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ANTENNA TEST REPORT

16.6.2025

1. Product and manufacturer information

Product identity:

Treon Industrial Node C
Model number: 2311

Manufacturer:

Treon Oy
Visiokatu 6
33720 Tampere
Finland

2. Antenna test procedure

PCB integrated antenna is measured according to procedure described in Appendix of this report.

3. Measurement uncertainty

Estimated antenna gain measurement uncertainty is:

1.18 dB (k=1, 68.3% confidence interval)
2.35 dB (k≈2, 95% confidence interval)

Measurement uncertainty analysis is disclosed in Appendix A.

4. Antenna Electrical Parameters

Antenna Type	Integrated F-antenna integrated to PCB
Nominal frequency range	2400MHz – 2500MHz
Nominal impedance	50Ω
Maximum gain at specified frequency range	0 dBi
S11	-6dB nominal

5. Antenna photographs

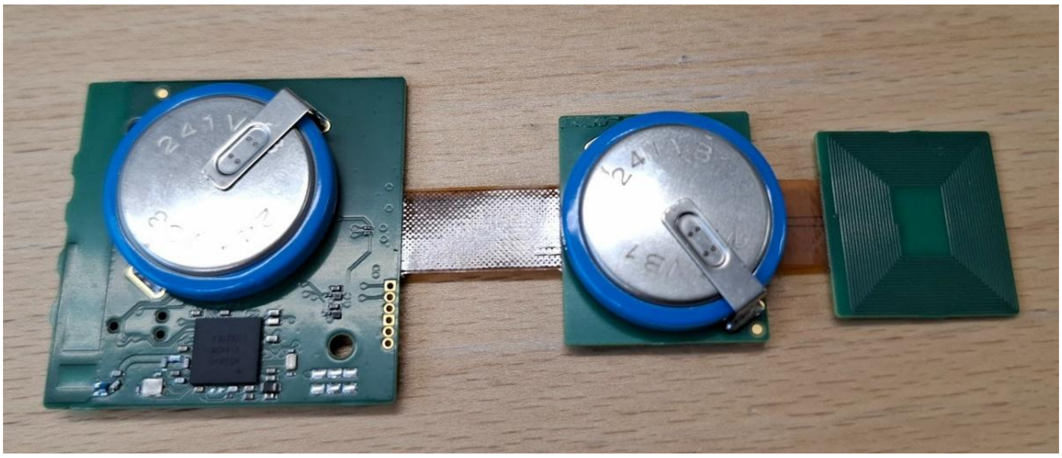

Figure 1 Product PCBA with integrated antenna. Antenna on the left

Figure 2 Photograph of the fully assembled product with test cable attached

6. Antenna test data

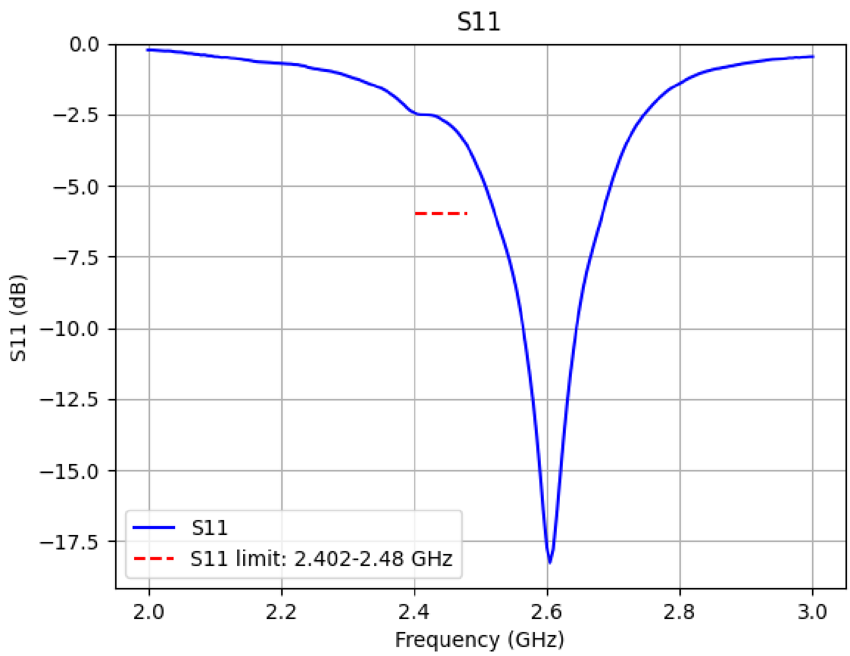

Figure 3 Antenna S11 in free space condition

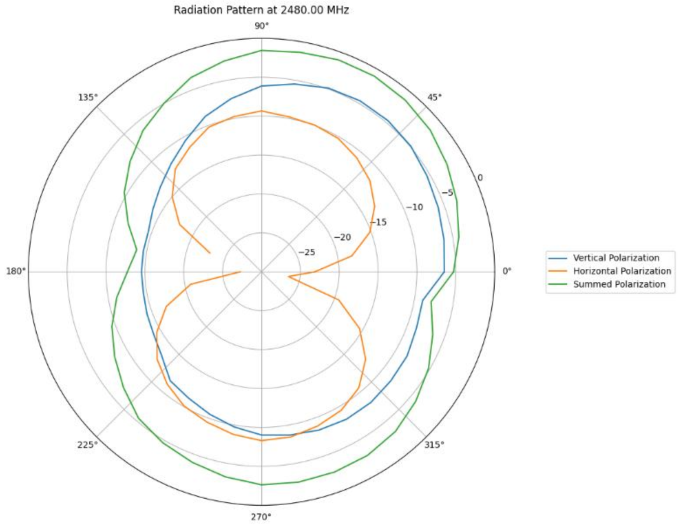

Figure 4 Antenna radiation pattern at maximum gain frequency within spesified frequency range

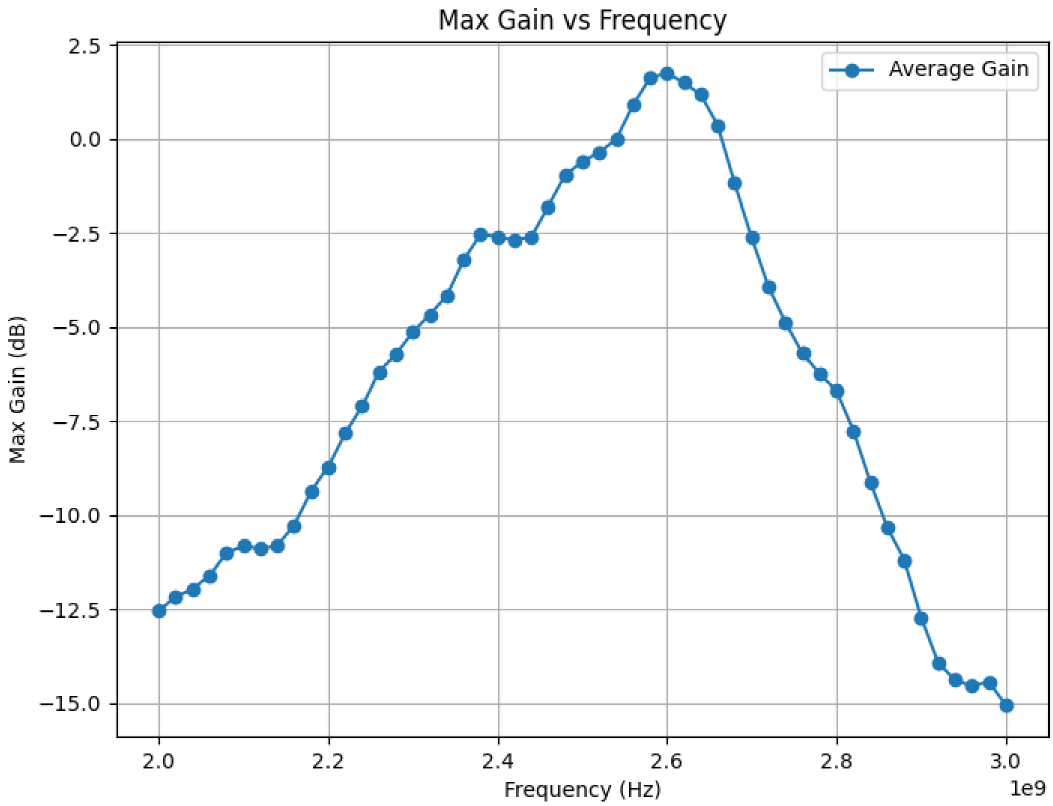

Figure 5 Antenna maximum gain vs. frequency

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TEST PROCEDURE

18.3.2025

Test procedure for antenna gain measurements

1. Table of contents

2. Purpose of this document

This document provides detailed description of the test arrangement and test procedure used for antenna gain measurements at the test laboratory of Saku Lahti Oy. Also analysis of test uncertainty is presented.

3. Test setup description

Block diagram of the test arrangement is shown at Figure 1

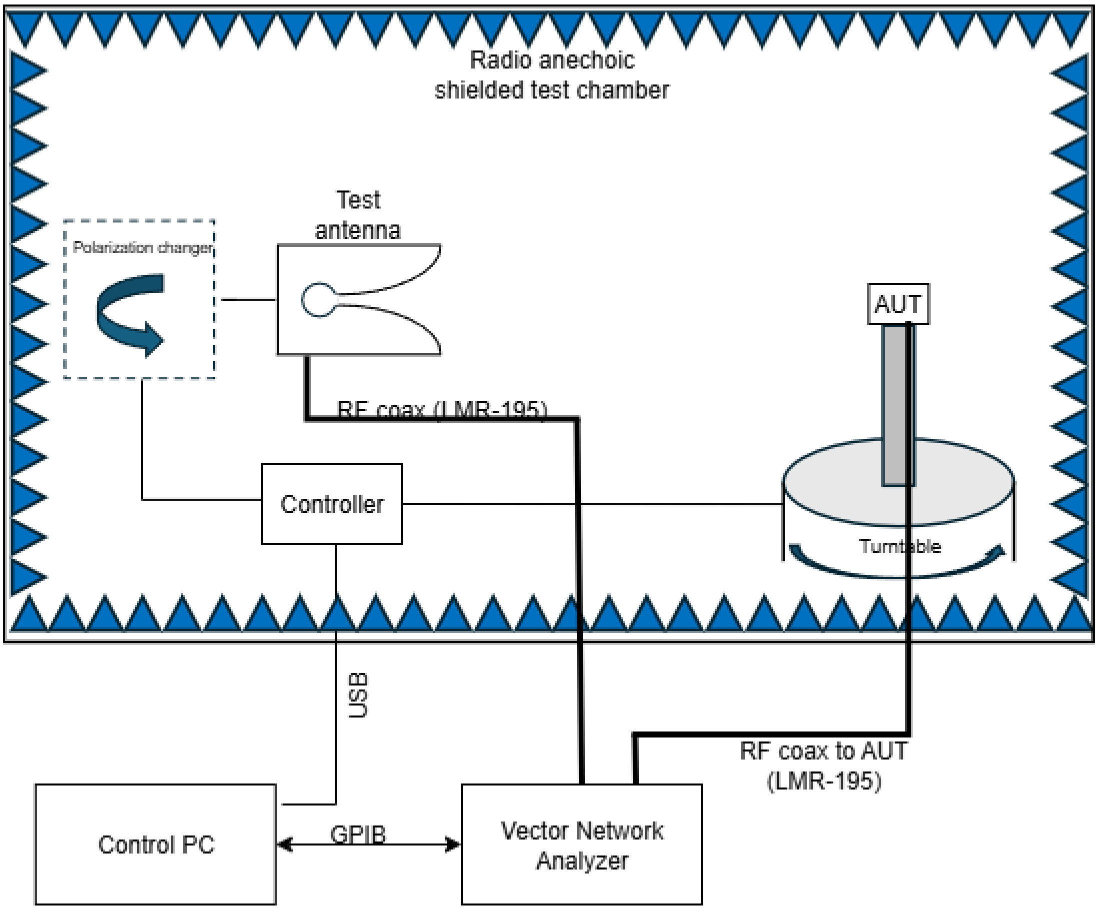

Figure 1 Antenna test arrangement block diagram

Key components in the test arrangement are:

1. Vector Network Analyzer used for measuring the (complex) signal attenuation between Antenna Under Test (AUT) and test antenna

2. Turntable. Used for rotating the AUT in azimuth plane. **Note**: Manually adjustable test fixtures are used to rotate the AUT around its secondary axis to measure antenna radiation patterns at more than one planes.

3. Polarization changer. Used for turning the test antenna polarization between horizontal and vertical.

4. Controller. Used for controlling the turntable and polarization changer. Communicates with test PC via USB interface.

5. Test antenna. Used as a receiving antenna. Note: Exact gain of this antenna does not need to be known, but this antenna must have sufficiently good cross polarization characteristics. PCB integrated Vivaldi type antenna is used.

6. Reference antenna. Antenna with known gain characteristics is used for calibration (reference measurement). This antenna is same type as the one used as test antenna. Gain information of this antenna is obtained using so called 3-antenna test method as described in chapter 6 of this document

Table 1 Test chamber characteristics

Test chamber dimensions	2.3m x 2.2m x 2.2m (length x width x height)
Test distance	1.6m
Maximum AUT size	19cm (1)
Absorber type	PFA-500 (pyramidal 50cm) Backwall PFA-400 (pyramidal 40cm) Other walls
Nominal frequency range	700MHz-6000MHz
Reflectivity	< -30dB @ 700MHz < - 50dB @6000MHz
Shielding effectivenes	>60dB

(1) Maximum AUT dimension is limited by fulfilling the far field criteria $r = \frac{2D^2}{\lambda}$, where r is the test distance, D is the maximum tested antenna dimension and λ the RF wavelength.

Table 2 Main instruments

Vector Network Analyzer (VNA)	HP 8753D
Turntable	Custom
Polarization changer	Custom
Controller	Custom
Test & reference antenna type	PCB integrated Vivaldi type (600MHz- 6GHz)

4. Antenna gain test procedure

The gain of the Antenna Under Test (AUT) is determined using the gain comparison method, which is a well-established technique for antenna characterization. The procedure follows the principles outlined in IEEE Standard 149, IEEE Standard Test Procedures for Antennas.

A calibrated reference antenna with known gain is first positioned in the test chamber at a fixed distance and orientation relative to the transmitting antenna (Figure 4). The transmission coefficient (S21) between the two antennas is measured with a vector network analyzer (VNA) over the frequency range of interest, establishing a reference transmission level for the given configuration.

The reference antenna is then replaced by the AUT, maintaining identical positioning, polarization, and measurement conditions. For each polarization case, the AUT is rotated in the azimuth plane to identify the direction of maximum radiation. The gain of the AUT is then determined from the S21 measurement at this orientation, relative to the previously measured reference antenna.

Separate measurements are performed for two orthogonal polarizations (vertical and horizontal). Based on these results, the following gain values are derived:

Vertical Polarization Gain – computed directly from the vertical polarization measurement.

Horizontal Polarization Gain – computed directly from the horizontal polarization measurement.

ABS Gain – a theoretical maximum obtained by summing the measured vertical and horizontal polarization responses in amplitude.

Circular Polarization Gain (RHCP and LHCP) – obtained by forming a complex combination of the vertical and horizontal responses, applying ±90° phase shifts to generate right-handed and left-handed circular polarization components.

Depending on reporting requirements, one or more of these gain values are provided. For regulatory purposes ABS gain is typically reported, as it provides the most conservative (highest) gain value for the AUT.

In practise all the test steps are automated using test SW running in the control PC. This software is custom wrote with Python.

Furthermore, the test procedure is typically repeated, rotating the AUT along its secondary axis. AUT specific test fixtures are typically used for measuring total of 4 “cuts” at 45 degree increments. Whichever of these measurements yields the highest gain values, is then reported as the AUT gain.

This method allows the AUT gain to be determined relative to a known reference antenna while accounting for polarization characteristics, and minimizes the influence of chamber characteristics and systematic measurement uncertainties.

5. Reference antenna

Reference antenna is classic Vivaldi (also known as tapered slot antenna) manufactured on FR-4 PCB substrate. This antenna design is known to have broad frequency range and good cross polarization characteristics.

Antenna gain is determined by measuring 3 (identical) antennas using classic 3-antenna method as described in chapter 6

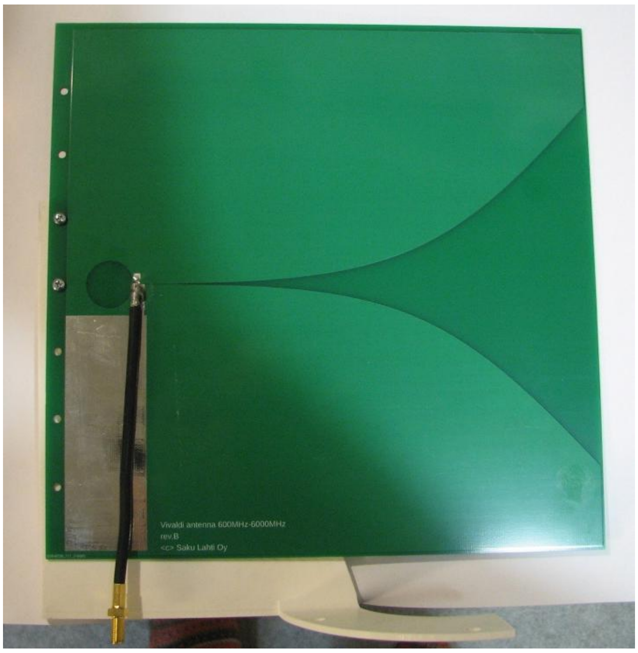

Figure 2 Reference antenna

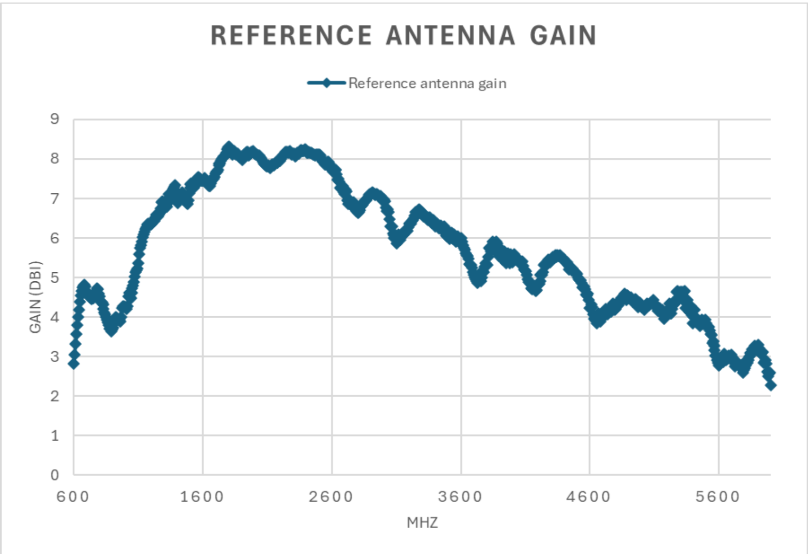

Figure 3 Reference antenna gain. Gain is obtained using 3-antenna method

Figure 4 Photograph of the reference measurement setup

6. Reference antenna gain measurement

The gain of the reference antenna is determined using the **three-antenna method**, which is a classical procedure for deriving absolute antenna gains without relying on a pre-calibrated standard. This method is described in *IEEE Standard 149, IEEE Standard Test Procedures for Antennas*.

In this method, three antennas of unknown gain are measured pairwise in a transmission setup, with the forward transmission coefficient (**S21**) recorded between each antenna pair using a vector network analyzer (VNA). All measurements are performed under identical conditions, with fixed separation distance, frequency range, and polarization.

For each antenna pair (i, j), the Friis transmission equation relates the measured transmission coefficient to the product of the antenna gains:

$$P_{r,ij} = P_t\, G_i\, G_j \left(\frac{\lambda}{4\pi R} \right)^2$$

where

- $P_{r,ij}$ is the received power for the i–j antenna pair,
- P_t is the transmitted power,
- G_i and G_j are the gains of antennas i and j,
- λ is the wavelength, and
- R is the antenna separation distance.

By performing measurements for all three antenna pairs, a system of three equations is obtained that can be solved simultaneously to yield the individual gains of the three antennas.

The gain of the chosen **reference antenna** was thus established from these calculations and subsequently used as the calibrated standard for the gain comparison method described in the previous section.

7. Measurement uncertainty analysis

This section summarizes the principal sources of uncertainty in the antenna gain results and provides a combined estimate based on root-sum-square (RSS) aggregation. Unless stated otherwise, components are treated as independent.

Table 3 Main measurement uncertainty contributors

ID	Source of Uncertainty	Estimate (dB)	Notes / Assumptions
U1	Reference antenna gain	1	Calibration uncertainty of the reference antenna gain (traceable value).
U2	Chamber reflections	0.2	Residual multi-path and absorber imperfections in the chamber.
U3	Reference alignment repeatability	0.2	Small misalignment between reference and AUT setups.
U4	Distance mismatch (±10 cm at 1.6 m)	0.31 (std) / 0.53 (cons.)	Path length change relative to 1.6 m separation. "Std" = uniform distribution model ($\sigma = \Delta/\sqrt{3}$). "Cons." = worst-case treated as 1σ.
U5	VNA relative level accuracy	0.1	Repeatability of relative S21 readings between runs.

It should be noted, that chamber reflectivity has only minor impact for the AUT gain measurement uncertainty. This is because the gain is by definition measured at the direction of maximum radiation from the AUT. When measuring other antenna characteristics, like side-lobe or null levels, this factor becomes easily dominant error source.

As can be seen from Table 3, the dominating factors in uncertainty for gain measurement are the reference antenna gain and the distance mismatch. Distance mismatch is due to relatively short measurement distance, and uncertainty related to actual phase center point of both reference antenna and AUT, which generally are not exactly known, or don't even explicitly exist.

Combined uncertainty (RMS, k = 1):

$$u_c = \sqrt{\sum u_i^2}.$$

Reported uncertainty: Unless otherwise specified, results are stated with a **combined standard uncertainty** of **1.09 dB (k=1)**.

For a 95% coverage, an **expanded uncertainty** of **2.18 dB (k≈2)** may be quoted. A conservative alternative using the worst-case distance yields **1.18 dB (k=1)** and **2.35 dB (k≈2)**.