is based on Simple Acceptance. If the measured value is on the limit, the result is defined as a pass. In this case the risk of a false positive is 50%. For further information regarding risk assessment refer to ILAC G8:09/2019.

Measurement Uncertainty

The reported expanded uncertainties below are based on a standard uncertainty multiplied by an appropriate coverage factor such that a confidence level of approximately 95% is maintained. For the purposes of this document “approximately” is interpreted as meaning “effectively” or “for most practical purposes”.

Measurement Type	Confidence Level (%)	Calculated Uncertainty
DFS Channel Shutdown Timing	95%	±0.45 ms
DFS Non-Occupancy Timing	95%	±79.25 ms
DFS Radar Amplitude	95%	±2.17 dB

The methods used to calculate the above uncertainties are in line with those recommended within the various measurement specifications. Where measurement specifications do not include guidelines for the evaluation of measurement uncertainty the published guidance of the appropriate accreditation body is followed.

2.4 Test and Measurement Equipment

Test Equipment Used:

Asset No.	Instrument	Manufacturer	Type No.	Serial No.	Date Calibration Due	Cal. Interval (Months)
M2002	Thermohygrometer	Testo	608-H1	45041825	09 Dec 2023	12
M1835	Signal Analyser	Rohde & Schwarz	FSV30	103050	19 Sep 2023	12
G0615	Vector Signal Generator	Rohde & Schwarz	SMBV100A	261847	30 Jan 2026	36
A1065	Step Attenuator	Hewlett Packard	8494B	3308A38165	Calibrated before use	-
A1536	Step Attenuator	Hewlett Packard	8494B & 8496B	A30801 & A19649	Calibrated before use	-
A090	Step Attenuator	Narda	743-60	1057	Calibrated before use	-
A215492	Power Splitter	MCS	AAMCS-PWD-2W-2G-18G-10W-Sf	000080	Calibrated before use	-
A215491	Power Splitter	MCS	AAMCS-PWD-2W-2G-18G-10W-Sf	000082	Calibrated before use	-

3 Equipment Under Test (EUT)

3.1 Identification of Equipment Under Test (EUT)

Brand Name:	Raspberry Pi
Model Name or Number / HVIN:	V2.0
PMN:	Raspberry Pi 5
Test Sample Serial Number:	C13 *(Conducted Sample)*
Hardware Version:	V2.0
Software Version:	V1.0
FCC ID:	2ABCB-RPI5
ISED Canada Certification Number:	IC: 20953-RPI5
Date of Receipt:	18 May 2023

3.2 Modifications Incorporated in the EUT

No modifications were applied to the EUT during testing.

3.3 Additional Information Related to Testing

Technology Tested:	WLAN (IEEE 802.11a,n,ac) / U-NII	
Type of Unit:	Transceiver	
Modulation Types:	BPSK, QPSK, 16QAM, 64QAM & 256QAM	
Transmit / Receive Frequency Range:	5250 to 5350 MHz 5470 to 5850 MHz	
Transmit / Receive Channels Tested at 80 MHz Bandwidth setting:	**Channel ID**	**Channel Centre Frequency (MHz)**
	58 (Control Channel 52)	5290

3.4 Description of Available Antennas

The radio utilizes an integrated antenna, with the following maximum gain:

Frequency Range (MHz)	Antenna Gain (dBi)
5150 to 5850	2.5

3.5 Description of Test Setup

Support Equipment

The following support equipment was used to exercise the EUT during testing:

Description:	Wireless Dual Band Router (DFS Master)
Brand Name:	Cisco
Model Name or Number:	AIR-CAP3702E-A-K9 V04
FCC ID:	LDK102087
ISED Canada Certification Number:	IC: 2461B-102087
Serial Number:	FJC1938F3G6

Description:	Test Laptop
Brand Name:	Lenovo
Model Name or Number:	ThinkPad L480
Serial Number:	PF1EHZQ0

Operating Modes

The EUT was tested in the following operating modes, unless otherwise stated:

- Operating on the channel selected by the Master device in either band U-NII-2A or U-NII-2C.
- The Master device controls the channel bandwidth of the EUT. Both the Master and Client device were set to 802.11ac / MCS0x1 with 80 MHz channel bandwidth to ensure a stable channel loading.
- KDB 905462 D02 v02 *UNII DFS Compliance Procedures* states in Table 2 the EUT should be tested at maximum channel bandwidth (80 MHz for 802.11ac mode).
- For the required channel loading of >17% in KDB 905642 D02 7.7 c), a UDP data transfer of 3 Mbps was performed between a test computer connected to the DFS master router and the EUT. This gave a channel loading (duty cycle) of 26.8% at the modulation scheme and bandwidth above.

Configuration and Peripherals

The EUT was tested in the following configuration(s):

- The EUT is a DFS Client without Radar Detection capability. It was tested in combination with an FCC / ISEDC approved Cisco DFS enabled router acting as the Master. A Radar Type 0 was injected to the Master to test the Clients Channel Move Time and Channel Closing Transmission Time after receiving the channel shutdown command from the Master.
- All measurements were made using a conducted link. The EUT has an antenna connectors fitted for test purposes. System losses for the interconnecting hardware were measured and taken into consideration.
- The DFS detection threshold of -61.0 dBm (-62 + 1 dB) was used at the Master device antenna port. Note this is not dependent on the EUT EIRP, Spectral Density or EUT Antenna Gain, only the antenna gain of the master device, as the EUT does not have radar detection. The Cisco DFS Master test router was configured with an internal setting for a 0 dBi antenna.

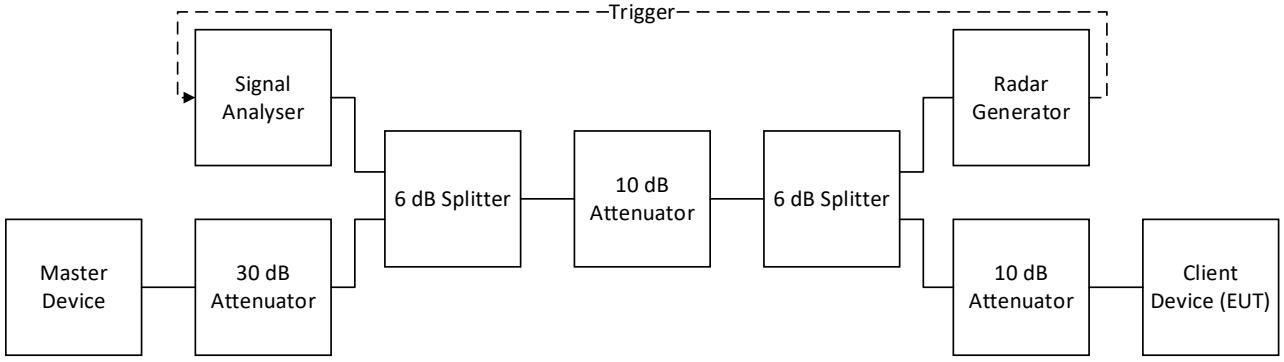
KDB 905462 D02 Table 3: DFS Detection Thresholds for Master Devices and Client Devices With Radar Detection

Maximum Transmit Power	Value (see notes)
EIRP ≥ 200 milliwatt	-64 dBm
EIRP < 200 milliwatt and power spectral density < 10 dBm/MHz	-62 dBm
EIRP < 200 milliwatt that do not meet the power spectral density requirement	-64 dBm
Note 1: This is the level at the input of the receiver assuming a 0 dBi receive antenna **Note 2:** Throughout these test procedures an additional 1dB has been added to the amplitude of the test transmission waveforms to account for variations in measurement equipment. This will ensure that the test signal is at or above the detection threshold level to trigger a DFS response. **Note 3:** EIRP is based on the highest antenna gain. For MIMO devices refer to KDB Publication 662911 D01.	

- The Master device used for test was set to 17 dBm / 50 mW with TPC enabled.
- Plots and data were captured using a Rohde and Schwarz FSV 30 Spectrum Analyser. The number of data points was increased to maximum and the trace data exported so it could be analysed in far greater detail than available on the built-in display.
- The Channel Move Time was the time taken from the end of the radar waveform to the time the Client ceased transmissions. The Channel Closing Transmission Time was calculated to the nearest sample from any additional pulses occurring >200 ms after the end of the radar.

Test Setup Diagrams

Setup diagram for test of DFS Client without Radar Detection:



4 Test Results

4.1 Channel Closing Transmission Time and Channel Move Time

Test Summary:

Test Engineer:	Chanthu Thevarajah	**Test Date:**	02 June 2023
Test Sample Serial Number:	C13		

FCC Reference:	Part 15.407(h)(2)(iii)
ISED Canada Reference:	RSS-247 6.3.2(c) & RSS-247(d)
Test Method Used:	KDB 905462 D02 Section 7.8.3

Environmental Conditions:

Temperature (°C):	24
Relative Humidity (%):	38

Note(s):

1. In accordance with KDB 905462 D02 Table 2, the Channel Closing Transmission Time and Channel Move test was performed on the widest channel bandwidth. It was therefore tested only on an 80 MHz channel bandwidth.
2. The channel move time is the time taken from the end of the radar burst to the ceasing of transmissions of the EUT.
3. The Total Aggregate Channel Closing Transmission Time shown in the table below was measured from 200 ms after the end of the radar burst and compared to the 60 ms limit.
4. Although the EUT and DFS master device 80 MHz operating channel was centred on 5530 MHz, the spectrum analyser was tuned to zero span at 5500 MHz. The radar was also fired at 5500 MHz. This allowed any control signals to be monitored in addition to the 80 MHz data transfer.
5. The transmissions seen in the plot below 0 dBm, originate from the Master device and not from the EUT. These transmissions can be ignored for the below results.

Channel Closing Transmission Time and Channel Move Time (continued)

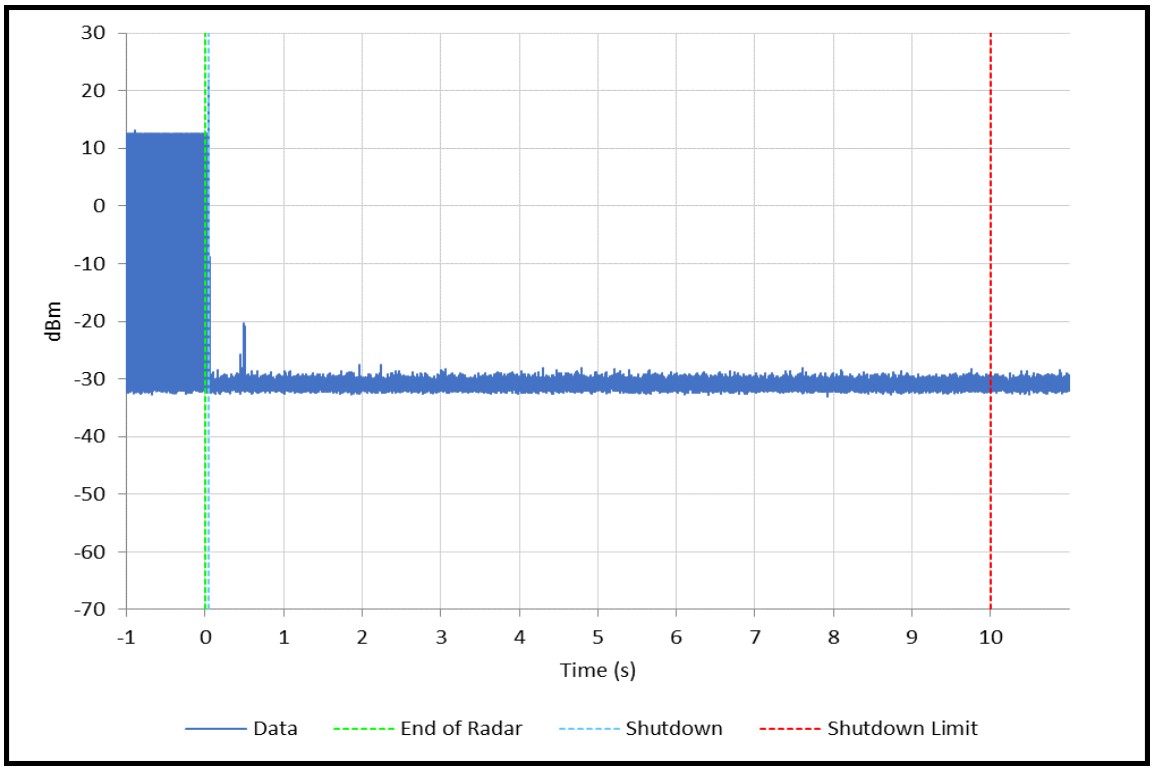
Results: Channel Move Time

Channel (MHz)	Move Time (ms)	Limit (ms)	Margin (ms)	Result
5290	41.4	10000	9958.6	Complied

Results: Channel Closing Transmission Time

Channel (MHz)	Total Aggregate Tx Time Occurring After time [t_1+200 ms] (ms)	Limit (ms)	Margin (ms)	Result
5290	0.0	60.0	60.0	Complied

Results: 80 MHz EUT to Master



Plot showing the full 10 second shutdown limit

Channel Closing Transmission Time and Channel Move Time (continued)

Limits:

Part 15.407(h)(2)(iii)

After a radar's presence is detected, all transmissions shall cease on the operating channel within 10 seconds. Transmissions during this period shall consist of normal traffic for a maximum of 200 ms after detection of the radar signal. In addition, intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating channel.

RSS-247 Section 6.3.2(c) & 6.3.2(d)

Channel move time: after a radar signal is detected, the device shall cease all transmissions on the operating channel within 10 seconds.

Channel closing transmission time: is comprised of 200 ms starting at the beginning of the channel move time plus any additional intermittent control signals required to facilitate a channel move (an aggregate of 60 ms) over the remaining 10-second period of the channel move time.

KDB 905462 D02 Table 4: DFS Response Requirement Values

Parameter	Value
Channel Move Time	10 seconds See Note 1.
Channel Closing Transmission Time	200 milliseconds + an aggregate of 60 milliseconds over remaining 10 second period. See Notes 1 and 2.

Note 1: *Channel Move Time* and the *Channel Closing Transmission Time* should be performed with Radar Type 0. The measurement timing begins at the end of the Radar Type 0 burst.

Note 2: The *Channel Closing Transmission Time* is comprised of 200 milliseconds starting at the beginning of the *Channel Move Time* plus any additional intermittent control signals required to facilitate a *Channel* move (an aggregate of 60 milliseconds) during the remainder of the 10 second period. The aggregate duration of control signals will not count quiet periods in between transmissions.

4.2 Non-occupancy Period

Test Summary:

Test Engineer:	Chanthu Thevarajah	**Test Date:**	02 June 2023
Test Sample Serial Number:	C13		

FCC Reference:	Part 15.407(h)(2)(iv)
ISED Canada Reference:	RSS-247 6.3.2(e)
Test Method Used:	KDB 905462 D02 Section 7.8.3

Environmental Conditions:

Temperature (°C):	24
Relative Humidity (%):	38

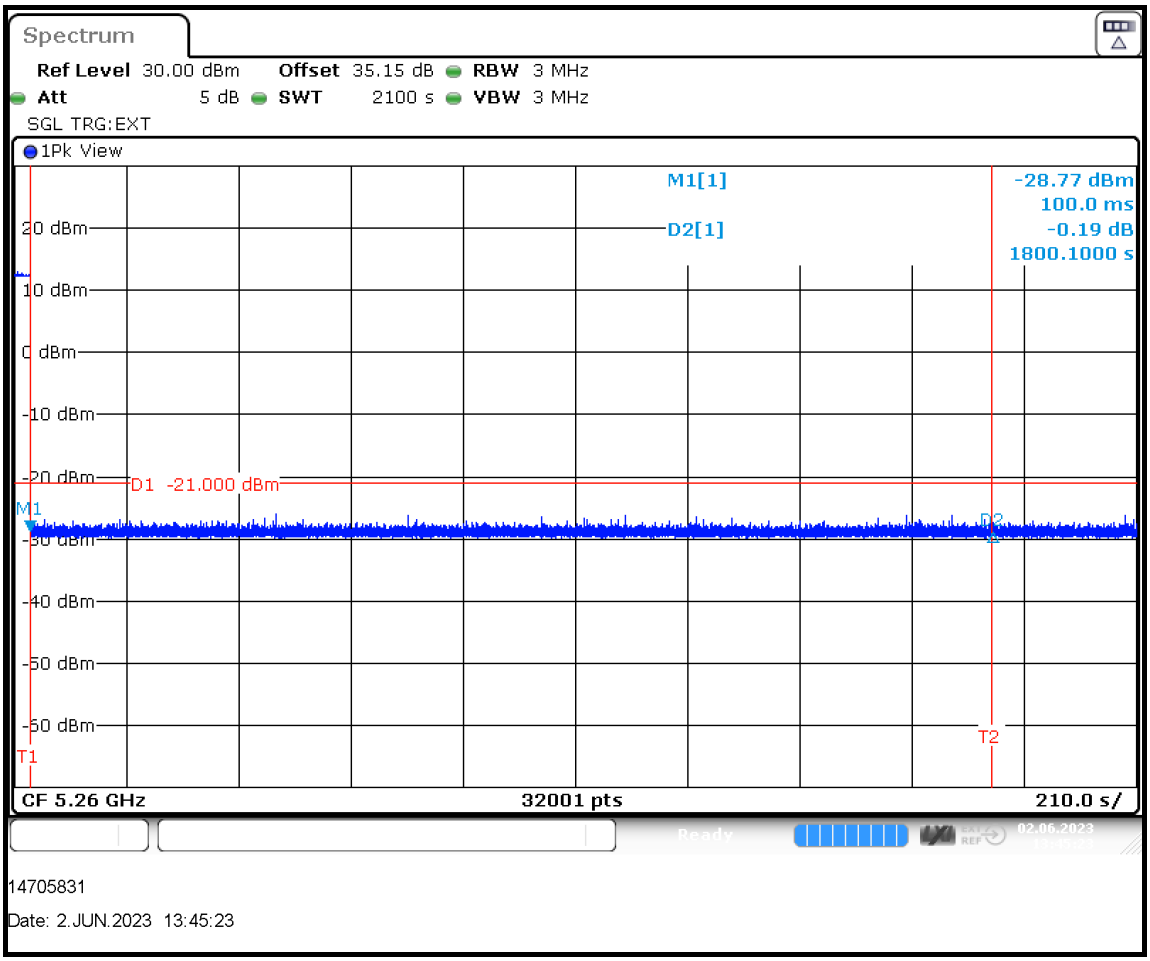
Notes:

1. This test is not required for a client without radar detection according to Tables 1 and 2 of KDB 905462 D02, however it was performed to show compliance with KDB 905462 D02 5.1.2 e) and KDB 905462 D03, section (b)(5) and (b)(6). Therefore no specified bandwidth requirement is given and so was performed using an 80 MHz channel bandwidth; as used for *Channel Closing Transmission Time and Channel Move Time*.
2. Radar burst type 0 was detected and the channel was vacated for >1800 seconds. Since the client has no radar detection and is therefore not performing an ‘intelligent’ blacklisting of the channel, the device was shown not to transmit for greater than 30 minutes after its own shutdown time, not the shutdown of the DFS master.
3. Although the EUT and DFS master device 80 MHz operating channel was centred on 5290 MHz, the spectrum analyser was tuned to zero span at 5260 MHz. The radar was also fired at 5260 MHz. This allowed any control signals to be monitored in addition to the 80 MHz data transfer
4. The noise floor remained below the -21.2 dBm/MHz (74 dBµV/m at 3m) unintentional radiator limit for the 30 minute (1800 seconds) non-occupancy period. Therefore the EUT is deemed to comply.

Non-occupancy Period (continued)

Results:

Channel (MHz)	Non-occupancy (min)	Limit (min)	Margin (min)	Result
5290	>34.5	30.0	>4.5	Complied



Limits:

Part 15.407(h)(2)(iv)

A channel that has been flagged as containing a radar system, either by a channel availability check or in-service monitoring, is subject to a non-occupancy period of at least 30 minutes. The non-occupancy period starts at the time when the radar system is detected.

RSS-247 Section 6.3.2(e)

A channel that has been flagged as containing a radar signal, either by a channel availability check or in-service monitoring, is subject to a 30 minute non-occupancy period where the channel cannot be used by the LE-LAN device. The non-occupancy period starts from the time that the radar signal is detected.

KDB 905462 D02 Table 4: DFS Response Requirement Values

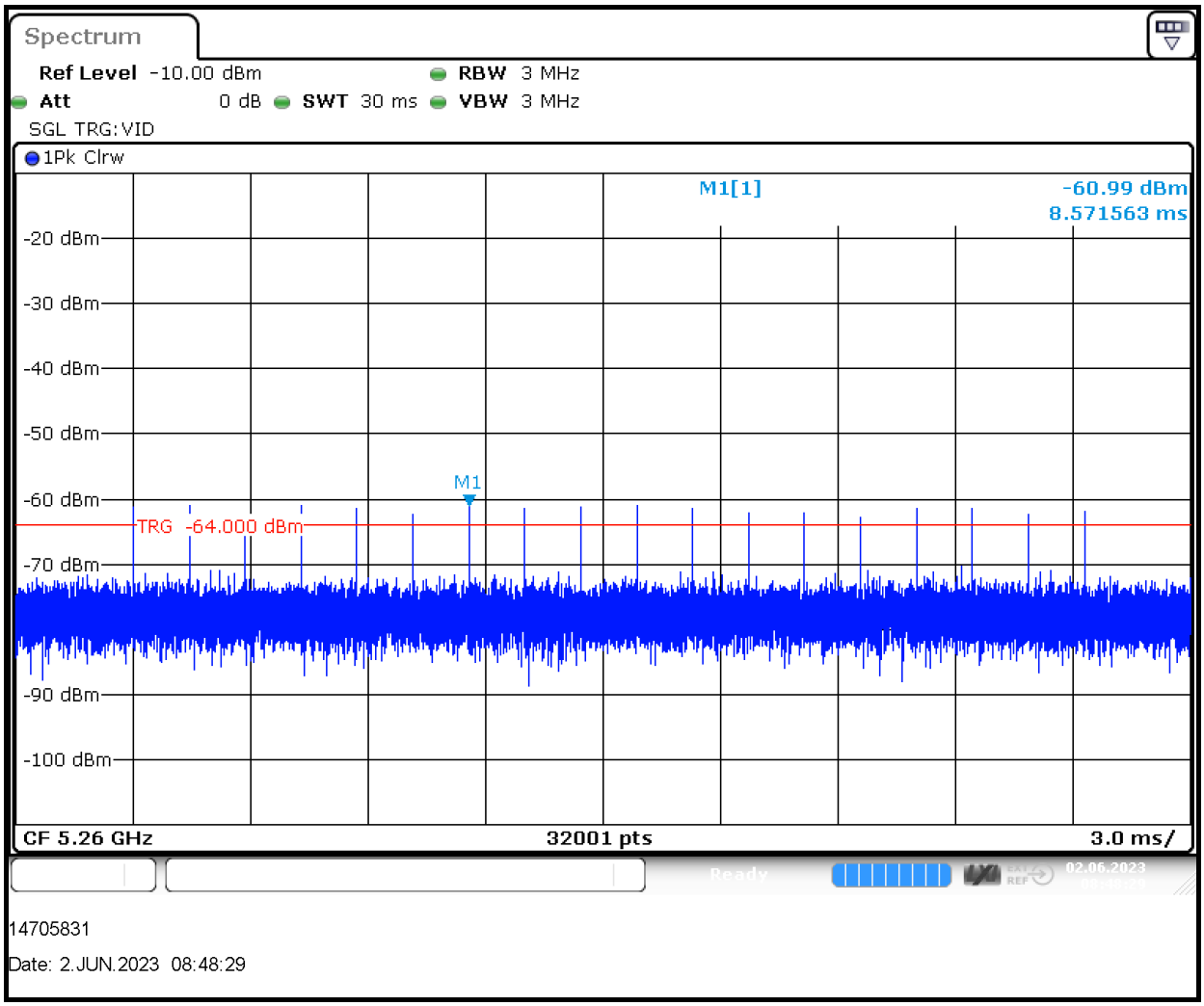
Parameter	Value
Non-occupancy period	Minimum 30 minutes

Appendix 1. Radar Type 0 Calibration

Radar calibration procedure.

The system was configured as shown in section 3.5, but with the path from the EUT to the signal analyser terminated into a 50Ω load, and the path from the radar generator to the master connected to the signal analyser. The radar was then replayed by the SMBV100A vector signal generator, the waveform captured, and the amplitude adjusted until correct.

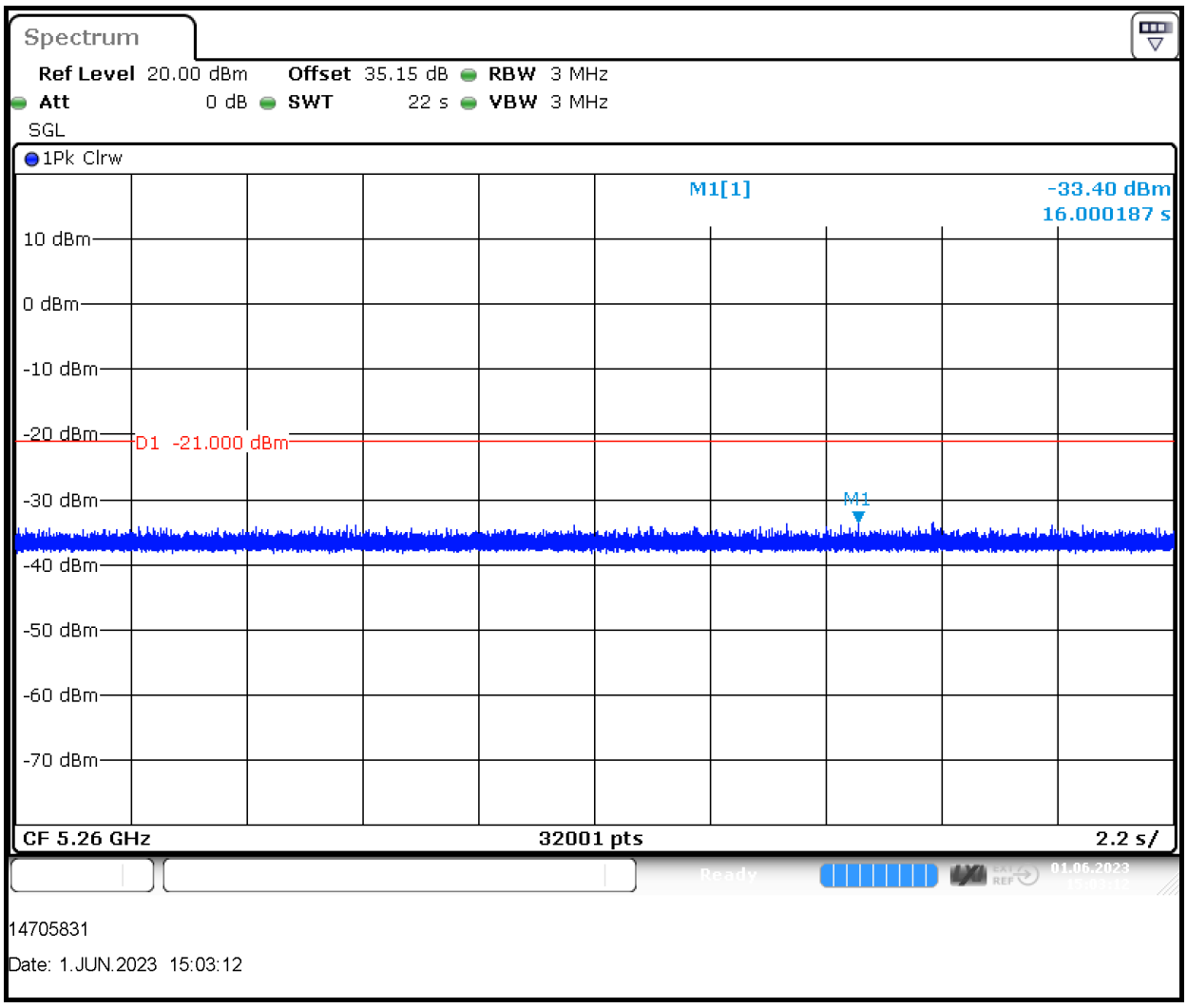
Below is an example plot of the type 0 radar burst at the master port of the attenuation network. The vector signal generator was set to –11.2 dBm output to give the -61.0 dBm level.



Radar Type 0 – full 18 pulse waveform

Appendix 2. System Noise Floor Reference Plots

As required by Section 8.3 d)3) and 8.3 g) of KDB 905462 D02, the following plot shows the reference noise floor of the system used during measurement. It also shows compliance with Section 8.3.7 of KDB 905462 D02 when the path loss of the coupling network shows in Section 3.5 Configuration and peripherals is added to the noise floor.



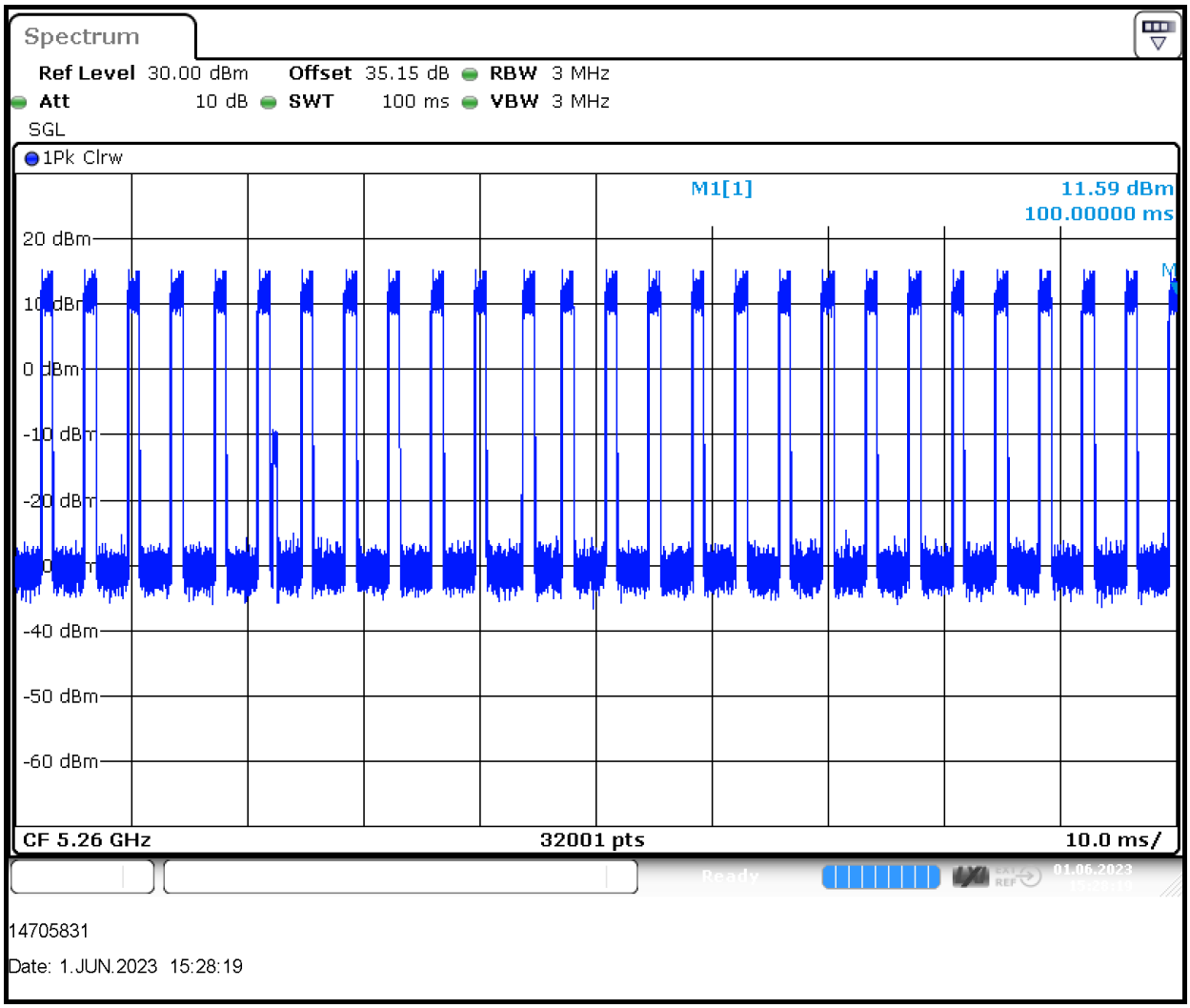
Noise Floor of Spectrum Analyser

Appendix 3. Channel Loading

As required by Section 8.3. c) 6) of KDB 905462 D02, the following plot and calculations shows the duty cycle of the channel used during testing.

When using an 80 MHz channel bandwidth, streaming representative file types as defined in Section 7.7 a) of KDB 905462 D02, were found not to produce a high enough duty cycle of >17%, as required by 7.7 c), and gave very irregular loading due to large video buffers. Therefore an alternative UDP pseudo-random data transfer as per 7.7 b) was streamed to simulate data transfer.

The duty cycle was calculated over 100 milliseconds. This was captured on a spectrum analyser in the time domain using a 0 Hz span and 32001 sweep points to ensure it included any longer term variations, whilst maintaining accurate to a 3.125 µs sample size.



The number of samples greater than -0 dBm was compared to the total number of samples to calculate the duty cycle. The EUT was found to be transmitting above this threshold for 26.9 % of the total, and hence meeting the requirement of greater than 17 % channel loading.

--- END OF REPORT ---