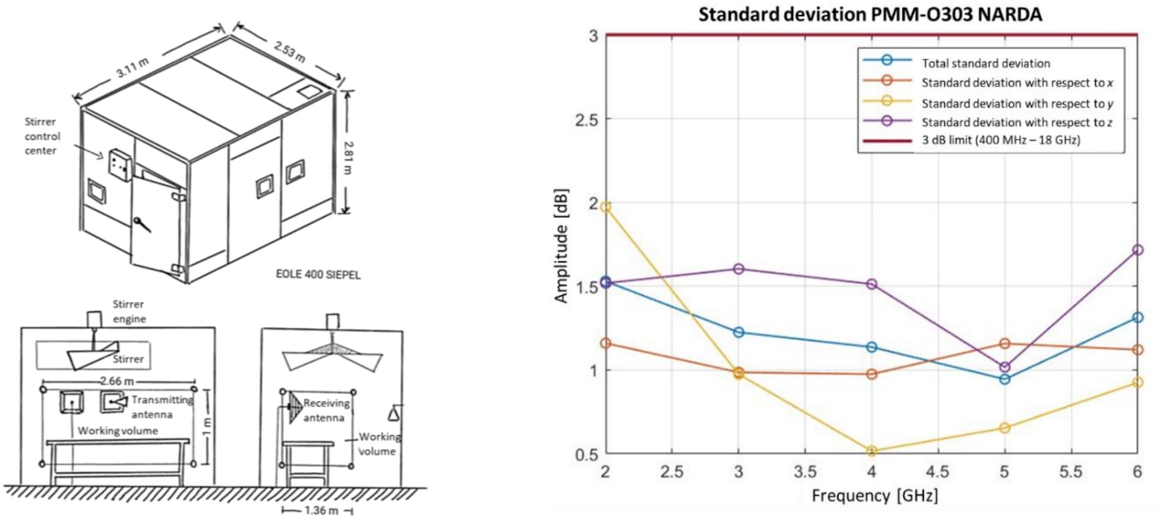
Radiated Emissions from Wearable Devices Using a Reverberation Chamber

Fabrizio Marra, Francesca Lautizi, Alessio Tamburrano, Federico Cozzolino, Maria Sabrina Sarto

Dept. of Astronautical, Electrical and Energy Engineering (DIAEE)
Research Center for Nanotechnology applied to Engineering (CNIS)
Sapienza University of Rome, Rome, Italy, Via Eudossiana 18, 00184, Rome

Nowadays, wearable devices have become established as essential tools across a wide range of application areas, including sports, healthcare, and occupational safety [1]. These devices rely on a wireless communication paradigm operating in the frequency range between 2 and 4 GHz. Due to their widespread use, there is an increasing need to ensure their proper functioning, preventing them from generating and/or experiencing electromagnetic (EM) interference. In this context, there is a broad range of electromagnetic compatibility (EMC) tests.

This study aims, firstly, to characterize the electromagnetic environment within a reverberation chamber (RC) (Fig. 1(a)), and subsequently to evaluate the radiated emissions of a wearable device in a RC according with IEC 61000-4-21 standard.



(a) (b)

Figure 1. (a) Sketchup of the EOLE 400 reverberation chamber a the EMC Lab of DIAEE, in Sapienza. (b) Standard deviation in dB, of the measurements carried out with the NARDA PMM-OR03 probe.

Table 1 shows the tolerance ranges of the standard deviation according to IEC 61000-4-21.

Frequency range	Standard deviation tolerance ranges
100 MHz	Below 4 dB
100 MHz – 400 MHz	Decreases linearly from 4 dB @ 100 MHz to 3 dB @ 400 MHz
400 MHz – 18/40 GHz	Below 3 dB

Table 1: Uncertainty ranges described by IEC EN 61000-4-21

The characterization of the EM environment inside the reverberation chamber (RC) was carried out using a setup consisting of a signal generator connected to an amplifier, both located outside the chamber, and an EM-6961 horn antenna used as the transmitting antenna. The receiving system included a signal detector connected externally to a receiving horn antenna EM-6961. The EM field distribution inside the RC was statistically uniform thanks to the rotation of the internal stirrer driven by a stepper motor. The tests were conducted in the frequency range 2 GHz and 4 GHz, which is typical of wireless communication systems used in wearable electronics.

The RM field uniformity was assessed inside the chamber according to standards. Four isotropic electric field probes (model PMM OR03 Narda, Fig. 1(b)) were used and sequentially positioned at the eight corners and at the center of the working volume of the chamber, covering a total of nine measurement points. The electric field was measured in each measurement point, for 12 different angular positions of the stirrer over a complete 360° rotation, considering an input power of 1 W.

After completing the characterization of the EM environment inside the reverberation chamber (RC), emission measurements were carried out on a prototype of signal conditioning and measurement electronics for wearable sensing applications. The device under test was placed at the center of the chamber, at a height of 1.5 meters from the floor. Electric field measurements were performed in the far field condition, at 40 cm and at 80 cm from the emitting device. For each full rotation of the stirrer, the root mean square (RMS) values of the electric field were recorded both in the presence and in the absence of the sensor. For each frequency, the difference between the average electric field values with and without the sensor was calculated. The power radiated by the sensor was then determined as the average of the values measured at the two distances. Table 2 summarizes the electric field values at each position and the corresponding emitted power.

Frequency (GHz)	E_{irr} (V/m) -40 cm	E_{irr} (V/m) 80 cm	P_{irr} (mW)
2	3.242	0.955	22
3	1.186	2.874	54
4	2.199	1.469	21

Table 2: Effective electric field values radiated at 40 cm and 80 cm from the sensor and estimate of the radiated power as a function of the analyzed frequencies

The results obtained are consistent with the expected emission levels for wearable devices using low-power, short-range wireless technologies such as Bluetooth and Wi-Fi. Typically, Wi-Fi devices emit power between 10 and 100 mW in the 2.4 GHz and 5 GHz bands, while Bluetooth devices can emit up to 100 mW, depending on the class. In accordance with Directive RED 2014/53/EU, the maximum allowed transmission power is 100 mW for Bluetooth and 100 mW (2.4 GHz) or 200 mW (5 GHz) for Wi-Fi. The measurements confirm that the tested device falls within these limits, ensuring compliance with European regulations and safe operation without interference. The results validate both the prototype's compliance and the effectiveness of the reverberation chamber-based approach for realistic emission assessment. Overall, the study supports the integration of reverberation chamber testing into standard EMC protocols for next-generation wearable electronics, providing a practical, statistically robust methodology fully aligned with certification requirements. Furthermore, reverberation chamber characterizations represent a promising tool for improving devices' electromagnetic compatibility during the early stages of development.

We acknowledge this research work was supported by Rome Technopole Project ECS00000024 – Spoke 1, supported by MUR under PNRR, Mission 4, Investment 1.5.

References

1. F. Marra *et al*., Study, Design and Development of Biocompatible Graphene-Based Piezoresistive Wearable Sensors for Human Monitoring *IEEE Sensors Journal*, 2024, doi: 10.1109/JSEN.2023.3336518.
2. IEC 61000-4-21. Electromagnetic compatibility (EMC)--Part 4--21: Testing and measurement techniques--Reverberation chamber test methods. s.l. : International Electrotechnical Commission (IEC), 2003.