SAR Compliance Test Report

Date of Report	11/09/2023	**Client's Contact person:**	Oliver Engström
Number of pages:	35	**Responsible Test engineer:**	Ilari Kinnunen
Testing laboratory:	**Verkotan Oy** Elektroniikkatie 17 90590 Oulu Finland	**Client:**	**Mirka Ltd** Pensalantie 210 66850 Jepua Finland
Tested device	ESP32-PICO-DevKitM-2_V1.0, ESP32-PICO-MINI-02		
Related reports:	-		
Testing has been carried out in accordance with:	**47CFR §2.1093** Radiofrequency Radiation Exposure Evaluation: Portable Devices **FCC published RF exposure KDB procedures** **RSS-102, Issue 5** Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)		
Documentation:	The test report must always be reproduced in full; reproduction of an excerpt only is subject to written approval of the testing laboratory		
Test Results:	**The EUT complies with the requirements in respect of all parameters subject to the test.** The test results relate only to devices specified in this document		
Date and signatures:	11.09.2023 Miia Nurkkala **Laboratory Manager**		

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1. SUMMARY OF SAR TEST REPORT

1.1 Test Details

Equipment under Test (DUT):

Product:	ESP32-based development board
Manufacturer:	Espressif
Model:	ESP32-PICO-DevKitM-2_V1.0
Serial Number:	N/A
FCC ID Number:	2AK2S-BWM
ISED ID Number:	22379-BWM
DUT Number:	21439
Battery Type used in testing:	No Battery, powered by USB
State of the Sample	Production sample

Product:	ESP32-PICO-MINI-02
Manufacturer:	Espressif
Model:	ESP32-PICO-MINI-02
Serial Number:	N/A
FCC ID Number:	2AK2S-BWM
ISED ID Number:	22379-BWM
DUT Number:	21401
Battery Type used in testing:	No Battery, powered by USB
State of the Sample	Production sample

Testing information:

Testing performed:	25.11.2022 – 06.12.2022, 19.01.2023 – 20.01.2023
Notes:	-
Document ID:	FCC SAR report ESP32-PICO-MINI-02 ID5824 11092023.docx
Document history & changes:	Initial version
Temperature °C	22±2 / Controlled
Humidity RH%	30±20 / Controlled
FCC Test Firm Designation Number	FI0005
ISED Company Number:	22218
Measurement performed by:	Ilari Kinnunen

1.2 Maximum Results

The maximum reported* SAR values for extremity configuration for transmitting systems are shown in a table below. The device conforms to the requirements of the standards when the maximum reported SAR value is less than or equal to the limit. The SAR limit specified in FCC 47 CFR part 2 (2.1093) and Health Canada's RF exposure guideline, Safety Code 6 for extremity SAR_{10g} is 4 W/kg.

1.2.1 Standalone SAR

System	Highest Reported* SAR_{10g}(W/kg) in Extremity Configuration, 5mm separation distance	Result
WLAN 2.4GHz	**0.46**	**PASS**
Bluetooth	**0.09**	**PASS**

* Reported SAR Values are scaled to upper limit of power tuning tolerance.

1.2.2 Maximum Drift

Maximum Drift During Measurements	0.74dB

*Larger than 5% drifts included to scaling factors

1.2.3 Measurement Uncertainty

Uncertainty 300MHz-3GHz

Expanded Uncertainty (k=2) 95 %	±22.1 %

2. DESCRIPTION OF THE DEVICE UNDER TEST (DUT)

Two DUT's were used during the testing:

- ESP32-based development board produced by Espressif. The core of this board is ESP32-PICO-MINI-02 module with on-board PCB antenna. This sample was used to enable SAR measurements at 5mm separation distance from the antenna.
- ESP32-PICO-MINI-02 module with on-board PCB antenna attached to ESP-Prog development and debugging tool produced by Espressif. This sample was used to enable SAR measurements at 0mm separation distance from the bottom side of the module to represent worst-case exposure condition. The test separation distance to the antenna from bottom side is longer than 5mm because the shielding of the module prevents access at that separation.

The DUT's support 2.4GHz WLAN and Bluetooth.

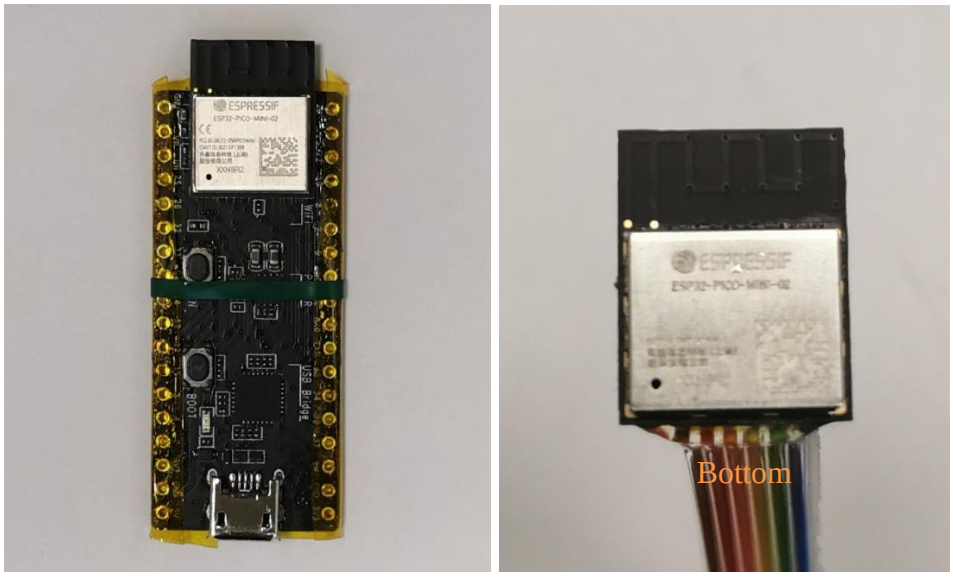


Figure 1 ESP32-PICO-DevKitM-2 and ESP32-PICO-MINI-02 module

Device Category	Portable
Exposure Environment	General population uncontrolled

2.1 Supported Frequency Bands and Operational Modes

TX Frequency bands	Modes of Operation	Transmitter Frequency Range (MHz)
	2.4GHz WLAN	2412 – 2462
	Bluetooth	2402 – 2480

3. OUTPUT POWER

3.1 Maximum specified conducted output power

From the customer;

WLAN 2.4GHz	Channel	Max Output Power [dBm]
802.11b	1	13.0
802.11b	6	18.0
802.11b	11	18.0

Bluetooth	Frequency [MHz]	Max Output Power [dBm]
	2402	9
	2441	9
	2480	9

The WLAN transmission modes for testing were selected according to power, largest channel bandwidth configuration, lowest order modulation and lowest data rate.

TX power settings used for FCC certification of 2AC7Z-ESPPICOMINI. Measured output power may exceed the setting.

Channel	11b	11g/n 20M	11g/n 40M
1.0	12	12.0	NA
2.0	17.0	15.0	NA
3.0	17.0	15.0	14.0
4.0	17.0	15.0	16.5
5.0	17.0	15.0	16.5
6.0	17.0	15.0	16.5
7.0	17.0	15.0	16.5
8.0	17.0	15.0	16.5
9.0	17.0	15.0	13.0
10.0	17.0	15.0	13.0
11.0	17.0	13.0	13.0

3.2 Tested conducted power

Standard	Transmission mode	Data rate [Mbps]	Output power [dBm]		
			CH 1 2412 MHz	CH 6 2437 MHz	CH 11 2462 MHz
802.11b	DSSS	1	12.15	16.65	16.35

Standard	Data rate [Mbps]	Output power [dBm]		
		2402 MHz	2441 MHz	2480 MHz
Bluetooth	1	8.56	8.72	8.47

4. TEST EQUIPMENT

Dasy52 near field scanning system, manufactured by SPEAG was used for SAR testing. The test system consists of high precision robotics system (Staubli), robot controller, computer, near-field probe, probe alignment sensor, and a phantom containing the tissue equivalent material. The robot is a six-axis industrial robot performing precise movements to position the probe to the location of maximum electromagnetic field.

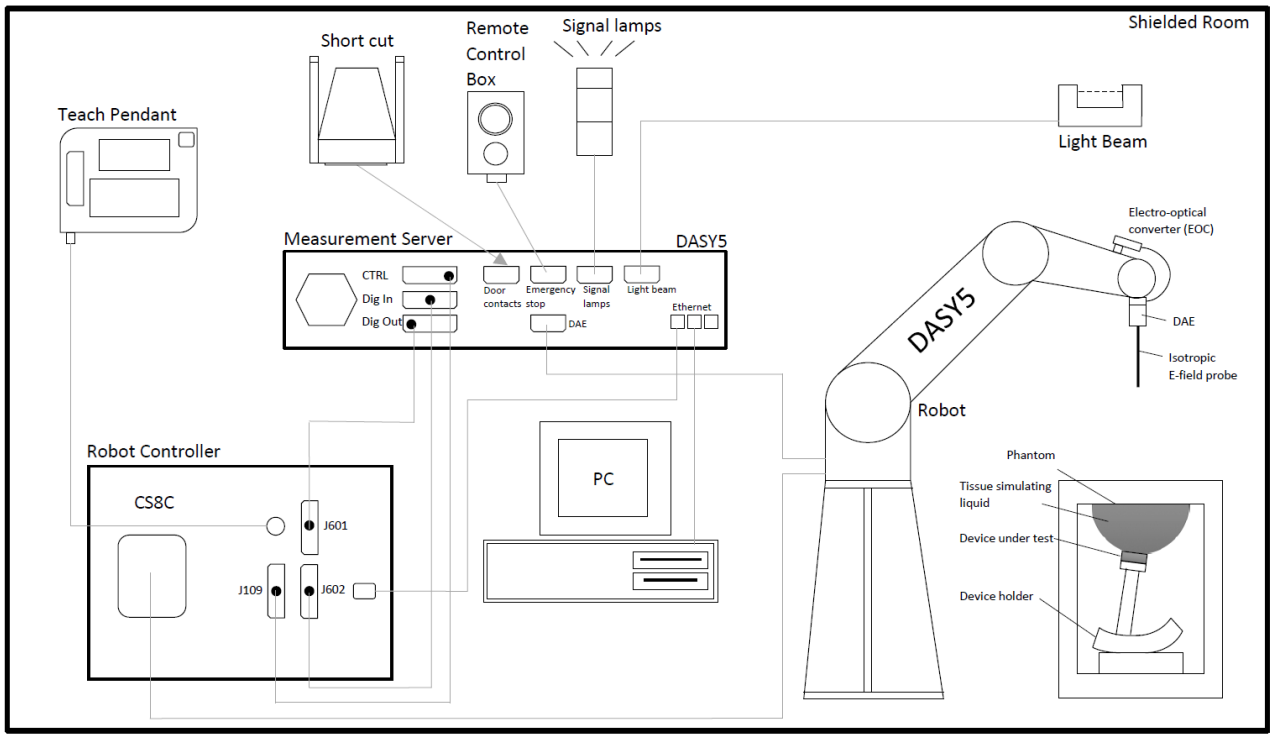


Figure 2 Schematic Laboratory Picture

4.1 Test Equipment List

Main used test system components are listed below. For full equipment list and calibration intervals, please contact the testing laboratory.

Test Equipment	Model	Serial Number	Calibration Date
DAE	DAE4	710	10.2022
Probe	EX3DV4	3852	10.2022
Dipole	D2450V2	729	10.2022
DASY5 Software	52.8.8.1258	-	NA
Signal Generator	Anritsu MG3710A	6261911026	02.2022
Amplifier	AR 10S1G4A	320421	NA
Power meter	NRP-Z11	100265	12.2022
Inline Peak Power Sensor	Anritsu MA24105A	2102058	11.2022

4.1.1 Isotropic E-field Probe Type EX3DV4

Construction	Symmetrical design with triangular core Built-in shielding against static charges PEEK enclosure material (resistant to organic solvents, e.g., DGBE)
Calibration	Calibration certificate in Appendix D
Frequency	10 MHz to >6 GHz (dosimetry); Linearity: ± 0.2 dB (30 MHz to 6 GHz)
Directivity	± 0.3 dB in HSL (rotation around probe axis) ± 0.5 dB in tissue material (rotation normal to probe axis)
Dynamic Range	10 µW/g to > 100 mW/g, Linearity: ± 0.2 dB
Dimensions	Overall length: 330 mm Tip length: 10 mm Body diameter: 12 mm
Application	General dosimetry up to 6 GHz Compliance tests of mobile phones Fast automatic scanning in arbitrary phantoms

4.2 Phantoms

Modular flat phantom:

The Triple Modular Phantom consists of three identical modules that can be installed and removed separately without emptying the liquid. It is used for compliance testing of small wireless devices in body-worn configurations. The phantom conforms to the requirements of IEEE 1528 and FCC published RF Exposure KDB Procedures. The shell thickness of the bottom plate is 2±0.2mm. The dimensions are 308x192x182mm and filling volume is 9.2 liters giving a filling height of 155mm.

4.3 Tissue Simulants

Recommended values for the dielectric parameters of the tissue simulants are given in IEEE 1528 and FCC published RF Exposure KDB Procedures. The dielectric parameters of the used tissue simulants were within ±10% of the recommended values at frequencies up to 3GHz. A liquid compensation algorithm was used in DASY5 with which measured peak average SAR values were corrected for the deviation of used liquid. Depth of the tissue simulant was at least 15.0 cm from the inner surface of the flat phantom. Tissue simulant consists of:

Head tissue simulant liquid Ingredients
Deionized Water, Tween, salt

4.4 System Validation Status

Frequency [MHz]	Dipole Type / SN	Probe Type / SN	Calibrated Signal Type	Validation Signal Type	DAE Unit / SN	Dielectric Constant ε	Conductivity, σ [S/m]	Validation Done
								Head tissue simulant
2450	D2450V2 / 758	EX3DV4 / 3852	CW	CW/DSSS	DAE 4 / 710	40.46	1.75	11.2022

4.5 System Check

Date	Tissue Type	Tissue Temp. [°C]	Frequency [MHz]	Input Power [mW]	Measured SAR_{1g} [W/kg]	1 W Target SAR_{1g} [W/kg]	1 W Normalized SAR_{1g} [W/kg]	Deviation (%)	Plot #
23.11.2022	WB Head	22	2450	250	12.1	52.3	48.4	-7.5	1
05.12.2022	WB Head	22	2450	250	12.1	52.3	48.4	-7.5	2
19.01.2023	WB Head	22	2450	250	12.0	52.3	48.0	-8.2	3

4.5.1 Tissue Simulant Verification

				Target		Measured		Deviation	
Date	Tissue Type	Tissue Temp [°C]	Frequency [MHz]	Dielectric Constant [ε] Target	Conductivity σ [S/m] Target	Dielectric Constant [ε]	Conductivity σ [S/m]	ε (%)	σ (%)
23.11.2022	WB Head	22	2412	39.27	1.77	42.42	1.7	8.0	-3.8
23.11.2022	WB Head	22	2437	39.22	1.79	42.38	1.72	8.1	-4.0
23.11.2022	WB Head	22	2450	39.2	1.8	42.35	1.73	8.0	-4.1
23.11.2022	WB Head	22	2462	39.18	1.81	42.34	1.73	8.1	-4.3
28.11.2022	WB Head	22	2412	39.27	1.77	41.85	1.71	6.6	-3.2
28.11.2022	WB Head	22	2437	39.22	1.79	41.81	1.73	6.6	-3.5
28.11.2022	WB Head	22	2450	39.2	1.8	41.78	1.74	6.6	-3.6
28.11.2022	WB Head	22	2462	39.18	1.81	41.76	1.74	6.6	-3.8
05.12.2022	WB Head	22	2402	39.29	1.76	41.14	1.68	4.7	-4.5
05.12.2022	WB Head	22	2441	39.22	1.79	41.09	1.71	4.8	-4.8
05.12.2022	WB Head	22	2450	39.2	1.8	41.07	1.71	4.8	-5.0
05.12.2022	WB Head	22	2480	39.16	1.83	41.04	1.73	4.8	-5.5
19.01.2023	WB Head	22	2437	39.22	1.79	39.61	1.62	1.0	-9.2
19.01.2023	WB Head	22	2441	39.22	1.79	39.60	1.63	1.0	-9.2
19.01.2023	WB Head	22	2450	39.2	1.8	39.59	1.63	1.0	-9.2

5. TEST PROCEDURE

Testing was carried out in accordance with FCC KDB Publications 447498 D01 General RF Exposure Guidance v06, 248227 D01 and Industry Canada RSS-102.

Control software was used to set the DUT to transmit at maximum power.

The WLAN transmission modes for testing were selected according to power, largest channel bandwidth configuration, lowest order modulation and lowest data rate. 2.4GHz WLAN was tested with 802.11b standard with data rate of 1Mbit/s.

Bluetooth was tested using 1Mbit/s data rate.

5.1 Test Positions

5.1.1 Extremity Configuration, 5mm separation distance from the antenna

ESP32-PICO-DevKitM-2 was placed on the device holder and lifted towards the phantom until the distance between the phantom and the antenna of the DUT was 5mm.
The device was tested from 5 sides around the antenna (front, back, left, right and top).

Photos of the test positions are presented in appendix A.

5.1.2 Extremity Configuration, 0mm separation distance from the edge of the device

ESP32-PICO-MINI-02 module was placed on the device holder and lifted towards the phantom until the distance between the phantom and the bottom side edge of the DUT was 0mm to represent worst-case exposure condition as separation distance to the antenna from the bottom side is longer than 5mm.

Photos of the test positions are presented in appendix A.

5.2 Scan Procedures

First, area scans were used for determination of the field distribution. Next, a zoom scan was performed around the highest E-field value to determine the averaged SAR value. Drift was determined by measuring the same point at the start of the area scan and again at the end of the zoom scan.

5.3 SAR Averaging Methods

The maximum SAR value was averaged over a cube of tissue using interpolation and extrapolation.
The interpolation, extrapolation and maximum search routines within Dasy52 are all based on the modified Quadratic Shepard's method (Robert J. Renka," Multivariate Interpolation of Large Sets of Scattered Data", University of North Texas ACM Transactions on Mathematical Software, vol. 14, no. 2, June 1988, pp. 139-148).
The interpolation scheme combines a least-square fitted function method with a weighted average method. A trivariate 3-D / bivariate 2-D quadratic function is computed for each measurement point and fitted to neighboring points by a least-square method. For the zoom scan, inverse distance weighting is incorporated to fit distant points more accurately. The interpolating function is finally calculated as a weighted average of the quadratics.

In the zoom scan, the interpolation function is used to extrapolate the Peak SAR from the deepest measurement points to the inner surface of the phantom.

6. MEASUREMENT UNCERTAINTY

DASY5 Uncertainty Budget According to IEC/IEEE 62209-1528 (Frequency band: 300MHz - 3GHz range)								
Symbol	Error Description	Uncert. value	Prob. Dist.	Div.	(c_i) 1g	(c_i) 10g	Std. Unc. (1g)	Std. Unc. (10g)
Measurement System Errors								
CF	Probe Calibration	±12.0%	N	√2	1	1	±6.0%	±6.0%
CFdrift	Probe Calibration Drift	±1.7%	R	√3	1	1	±1.0%	±1.0%
LIN	Probe Linearity	±4.7%	R	√3	1	1	±2.7%	±2.7%
BBS	Broadband Signal	±3.0%	R	√3	1	1	±1.7%	±1.7%
ISO	Probe Isotropy	±7.6%	R	3	1	1	±4.4%	±4.4%
DAE	Data Acquisition	±0.3%	N	1	1	1	±0.3%	±0.3%
AMB	RF Ambient	±1.8%	N	1	1	1	±1.8%	±1.8%
Δsys	Probe Positioning	±3.9%	N	1	0.14	0.14	±0.5%	±0.5%
DAT	Data Processing	±1.2%	N	1	1	1	±1.2%	±1.2%
Phantom and Device Errors								
LIQ(σ)	Conductivity (meas.)^{DAK}	±2.5%	N	√1	0.78	0.71	±2.0%	±1.8%
LIQ(T_σ)	Conductivity (temp.)^{BB}	±3.3%	R	√3	0.78	0.71	±1.5%	±1.4%
EPS	Phantom Permittivity	±14.0%	R	3	0	0	±0%	±0%
DIS	Distance DUT - TSL	±2.0%	N	1	2	2	±4.0%	±4.0%
Dxyz	Device Positioning (±0.5mm)	±1.0%	N	1	1	1	±1.0%	±1.0%
H	Device Holder	±3.6%	N	√1	1	1	±3.6%	±3.6%
MOD	DUT Modulation^{m}	±2.4%	R	√3	1	1	±1.4%	±1.4%
TAS	Time-average SAR	±2.6%	R	3	1	1	±1.5%	±1.5%
RFdrift	DUT drift	±2.5%	N	1	1	1	±2.5%	±2.5%
VAL	Val Antenna Unc.^{val}	±0.0%	N	1	1	1	±0%	±0%
RF_{in}	Unc. Input Power^{val}	±0.0%	N	1	1	1	±0%	±0%
Correction to the SAR results								
C(ε, σ)	Deviation to Target	±1.9%	N	√1	1	0.84	±1.9%	±1.6%
C(R)	SAR scaling^{p}	±0%	R	3	1	1	±0%	±0%
u(ΔSAR)	Combined Uncertainty						±11.0%	±10.9%
U	**Expanded Uncertainty**						±22.1%	±21.9%

7. TEST RESULTS

7.1 SAR Results Extremity Condition with 5mm separation distance from the antenna

2.4GHz WLAN:

Mode	Freq [MHz]	CH	Data Rate [Mbps]	Test position	Maximum Power [dBm]	Conducted Power [dBm]	Measured SAR10g [W/kg]	Power Drift* [dB]	Scaling Factor	Duty Cycle	Reported SAR10g [W/kg]	Plot #
802.11b	2437	6	1	Front 5mm	18	16.65	0.18	0.18	1.36	1:1	0.24	
802.11b	2437	6	1	Back 5mm	18	16.65	0.30	0.03	1.36	1:1	0.41	
802.11b	2437	6	1	Left 5mm	18	16.65	0.12	0.36	1.48	1:1	0.18	
802.11b	2437	6	1	Right 5mm	18	16.65	0.24	-0.11	1.36	1:1	0.33	
802.11b	2437	6	1	Top 5mm	18	16.65	0.01	0.74	1.62	1:1	0.02	
802.11b	2437	6	1	Bottom 0mm**	18	16.65	0.16	0.53	1.54	1:1	0.25	
802.11b	2412	1	1	Back 5mm	13	12.15	0.14	0.37	1.32	1:1	0.18	
802.11b	2462	11	1	Back 5mm	18	16.35	0.32	-0.12	1.46	1:1	0.46	4

*Larger than 5% drifts included to scaling factors
**Bottom side has longer separation distance than 5mm measured from the antenna to the edge of the module, thus it has been measured with 0mm separation distance

Bluetooth:

Mode	Freq [MHz]	Data Rate [Mbps]	Test position	Maximum Power [dBm]	Conducted Power [dBm]	Measured SAR10g [W/kg]	Power Drift* [dB]	Scaling Factor	Duty Cycle	Reported SAR10g [W/kg]	Plot #
BT	2441	1	Front 5mm	9	8.72	0.031	0.14	1.07	1:1.3	0.03	
BT	2441	1	Back 5mm	9	8.72	0.063	0.32	1.15	1:1.3	0.07	
BT	2441	1	Left 5mm	9	8.72	0.014	NA***	1.07	1:1.3	0.01	
BT	2441	1	Right 5mm	9	8.72	0.045	0.23	1.12	1:1.3	0.05	
BT	2441	1	Top 5mm	9	8.72	0.00004	NA***	1.07	1:1.3	0.00004	
BT	2441	1	Bottom 0mm**	9	8.72	0.0485	0.47	1.19	1:1.3	0.06	
BT	2402	1	Back 5mm	9	8.56	0.063	0.49	1.24	1:1.3	0.08	
BT	2480	1	Back 5mm	9	8.47	0.078	0.12	1.13	1:1.3	0.09	5

*Larger than 5% drifts included to scaling factors.
**Bottom side has longer separation distance than 5mm measured from the antenna to the edge of the module, thus it has been measured with 0mm separation distance
***Drift measurement not applicable due to the low e-field in the drift measurement location

7.2 RF Energy Coupling Enhancement

Additional measurements were conducted at the highest reported SAR configuration to consider RF Energy Coupling Enhancement at increased separation distance. Following procedure was used for the testing:

- For the highest reported SAR configuration, the probe was positioned at the peak SAR location of the zoom scan, at a distance half of the probe tip diameter, rounded to the nearest mm from the phantom surface.
- DUT was positioned at direct contact with the phantom and then moved away in 5mm increments, until the measured SAR is < 50 % of that measured in direct contact with the phantom. Three single-point SAR repeated measurements were done at each separation distance as there were no variation higher than 15% between the measurements.
- Since the highest measured single-point SAR among all positions is less than 25% from that measured with the device positioned at 5mm separation distance from the phantom, no further measurements were required.

Mode	Freq [MHz]	Channel	Data Rate	Test position	Maximum Power [dBm]	Conducted Power [dBm]	Single-point SAR [W/kg]	Scaling Factor	Reported Single-point SAR [W/kg]
802.11b	2462	11	1 Mbps	Back 0mm	18	16.35	1.95	1.46	2.84
802.11b	2462	11	1 Mbps	Back 0mm	18	16.35	2.02	1.46	2.95
802.11b	2462	11	1 Mbps	Back 0mm	18	16.35	2.13	1.46	3.11
802.11b	2462	11	1 Mbps	Back 5mm	18	16.35	1.07	1.46	1.56
802.11b	2462	11	1 Mbps	Back 5mm	18	16.35	1.06	1.46	1.55
802.11b	2462	11	1 Mbps	Back 5mm	18	16.35	1.10	1.46	1.61
802.11b	2462	11	1 Mbps	Back 10mm	18	16.35	0.41	1.46	0.60
802.11b	2462	11	1 Mbps	Back 10mm	18	16.35	0.41	1.46	0.60
802.11b	2462	11	1 Mbps	Back 10mm	18	16.35	0.42	1.46	0.61

Mode	Freq [MHz]	Data Rate	Test position	Maximum Power [dBm]	Conducted Power [dBm]	Single-point SAR [W/kg]	Scaling Factor	Reported Single-point SAR [W/kg]
BT	2480	1 Mbps	Back 0mm	9	8.47	0.48	1.13	0.55
BT	2480	1 Mbps	Back 0mm	9	8.47	0.47	1.13	0.53
BT	2480	1 Mbps	Back 0mm	9	8.47	0.47	1.13	0.53
BT	2480	1 Mbps	Back 5mm	9	8.47	0.25	1.13	0.28
BT	2480	1 Mbps	Back 5mm	9	8.47	0.25	1.13	0.28
BT	2480	1 Mbps	Back 5mm	9	8.47	0.25	1.13	0.29
BT	2480	1 Mbps	Back 10mm	9	8.47	0.10	1.13	0.11
BT	2480	1 Mbps	Back 10mm	9	8.47	0.10	1.13	0.11
BT	2480	1 Mbps	Back 10mm	9	8.47	0.10	1.13	0.11

7.3 IEC 62209-2 AMD1:2019

According to IEC 62209-2 AMD1:2019, the zoom scan complies if the peak spatial-average SAR is below 0.1 W/kg, or if the following criteria is met:

1. The smallest horizontal distance from the local SAR peaks to all points 3 dB below the SAR peak is larger than the horizontal grid step.

2. Ratio of SAR at the second measured point (M2) to the SAR at the closest measured point (M1) at the x-y location of the measured maximum is at least 30%.

Zoom scan compliance according to IEC 62209-2 AMD1:2019 is automatically verified by DASY5 software and all zoom scans in this test report do pass the criteria. The smallest horizontal distance and Ratio between measurement points M2 and M1 of the highest SAR results is available in Appendix C.

APPENDIX A: PHOTOS OF THE DUT

Size of the DUT is 47 ×20.3 × 4 mm

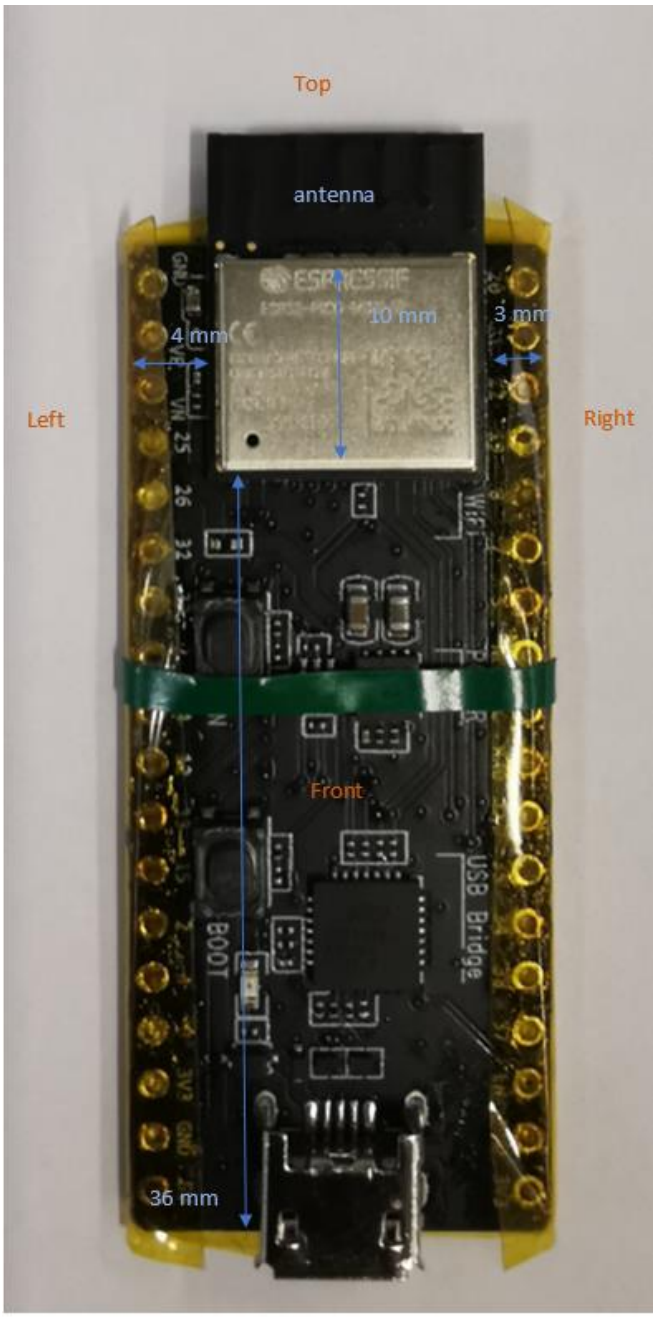


Figure 3 ESP32-PICO-DevKitM-2_V1.0

Figure 4 ESP32-PICO-MINI-02 Module attached with wires

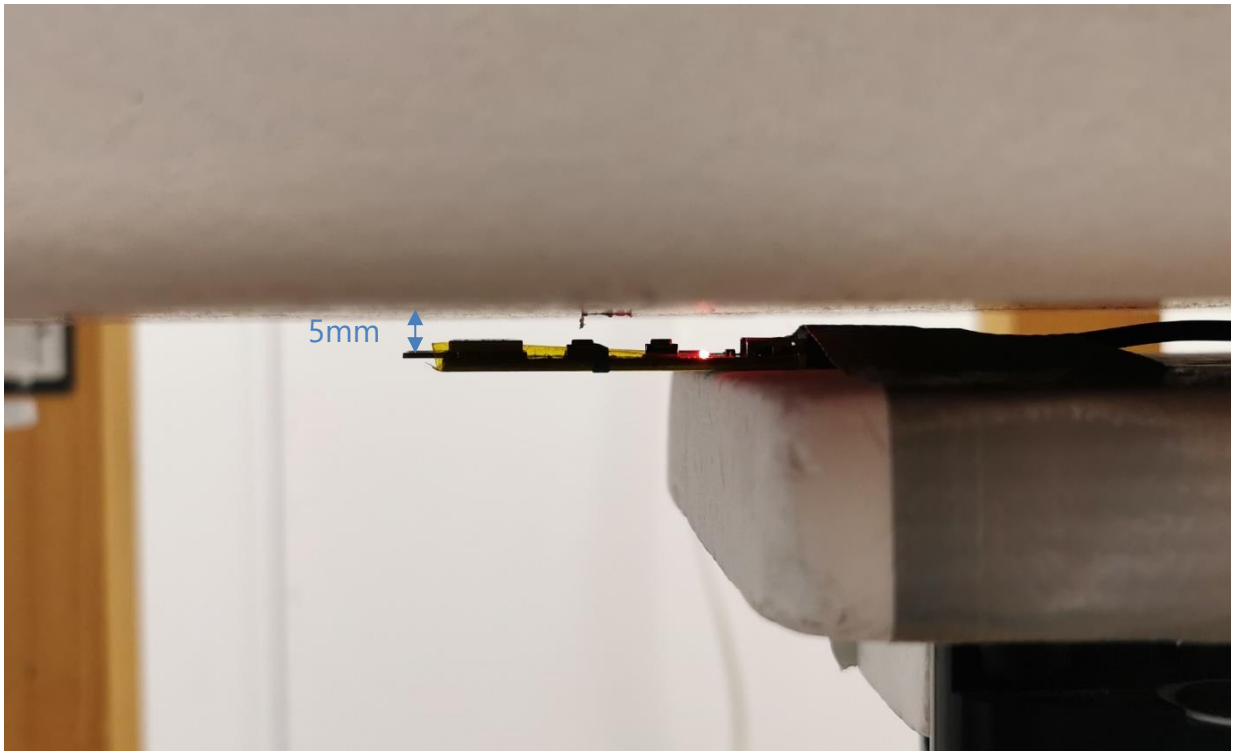


Figure 5 Front side of the device against the phantom with 5 mm separation

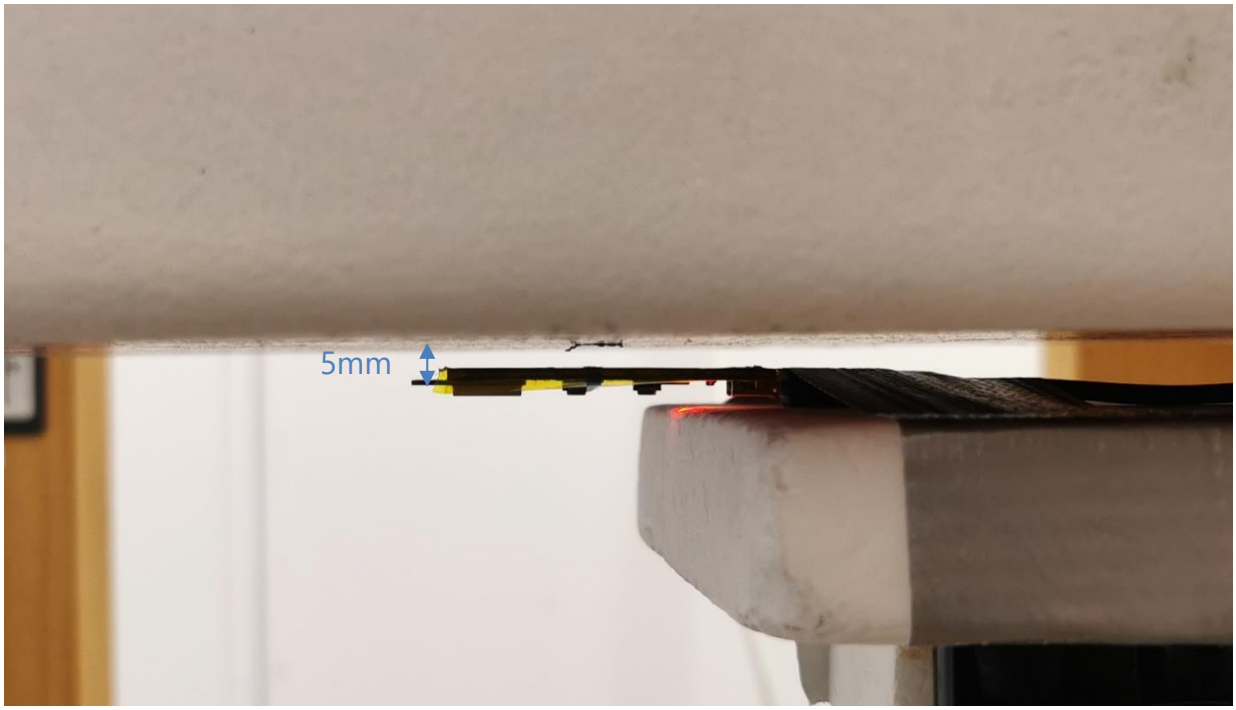


Figure 6 Back side of the device against the phantom with 5mm separation

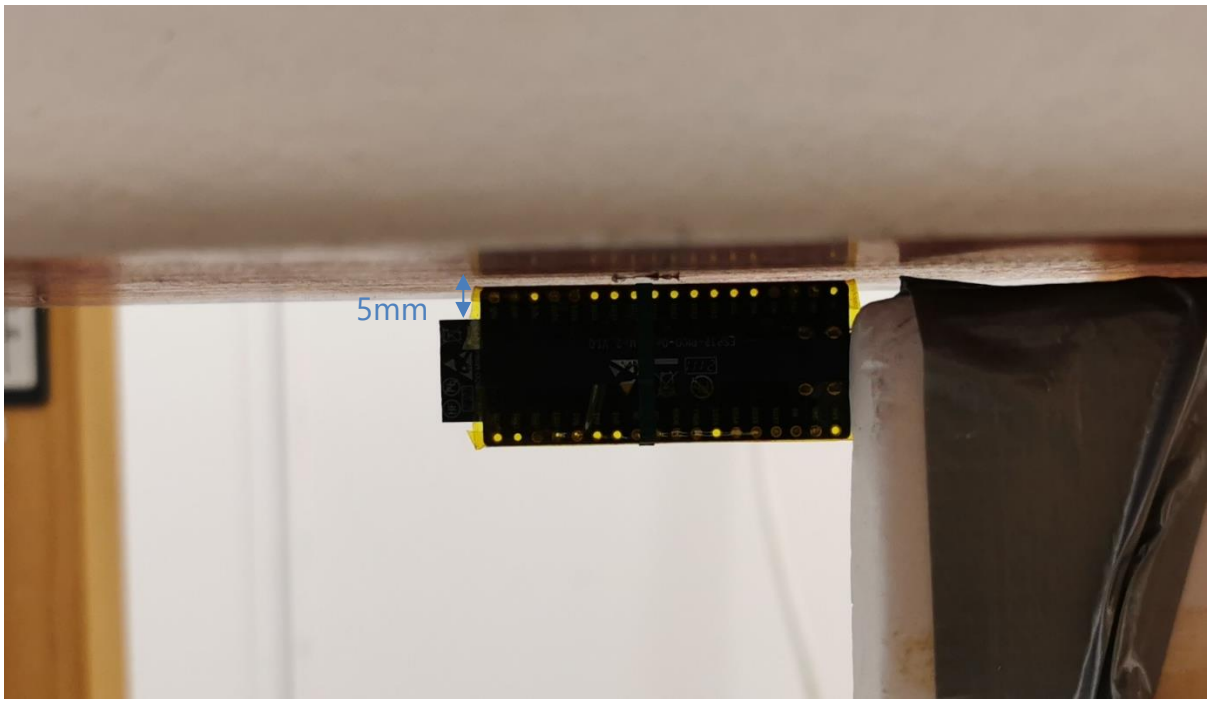


Figure 7 Left side of the device against the phantom with 5mm separation

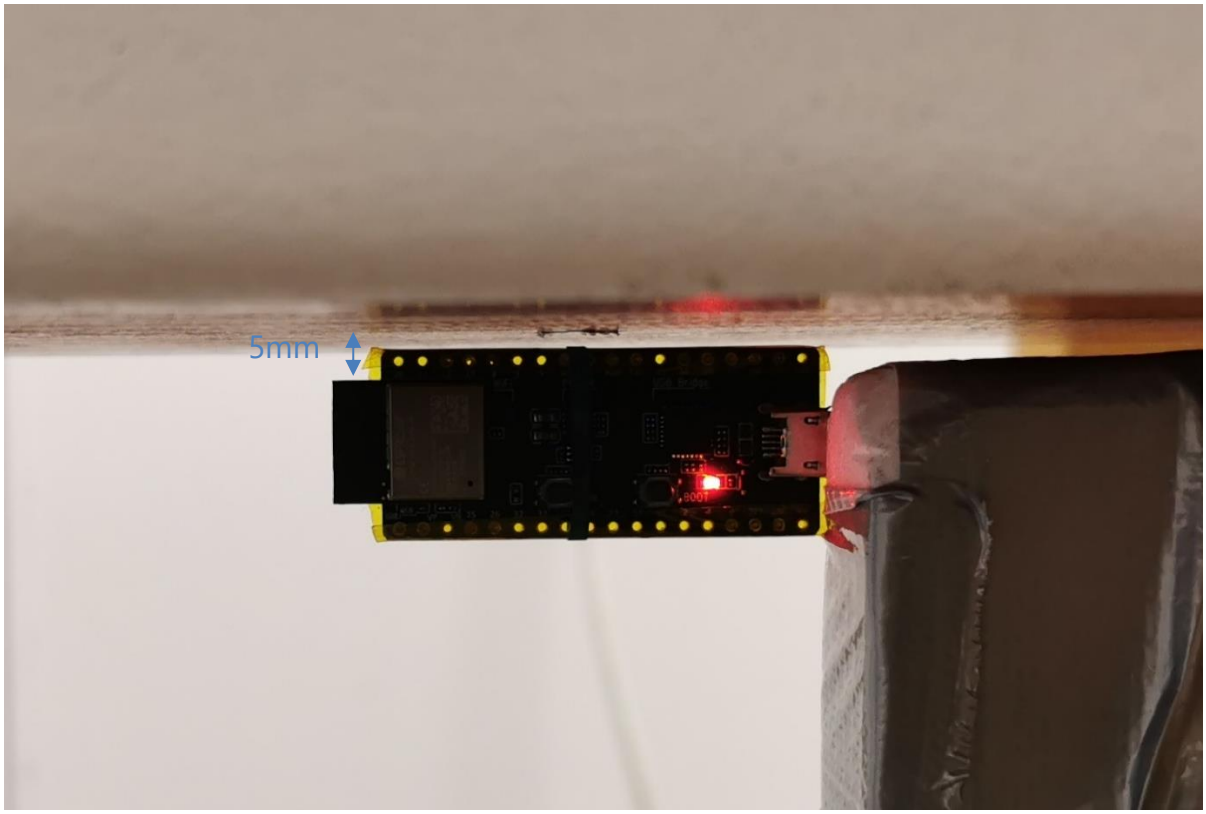


Figure 8 Right side of the device against the phantom with 5mm separation

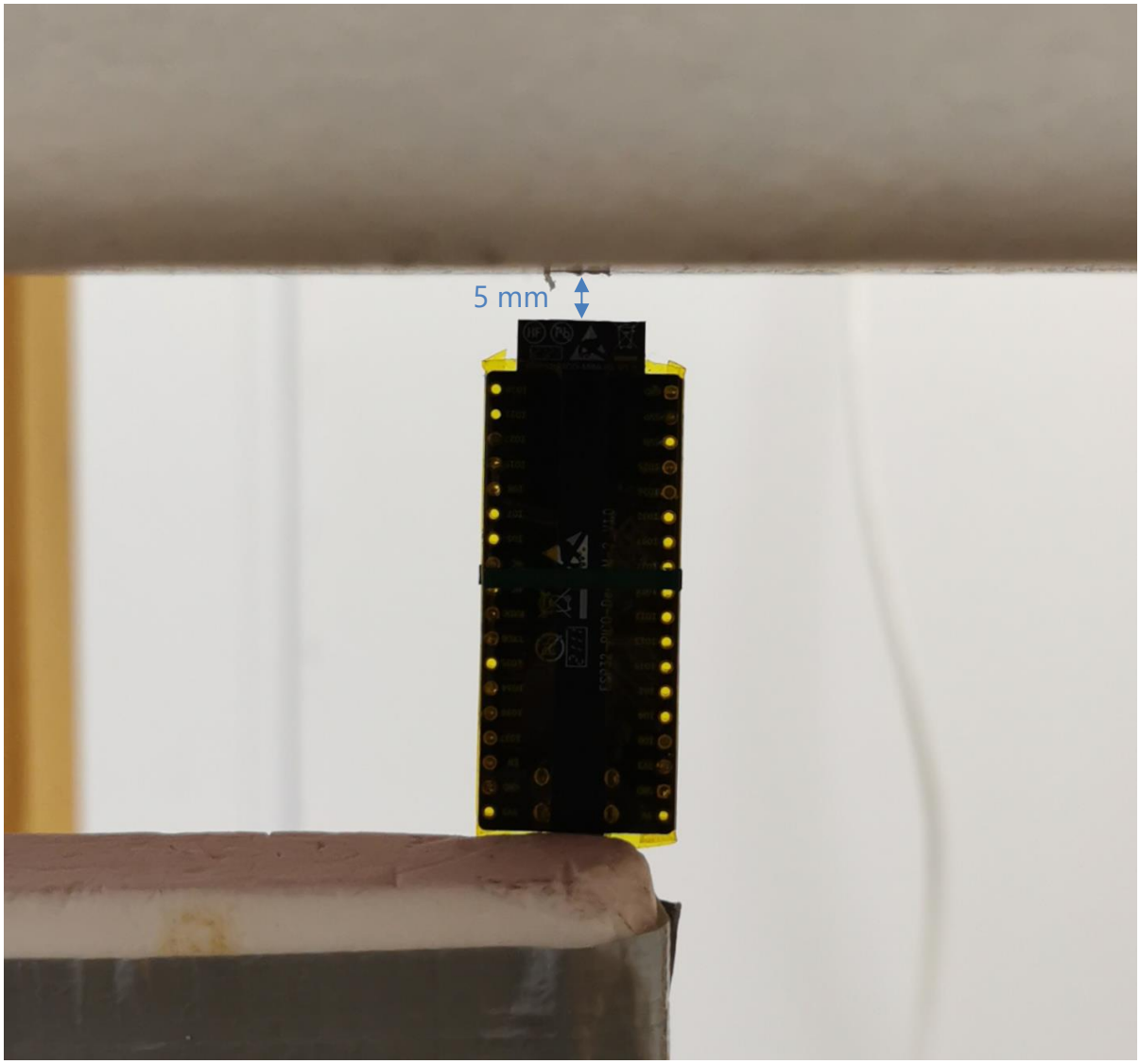


Figure 9 Top side of the device against the phantom with 5mm separation

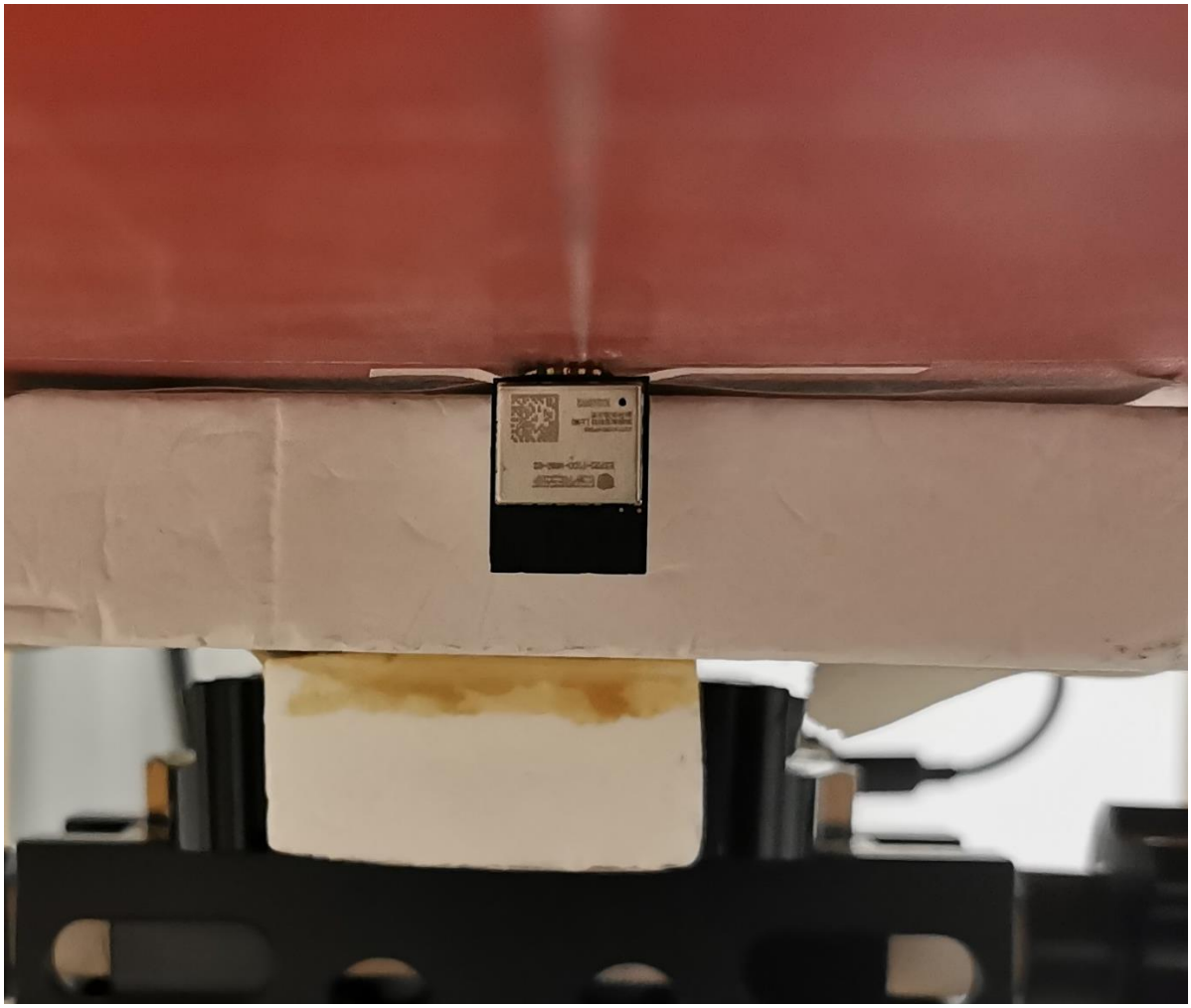


Figure 10 Bottom side of the device against the phantom with 0mm separation

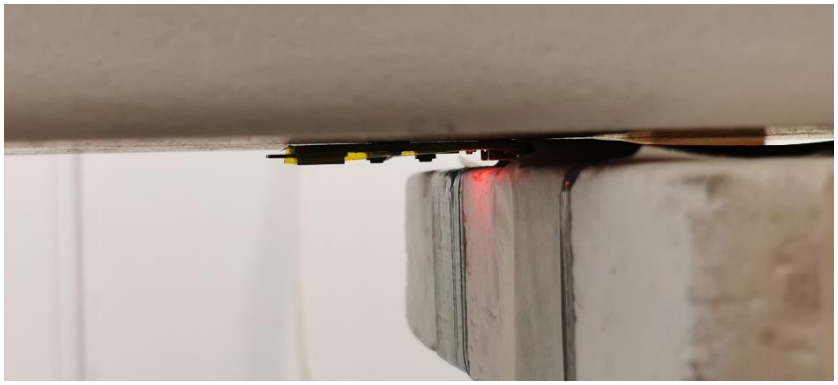


Figure 11 Back Test Position, RF Energy Coupling Enhancement, 0mm separation distance

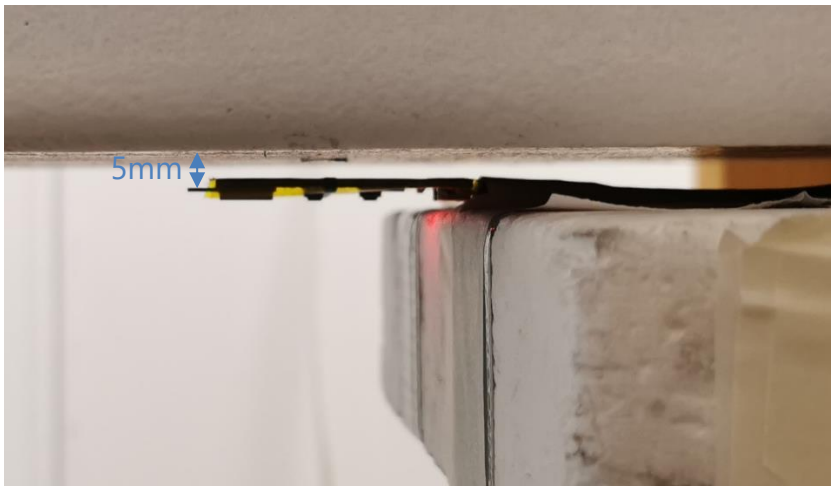


Figure 12 Back Test Position, RF Energy Coupling Enhancement, 5mm separation distance

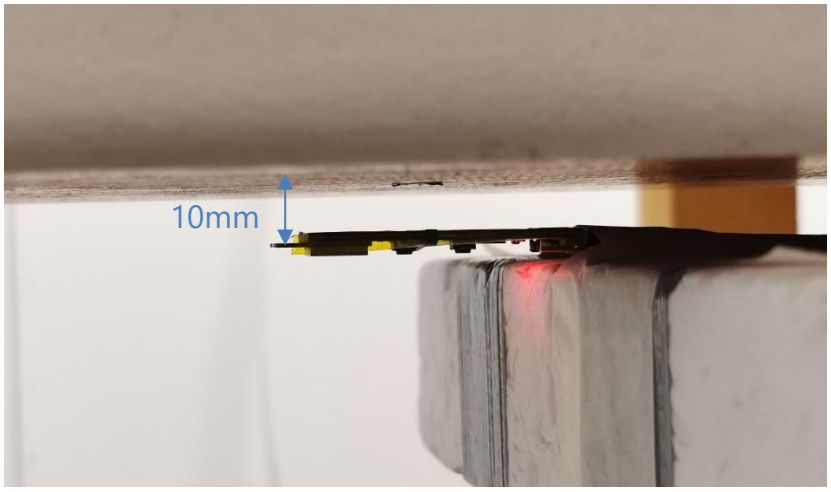


Figure 13 Back Test Position, RF Energy Coupling Enhancement, 10mm separation distance

APPENDIX B: SYSTEM CHECK SCAN

Plot 1

Date/Time: 23.11.2022 14.24.47

Test Laboratory: Verkotan Oy

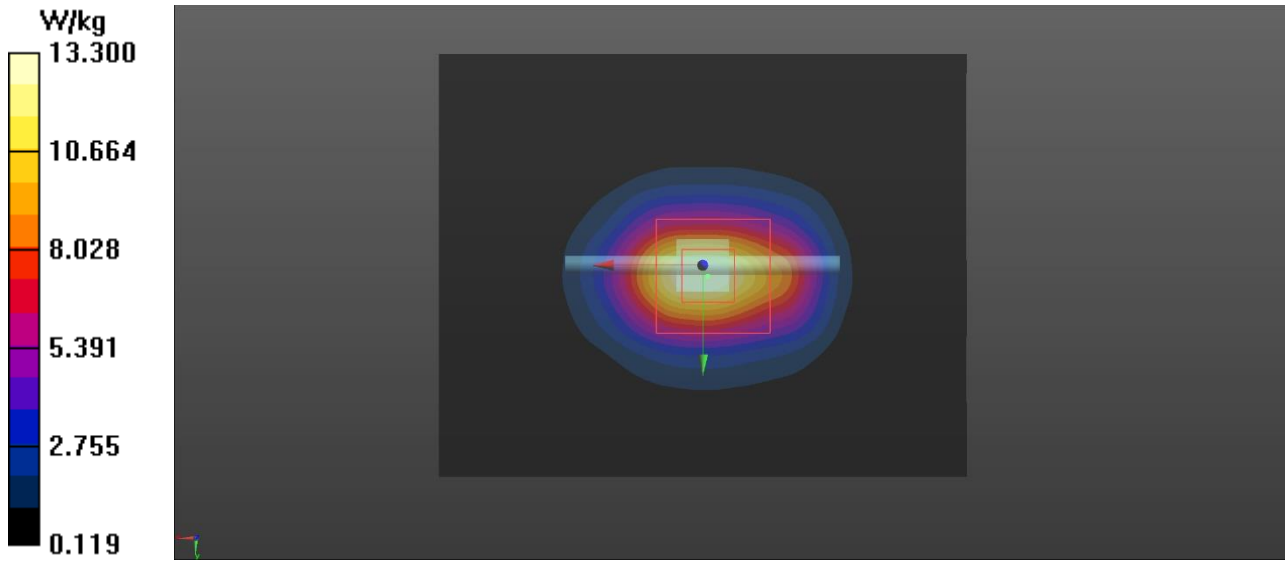
DUT: Dipole 2450 MHz D2450V2; Type: D2450V2; Serial: D2450V2 - SN:729

Communication System: UID 0, CW (0); Communication System Band: D2450 (2450.0 MHz); Frequency: 2450 MHz;
Communication System PAR: 0 dB;
Medium parameters used (interpolated): f = 2450 MHz; σ = 1.726 S/m; ε_r = 42.355; ρ = 1000 kg/m^3
Phantom section: Center Section
Measurement Standard: DASY5 (IEEE/IEC)

DASY Configuration:

- Probe: EX3DV4 - SN3852; ConvF(7.48, 7.48, 7.48) @ 2450 MHz; Calibrated: 27.10.2022
  - Sensor-Surface: 4mm (Mechanical Surface Detection), z = -4.0, 31.0
  - Electronics: DAE4 Sn710; Calibrated: 19.10.2022
  - Phantom: MFP_V5.1C (20deg probe tilt); Type: QD 000 P51 Cx;
  - DASY52 52.10.4(1527); SEMCAD X 14.6.14(7483)

Configuration/System check, 23.11.2022/Area Scan (101x81x1): Interpolated grid: dx=1.000 mm, dy=1.000 mm
Maximum value of SAR (interpolated) = 13.2 W/kg
Configuration/System check, 23.11.2022/Zoom Scan (7x7x7)/Cube 0: Measurement grid: dx=5mm, dy=5mm, dz=5mm
Reference Value = 87.32 V/m; Power Drift = -0.14 dB
Peak SAR (extrapolated) = 23.2 W/kg
SAR(1 g) = 12.1 W/kg; SAR(10 g) = 5.74 W/kg (SAR corrected for target medium)
Smallest distance from peaks to all points 3 dB below = 10 mm
Ratio of SAR at M2 to SAR at M1 = 52.6%
Maximum value of SAR (measured) = 13.3 W/kg



Plot 2

Date/Time: 05.12.2022 8.48.49

Test Laboratory: Verkotan Oy

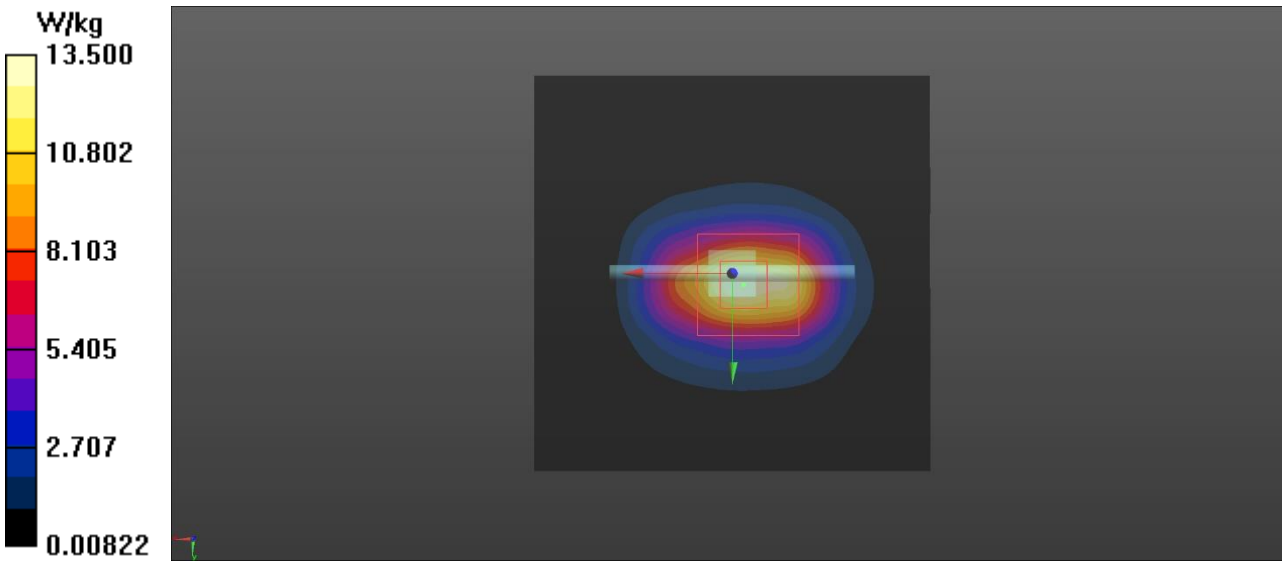
DUT: Dipole 2450 MHz D2450V2; Type: D2450V2; Serial: D2450V2 - SN:729

Communication System: UID 0, CW (0); Communication System Band: D2450 (2450.0 MHz); Frequency: 2450 MHz;
Communication System PAR: 0 dB;
Medium parameters used (interpolated): f = 2450 MHz; σ = 1.711 S/m; ε_r = 41.067; ρ = 1000 kg/m^3
Phantom section: Center Section
Measurement Standard: DASY5 (IEEE/IEC)

DASY Configuration:

- Probe: EX3DV4 - SN3852; ConvF(7.48, 7.48, 7.48) @ 2450 MHz; Calibrated: 27.10.2022
  - Sensor-Surface: 4mm (Mechanical Surface Detection), z = 31.0, -4.0
  - Electronics: DAE4 Sn710; Calibrated: 19.10.2022
  - Phantom: MFP_V5.1C (20deg probe tilt); Type: QD 000 P51 Cx;
  - DASY52 52.10.4(1527); SEMCAD X 14.6.14(7483)

System check 2450MHz/Zoom Scan (7x7x7)/Cube 0: Measurement grid: dx=5mm, dy=5mm, dz=5mm
Reference Value = 85.78 V/m; Power Drift = -0.12 dB
Peak SAR (extrapolated) = 23.2 W/kg
SAR(1 g) = 12.1 W/kg; SAR(10 g) = 5.72 W/kg (SAR corrected for target medium)
Smallest distance from peaks to all points 3 dB below = 10 mm
Ratio of SAR at M2 to SAR at M1 = 52.4%
Maximum value of SAR (measured) = 13.3 W/kg
System check 2450MHz/Area Scan (71x71x1): Interpolated grid: dx=1.200 mm, dy=1.200 mm
Maximum value of SAR (interpolated) = 13.5 W/kg



Plot 3

Date/Time: 19.01.2023 13.26.46

Test Laboratory: Verkotan Oy

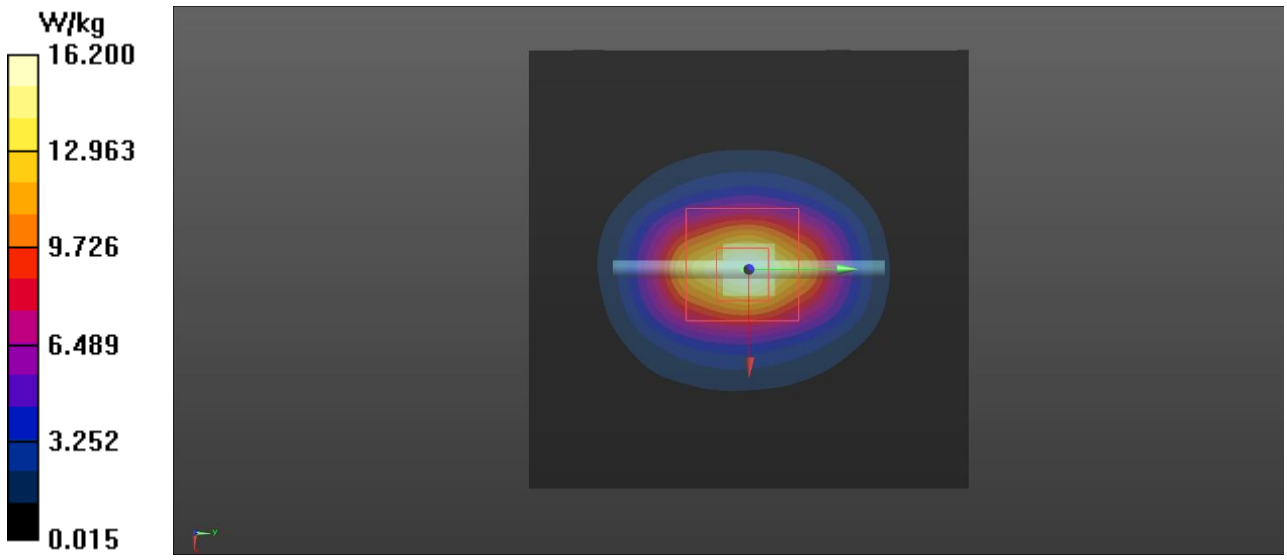
DUT: Dipole 2450 MHz D2450V2; Type: D2450V2; Serial: D2450V2 – SN:729

Communication System: UID 0, CW (0); Communication System Band: D2450 (2450.0 MHz); Frequency: 2450 MHz;
Communication System PAR: 0 dB;
Medium parameters used (interpolated): f = 2450 MHz; σ = 1.634 S/m; ε_r = 39.588; ρ = 1000 kg/m^3
Phantom section: Flat Section
Measurement Standard: DASY5 (IEEE/IEC)

DASY Configuration:

- Probe: EX3DV4 - SN3852; ConvF(7.48, 7.48, 7.48) @ 2450 MHz; Calibrated: 27.10.2022
  - Sensor-Surface: 1.4mm (Mechanical Surface Detection), z = 31.0, -4.0
  - Electronics: DAE4 Sn710; Calibrated: 19.10.2022
  - Phantom: SAR2_Phantom1_ELI; Type: QD OVA 002 AA;
  - DASY52 52.10.4(1527); SEMCAD X 14.6.14(7483)

System check 2450MHz/Zoom Scan (7x7x7)/Cube 0: Measurement grid: dx=5mm, dy=5mm, dz=5mm
Reference Value = 91.16 V/m; Power Drift = -0.11 dB
Peak SAR (extrapolated) = 22.2 W/kg
SAR(1 g) = 12 W/kg; SAR(10 g) = 5.67 W/kg (SAR corrected for target medium)
Smallest distance from peaks to all points 3 dB below = 7 mm
Ratio of SAR at M2 to SAR at M1 = 53.1%
Maximum value of SAR (measured) = 18.3 W/kg
Configuration/System check 2450MHz/Area Scan (71x71x1): Interpolated grid: dx=1.200 mm, dy=1.200 mm
Maximum value of SAR (interpolated) = 16.2 W/kg



APPENDIX C: MEASUREMENT SCANS

Plot 4

Date/Time: 28.11.2022 12.11.48

Test Laboratory: Verkotan Oy

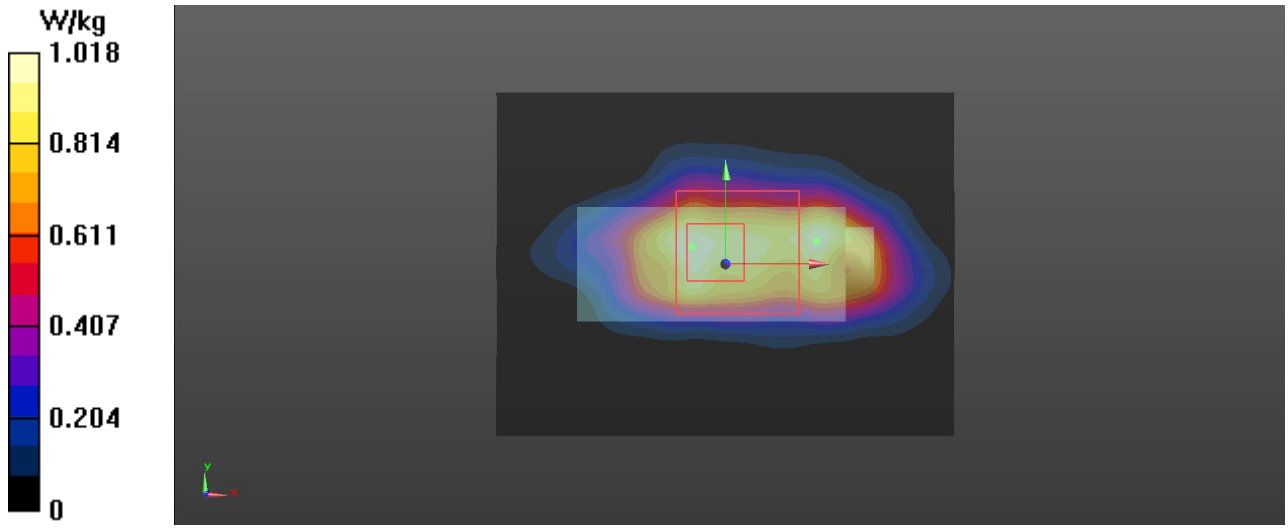
DUT: ESP32-PICO-DevKitM-2_V1.0

Communication System: UID 0, WLAN 2.4 (0); Communication System Band: WLAN2.4GHz; Frequency: 2462 MHz;
Communication System PAR: 0 dB;
Medium parameters used: f = 2462 MHz; σ = 1.745 S/m; ε_r = 41.763; ρ = 1000 kg/m^3
Phantom section: Center Section
Measurement Standard: DASY5 (IEEE/IEC)

DASY Configuration:

- Probe: EX3DV4 - SN3852; ConvF(7.48, 7.48, 7.48) @ 2462 MHz; Calibrated: 27.10.2022
  - Sensor-Surface: 1.4mm (Mechanical Surface Detection), z = -4.0, 31.0
  - Electronics: DAE4 Sn710; Calibrated: 19.10.2022
  - Phantom: MFP_V5.1C (20deg probe tilt); Type: QD 000 P51 Cx;
  - DASY52 52.10.4(1527); SEMCAD X 14.6.14(7483)

WLAN 2.4GHz, CH11, Back 5mm/Area Scan (81x61x1): Interpolated grid: dx=1.000 mm, dy=1.000 mm
Maximum value of SAR (interpolated) = 1.02 W/kg
WLAN 2.4GHz, CH11, Back 5mm/Zoom Scan (8x7x7)/Cube 0: Measurement grid: dx=5mm, dy=5mm, dz=5mm
Reference Value = 20.29 V/m; Power Drift = -0.12 dB
Peak SAR (extrapolated) = 1.10 W/kg
SAR(1 g) = 0.632 W/kg; SAR(10 g) = 0.315 W/kg (SAR corrected for target medium)
Smallest distance from peaks to all points 3 dB below = 9 mm
Ratio of SAR at M2 to SAR at M1 = 57.7%
Maximum value of SAR (measured) = 0.929 W/kg



Plot 5

Date/Time: 06.12.2022 8.14.43

Test Laboratory: Verkotan Oy

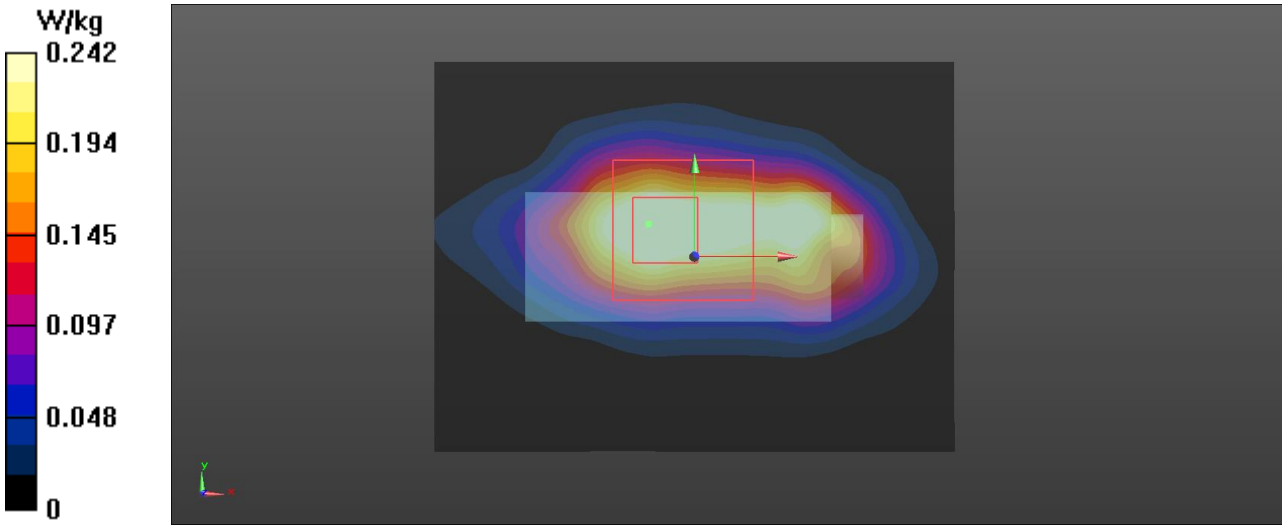
DUT: ESP32-PICO-DevKitM-2_V1.0

Communication System: UID 0, Bluetooth (0); Communication System Band: Bluetooth; Frequency: 2480 MHz;
Communication System PAR: 4.771 dB;
Medium parameters used: f = 2480 MHz; σ = 1.732 S/m; ε_r = 41.04; ρ = 1000 kg/m^3
Phantom section: Center Section
Measurement Standard: DASY5 (IEEE/IEC)

DASY Configuration:

- Probe: EX3DV4 - SN3852; ConvF(7.48, 7.48, 7.48) @ 2480 MHz; Calibrated: 27.10.2022
  - Sensor-Surface: 1.4mm (Mechanical Surface Detection (Locations From Previous Scan Used)), Sensor-Surface: 1.4mm (Mechanical Surface Detection), z = -4.0, 31.0
  - Electronics: DAE4 Sn710; Calibrated: 19.10.2022
  - Phantom: MFP_V5.1C (20deg probe tilt); Type: QD 000 P51 Cx;
  - DASY52 52.10.4(1527); SEMCAD X 14.6.14(7483)

BT, HIGH, Back 5mm 2 2/Area Scan (81x61x1): Interpolated grid: dx=1.000 mm, dy=1.000 mm
Maximum value of SAR (interpolated) = 0.287 W/kg
BT, HIGH, Back 5mm 2 2/Zoom Scan (8x7x7)/Cube 0: Measurement grid: dx=5mm, dy=5mm, dz=5mm
Reference Value = 9.528 V/m; Power Drift = 0.12 dB
Peak SAR (extrapolated) = 0.292 W/kg
SAR(1 g) = 0.164 W/kg; SAR(10 g) = 0.077 W/kg (SAR corrected for target medium)
Smallest distance from peaks to all points 3 dB below = 9 mm
Ratio of SAR at M2 to SAR at M1 = 57.1%
Maximum value of SAR (measured) = 0.242 W/kg



APPENDIX D: RELEVANT PAGES FROM PROBE CALIBRATION REPORTS

Calibration Laboratory of
Schmid & Partner
Engineering AG
Zeughausstrasse 43, 8004 Zurich, Switzerland

S Schweizerischer Kalibrierdienst
C Service suisse d'étalonnage
S Servizio svizzero di taratura
S Swiss Calibration Service

Accredited by the Swiss Accreditation Service (SAS)
The Swiss Accreditation Service is one of the signatories to the EA Multilateral Agreement for the recognition of calibration certificates

Accreditation No.: SCS 0108

Client	Verkotan	Certificate No	EX-3852_Oct22

CALIBRATION CERTIFICATE

Object	EX3DV4 - SN:3852
Calibration procedure(s)	QA CAL-01.v9, QA CAL-12.v9, QA CAL-14.v6, QA CAL-23.v5, QA CAL-25.v7 Calibration procedure for dosimetric E-field probes
Calibration date	October 27, 2022

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements (SI).
The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature (22 ± 3) °C and humidity < 70%.

Calibration Equipment used (M&TE critical for calibration)

Primary Standards	ID	Cal Date (Certificate No.)	Scheduled Calibration
Power meter NRP	SN: 104778	04-Apr-22 (No. 217-03525/03524)	Apr-23
Power sensor NRP-Z91	SN: 103244	04-Apr-22 (No. 217-03524)	Apr-23
OCP DAK-3.5 (weighted)	SN: 1249	20-Oct-22 (OCP-DAK3.5-1249_Oct22)	Oct-23
OCP DAK-12	SN: 1016	20-Oct-22 (OCP-DAK12-1016_Oct22)	Oct-23
Reference 20 dB Attenuator	SN: CC2552 (20x)	04-Apr-22 (No. 217-03527)	Apr-23
DAE4	SN: 660	10-Oct-22 (No. DAE4-660_Oct22)	Oct-23
Reference Probe ES3DV2	SN: 3013	27-Dec-21 (No. ES3-3013_Dec21)	Dec-22

Secondary Standards	ID	Check Date (in house)	Scheduled Check
Power meter E4419B	SN: GB41293874	06-Apr-16 (in house check Jun-22)	In house check: Jun-24
Power sensor E4412A	SN: MY41498087	06-Apr-16 (in house check Jun-22)	In house check: Jun-24
Power sensor E4412A	SN: 000110210	06-Apr-16 (in house check Jun-22)	In house check: Jun-24
RF generator HP 8648C	SN: US3642U01700	04-Aug-99 (in house check Jun-22)	In house check: Jun-24
Network Analyzer E8358A	SN: US41080477	31-Mar-14 (in house check Oct-22)	In house check: Oct-24

	Name	Function	Signature
Calibrated by	Michael Weber	Laboratory Technician	
Approved by	Sven Kühn	Technical Manager	

Issued: October 27, 2022

This calibration certificate shall not be reproduced except in full without written approval of the laboratory.

Certificate No: EX-3852_Oct22 Page 1 of 9

Parameters of Probe: EX3DV4 - SN:3852

Basic Calibration Parameters

	Sensor X	Sensor Y	Sensor Z	Unc ($k = 2$)
Norm ($\mu V/(V/m)^2$) [A]	0.41	0.39	0.46	±10.1%
DCP (mV) [B]	99.8	98.2	99.9	±4.7%

Calibration Results for Modulation Response

UID	Communication System Name		A dB	B dB$\sqrt{\mu V}$	C	D dB	VR mV	Max dev.	Max Unc[E] $k = 2$
0	CW	X	0.00	0.00	1.00	0.00	147.5	±2.5%	±4.7%
		Y	0.00	0.00	1.00		138.0		
		Z	0.00	0.00	1.00		137.1		

The reported uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k=2, which for a normal distribution corresponds to a coverage probability of approximately 95%.

[A] The uncertainties of Norm X,Y,Z do not affect the E^2-field uncertainty inside TSL (see Page 5).
[B] Linearization parameter uncertainty for maximum specified field strength.
[E] Uncertainty is determined using the max. deviation from linear response applying rectangular distribution and is expressed for the square of the field value.

Parameters of Probe: EX3DV4 - SN:3852

Other Probe Parameters

Sensor Arrangement	Triangular
Connector Angle	126.7°
Mechanical Surface Detection Mode	enabled
Optical Surface Detection Mode	disabled
Probe Overall Length	337 mm
Probe Body Diameter	10 mm
Tip Length	9 mm
Tip Diameter	2.5 mm
Probe Tip to Sensor X Calibration Point	1 mm
Probe Tip to Sensor Y Calibration Point	1 mm
Probe Tip to Sensor Z Calibration Point	1 mm
Recommended Measurement Distance from Surface	1.4 mm

Note: Measurement distance from surface can be increased to 3–4 mm for an *Area Scan* job.

Parameters of Probe: EX3DV4 - SN:3852

Calibration Parameter Determined in Head Tissue Simulating Media

f (MHz)[C]	Relative Permittivity[F]	Conductivity[F] (S/m)	ConvF X	ConvF Y	ConvF Z	Alpha[G]	Depth[G] (mm)	Unc ($k = 2$)
6	55.0	0.75	15.18	15.18	15.18	0.00	1.00	±13.3%
30	55.0	0.75	13.34	13.34	13.34	0.00	1.00	±13.3%
64	54.2	0.75	11.88	11.88	11.88	0.00	1.00	±13.3%
128	52.8	0.76	11.57	11.57	11.57	0.00	1.00	±13.3%
220	49.0	0.81	10.92	10.92	10.92	0.00	1.00	±13.3%
450	43.5	0.87	10.20	10.20	10.20	0.16	1.30	±13.3%
900	41.5	0.97	8.82	8.82	8.82	0.44	0.94	±12.0%
1300	40.8	1.14	8.54	8.54	8.54	0.27	1.22	±12.0%
1450	40.5	1.20	8.63	8.63	8.63	0.39	0.80	±12.0%
1640	40.2	1.31	8.33	8.33	8.33	0.34	0.90	±12.0%
1810	40.0	1.40	7.90	7.90	7.90	0.38	0.90	±12.0%
1900	40.0	1.40	7.72	7.72	7.72	0.36	0.90	±12.0%
2450	39.2	1.80	7.48	7.48	7.48	0.41	0.90	±12.0%
3300	38.2	2.71	6.85	6.85	6.85	0.30	1.30	±13.1%
3500	37.9	2.91	6.83	6.83	6.83	0.30	1.35	±13.1%
3700	37.7	3.12	6.65	6.65	6.65	0.30	1.35	±13.1%
3900	37.5	3.32	6.38	6.38	6.38	0.40	1.60	±13.1%
4100	37.2	3.53	6.19	6.19	6.19	0.40	1.60	±13.1%
5250	35.9	4.71	4.90	4.90	4.90	0.40	1.80	±13.1%
5600	35.5	5.07	4.61	4.61	4.61	0.40	1.80	±13.1%
5750	35.4	5.22	4.65	4.65	4.65	0.40	1.80	±13.1%

[C] Frequency validity above 300 MHz of ±100 MHz only applies for DASY v4.4 and higher (see Page 2), else it is restricted to ±50 MHz. The uncertainty is the RSS of the ConvF uncertainty at calibration frequency and the uncertainty for the indicated frequency band. Frequency validity below 300 MHz is ±10, 25, 40, 50 and 70 MHz for ConvF assessments at 30, 64, 128, 150 and 220 MHz respectively. Validity of ConvF assessed at 6 MHz is 4–9 MHz, and ConvF assessed at 13 MHz is 9–19 MHz. Above 5 GHz frequency validity can be extended to ±110 MHz.

[F] At frequencies below 3 GHz, the validity of tissue parameters (ε and σ) can be relaxed to ±10% if liquid compensation formula is applied to measured SAR values. At frequencies above 3 GHz, the validity of tissue parameters (ε and σ) is restricted to ±5%. The uncertainty is the RSS of the ConvF uncertainty for indicated target tissue parameters.

[G] Alpha/Depth are determined during calibration. SPEAG warrants that the remaining deviation due to the boundary effect after compensation is always less than ±1% for frequencies below 3 GHz and below ±2% for frequencies between 3–6 GHz at any distance larger than half the probe tip diameter from the boundary.

APPENDIX E: RELEVANT PAGES FROM DIPOLE CALIBRATION REPORTS

Calibration Laboratory of
Schmid & Partner
Engineering AG
Zeughausstrasse 43, 8004 Zurich, Switzerland

S Schweizerischer Kalibrierdienst
C Service suisse d'étalonnage
S Servizio svizzero di taratura
S Swiss Calibration Service

Accredited by the Swiss Accreditation Service (SAS)
The Swiss Accreditation Service is one of the signatories to the EA Multilateral Agreement for the recognition of calibration certificates

Accreditation No.: SCS 0108

Client **Verkotan** Certificate No: **D2450V2-729_Jul22**

CALIBRATION CERTIFICATE

Object	D2450V2 - SN:729
Calibration procedure(s)	QA CAL-05.v11 Calibration Procedure for SAR Validation Sources between 0.7-3 GHz
Calibration date:	July 15, 2022

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements (SI).
The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature (22 ± 3)°C and humidity < 70%.

Calibration Equipment used (M&TE critical for calibration)

Primary Standards	ID #	Cal Date (Certificate No.)	Scheduled Calibration
Power meter NRP	SN: 104778	04-Apr-22 (No. 217-03525/03524)	Apr-23
Power sensor NRP-Z91	SN: 103244	04-Apr-22 (No. 217-03524)	Apr-23
Power sensor NRP-Z91	SN: 103245	04-Apr-22 (No. 217-03525)	Apr-23
Reference 20 dB Attenuator	SN: BH9394 (20k)	04-Apr-22 (No. 217-03527)	Apr-23
Type-N mismatch combination	SN: 310982 / 06327	04-Apr-22 (No. 217-03528)	Apr-23
Reference Probe EX3DV4	SN: 7349	31-Dec-21 (No. EX3-7349_Dec21)	Dec-22
DAE4	SN: 601	02-May-22 (No. DAE4-601_May22)	May-23

Secondary Standards	ID #	Check Date (in house)	Scheduled Check
Power meter E4419B	SN: GB39512475	30-Oct-14 (in house check Oct-20)	In house check: Oct-22
Power sensor HP 8481A	SN: US37292783	07-Oct-15 (in house check Oct-20)	In house check: Oct-22
Power sensor HP 8481A	SN: MY41093315	07-Oct-15 (in house check Oct-20)	In house check: Oct-22
RF generator R&S SMT-06	SN: 100972	15-Jun-15 (in house check Oct-20)	In house check: Oct-22
Network Analyzer Agilent E8358A	SN: US41080477	31-Mar-14 (in house check Oct-20)	In house check: Oct-22

	Name	Function	Signature
Calibrated by:	Aidonia Georgiadou	Laboratory Technician	
Approved by:	Niels Kuster	Quality Manager	

Issued: July 19, 2022

Measurement Conditions

DASY system configuration, as far as not given on page 1.

DASY Version	DASY52	V52.10.4
Extrapolation	Advanced Extrapolation	
Phantom	Modular Flat Phantom	
Distance Dipole Center - TSL	10 mm	with Spacer
Zoom Scan Resolution	dx, dy, dz = 5 mm	
Frequency	2450 MHz ± 1 MHz	

Head TSL parameters

The following parameters and calculations were applied.

	Temperature	Permittivity	Conductivity
Nominal Head TSL parameters	22.0 °C	39.2	1.80 mho/m
Measured Head TSL parameters	(22.0 ± 0.2) °C	37.9 ± 6 %	1.85 mho/m ± 6 %
Head TSL temperature change during test	< 0.5 °C	---	---

SAR result with Head TSL

SAR averaged over 1 cm³ (1 g) of Head TSL	Condition	
SAR measured	250 mW input power	13.4 W/kg
SAR for nominal Head TSL parameters	normalized to 1W	**52.3 W/kg ± 17.0 % (k=2)**

SAR averaged over 10 cm³ (10 g) of Head TSL	condition	
SAR measured	250 mW input power	6.21 W/kg
SAR for nominal Head TSL parameters	normalized to 1W	**24.5 W/kg ± 16.5 % (k=2)**