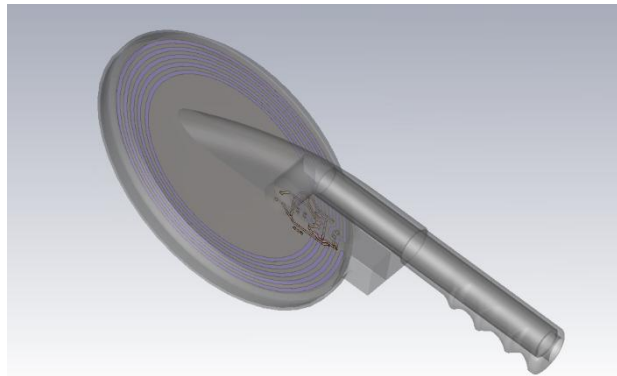


**SAR Simulation Report Using
Finite Element Method (FEM) Computation in CST Studio Suite 2026 for External
Wand Antenna**



1. Introduction

The wand antenna is a handheld antenna connected to the external port of the MDR-4330AT via a 1.5-meter coaxial cable. The reader operates at power level 1 (2.2 W Max) to scan tags located in the vicinity of the antenna. Power is transferred to the tags through near-field coupling. The objective of this analysis is to demonstrate that the system's Specific Absorption Rate (SAR) complies with the limits specified in FCC 47 CFR § 1.1310. Compliance is demonstrated using an FEM calculation performed with CST commercial software. The results are summarised in the table below.

Summary

Company:	SATO Vicinity Pty Ltd	
Address:	42 burrows road, St Peters, NSW 2044, Australia	
Equipment Name:	MDR-4330AT	
FCC ID No:	2ACXQ-MDR-4330ATE	
Equipment Description:	Desktop PJM RFID Read/Write system operating at 13.56 MHz	
Simulation is done by:	Parya Fathi	
Simulation Software:	CST Studio Suite 2026	
Simulation method:	Finite Element Method (FEM)	
	Maximum 1g average SAR value	1.41
Simulation date:	2nd Feb-9th Feb 2026	

These simulation results show that the wand antenna can safely be used in its intended application with respect to the energy emitted during normal operation.

2. Computational resources

Hardware and Software used

The SAR simulations were performed using the Finite Element Method (FEM) solver in CST Studio Suite 2026 on a workstation equipped with an Intel(R) Core(TM) i7-14700HX with base speed of 2.10 GHz, 20 cores and 28 logical processors and 32 GB of RAM. Each full steady-state SAR computation required approximately 1 hour, and a total of three simulations were completed.

The frequency-domain FEM solver was selected for this study because the time-domain solver is not well suited for low-frequency, resonant simulations. At 13.56 MHz, the long signal period requires a very large number of time steps for the fields to reach steady state in time-domain analysis, resulting in excessive simulation time and computational cost. This limitation is further amplified by the resonant nature of the loop antenna and its matching network, which store electromagnetic energy and require many excitation cycles for accurate field buildup and stabilization. In contrast, the FEM frequency-domain approach directly solves the steady-state electromagnetic fields at the operating frequency, enabling accurate characterization of resonance effects, current distribution, impedance behaviour, and localized SAR hotspots with significantly improved numerical efficiency. Therefore, FEM is particularly well suited for low-frequency, resonant structures such as the 13.56 MHz system investigated in this work.

Numerical modelling and validation

To ensure accurate prediction of peak SAR under normal device operation, a refined tetrahedral mesh was applied in the vicinity of the loop antenna and the phantom interface. The minimum edge length was set to 0.000334762 mm, with an average mesh quality of approximately 0.65. The number of cells per maximum model box edge was set to 20 for the model and 1 for the background. Figure 1 shows the mesh property settings and mesh view used in the simulation.

The simulation was carried out using a frequency-domain FEM solver with adaptive mesh refinement to improve field accuracy until the convergence criteria were satisfied. The computational domain was defined as 11,402 mm × 11,402 mm × 11,402 mm and terminated with open (add space) boundary conditions, ensuring that at least $\lambda/4$ free space surrounded the model. An accuracy level of 1×10^{-6} was selected for the solver, with the adaptive tetrahedral mesh refinement settings shown in Figure 1. Representative views of the computational mesh used in the simulation are depicted in Figure 2.

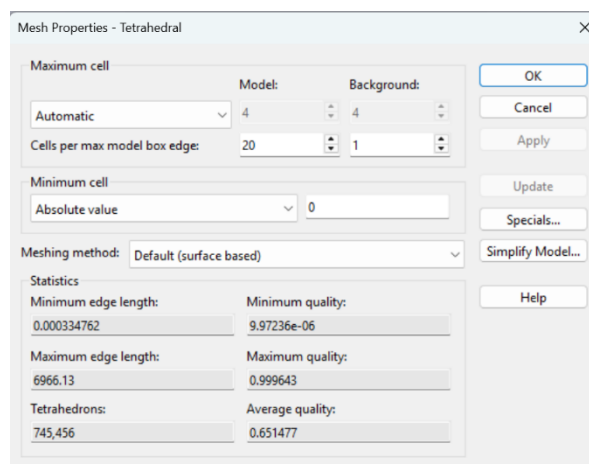


Figure 1. Tetrahedral mesh settings.

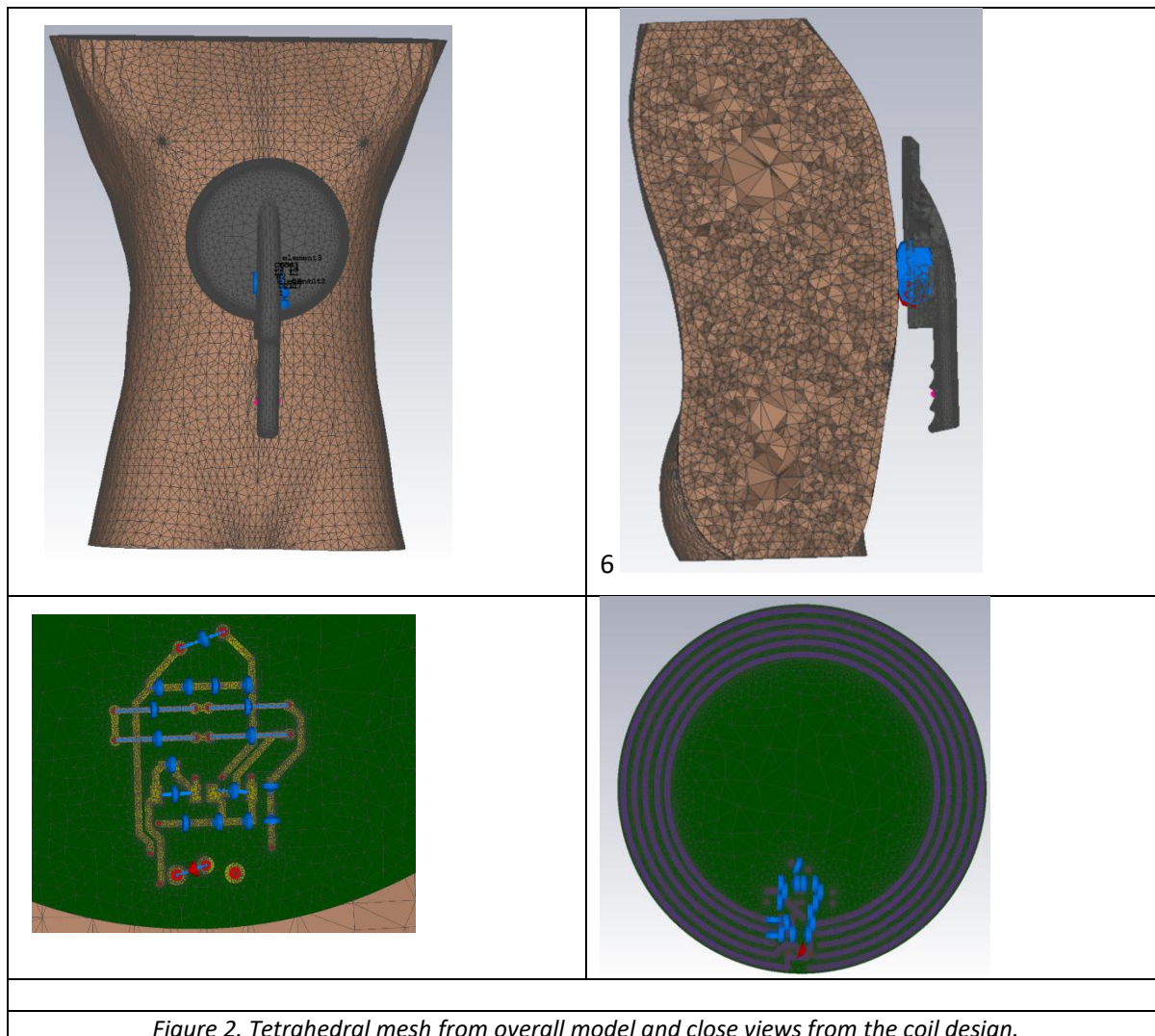


Figure 2. Tetrahedral mesh from overall model and close views from the coil design.

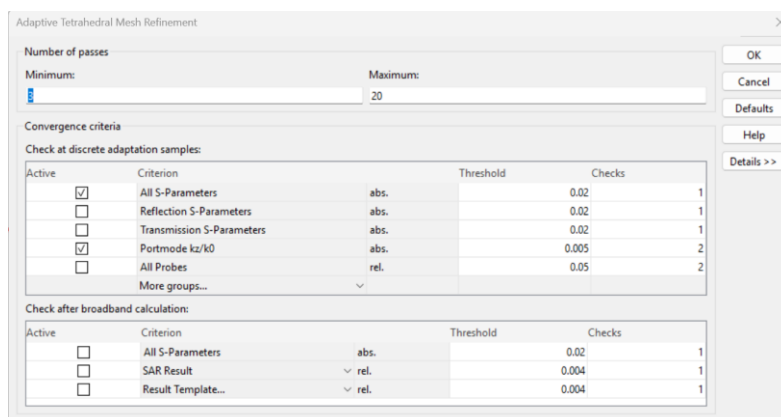


Figure 3. Adaptive tetrahedral mesh refinement settings.

A single discrete port was used to excite the structure over a frequency span of 12.5–14.5 MHz. The matching circuit is added to the antenna in schematic to match the antenna 50 ohm input impedance. Combined AC1 results from loss density is used to calculate SAR.

The convergence behaviour of the simulation is evaluated through the stabilization of the S-parameters, the progression of solver iterations, and the reduction of the relative residual, as shown in the figures below. The S-parameters converge to stable values as the adaptive mesh refinement proceeds, indicating that the electromagnetic response of the structure is affected less than 2% by further mesh updates. In parallel, the number of solver iterations demonstrates consistent convergence behaviour, confirming numerical stability of the FEM solution. The relative residual decreases predefined convergence threshold, verifying that the governing field equations are solved with sufficient accuracy. Collectively, these results confirm that the simulation has achieved reliable convergence and that the reported SAR and field quantities are numerically robust.

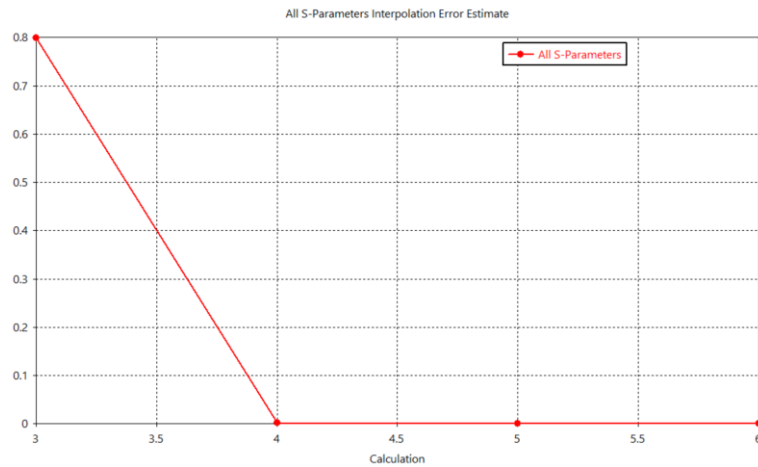


Figure 4. S-paramter interpolation error estimation vs number of passes.

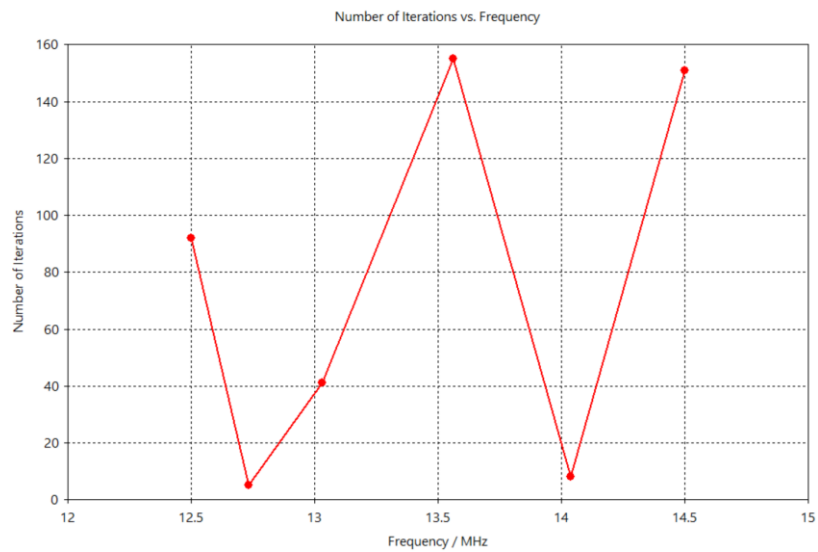


Figure 5. FEM solver number of iterations.

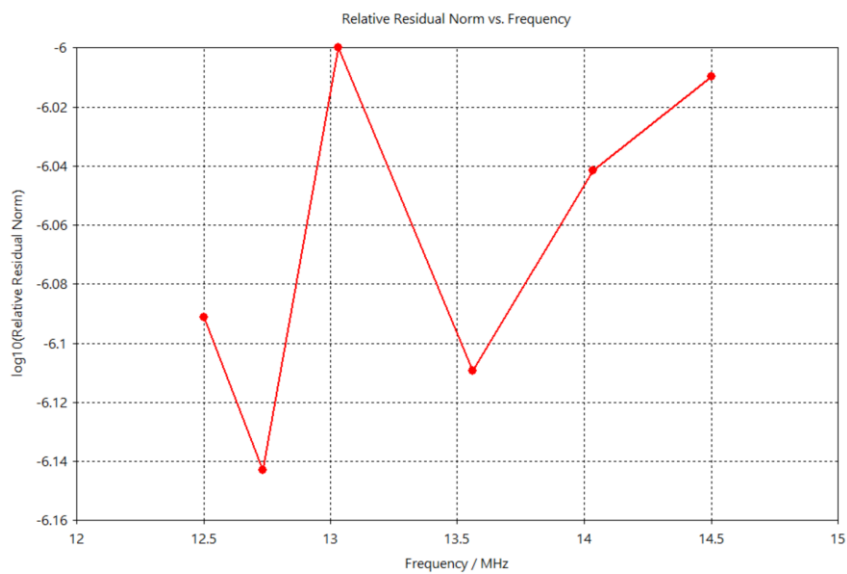


Figure 6. FEM solver relative residual.

Metal traces and conductor layers were modelled using their actual physical thickness, represented volumetric models, to preserve correct current distribution. The substrate was FR-4, using the default CST material template. The device housing was modelled as acetal (a hard engineering plastic), using dielectric parameters shown in the table below.

	Dielectric constant	Dielectric loss	Mass density (kg/m3)
Muscle	75.14	436.5	1000
Substrate of antenna	4.3	0.025 at 10GHz	-
Housing material	3.5	0.003	1410

The dielectric properties of biological tissues specifically the real permittivity (ϵ') and imaginary permittivity (ϵ'') were modelled using the four-pole Cole–Cole formulation, as reported in “Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies” by Camelia Gabriel. The corresponding tissue material parameters were implemented using the Human Material Add-On available in CST Studio Suite.

Since the handheld device is designed to scan RFID tags over the body, a homogeneous male phantom model in the scanner poses and tight from the CST Micro Scanning Add-On were selected to represent hand grip the scanning scenario. The male phantom configuration is appropriate for evaluating whole-body exposure under scanning conditions and tight hand grip is appropriate for evaluating the hand exposure of the operator. To reduce simulation time, the male phantom was truncated at the top and bottom, and only the torso region was simulated. This configuration ensures direct radiation from the antenna toward the body, with the entire antenna aperture covering the phantom surface and represents a worst-case exposure scenario.

The dielectric properties of the male phantom and hand phantom used in this study are presented in the graphs below. An average muscle-fat tissue model was chosen to represent overall body exposure, as it provides an appropriate approximation for whole-body scanning applications.

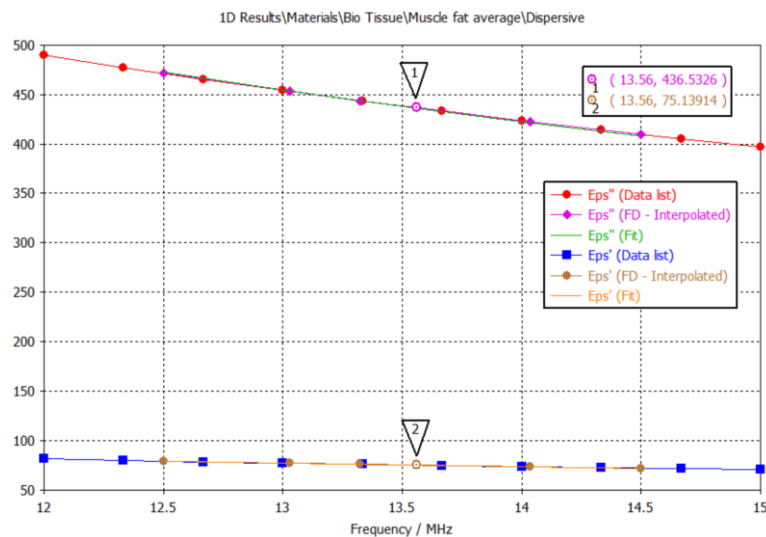


Figure 7. Dielectric properties of the bio-tissue used in torso model.

Computational parameters

Table below summarises the computational parameters used for accurate SAR evaluation using the CST frequency-domain FEM solver.

Parameter	Description / Value
Cell / Voxel	Adaptive tetrahedral mesh
Domain Size	11402 mm × 11402 mm × 11402 mm
Excitation Type	Discrete port
Boundary Condition Type	Open add space boundary
Minimum distance from Device to Absorbing Boundary	5480 mm
Minimum distance from Phantom/Tissue to Absorbing Boundary	5420 mm
Mesh Refinement Strategy	Adaptive mesh
Material Models	4-Cole-Cole Model found in FCC 13.56 MHz database
Simulation Solver	Frequency-domain FEM solver

To achieve a balance between computational efficiency and modelling accuracy, an adaptive tetrahedral mesh was employed. Finer mesh elements were applied in regions exhibiting strong electromagnetic field gradients by adaptive mesh setting, including the antenna feed point, current-carrying conductors. Coarser mesh elements were used in electrically homogeneous regions to limit the overall number of elements without compromising solution accuracy.

Metal traces and conductor layers were modelled using their actual physical thickness as volumetric solids, ensuring accurate current distribution and field coupling while avoiding excessive mesh refinement. The simulation boundaries were placed sufficiently far from both the device and the anatomical phantom to minimise spurious reflections, and open (add space) boundary conditions were applied on all sides to emulate free-space radiation.

Frequency-dependent tissue dielectric properties were modelled using the 4-Cole-Cole parameters provided in the FCC 13.56 MHz database, allowing accurate representation of permittivity and conductivity at the operating frequency. The FEM solver iteratively refined the solution until the energy and field residuals met the specified convergence criteria ($1e-6$), ensuring stable field solutions prior to SAR calculation.

Transmitter model implementation and validation

The PJM RFID wand operates at a single fixed frequency (13.56 MHz) and does not implement multiple channels or adjustable operating bands. Therefore, SAR verification was performed at this single operating point using the maximum drive current of 1.2 A, representing the device's worst-case exposure condition.

The antenna consists of a transmitting/receiving PCB based coil with 4 turns and measures 4.3 uH nominally in free air. Bottom layer is layout with the coil tracks and top layer is used to for biasing and circuit and capacitors that makes the resonant at 13.56 MHz. An extra turn is used to carry the grounding current that is the most outer turn

Coil type	PCB based circular coil
Number of turns	4
Inner radius (mm)	62
Outer radius(mm)	77
Grounding turn radius (mm)	82
Cross section	rectangular
Thickness of metal (mm)	0.035
Metal Width (mm)	2.54
Gap	2.46

Some other key parameters that is used in the coil design and need to be considered in SAR estimation.

Item	Description
Max power delivered to the antenna	2.2 W
Max current delivered to the antenna	1.2 A peak
Operating frequency	13.56 MHz
Communication mode	Phase Jitter Modulation (PJM) -> Reader to tag BPSK -> Tag to reader

To ensure the SAR evaluation accurately represents the PJM RFID wand antenna and transmitter, the computational model was constructed to match the physical device in shape, size, dimensions, and electromagnetic behaviour. All external geometrical features including the wand's overall length, cross-sectional profile, housing thickness, and antenna position were replicated in the simulation

environment based on engineering CAD drawings. Internal features that affect resonant behaviour and near-field radiation, such as antenna geometry, feed routing, and resonance-defining circuit components, were also modelled to reflect their real-world configuration. Illustrations comparing the actual device with the simulated model demonstrate this correspondence, showing alignment in structural layout and antenna placement. More information regarding the circuit of the antenna is also shown in the figure below.

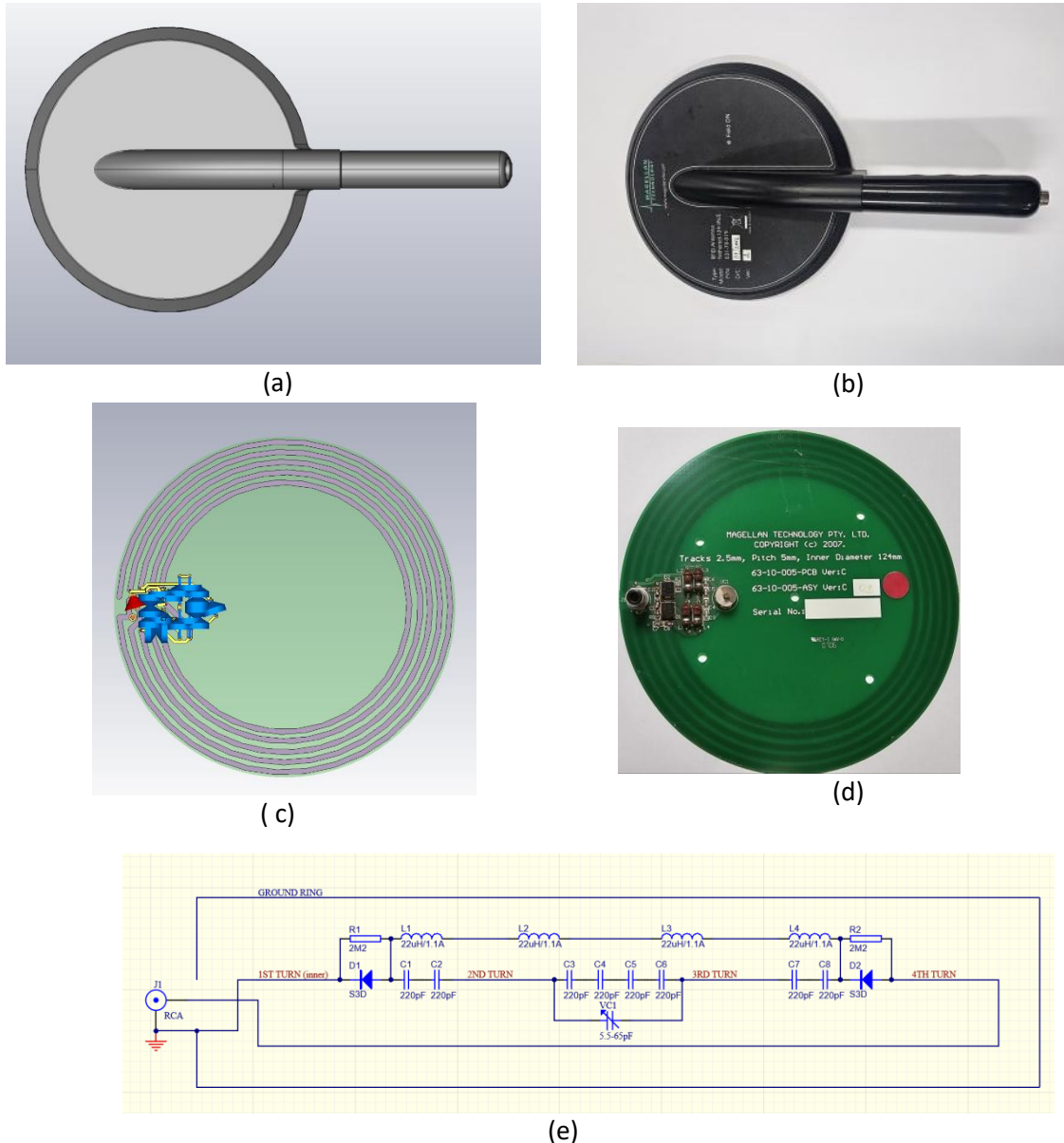
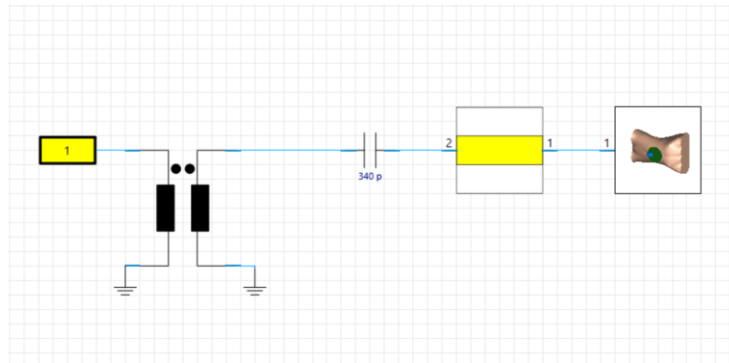


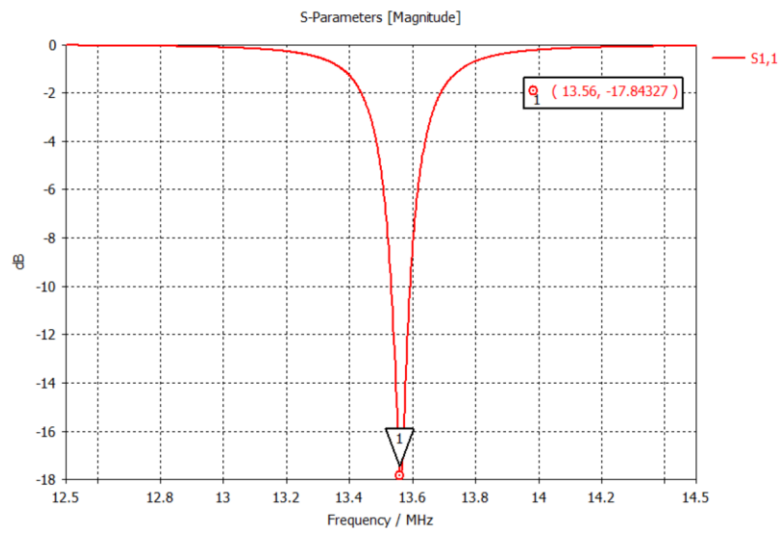
Figure 8. Comparison between the simulated model and the fabricated device: (a) complete simulated model, (b) fabricated antenna, (c) simulated antenna PCB, (d) fabricated antenna PCB, and (e) detailed antenna circuit.

The transmitter and antenna model was validated to ensure functional equivalence with the actual PJM RFID wand device for SAR prediction. Validation was carried out by confirming that the modeled device reproduces the resonant response of the physical unit and it is driven at the maximum operating current of 1.2 A. The simulated port current and S-parameters are shown in the figure below. The reader's matching network

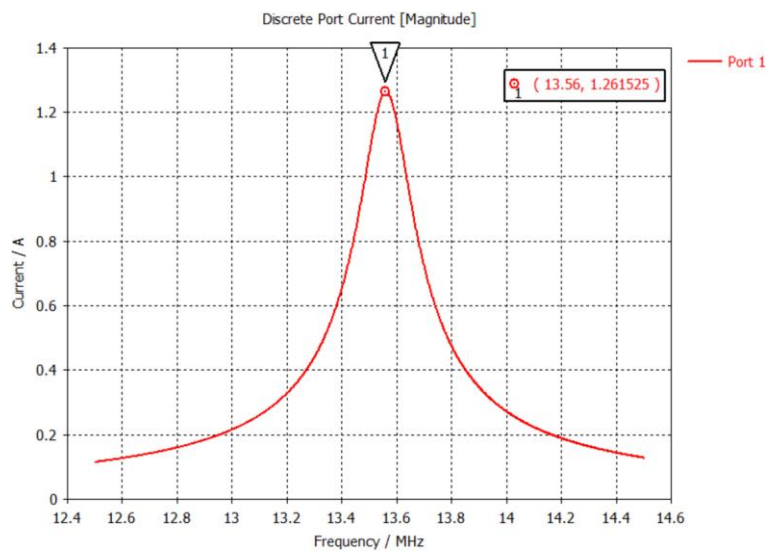
comprising a 1.5-m 50- Ω cable, a capacitor to cancel the imaginary component of the impedance, and a 4:1 transformer was incorporated into the antenna model to ensure overall 50- Ω impedance matching



(a)



(b)



(c)

Figure 10. (a) Matching network configuration, (b) S_{11} measured at the antenna 50- Ω port, (c) antenna port current.

Additional H-field verification of the CST modeling was carried out by confirming that the simulated device reproduces the same near-field (H-field) behaviour as the physical unit when operated at the maximum output power of 2.2 W, which is the power level used in the simulation.

For the H-field measurements, a calibrated near-field probe was used. The probe's antenna factor, as shown in the figures below, was determined from the calibration data. From the plot, an antenna factor of 41 dB($\mu\text{A}/\text{m}$ per μV) was considered at the frequency of interest (13.56 MHz). The magnetic field strength was then calculated using the equation provided in the datasheet. It is also noted that the probe's sensing loop is located 2.5 mm from the tip of the probe. This offset was taken into account when defining the measurement distance during the experimental setup.



(a)

3-4. Antenna Factors

3-5. The specific antenna factors of each HP 11941A are measured to within ± 2 dB at five frequencies: 9 kHz, 100 kHz, 1 MHz, 10 MHz, and 30 MHz. This calibration information is listed on the bottom cover of each probe. The antenna factors are given in the units of dB($\mu\text{A}/\text{m}/\mu\text{V}$). To calculate the magnetic field strength in dB($\mu\text{A}/\text{m}$) at a specific frequency, add the amplitude of the measured voltage in dB(μV) (as indicated on the spectrum analyzer) to the antenna factor for that specific frequency. To compensate for cable losses and preamplifier gains, add the losses and subtract the gains (in dB). Refer to the following equation:

$$\bar{H}\text{-Field Strength} \left(\text{dB} \frac{\mu\text{A}}{\text{m}} \right) = V_{\text{SA}} + \text{AF} + K$$

where

V_{SA} = voltage in dB μV measured on analyzer

AF = HP 11941A Antenna Factor in dB($\frac{\mu\text{A}/\text{m}}{\mu\text{V}}$)

K = loss or gain in dB between HP 11941A and spectrum analyzer
(Positive value if loss, negative value if gain.)

(b)

Figure 11. Agilent 11941A Close-Field Probe. (a) Photograph of the H-field probe. (b) Relationship between the measured voltage and the magnetic field strength (H-field), showing the equation used to convert voltage to H.

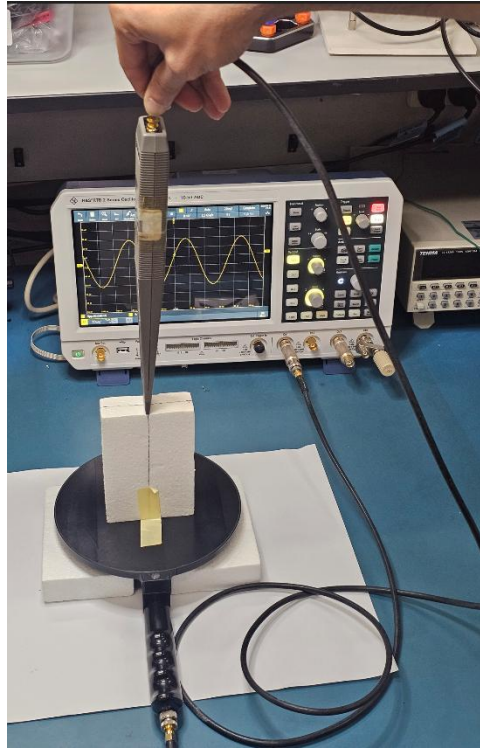


Figure 12. Near field measurement setup.

H-field measurements were performed at two different distances from the antenna radiating surface: 12.5 mm and 126.5 mm. The figure below illustrates the measurement setup for the 126.5 mm separation. The antenna was connected to the reader using a 1.5 m RG58 (50 Ω) cable. An Rohde & Schwarz RTB24 oscilloscope was used to measure the induced voltage corresponding to the magnetic field strength. The oscilloscope was connected via a 2 m, 50 Ω coaxial cable. A matching transformer was installed at the oscilloscope input to ensure proper 50 Ω impedance matching.

The measured insertion loss of the 2 m cable was 0.02 dB. Accordingly, a cable loss/gain correction factor (K) of 1.0023 was applied in the H-field calculations. The measured H-field values are compared with the simulated results in the table below. The comparison indicates a maximum deviation of approximately 0.759 dB between measurement and simulation, which falls within the probe measurement uncertainty of ± 2 dB. The simulated H-field distributions at distances of 12.5 mm and 126.5 mm from the antenna surface are presented in the figure below. The H-field measurement results indicate good agreement between the measurement and simulation.

	Distance from antenna (mm)	Voltage level (mV_{peak})	H-field peak (A/m)	H-field peak dB(A/m)	Measurement vs simulation error (dB)	Measurement uncertainty (dB)
Simulation	12.5		34.398	30.731		
Measurement	12.5	280.284	31.521	29.972	0.759	± 2
Simulation	126.5		3.168	10.016		
Measurement	126.5	26.019	2.926	9.325	0.691	± 2

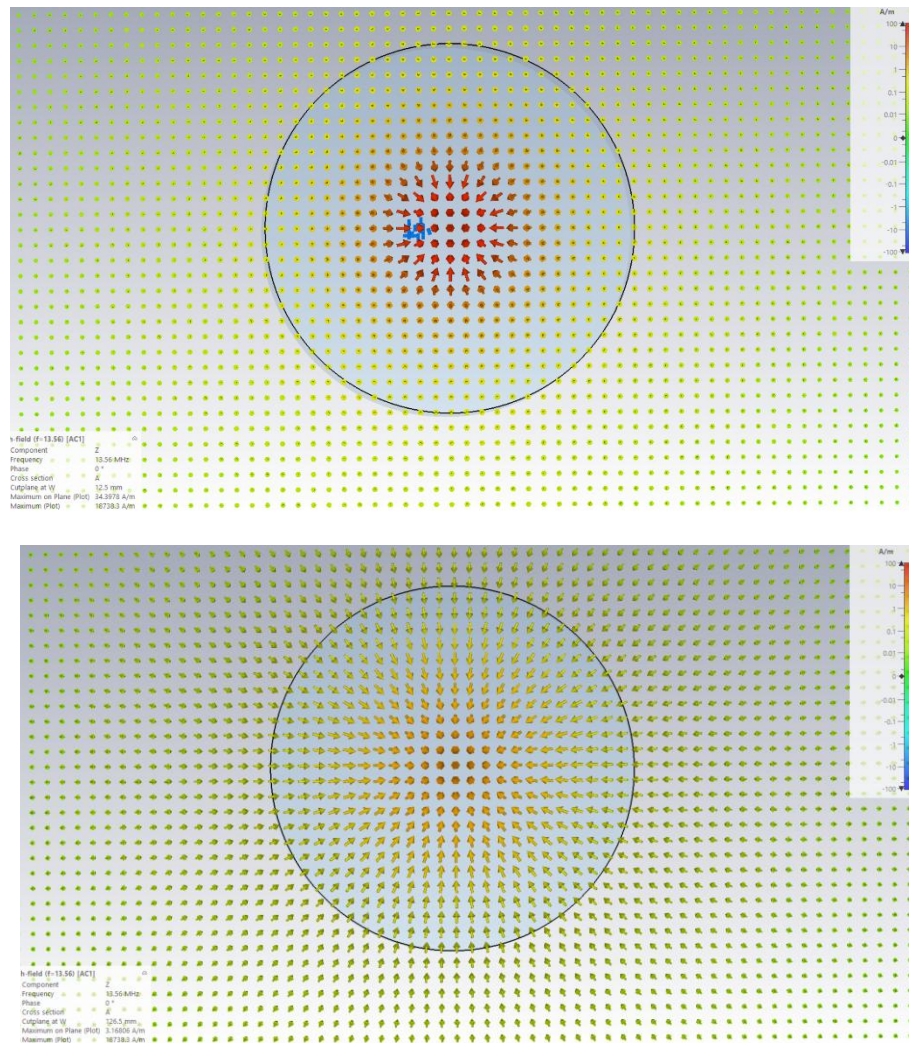


Figure 13. H-field value from the CST modelling. (a) 12.5 mm and (b) 126.5 mm

Test device positioning

During normal operation, the handheld wand may be brought close to the human body during manual scanning. To represent a conservative worst-case exposure condition, SAR simulations were conducted with the antenna positioned adjacent to the phantom (minimum separation distance of 10 mm). Because the device is handheld and is not operated in standardized usage configurations such as cheek, tilt, or body-worn modes, only the surface-proximity exposure scenario is considered relevant for this application. The selected 10 mm spacing represents the smallest practical distance achievable during real-world operation and therefore provides a conservative estimate of user exposure. Illustrations included in the report show the modeled placement of the wand against the phantom torso and confirm that the simulation geometry represents the closest practical approach expected during real-world use. This ensures that the computed SAR distribution reflects the maximum plausible exposure scenario for users or bystanders during normal scanning operation. In addition, hand exposure of the operator was included as a potential operating scenario for this device.

Computing peak SAR and 1-g averaged from field components

Electromagnetic field distributions were computed using the CST Studio Suite Frequency Domain Solver, which solves Maxwell's equations in the frequency domain using the finite element method (FEM).

The device under test was excited with a single-frequency sinusoidal sources corresponding to its normal operating frequency and lower and upper limits of the frequency span and interpolated for other frequency points in the frequency range. The solver computes the steady-state complex electric field components E_x , E_y , and E_z throughout the tissue phantom at this frequency.

The resulting field components represent the RMS steady-state electric fields at each spatial location. The total RMS electric field magnitude is calculated as:

$$|E_{\text{rms}}| = \sqrt{|E_x|^2 + |E_y|^2 + |E_z|^2}$$

Field sampling is performed throughout the discretised tissue phantom using an adaptive finite-element mesh.

The local specific absorption rate (SAR) at each tissue voxel is computed from the RMS electric field using the standard relationship:

$$\text{SAR} = \frac{\sigma |E_{\text{rms}}|^2}{\rho}$$

where:

- σ is the electrical conductivity of the tissue (S/m),
- $|E_{\text{rms}}|$ is the RMS magnitude of the total electric field (V/m), and
- ρ is the mass density of the tissue (kg/m³).

CST calculates point SAR values at each voxel and subsequently determines the spatially averaged SAR (1 g) using a sliding cubic averaging algorithm in accordance with IEC/IEEE 62704-1 SAR standards. The peak SAR is defined as the maximum spatially averaged 1-g SAR value within the tissue model. SAR and power-loss density calculations in CST are performed assuming an input power of 0.5 W RMS; therefore, the results were scaled to the measured input power at the antenna, which was 2.2 W. A 1-g averaging mass was selected using the advanced settings specified in IEC/IEEE 62704-1. The figure below shows the post-processing settings used for SAR calculation.

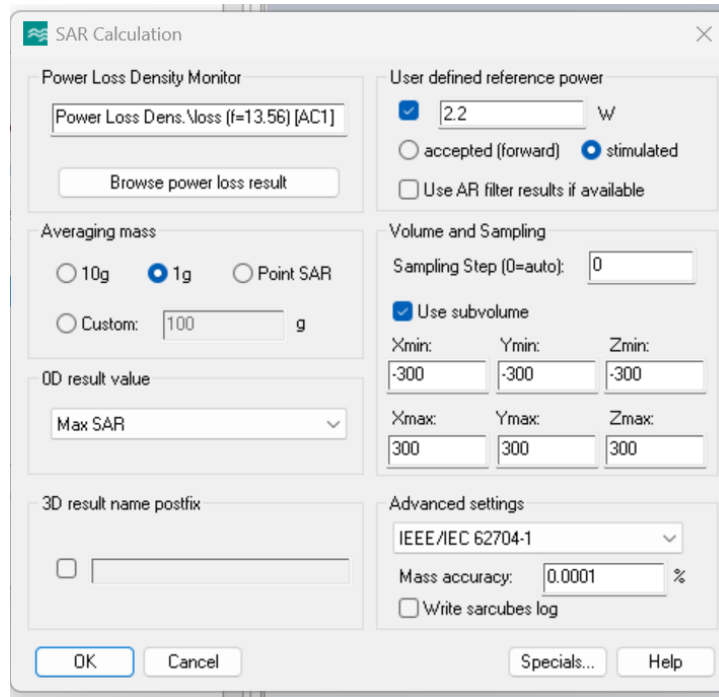


Figure 14. Post-processing setting for SAR calculation in CST 2026.

Total computational uncertainty

The uncertainty in SAR values computed using frequency domain solver is influenced by the following factors:

The frequency-domain FEM solver directly computes steady-state electromagnetic fields at the operating frequency, eliminating uncertainties associated with temporal discretization and transient-to-steady-state field extraction. The accuracy of the solution is governed by iterative convergence of the frequency-domain field residuals in combination with the spatial discretization of the computational domain.

An adaptive tetrahedral mesh is employed, with localized refinement applied in regions exhibiting high electric-field gradients, including antenna conductors, feed points, and tissue device interfaces. This adaptive meshing strategy ensures accurate resolution of near-field coupling and localized power absorption while maintaining computational efficiency in electrically homogeneous regions. Once the solver convergence criteria are satisfied, residual numerical errors associated with the FEM formulation, mesh discretization, and SAR post-processing are minimal. The typical combined uncertainty contribution from numerical solution accuracy and spatial discretization is less than 2% [1]

Tissue permittivity and conductivity values are obtained from established literature sources and implemented using the 4-Cole-Cole dispersion model. Variability in reported tissue dielectric

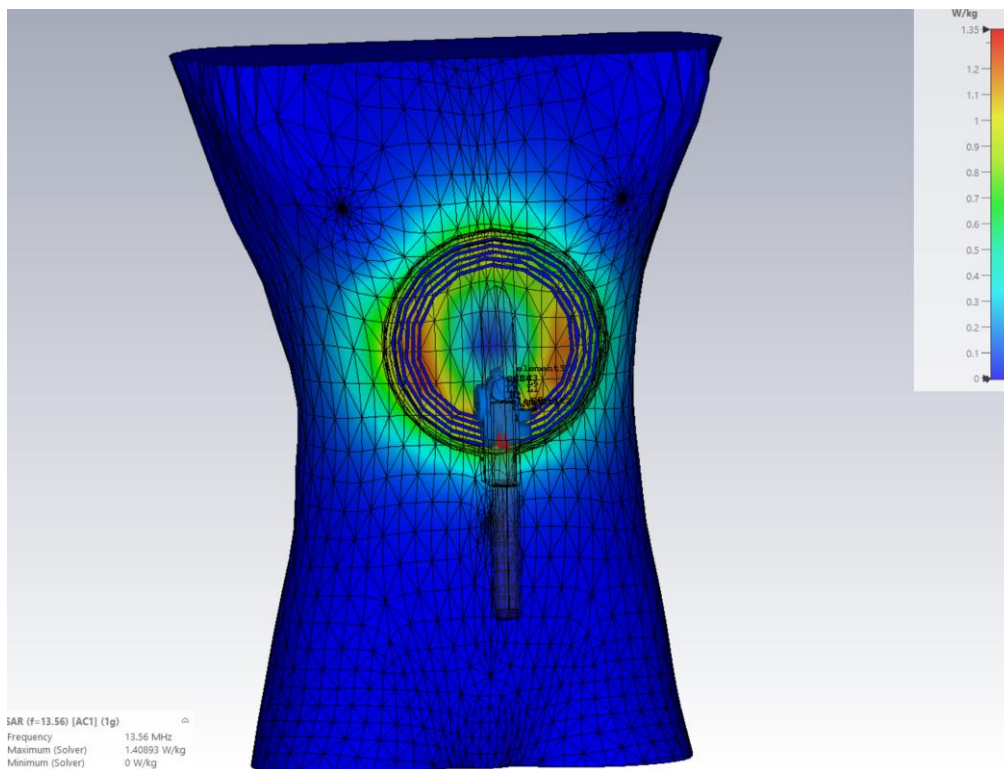
properties, inter-subject biological differences, and measurement uncertainties constitute the dominant source of SAR uncertainty, with an estimated contribution of approximately ± 15 [2].

Considering all contributing factors, the overall uncertainty of the computed SAR values is conservatively estimated to be within $\pm 15\%$.

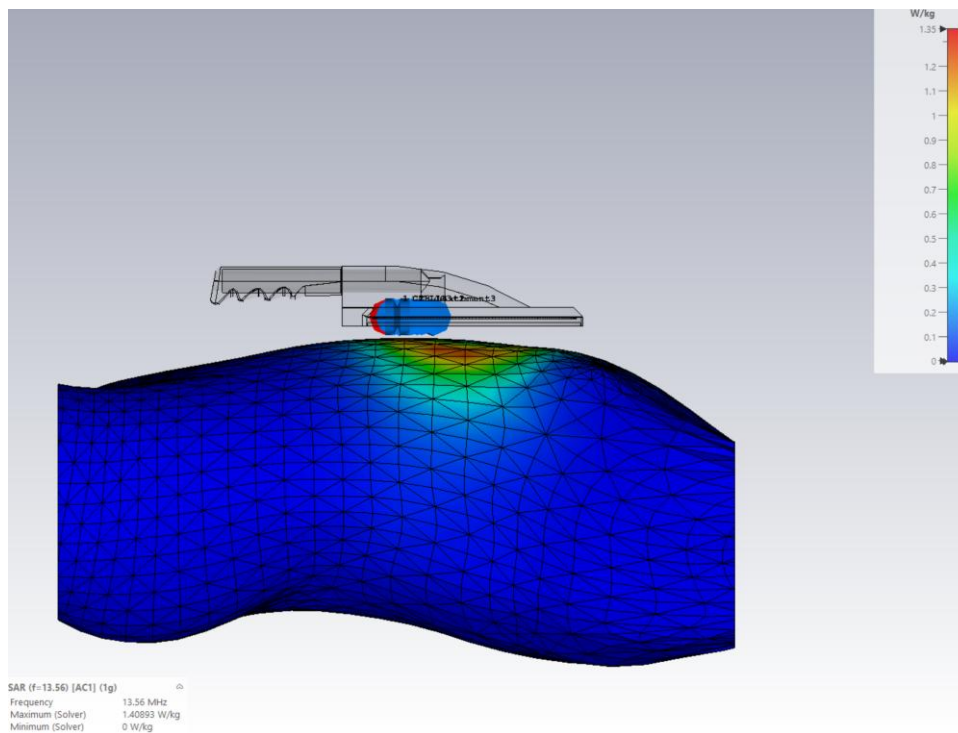
SAR calculation results

The SAR results obtained from the FEM simulations are presented in the figures below. The simulations were performed for multiple representative exposure scenarios, including placement of the antenna in front of the torso, at the back of the torso. In addition, SAR was evaluated for a tight hand-grip configuration to assess potential operator exposure.

Across all simulated scenarios, the maximum localized 1g SAR remains below 1.41 W/kg demonstrating compliance with the applicable exposure limits.

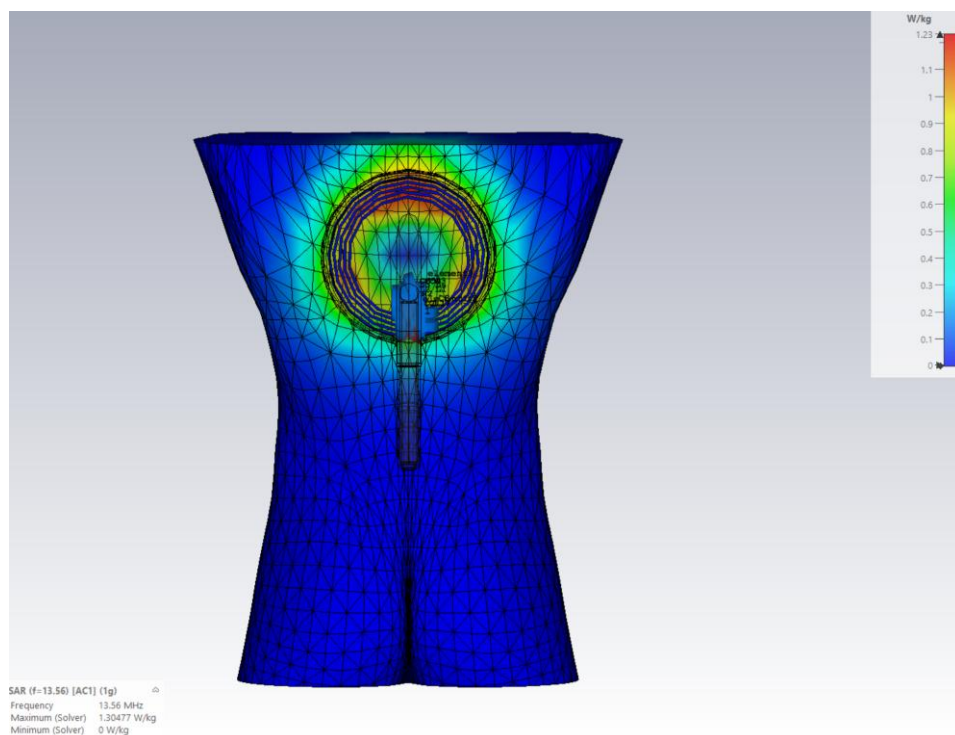


(a)

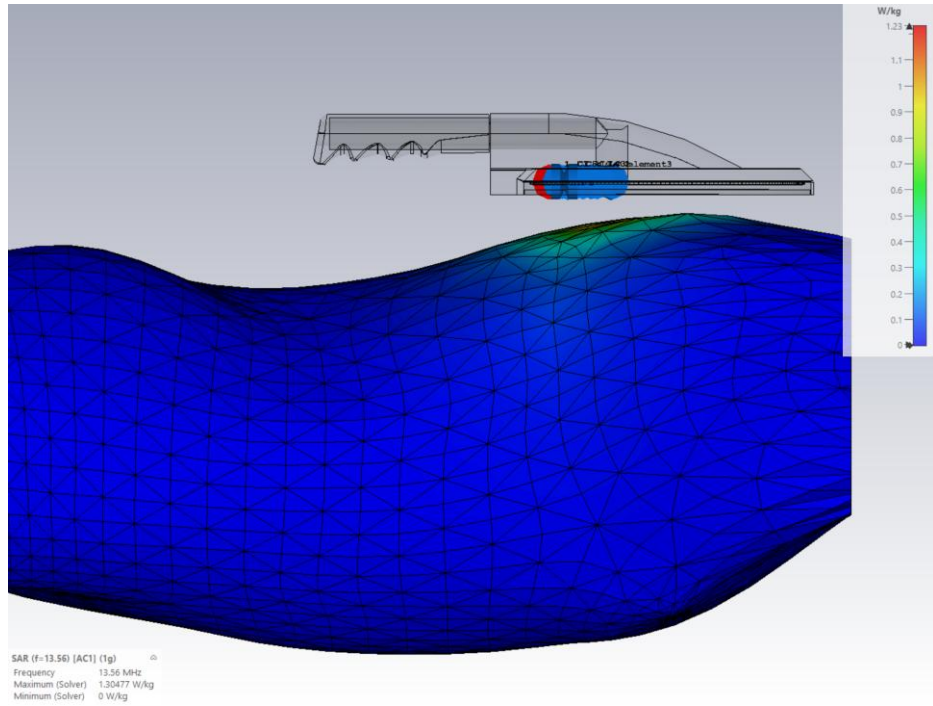


(b)

Figure 15. 3D view of the 1-g peak SAR distribution on the torso: (a) front view and (b) side view. The antenna is positioned in front of the torso. The overall maximum 1-g SAR value of 1.41 W/kg is observed.

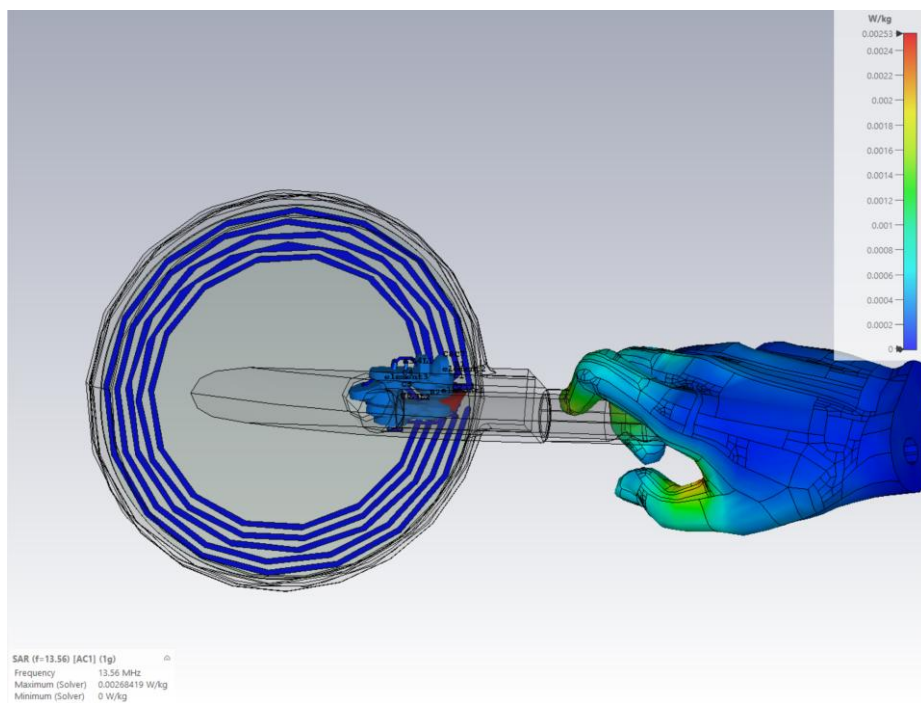


(a)



(b)

Figure 16. 3D view of the 1-g peak SAR distribution the torso: (a) front view and (b) side view. The antenna is positioned at the back of the torso. The overall maximum 1-g SAR value of 1.3 W/kg is observed.



(a)

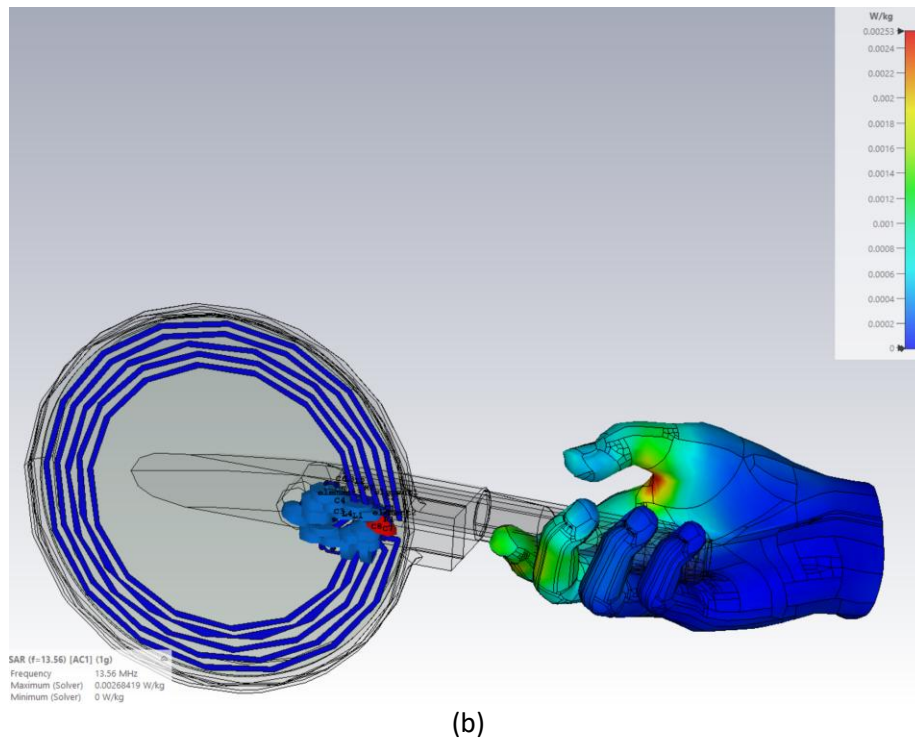


Figure 17. Three-dimensional view of the 1-g peak SAR distribution in the tight grip hand configuration: (a) top view and (b) bottom view. The antenna handle is positioned inside the grip. The overall maximum 1-g SAR value observed is 0.0027 W/kg.

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Revision Status

Revision	Date	Description	Approved by
1.0	9/02/2026	Initial Release	
1.1	16/02/2026	H field measurement was added for verification	