Antenna Test Report:

PALIoT PIM-C BLE Antenna

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Date: 11 April 2025

Revision: 0

Document Status: Company Confidential

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1. Introduction

The PALIoT Integrated Module (PIM) version C ("PIM-C") is an asset-tracking unit, developed by PALIoT Solutions LLC ("PALIoT"). The PIM-C tracks several environmental (e.g. temperature, humidity) and motion-based (e.g. acceleration) parameters via a built-in sensor stack and relays this information to a gateway via a Bluetooth Low Energy (BLE) wireless connection.

The PIM-C utilises a Nordic Semiconductor ASA ("Nordic") nRF52840 System-on-a-Chip (SoC), which is based on the 32-bit ARM® Cortex™-M4 Central Processing Unit (CPU) and includes a multiprotocol-capable 2.4 GHz transceiver. This transceiver is coupled with a proprietary Printed Circuit Board (PCB) based BLE antenna, which is based on a reference design by Mist Systems ("MIST").

This document describes the methodology employed in the characterisation of this antenna following its integration into the PIM-C PCB (i.e. in its "as-built" state), as well as the results.

2. Measurement Setup

The design and testing of the BLE antenna was performed by Austin Circuit Design ("ACD"), a global design, manufacturing, and sourcing firm.

Note 1: At present, two versions of the PIM exist – version H ("PIM-H") and version C ("PIM-C"). The PIM-H and PIM-C share an identical PCB layout; however, the PIM-H integrates further discrete radio modules and external antennas which enable Long Term Evolution (LTE) and Global Positioning System (GPS) capabilities.

Note 2: The PIM-C is thus a depopulated version of the PIM-H. As a result, all PIM PCBs will include a BLE antenna, and connections for external GPS and LTE antennas. The latter two antennas, however, are not included on PIM-C devices.

Note 3: All three (BLE, GPS, LTE) antennas were assessed in this characterisation sequence. However, this report exclusively focusses on the BLE antenna characteristics.

To facilitate the antenna characterisation, a semi-rigid coaxial cable with a SubMiniature version A (SMA) termination was connected to the input of the BLE antenna. Figure 1 shows the assessed PIM unit, with the coaxial cable connection highlighted in the red rectangle.

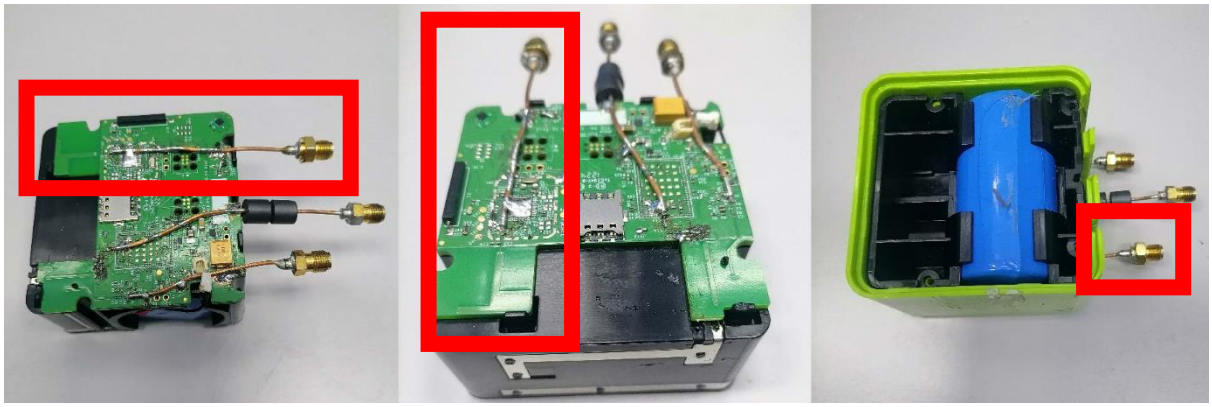

Figure 1 - The assessed PIM unit, with the LTE, GPS, and BLE modules removed and with coaxial cables (with SMA terminations) affixed to allow the antennas to be driven externally.

As the PIM-C will be fitted within a wooden pallet during general use, the influence of the pallet on the radiation pattern was of interest. Thus, the BLE antenna radiation pattern was assessed both with and without a wooden block – as shown in Figure 2. When employed, this wooden block surrounded the PIM-C on 5 of the 6 sides.

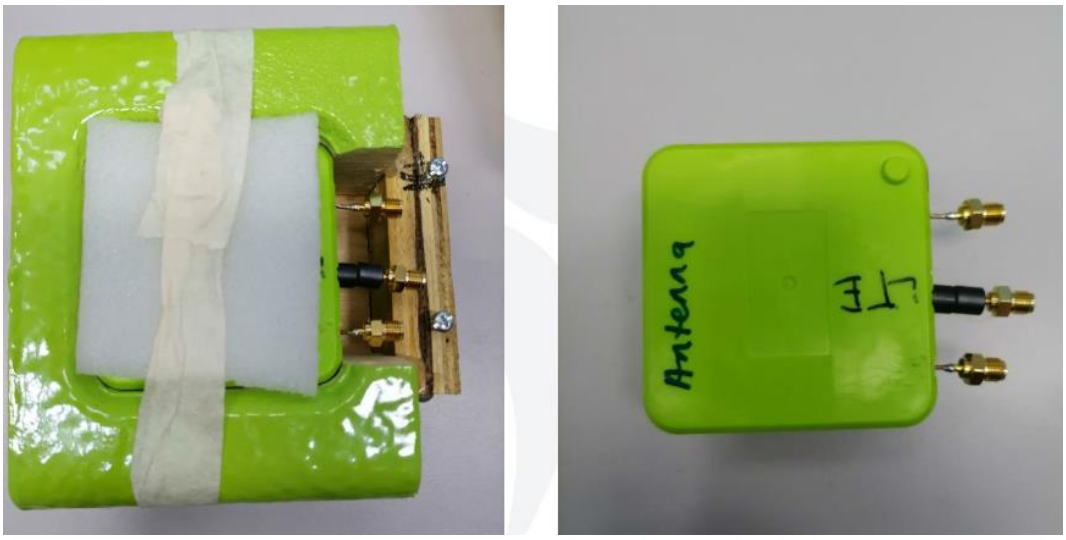

Figure 2 - The PIM-C BLE antenna radiation pattern was assessed both with (left) and without (right) a wooden block. This enabled the influence of the wooden block, which mimics a wooden transportation pallet, to be quantified.

Figure 3 and Figure 4 show how the PIM-C was positioned within a **shielded anechoic chamber** for the BLE antenna gain characterisation, both with and without the wooden block, respectively. This shielded anechoic chamber forms part of the larger **Atenlab Far-Field Free-Space measurement system** which was used to characterise the PIM-C radiation patterns.

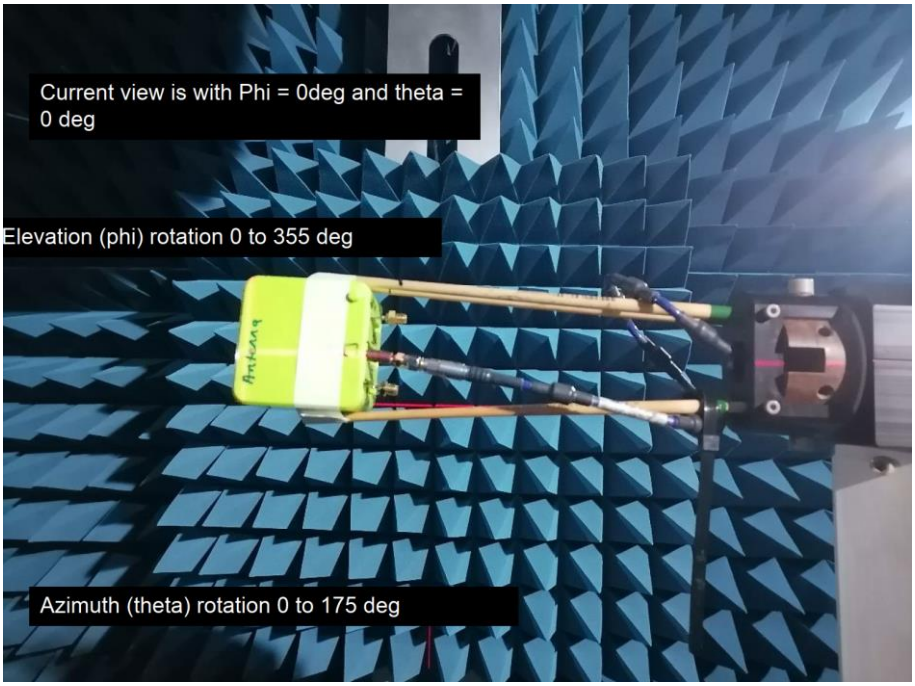

Figure 3 - An example of the placement of the PIM-C antenna measurement setup, within the anechoic chamber. In this case, the wooden block is not present.

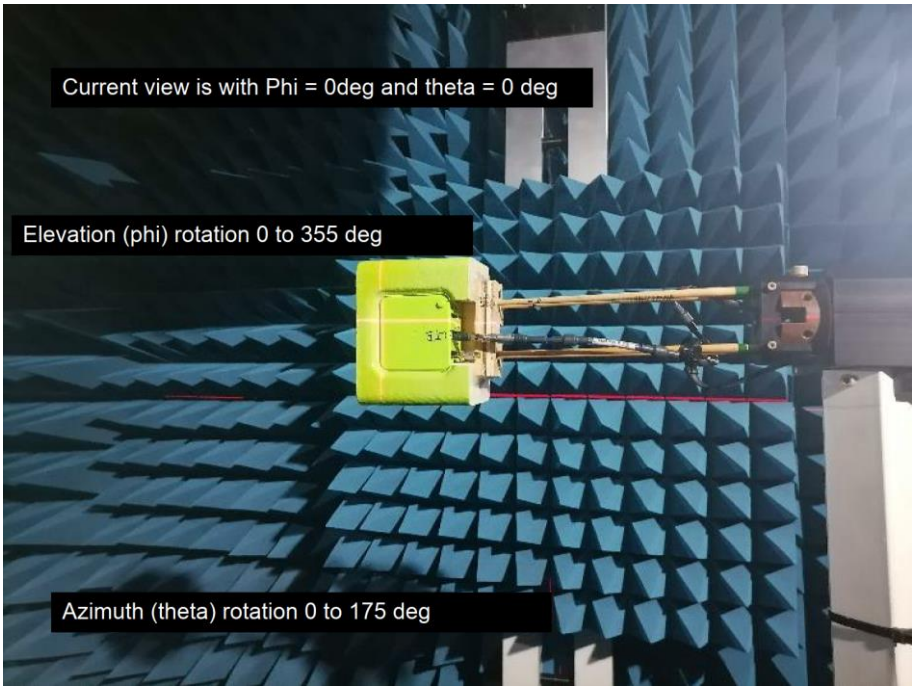

Figure 4 - A further example of the placement of the PIM-C antenna measurement setup, within the anechoic chamber. In this case, the PIM-C is placed within a wooden block, which is representative of how it will be used in the field.

This chamber utilised a turntable which allowed for an elevation (phi) angle range of between 0° and 355° and an azimuth (theta) angle range of between 0° and 175°.

The PIM-C was positioned as necessary to capture the full radiation pattern across the Azimuth, Elevation (0°) and Elevation (90°) planes.

Note: As the presence of the PIM-C battery influences the radiation pattern, it was included within the PIM-C enclosure during these measurements.

3. Results

Measurements were performed by Lead Antenna Engineer Chee Seong Por on 18 April 2024.

Firstly, the impedance match of the BLE antenna was assessed between **500 MHz and 3 GHz** by measuring the free-space **Voltage Standing Wave Ratio (VSWR)** using an **Anritsu ShockLine MS4612B Vector Network Analyser (VNA).** This was done both with and without the wooden block in place. These VSWR results are presented in Figure 5 and Figure 6 for the case with and without the wooden block present, respectively.

Then, once the VSWR was confirmed to be satisfactory, the **radiation patterns were assessed at 10 MHz intervals between 2.39 GHz and 2.51 GHz (inclusive),** both with and without the wooden block in place. Thus, 13 measurement frequencies were used.

- Figure 7 shows the radiation pattern results for the **Azimuth plane**.
- Figure 8 shows the radiation pattern results for the **Elevation (0°) plane**.
- Figure 9 shows the radiation pattern results for the **Elevation (90°) plane**.

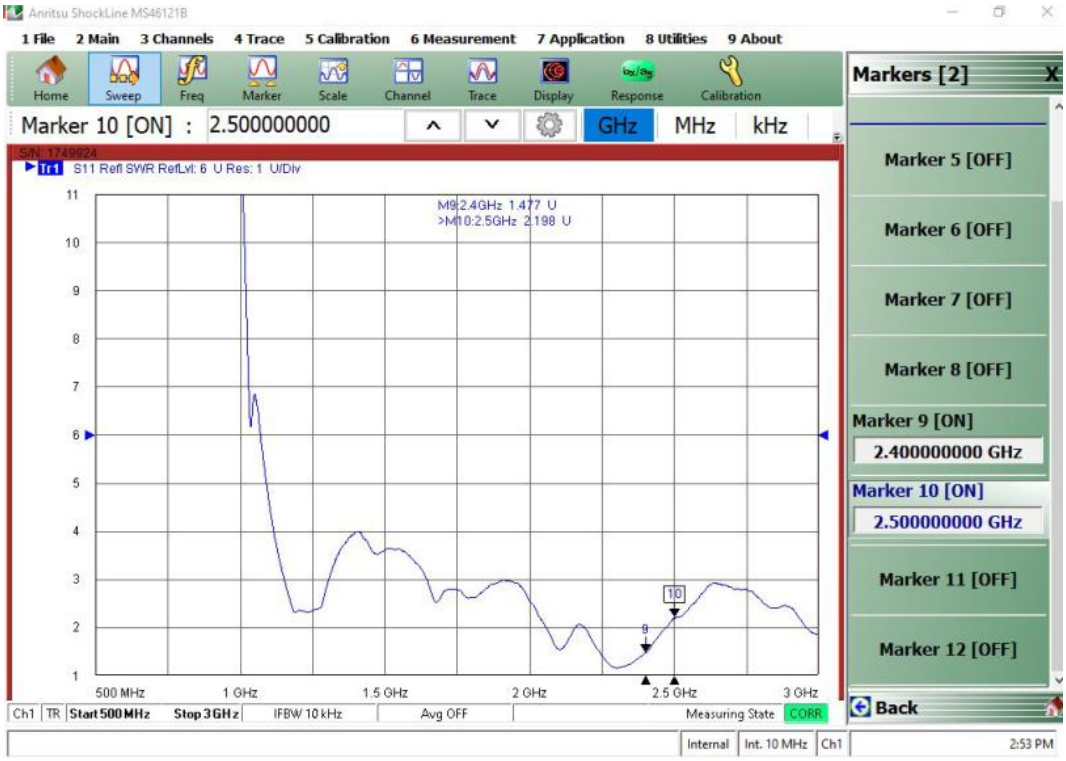

Figure 5 - The free-space VSWR of the PIM-C BLE antenna, without the wooden block present, as measured with an Anritsu ShockLine MS46121B VNA.

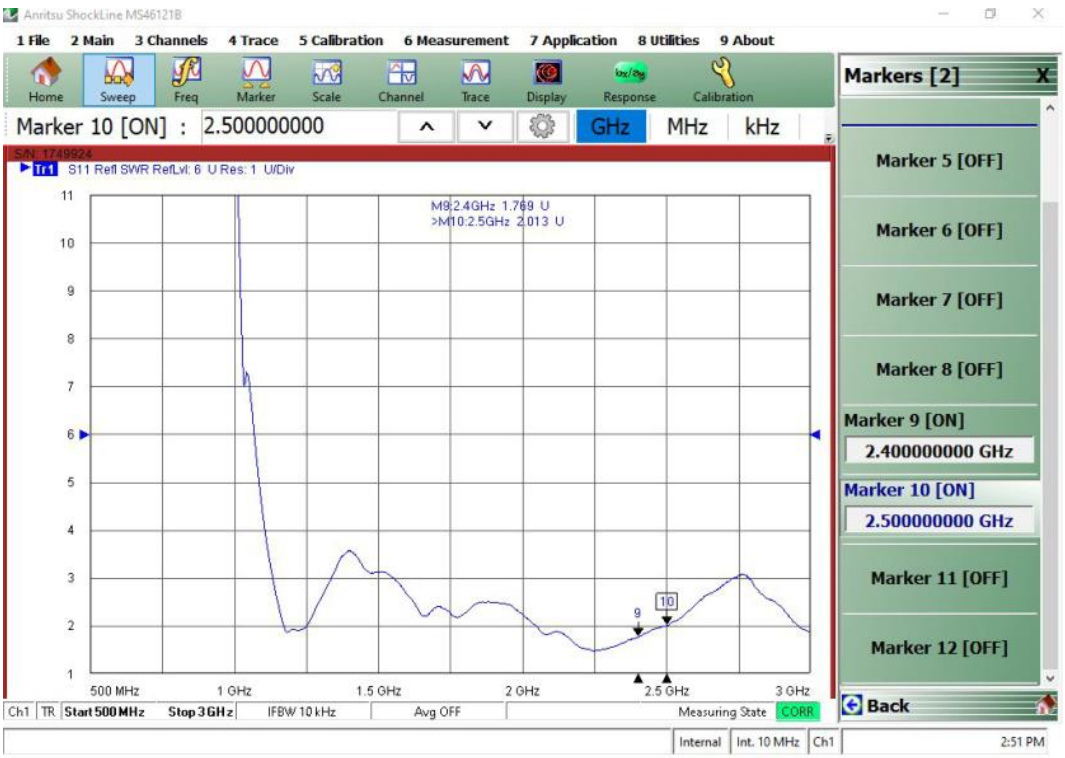

Figure 6 - The free-space VSWR of the PIM-C BLE antenna, with the wooden block present, as measured with an Anritsu ShockLine MS46121B VNA.

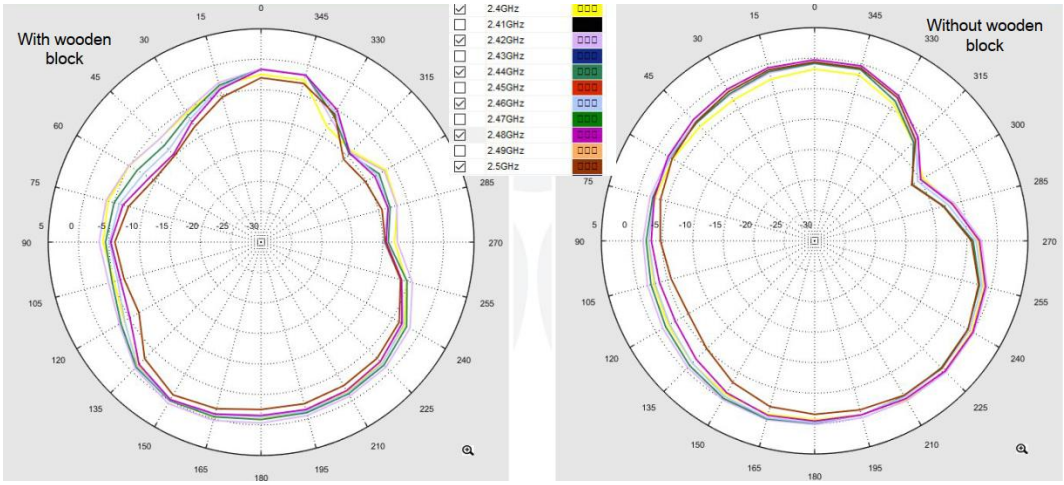

Figure 7 - The Azimuth plane radiation patterns of the PIM-C BLE antenna, measured both with (left) and without (right) the wooden block in place.

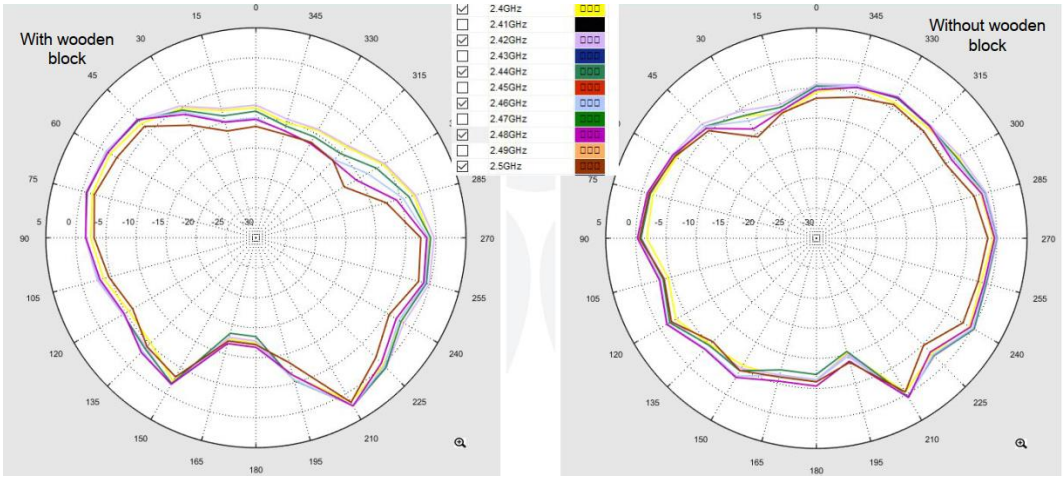

Figure 8 - The Elevation (0°) plane radiation patterns of the PIM-C BLE antenna, measured both with (left) and without (right) the wooden block in place.

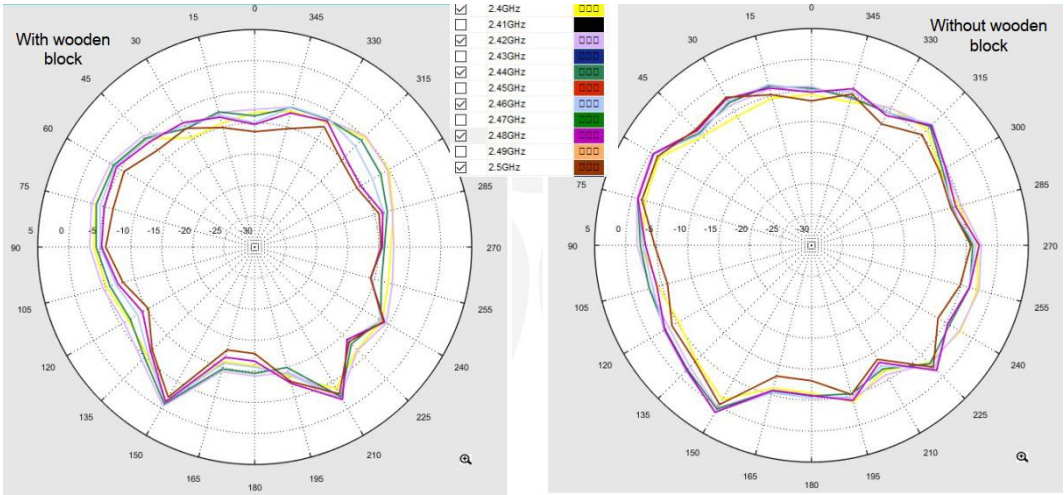

Figure 9 - The Elevation (90°) plane radiation patterns of the PIM-C BLE antenna, measured both with (left) and without (right) the wooden block in place.

The peak gain results are summarised on a per-frequency basis in Table 1 and Table 2, for the case with and without the wooden block present, respectively.

Table 1 - The measured peak gain and corresponding efficiency of the PIM-C BLE antenna, presented on a per-frequency basis for the case with the wooden block. The peak gain is highlighted in green.

Frequency (GHz)	**2.39**	**2.40**	**2.41**	**2.42**	**2.43**	**2.44**	**2.45**	**2.46**	**2.47**	**2.48**	**2.49**	**2.50**	**2.51**
Gain (dBi)	**2.29**	**2.07**	**2.53**	**2.88**	**2.86**	**2.74**	**2.88**	**2.68**	**2.54**	**2.72**	**2.86**	**2.22**	**3.23**
Efficiency (dB)	-3.74	-3.91	-3.41	-3.19	-3.40	-3.69	-3.66	-3.93	-4.23	-4.17	-4.23	-5.09	-4.39
Efficiency (%)	42.27	40.64	45.60	47.97	45.71	42.76	43.05	40.46	37.76	38.28	37.76	30.97	36.39

Table 2 - The measured peak gain and corresponding efficiency of the PIM-C BLE antenna, presented on a per-frequency basis for the case without the wooden block. The peak gain is highlighted in green.

Frequency (GHz)	**2.39**	**2.40**	**2.41**	**2.42**	**2.43**	**2.44**	**2.45**	**2.46**	**2.47**	**2.48**	**2.49**	**2.50**	**2.51**
Gain (dBi)	**1.05**	**0.64**	**1.10**	**1.55**	**1.52**	**1.39**	**1.54**	**1.35**	**0.99**	**1.31**	**1.15**	**-0.10**	**0.58**
Efficiency (dB)	-2.90	-3.07	-2.58	-2.28	-2.39	-2.58	-2.34	-2.48	-2.76	2.51	-2.45	-3.58	-2.88
Efficiency (%)	51.29	49.32	55.21	59.16	57.68	55.21	58.34	56.49	52.97	56.10	56.89	43.85	51.52

Appendix A – Summary List of Test Equipment

Table 3 below summarises the equipment used in the characterisation of the MIST antenna on the PIM on the test date - 18 April 2024.

Note: Atenlab Maxwell commercial measurement software was used to operate the measurement system and produce the radiation pattern and gain results.

Table 3 - Equipment List and Calibration Status

Equipment	**Calibration Status**
Anritsu ShockLine MS4612B Vector Network Analyser	Calibration up-to-date at time of measurements.
Shielded Anechoic Chamber	Shielding effectiveness status in order at time of measurements.
Atenlab Far-Field Free Space Measurement System including Turntable and Receiving Antenna	Calibration up-to-date at time of measurements.