313 West 12800 South, Suite 311
Draper, UT 84020
(801) 260-4040

# Test Report

## Certification

| | |
|---|---|
| **FCC ID** | SZV-TCM515U |
| **Equipment Under Test** | TCM 515U |
| **Test Report Serial No** | V040607_03 |
| **Dates of Test** | May 15 and 16, 2017 |
| **Report Issue Date** | May 19, 2017 |

| **Test Specifications:** | **Applicant:** |
|---|---|
| FCC Part 15, Subpart C | EnOcean GmbH<br>Kolpingring 18A<br>Oberhaching 82041<br>Germany |

Testing
NVLAP Lab Code 100272-0

# Certification of Engineering Report

This report has been prepared by VPI Laboratories, Inc. to document compliance of the device described below with the requirements of Federal Communications Commission (FCC) Part 15, Subpart C. This report may be reproduced in full. Partial reproduction of this report may only be made with the written consent of the laboratory. The results in this report apply only to the sample tested.

| | |
|---|---|
| **Applicant** | EnOcean GmbH |
| **Manufacturer** | EnOcean GmbH |
| **Brand Name** | EnOcean |
| **Model Number** | TCM 515U |
| **FCC ID** | SZV-TCM515U |

On this 19th day of May 2017, I, individually and for VPI Laboratories, Inc., certify that the statements made in this engineering report are true, complete, and correct to the best of my knowledge, and are made in good faith.

Although NVLAP has accredited the VPI Laboratories, Inc. EMC testing facilities, this report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

VPI Laboratories, Inc.

Norman P Hansen

Tested by: Norman P. Hansen

Mark M. Feil

Reviewed by: Mark M. Feil

| Revision History | | |
|---|---|---|
| **Revision** | **Description** | **Date** |
| 01 | Original Report Release | May 19, 2017 |
| 02 | Correct the antenna part number, AM11DG-ST01 to AM11DP-ST01T | June 15, 2017 |
| 03 | Correct tables of section 6 and better explain the measurements | June 28, 2017 |

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# 1 Client Information

## 1.1 Applicant

| | |
|---|---|
| **Company Name** | EnOcean GmbH<br>Kolpingring 18A<br>Oberhaching 82041<br>Germany |
| **Contact Name** | Armin Anders |
| **Title** | Director Product Marketing |

## 1.2 Manufacturer

| | |
|---|---|
| **Company Name** | EnOcean GmbH<br>Kolpingring 18A<br>Oberhaching 82041<br>Germany |
| **Contact Name** | Armin Anders |
| **Title** | Director Product Marketing |

# 2 Equipment Under Test (EUT)

## 2.1 Identification of EUT

| | |
|---|---|
| **Brand Name** | EnOcean |
| **Model Number** | TCM 515U |
| **Hardware Version** | Revision 2 |
| **Serial Number** | None |
| **Dimensions (cm)** | 1.3 x 1.75 x 0.2 |

## 2.2 Description of EUT

The TCM 515U is a transceiver module operating at 902.875 MHz. The TCM 515U is designed for integration by OEMs. Power will be provided by those systems. For testing, the TCM 515U was connected to a computer via USB port of the development PCB that the TCM 515U was connected to. The TCM 515U was tested using 5 different antenna configurations. An EnOcean wire whip antenna, an EnOcean ANT300 helical antenna, a Mitsubishi Material AM11DP-ST01T chip antenna, a Linx Technologies ANT-916-CW-HWR-RPS external mount antenna, and a trace antenna were used in testing.

This report covers the transmitter circuitry of the devices subject to FCC Part 15, Subpart C. The circuitry of the device subject to FCC Subpart B was found to be compliant and is covered in VPI Laboratories, Inc. report V040606.

## 2.3 EUT and Support Equipment

The EUT and support equipment used during the test are listed below.

| Brand Name<br>Model Number<br>Serial Number | Description | Name of Interface Ports / Interface Cables |
|---|---|---|
| BN: EnOcean<br>MN: TCM 515U (Note 1)<br>SN: None | Transceiver Module | See Section 2.4 |
| BN: EnOcean<br>MN: EOP350<br>SN: None | Development PCB | USB/Micro USB to USB A cable<br>EUT Header/4 conductors (Note 2) |
| BN: Dell<br>MN: D830<br>SN: None | Computer | USB/USB A to Micro USB |

Notes: (1) EUT

(2) Interface port connected to EUT (See Section 2.4)

The support equipment listed above was not modified in order to achieve compliance with this standard.

## 2.4 Interface Ports on EUT

| Name of Ports | No. of Ports Fitted to EUT | Cable Description/Length |
|---|---|---|
| System Interface | 1 | 4 conductors/15 cm |

## 2.5 Modification Incorporated/Special Accessories on EUT

The following modifications were made to the EUT by the Client during testing to comply with the specification. This report is not complete without an accompanying signed attestation, that the product will have all of the documented modifications incorporated into the product when manufactured and placed on the market.

- The firmware was changed to set the maximum power at 005A16.

## 2.6 Deviation from Test Standard

There were no deviations from the test specification.

# 3 Test Specification, Methods and Procedures

## 3.1 Test Specification

| | |
|---|---|
| **Title** | FCC PART 15, Subpart C (47 CFR 15)<br>15.203, 15.207, and 15.231<br>Periodic operation in the 40.66 – 40.70 MHz and above 70 MHz |
| **Purpose of Test** | The tests were performed to demonstrate initial compliance |

## 3.2 Methods & Procedures

### 3.2.1 §15.203 Antenna Requirement

An intentional radiator shall be designed to ensure that no antenna other than that furnished by the responsible party shall be used with the device. The use of a permanently attached antenna or of an antenna that uses a unique coupling to the intentional radiator shall be considered sufficient to comply with the provisions of this Section. The manufacturer may design the unit so that a broken antenna can be replaced by the user, but the use of a standard antenna jack or electrical connector is prohibited. This requirement does not apply to carrier current devices or to devices operated under the provisions of Sections 15.211, 15.213, 15.217, 15.219, or 15.221. Further, this requirement does not apply to intentional radiators that must be professionally installed, such as perimeter protection systems and some field disturbance sensors, or to other intentional radiators which, in accordance with Section 15.31(d), must be measured at the installation site. However, the installer shall be responsible for ensuring that the proper antenna is employed so that the limits in this Part are not exceeded.

### 3.2.2 §15.207 Conducted Limits

(a) Except as shown in paragraphs (b) and (c) of this section, for an intentional radiator that is designed to be connected to the public utility (AC) power line, the radio frequency voltage that is conducted back onto the AC power line on any frequency or frequencies, within the band 150 kHz to 30 MHz, shall not exceed the limits in the following table, as measured using a 50 μH/50 ohms line impedance stabilization network (LISN). Compliance with the provisions of this paragraph shall be based on the measurement of the radio frequency voltage between each power line and ground at the power terminal. The lower limit applies at the boundary between the frequency ranges.

| Frequency range (MHz) | Limit (dBμV) | |
|---|---|---|
| | Quasi-peak | Average |
| 0.15 to 0.50* | 66 to 56* | 56 to 46* |
| 0.50 to 5 | 56 | 46 |
| 5 to 30 | 60 | 50 |

*Decreases with the logarithm of the frequency.

**Table 1: Limits for conducted emissions at mains ports of Class B ITE.**

(c) Measurements to demonstrate compliance with the conducted limits are not required for devices which only employ battery power for operation and which do not operate from the AC power lines or contain provisions for operation while connected to the AC power lines. Devices that include, or make provisions for, the use of battery chargers which permit operating while charging, AC adapters or battery eliminators or that connect to the AC power lines indirectly, obtaining their power through another device which is connected to the AC power lines, shall be tested to demonstrate compliance with the conducted limits.

### 3.2.3 §15.231

a) (a) The provisions of this section are restricted to periodic operation within the band 40.66-40.70 MHz and above 70 MHz. Except as shown in paragraph (e) of this section, the intentional radiator is restricted to the transmission of a control signal such as those used with alarm systems, door openers, remote switches, etc. Continuous transmissions, voice, video and the radio control of toys are not permitted. Data is permitted to be sent with a control signal. The following conditions shall be met to comply with the provisions for this periodic operation:

  1) A manually operated transmitter shall employ a switch that will automatically deactivate the transmitter within not more than 5 seconds of being released.

  2) A transmitter activated automatically shall cease transmission within 5 seconds after activation.

  3) Periodic transmissions at regular predetermined intervals are not permitted. However, polling or supervision transmissions, including data, to determine system integrity of transmitters used in security or safety applications are allowed if the total duration of transmissions does not exceed more than two seconds per hour for each transmitter. There is no limit on the number of individual transmissions, provided the total transmission time does not exceed two seconds per hour.

  4) Intentional radiators which are employed for radio control purposes during emergencies involving fire, security, and safety of life, when activated to signal an alarm, may operate during the pendency of the alarm condition.

  5) Transmission of set-up information for security systems may exceed the transmission duration limits in paragraphs (a)(1) and (a)(2) of this section, provided such transmissions are under the control of a professional installer and do not exceed ten seconds after a manually operated switch is released or a transmitter is activated automatically. Such set-up information may include data.

b) In addition to the provisions of §15.205, the field strength of emission from intentional radiators operated under this section shall not exceed the following.

| Fundamental frequency (MHz) | Field strength of fundamental (microvolts/meter) | Field strength of spurious emissions (microvolts/meter) |
|---|---|---|
| 40.66 - 40.70 | 2,250 | 225 |
| 70 –130 | 1,250 | 125 |
| 130 – 174 | 1,250 to 3,750 ** | 125 to 375 ** |
| 174 – 260 | 3,750 | 375 |
| 260 – 470 | 3,750 to 12,500 ** | 375 to 1,250 ** |
| Above 470 | 12,500 | 1,250 |

** Linear interpolations

**Table 2: Limits for field strength of emissions from intentional radiators.**

  1) The above field strength limits are specified at a distance of 3 meters. The tighter limits apply at the band edges.

2) Intentional radiators operating under the provisions of this section shall demonstrate compliance with the limits on the field strength of emissions, as shown in the above table, based on the average value of the measured emissions. As an alternative, compliance with the limits in the above table may be based on the use of measurement instrumentation with a CISPR quasi-peak detector. The specific method of measurement employed shall be specified in the application for equipment authorization. If average emission measurements are employed, the provision in §15.35 for averaging pulsed emission and for limiting peak emissions apply. Further, compliance with the provisions of §15.205 shall be demonstrated using the measurement instrumentation specified in that section.

3) The limits on the field strength of the spurious emission in the above table are based on the fundamental frequency of the intentional radiator. Spurious emission shall be attenuated to the average (or, alternatively, CISPR quasi-peak) limits shown in this table or to the general limits shown in §15.209, whichever limit permits a higher field strength.

c) The bandwidth of the emission shall be no wider than 0.25% of the center frequency for devices operating above 70 MHz and below 900 MHz. For devices operating above 900 MHz, the emission shall be no wider than 0.5% of the center frequency. Bandwidth is determined at the points 20 dB down from the modulated carrier.

d) For devices operation within the frequency band 40.66-40.70 MHz, the bandwidth of the emission shall be confined within the band edges and the frequency tolerance of the carrier shall be ±0.01%. This frequency tolerance shall be maintained for a temperature variation of -20 degrees to +50 degrees C at normal supply voltage, and for a variation on the primary supply voltage from 85% to 115% of the rated supply voltage at a temperature of 20 degrees C. For battery operated equipment, the equipment tests shall be performed using a new battery.

e) Intentional radiators may operate at a periodic rate exceeding that specified in paragraph (a) of this section and may be employed for any type of operation, including operation prohibited in paragraph (a) of this section, provided that intentional radiator complies with the provisions of paragraphs (b) through (d) of this section except the field strength table in paragraph (b) of this section is replaced by the following.

| Fundamental frequency (MHz) | Field strength of fundamental (microvolts/meter) | Field strength of spurious emissions (microvolts/meter) |
|---|---|---|
| 40.66 - 40.70 | 1,000 | 100 |
| 70 –130 | 500 | 50 |
| 130 – 174 | 500 to 1,500 ** | 50 to 150 ** |
| 174 – 260 | 1,500 | 150 |
| 260 – 470 | 1,500 to 5,000 ** | 150 to 500 ** |
| Above 470 | 5,000 | 500 |

** Linear interpolations

**Table 3: Limits for field strength of emissions from intentional radiators.**

In addition, devices operated under the provisions of this paragraph shall be provided with a means for automatically limiting operation so that the duration of each transmission shall not be greater than one second and the silent periods between transmissions shall be at least 30 times the duration of the transmission but in no case less than 10 seconds.

## 3.3 Test Procedure

The conducted disturbance at mains ports and radiated disturbance testing was performed according to the procedures in ANSI C63.10:2013. Testing was performed at VPI Laboratories, Inc. Wanship Upper Open Area Test Site, located at 29145 Old Lincoln Highway, Wanship, UT. VPI Laboratories, Inc. is accredited by National Voluntary Laboratory Accreditation Program (NVLAP); NVLAP Lab Code: 100272-0, which is effective until September 30, 2017.

# 4 Operation of EUT During Testing

## 4.1 Operating Environment

| | |
|---|---|
| **Power Supply** | 5 VDC |

## 4.2 Operating Modes

The EUT was tested on 3 orthogonal axes, using all 5 antennas, while in a constant transmission mode.

## 4.3 EUT Exercise Software

Dolphin Viewer 3.6.2.0 was used to exercise the EUT.

# 5 Summary of Test Results

## 5.1 FCC Part 15, Subpart C

### 5.1.1 Summary of Tests

| Part 15, Subpart C Reference | Test Performed | Frequency Range (MHz) | Result |
|---|---|---|---|
| 15.203 | Antenna Requirement | N/A | Complied |
| 15.207 | Emissions at the AC Mains | 0.15 – 30 | Complied |
| 15.231 (a) | Periodic Operation | 902.875 | Complied |
| 15.231 (b) | Radiated Emissions | 0.009 – 9028.75 | Complied |
| 15.231 (c) | Bandwidth | 902.875 | Complied |
| 15.231 (d) | Frequency Stability | 40.66 – 40.70 | Not Applicable |
| 15.231 (e) | Radiated Emissions | 0.009 – 9028.75 | Not Applicable |

## 5.2 Result

In the configuration tested, the EUT complied with the requirements of the specification.

# 6 Measurements, Examinations and Derived Results

## 6.1 General Comments

This section contains the test results only. Details of the test methods used and a list of the test equipment used during the measurements can be found in Section 7 of this report.

## 6.2 Test Results

### 6.2.1 §15.203 Antenna Requirements

The EUT may be used with one of 5 different antennas. An EnOcean wire whip antenna, an EnOcean ANT300 helical antenna, a Mitsubishi Material AM11DP-ST01T chip antenna, and a trace antenna were used in testing and are soldered to a PCB or are etched into the PCB. A Linx Technologies ANT-916-CW-HWR-RPS uses a reverse polarity SMA connector at the antenna connection.

**Result**

The EUT complied with the specification

### 6.2.2 §15.207 Emissions at the AC Mains

| Frequency (MHz) | AC Mains Lead | Detector | Measured Level (dBμV) | Limit (dBμV) | Margin (dB) |
|---|---|---|---|---|---|
| 0.17 | Hot Lead | Quasi-Peak (Note 2) | 57.4 | 65.0 | -7.6 |
| 0.17 | Hot Lead | Average (Note 2) | 33.0 | 55.0 | -22.0 |
| 0.28 | Hot Lead | Peak (Note 1) | 46.7 | 50.9 | -4.2 |
| 0.39 | Hot Lead | Peak (Note 1) | 40.6 | 48.1 | -7.5 |
| 0.55 | Hot Lead | Peak (Note 1) | 36.8 | 46.0 | -9.2 |
| 2.74 | Hot Lead | Peak (Note 1) | 26.5 | 46.0 | -19.5 |
| 3.65 | Hot Lead | Peak (Note 1) | 26.5 | 46.0 | -19.5 |
| 0.15 | Neutral Lead | Quasi-Peak (Note 2) | 57.4 | 66.0 | -8.6 |
| 0.15 | Neutral Lead | Average (Note 2) | 39.3 | 56.0 | -16.7 |
| 0.25 | Neutral Lead | Quasi-Peak (Note 2) | 53.6 | 61.7 | -8.1 |
| 0.25 | Neutral Lead | Average (Note 2) | 32.9 | 51.7 | -18.8 |
| 0.33 | Neutral Lead | Peak (Note 1) | 42.7 | 49.5 | -6.8 |
| 0.41 | Neutral Lead | Peak (Note 1) | 37.3 | 47.7 | -10.4 |
| 0.61 | Neutral Lead | Peak (Note 1) | 32.3 | 46.0 | -13.7 |
| 3.64 | Neutral Lead | Peak (Note 1) | 26.7 | 46.0 | -19.3 |

Note 1: The reference detector used for the measurements was Quasi-Peak or Peak and the data was compared to the average limit; therefore, the EUT was deemed to meet both the average and quasi-peak limits.
Note 2: The reference detector used for the measurements was quasi-peak and average and the data was compared to the respective limits.

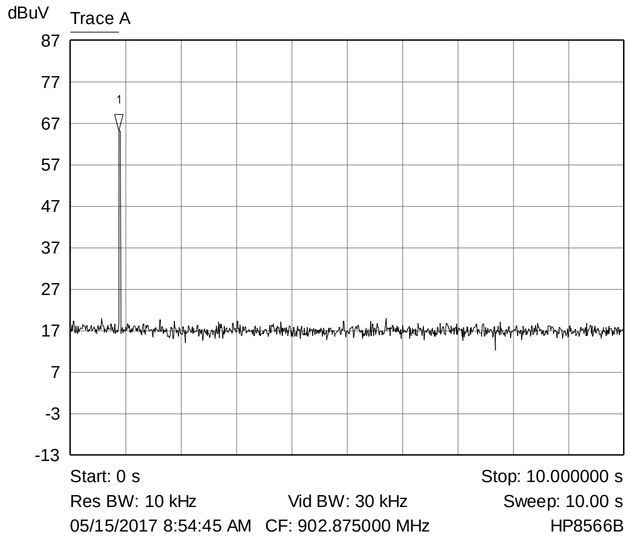
**Result**

The EUT complied with the specification limit by a margin of 4.2 dB.

### 6.2.3 §15.231 (a)

1) The EUT is not manually activated.

2) The EUT is automatically activated. When an event triggers the transmitter, 3 pulses are sent out within a 100 ms time frame. The transmitter does not activate again until after that 100 ms period ends and another event trigger the transmission.




| Mkr | X-Axis | Value | Notes |
|---|---|---|---|
| 1 ▽ | 880.000000 ms | 65.2000 dBuV | |

**Graph 1: Plot Showing EUT ceases transmission within 5 seconds of activation if automatically activated.**

3) The EUT does not transmit at regular predetermined intervals
4) The EUT may be used during an emergency that involves fire and safety of life.
5) The EUT does not require set up information transmissions by a professional installer. If setup is required, timing requirements must be met. Insert plot.

In the configuration tested, the EUT complied with the requirements of this section.

### 6.2.4 §15.231 (b) Radiated Emissions

The TCM 515U operates at 902.875 MHz, therefore; the field strength of the fundamental must be less than 12,500 µV/m (81.9 dBµV/m) at 3 meters. The maximum permitted field strength of any unwanted emission must be 20 dB below the maximum allowable fundamental field strength (61.9 dBµV/m).

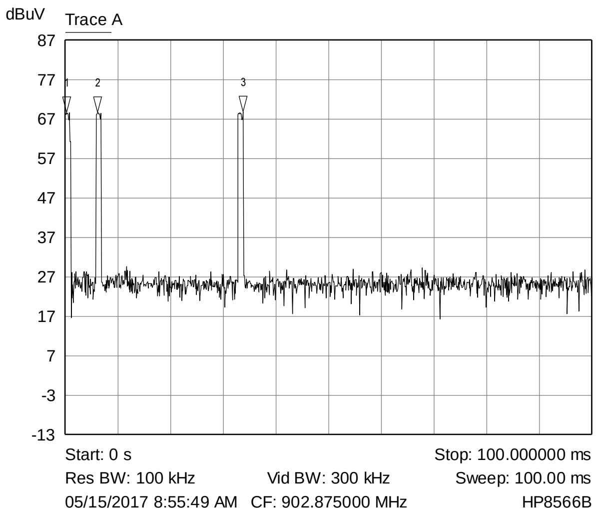
Emissions in the restricted bands of §15.205 must meet the limits specified in §15.209.

**Measurement Data Fundamental and Harmonic Emissions**

The frequency range from the lowest frequency used in the device to the tenth harmonic of the highest fundamental frequency was investigated to measure any radiated emissions. The emissions shown were measured using peak detection and applying an average factor to correct the field strength peak measurement to average. If the average field strength complies with the average limit and a maximum of 20 dB is used to calculate the average field strength from a peak measurement, the requirement of §15.35(b) for limiting the peak emission is met.

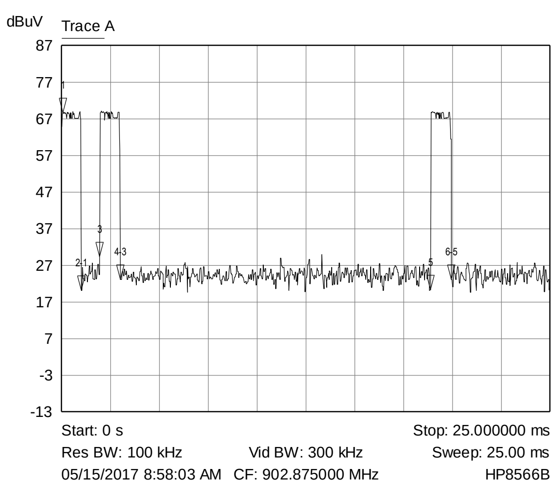
## Pulsed Emission Averaging Factor

The TCM 515U transmitter is a pulsed emission device; therefore, the method of §15.35 for averaging a pulsed emission may be used. A timing diagram of the pulsed transmission, plots of the pulse train, and the average factor calculations are shown below.




| Mkr | X-Axis | Value | Notes |
|---|---|---|---|
| 1 ▽ | 200.000000 us | 68.7000 dBuV | |
| 2 ▽ | 6.100000 ms | 68.7000 dBuV | |
| 3 ▽ | 33.700000 ms | 68.8000 dBuV | |

**Graph 2: Plot of the Emission Over 100 ms**




| Mkr | X-Axis | Value | Notes |
|---|---|---|---|
| 1 ▽ | 50.000000 us | 68.7000 dBuV | |
| 2-1 ▽ | 950.000000 us | -48.6000 dB | |
| 3 ▽ | 1.950000 ms | 29.3000 dBuV | |
| 4-3 ▽ | 1.050000 ms | -6.1000 dB | |
| 5 ▽ | 18.875000 ms | 20.3000 dBuV | |
| 6-5 ▽ | 1.075000 ms | 2.8000 dB | |

**Graph 3: Plot of the Emission Over 25 ms**

**Average factor calculation**

From the plots, the pulse train consists of 3 pulses. The duration of the pulses 0.95 ms, 1.05 ms, and 1.075 ms. The total on time is 3.075 ms. The Average Factor will be calculated using an on time of 3.075 ms in a period of 100 ms. The Average Factor is calculated by the equation:

Average Factor = 20 log (on time/pulse train time)

Pulse train time = 3.075 ms

On time = 100 ms

Average Factor = 20 log (3.075 / 100) = -30.2 dB

§15.35(b) specifies a 20 dB maximum between the peak and average measurements; therefore, a 20 dB averaging factor will be used.

### 6.2.5 Radiated Interference Measurements – Whip Antenna – Vertical Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBμV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBμV/m) | Limit (dBμV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 50.3 | -20.0 | 35.8 | 66.1 | 81.9 | -15.8 |
| 1805.750 | Peak | 16.5 | -20.0 | 30.3 | 26.8 | 61.9 | -35.1 |
| 2708.625* | Peak | 13.3 | -20.0 | 34.0 | 27.3 | 54.0 | -26.7 |
| 3611.500* | Peak | 13.3 | -20.0 | 37.2 | 30.5 | 54.0 | -23.5 |
| 4514.375* | Peak | 17.9 | -20.0 | 38.9 | 36.8 | 54.0 | -17.2 |
| 5417.250* | Peak | 15.1 | -20.0 | 41.1 | 36.2 | 54.0 | -17.8 |
| 6320.125 | Peak | 10.4 | -20.0 | 42.3 | 32.7 | 61.9 | -29.2 |
| 7223.000* | Peak | 10.1 | -20.0 | 44.3 | 34.4 | 54.0 | -19.6 |
| 8125.875* | Peak | 4.8 | -20.0 | 46.0 | 30.8 | 54.0 | -23.2 |
| 9028.750* | Peak | 4.1 | -20.0 | 47.5 | 31.6 | 54.0 | -22.4 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.6 Radiated Interference Measurements – Whip Antenna – Horizontal Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBμV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBμV/m) | Limit (dBμV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 51.6 | -20.0 | 35.8 | 67.4 | 81.9 | -14.5 |
| 1805.750 | Peak | 11.3 | -20.0 | 30.3 | 21.6 | 61.9 | -40.3 |
| 2708.625* | Peak | 7.9 | -20.0 | 34.0 | 21.9 | 54.0 | -32.1 |
| 3611.500* | Peak | 12.1 | -20.0 | 37.2 | 29.3 | 54.0 | -24.7 |
| 4514.375* | Peak | 15.0 | -20.0 | 38.9 | 33.9 | 54.0 | -20.1 |
| 5417.250* | Peak | 16.7 | -20.0 | 41.1 | 37.8 | 54.0 | -16.2 |
| 6320.125 | Peak | 7.0 | -20.0 | 42.3 | 29.3 | 61.9 | -32.6 |
| 7223.000* | Peak | 7.6 | -20.0 | 44.3 | 31.9 | 54.0 | -22.1 |
| 8125.875* | Peak | 4.2 | -20.0 | 46.0 | 30.2 | 54.0 | -23.8 |
| 9028.750* | Peak | 3.6 | -20.0 | 47.5 | 31.1 | 54.0 | -22.9 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.7 Radiated Interference Measurements – Chip Antenna – Vertical Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBμV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBμV/m) | Limit (dBμV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 65.7 | -20.0 | 35.8 | 81.5 | 81.9 | -0.4 |
| 1805.750 | Peak | 11.5 | -20.0 | 30.3 | 21.8 | 61.9 | -40.1 |
| 2708.625* | Peak | 7.4 | -20.0 | 34.0 | 21.4 | 54.0 | -32.6 |
| 3611.500* | Peak | 10.6 | -20.0 | 37.2 | 27.8 | 54.0 | -26.2 |
| 4514.375* | Peak | 17.4 | -20.0 | 38.9 | 36.3 | 54.0 | -17.7 |
| 5417.250* | Peak | 17.7 | -20.0 | 41.1 | 38.8 | 54.0 | -15.2 |
| 6320.125 | Peak | 4.1 | -20.0 | 42.3 | 26.4 | 61.9 | -35.5 |
| 7223.000* | Peak | 14.5 | -20.0 | 44.3 | 38.8 | 54.0 | -15.2 |
| 8125.875* | Peak | 7.4 | -20.0 | 46.0 | 33.4 | 54.0 | -20.6 |
| 9028.750* | Peak | 5.4 | -20.0 | 47.5 | 32.9 | 54.0 | -21.1 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.8 Radiated Interference Measurements – Chip Antenna – Horizontal Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBµV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBµV/m) | Limit (dBµV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 66.0 | -20.0 | 35.8 | 81.8 | 81.9 | -0.1 |
| 1805.750 | Peak | 9.2 | -20.0 | 30.3 | 19.5 | 61.9 | -42.4 |
| 2708.625* | Peak | 7.6 | -20.0 | 34.0 | 21.6 | 54.0 | -32.4 |
| 3611.500* | Peak | 12.5 | -20.0 | 37.2 | 29.7 | 54.0 | -24.3 |
| 4514.375* | Peak | 22.7 | -20.0 | 38.9 | 41.6 | 54.0 | -12.4 |
| 5417.250* | Peak | 24.6 | -20.0 | 41.1 | 45.7 | 54.0 | -8.3 |
| 6320.125 | Peak | 3.3 | -20.0 | 42.3 | 25.6 | 61.9 | -36.3 |
| 7223.000* | Peak | 7.6 | -20.0 | 44.3 | 31.9 | 54.0 | -22.1 |
| 8125.875* | Peak | 7.9 | -20.0 | 46.0 | 33.9 | 54.0 | -20.1 |
| 9028.750* | Peak | 4.1 | -20.0 | 47.5 | 31.6 | 54.0 | -22.4 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.9 Radiated Interference Measurements – Helical Antenna – Vertical Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBµV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBµV/m) | Limit (dBµV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 63.3 | -20.0 | 35.8 | 79.1 | 81.9 | -2.8 |
| 1805.750 | Peak | 11.8 | -20.0 | 30.3 | 22.1 | 61.9 | -39.8 |
| 2708.625* | Peak | 6.9 | -20.0 | 34.0 | 20.9 | 54.0 | -33.1 |
| 3611.500* | Peak | 6.9 | -20.0 | 37.2 | 24.1 | 54.0 | -29.9 |
| 4514.375* | Peak | 21.8 | -20.0 | 38.9 | 40.7 | 54.0 | -13.3 |
| 5417.250* | Peak | 15.5 | -20.0 | 41.1 | 36.6 | 54.0 | -17.4 |
| 6320.125 | Peak | 4.4 | -20.0 | 42.3 | 26.7 | 61.9 | -35.2 |
| 7223.000* | Peak | 9.9 | -20.0 | 44.3 | 34.2 | 54.0 | -19.8 |
| 8125.875* | Peak | 6.5 | -20.0 | 46.0 | 32.5 | 54.0 | -21.5 |
| 9028.750* | Peak | 4.1 | -20.0 | 47.5 | 31.6 | 54.0 | -22.4 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.10 Radiated Interference Measurements – Helical Antenna – Horizontal Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBμV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBμV/m) | Limit (dBμV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 63.6 | -20.0 | 35.8 | 79.4 | 81.9 | -2.5 |
| 1805.750 | Peak | 11.7 | -20.0 | 30.3 | 22.0 | 61.9 | -39.9 |
| 2708.625* | Peak | 7.2 | -20.0 | 34.0 | 21.2 | 54.0 | -32.8 |
| 3611.500* | Peak | 10.7 | -20.0 | 37.2 | 27.9 | 54.0 | -26.1 |
| 4514.375* | Peak | 25.4 | -20.0 | 38.9 | 44.3 | 54.0 | -9.7 |
| 5417.250* | Peak | 23.7 | -20.0 | 41.1 | 44.8 | 54.0 | -9.2 |
| 6320.125 | Peak | 7.9 | -20.0 | 42.3 | 30.2 | 61.9 | -31.7 |
| 7223.000* | Peak | 20.3 | -20.0 | 44.3 | 44.6 | 54.0 | -9.4 |
| 8125.875* | Peak | 5.5 | -20.0 | 46.0 | 31.5 | 54.0 | -22.5 |
| 9028.750* | Peak | 6.1 | -20.0 | 47.5 | 33.6 | 54.0 | -20.4 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.11 Radiated Interference Measurements – RP-SMA Antenna – Vertical Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBμV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBμV/m) | Limit (dBμV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 61.6 | -20.0 | 35.8 | 77.4 | 81.9 | -4.5 |
| 1805.750 | Peak | 11.2 | -20.0 | 30.3 | 21.5 | 61.9 | -40.4 |
| 2708.625* | Peak | 8.3 | -20.0 | 34.0 | 22.3 | 54.0 | -31.7 |
| 3611.500* | Peak | 11.3 | -20.0 | 37.2 | 28.5 | 54.0 | -25.5 |
| 4514.375* | Peak | 19.1 | -20.0 | 38.9 | 38.0 | 54.0 | -16.0 |
| 5417.250* | Peak | 17.3 | -20.0 | 41.1 | 38.4 | 54.0 | -15.6 |
| 6320.125 | Peak | 9.4 | -20.0 | 42.3 | 31.7 | 61.9 | -30.2 |
| 7223.000* | Peak | 9.7 | -20.0 | 44.3 | 34.0 | 54.0 | -20.0 |
| 8125.875* | Peak | 5.6 | -20.0 | 46.0 | 31.6 | 54.0 | -22.4 |
| 9028.750* | Peak | 3.3 | -20.0 | 47.5 | 30.8 | 54.0 | -23.2 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.12 Radiated Interference Measurements – RP-SMA Antenna – Horizontal Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBµV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBµV/m) | Limit (dBµV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 61.8 | -20.0 | 35.8 | 77.6 | 81.9 | -4.3 |
| 1805.750 | Peak | 18.6 | -20.0 | 30.3 | 28.9 | 61.9 | -33.0 |
| 2708.625* | Peak | 11.0 | -20.0 | 34.0 | 25.0 | 54.0 | -29.0 |
| 3611.500* | Peak | 10.6 | -20.0 | 37.2 | 27.8 | 54.0 | -26.2 |
| 4514.375* | Peak | 22.2 | -20.0 | 38.9 | 41.1 | 54.0 | -12.9 |
| 5417.250* | Peak | 19.7 | -20.0 | 41.1 | 40.8 | 54.0 | -13.2 |
| 6320.125 | Peak | 14.9 | -20.0 | 42.3 | 37.2 | 61.9 | -24.7 |
| 7223.000* | Peak | 7.8 | -20.0 | 44.3 | 32.1 | 54.0 | -21.9 |
| 8125.875* | Peak | 7.7 | -20.0 | 46.0 | 33.7 | 54.0 | -20.3 |
| 9028.750* | Peak | 4.0 | -20.0 | 47.5 | 31.5 | 54.0 | -22.5 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.13 Radiated Interference Measurements – Trace Antenna – Vertical Polarity

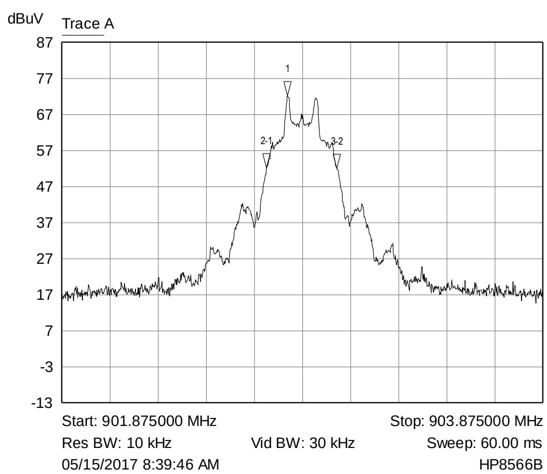
| Frequency (MHz) | Detector | Receiver Reading (dBµV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBµV/m) | Limit (dBµV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 64.8 | -20.0 | 35.8 | 80.6 | 81.9 | -1.3 |
| 1805.750 | Peak | 9.9 | -20.0 | 30.3 | 20.2 | 61.9 | -41.7 |
| 2708.625* | Peak | 8.3 | -20.0 | 34.0 | 22.3 | 54.0 | -31.7 |
| 3611.500* | Peak | 5.8 | -20.0 | 37.2 | 23.0 | 54.0 | -31.0 |
| 4514.375* | Peak | 14.2 | -20.0 | 38.9 | 33.1 | 54.0 | -20.9 |
| 5417.250* | Peak | 9.5 | -20.0 | 41.1 | 30.6 | 54.0 | -23.4 |
| 6320.125 | Peak | 3.7 | -20.0 | 42.3 | 26.0 | 61.9 | -35.9 |
| 7223.000* | Peak | 7.2 | -20.0 | 44.3 | 31.5 | 54.0 | -22.5 |
| 8125.875* | Peak | 3.7 | -20.0 | 46.0 | 29.7 | 54.0 | -24.3 |
| 9028.750* | Peak | 4.2 | -20.0 | 47.5 | 31.7 | 54.0 | -22.3 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.14 Radiated Interference Measurements – Trace Antenna – Horizontal Polarity

| Frequency (MHz) | Detector | Receiver Reading (dBμV) | Average Factor (dB) | Correction Factor (dB/m) | Field Strength (dBμV/m) | Limit (dBμV/m) | Delta (dB) |
|---|---|---|---|---|---|---|---|
| 902.875 | Peak | 63.3 | -20.0 | 35.8 | 79.1 | 81.9 | -2.8 |
| 1805.750 | Peak | 7.5 | -20.0 | 30.3 | 17.8 | 61.9 | -44.1 |
| 2708.625* | Peak | 8.0 | -20.0 | 34.0 | 22.0 | 54.0 | -32.0 |
| 3611.500* | Peak | 8.5 | -20.0 | 37.2 | 25.7 | 54.0 | -28.3 |
| 4514.375* | Peak | 21.0 | -20.0 | 38.9 | 39.9 | 54.0 | -14.1 |
| 5417.250* | Peak | 9.9 | -20.0 | 41.1 | 31.0 | 54.0 | -23.0 |
| 6320.125 | Peak | 3.5 | -20.0 | 42.3 | 25.8 | 61.9 | -36.1 |
| 7223.000* | Peak | 77.7 | -20.0 | 44.3 | 102.0 | 54.0 | 48.0 |
| 8125.875* | Peak | 4.3 | -20.0 | 46.0 | 30.3 | 54.0 | -23.7 |
| 9028.750* | Peak | 5.3 | -20.0 | 47.5 | 32.8 | 54.0 | -21.2 |
| *** Emissions within restricted bands** | | | | | | | |

### 6.2.15 §15.231 (c) Bandwidth

The bandwidth of the emission must not be wider than 0.5% of the center frequency. The center frequency is 902.875 MHz, therefore the bandwidth must not be wider than 4514.375 kHz. The TCM 515U 20 dB bandwidth was 292 kHz. See spectrum analyzer plot below.




| Mkr | X-Axis | Value | Notes |
|---|---|---|---|
| 1 ▽ | 902.813000 MHz | 72.2000 dBuV | |
| 2-1 ▽ | -88.000000 kHz | -20.1000 dB | |
| 3-2 ▽ | 292.000000 kHz | -0.1000 dB | |

**Graph 4: Bandwidth Plot.**

**Result**

In the configuration tested, the EUT complied with the requirements of this section.

## 6.3 Sample Field Strength Calculation

The field strength is calculated by adding the *Correction Factor* (*Antenna Factor* + *Cable Factor*), to the measured level from the receiver. The receiver amplitude reading is compensated for any amplifier gain. The basic equation with a sample calculation is shown below:

$$Receiver\ Amplitude\ Reading = Receiver\ Reading - Amplifier\ Gain$$

$$Correction\ Factor = Antenna\ Factor + Cable\ Factor$$

$$Field\ Strength = Receiver\ Amplitude\ Reading + Correction\ Factor + Averaging\ Factor$$

**Example**

Assuming a *Receiver Reading* of 42.5 dBμV is obtained from the receiver, the *Amplifier Gain* is 26.5 dB the *Antenna Factor* is 4.5 dB, the *Cable Factor* is 4.0 dB, and the *Averaging Factor* is -6.0. The *Field Strength* is calculated by subtracting the *Amplifier Gain* and adding the *Correction Factor* and *Averaging Factor*, giving a *Field Strength* of 18.5 dBμV/m.

$$Receiver\ Amplitude\ Reading = 42.5 - 26.5 = 16.0\ \mathrm{dB\mu V/m}$$

$$Correction\ Factor = 4.5 + 4.0 = 8.5\ \mathrm{dB}$$

$$Averaging\ Factor = -6.0$$

$$Field\ Strength = 16.0 + 8.5 + (-6.0) = 18.5\ \mathrm{dB\mu V/m}$$

# 7 Test Procedures and Test Equipment

## 7.1 Conducted Emissions at Mains Ports

The conducted emissions at mains and telecommunications ports from the EUT were measured using a spectrum analyzer with a quasi-peak adapter for peak, quasi-peak and average readings. The quasi-peak adapter uses a bandwidth of 9 kHz, with the spectrum analyzer's resolution bandwidth set at 100 kHz, for readings in the 150 kHz to 30 MHz frequency ranges.

The conducted emissions at mains ports measurements are performed in a screen room using a (50 Ω/50 μH) Line Impedance Stabilization Network (LISN).

Where mains flexible power cords are longer than 1 m, the excess cable is folded back and forth as far as possible so as to form a bundle not exceeding 0.4 m in length.

Where the EUT is a collection of devices with each device having its own power cord, the point of connection for the LISN is determined from the following rules:

- Each power cord, which is terminated in a mains supply plug, shall be tested separately.
- Power cords, which are not specified by the manufacturer to be connected via a host unit, shall be tested separately.
- Power cords which are specified by the manufacturer to be connected via a host unit or other power supplying equipment shall be connected to that host unit and the power cords of that host unit connected to the LISN and tested.
- Where a special connection is specified, the necessary hardware to effect the connection is supplied by the manufacturer for the testing purpose.
- When testing equipment with multiple mains cords, those cords not under test are connected to an artificial mains network (AMN) different than the AMN used for the mains cord under test.

For testing, desktop EUT are placed on a non-conducting table at least 0.8 meters from the metallic floor and placed 40 cm from the vertical coupling plane (copper plating in the wall behind EUT table). Floor standing equipment is placed directly on the earth grounded floor.

| Type of Equipment | Manufacturer | Model Number | Asset Number | Date of Last Calibration | Due Date of Calibration |
|---|---|---|---|---|---|
| Spectrum Analyzer | Hewlett Packard | 8566B | V034141 | 02/15/2017 | 02/15/2018 |
| Quasi-Peak Detector | Hewlett Packard | 85650A | V039474 | 03/16/2017 | 03/16/2018 |
| LISN | VPI Labs | LISN-COMM-50 | V034042 | 02/24/2017 | 02/24/2018 |
| Conductance Cable Wanship Upper Site | VPI Labs | Cable J | V034832 | 01/09/2017 | 01/09/2018 |
| Transient Limiter | Hewlett Packard | 11947A | V033591 | 01/09/2017 | 01/09/2018 |
| Test Software (AC) | VPI Labs | Revision 01 | V035674 | N/A | N/A |

**Table 4: List of equipment used for conducted emissions testing at mains ports.**

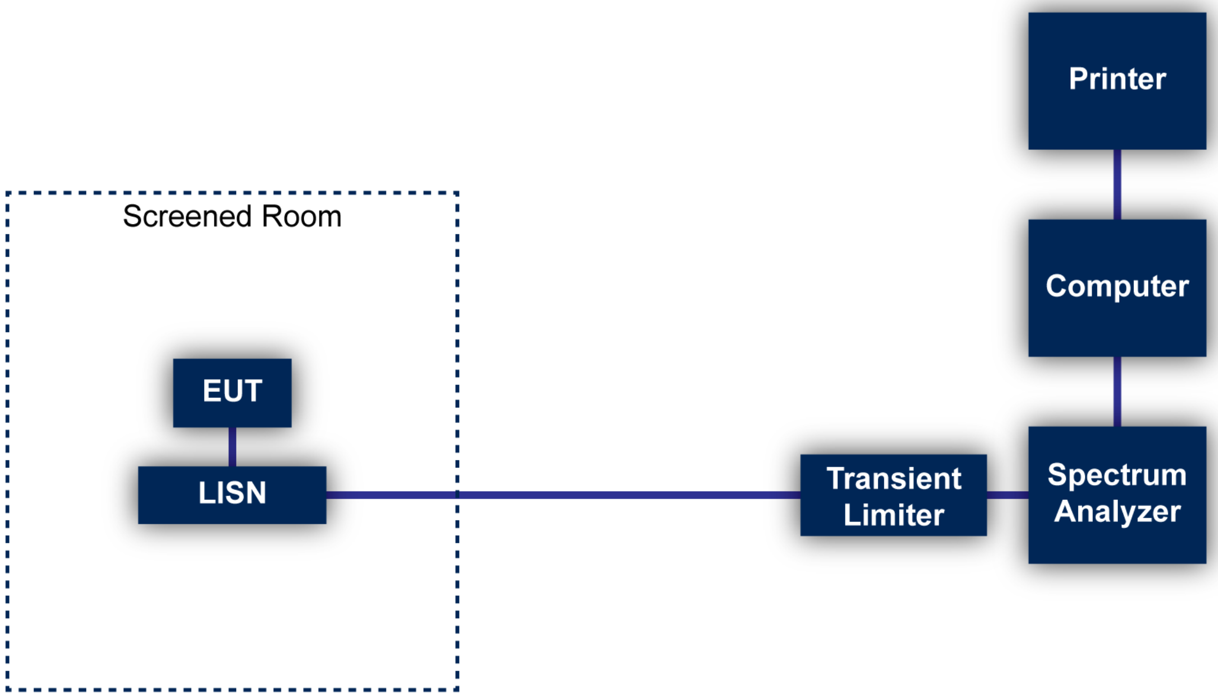



**Figure 1: Conducted Emissions Test**

## 7.2 Radiated Emissions

The radiated emissions from the EUT were measured using a spectrum analyzer with a quasi-peak adapter for peak and quasi-peak readings.

A preamplifier with a fixed gain of 26 dB and a power amplifier with a fixed gain of 22 dB were used to increase the sensitivity of the measuring instrumentation. The quasi-peak adapter uses a bandwidth of 120 kHz, with the spectrum analyzer's resolution bandwidth set at 1 MHz, for readings in the 30 to 1000 MHz frequency ranges. For frequencies below 30 MHz, a 9 kHz resolution bandwidth was used.

A loop antenna was used to measure frequencies below 30 MHz. A biconilog antenna was used to measure the frequency range of 30 to 1000 MHz, at a distance of 10 meters from the EUT. The readings obtained by these antennas are correlated to the levels obtained with a tuned dipole antenna by adding antenna factors. A double-ridged guide antenna was used to measure the emissions at frequencies above 1000 MHz at a distance of 3 and/or 1 meter from the EUT.

The configuration of the EUT was varied to find the maximum radiated emission. The EUT was connected to the peripherals listed in Section 2.3 via the interconnecting cables listed in Section 2.4. A technician manually manipulated these interconnecting cables to obtain worst-case radiated emissions. The EUT was rotated 360 degrees, and the antenna height was varied from 1 to 4 meters to find the maximum radiated emission. Where there were multiple interface ports all of the same type, cables are either placed on all of the ports or cables added to these ports until the emissions do not increase by more than 2 dB.

Desktop EUT are measured on a non-conducting table 0.8 meters above the ground plane. For frequencies above 1000 MHz, the EUT is placed on a table 1.5 meters above the ground plane. The table is placed on a turntable, which is level with the ground plane. For equipment normally placed on floors, the equipment shall be placed directly on the turntable.

For radiated emissions testing that is performed at distances closer than the specified distance; an inverse proportionality factor of 20 dB per decade is used to normalize the measured data for determining compliance.

| Type of Equipment | Manufacturer | Model Number | Asset Number | Date of Last Calibration | Due Date of Calibration |
|---|---|---|---|---|---|
| Spectrum Analyzer/Receiver | Rohde & Schwarz | ESU40 | V033119 | 06/17/2016 | 06/17/2017 |
| Spectrum Analyzer | Hewlett Packard | 8566B | V034141 | 02/15/2017 | 02/15/2018 |
| Quasi-Peak Detector | Hewlett Packard | 85650A | V039474 | 03/16/2017 | 03/16/2018 |
| Loop Antenna | EMCO | 6502 | V034216 | 01/25/2017 | 01/25/2019 |
| Biconilog Antenna | EMCO | 3142E-PA | V035736 | 06/24/2016 | 06/24/2018 |
| Double Ridged Guide Antenna | EMCO | 3115 | V033469 | 02/09/2016 | 02/09/2018 |
| Standard Gain Horn | ETS-Lindgren | 3160-09 | V034223 | ICO | ICO |
| High Frequency Amplifier | Miteq | AFS4-001018000-35-10P-4 | V033997 | 01/09/2017 | 01/09/2018 |
| 6' High Frequency Cable | Microcoax | UFB197C-0-0720-000000 | V033638 | 01/09/2017 | 01/09/2018 |
| 20' High Frequency Cable | Microcoax | UFB197C-1-3120-000000 | V033979 | 01/09/2017 | 01/09/2018 |
| 3 Meter Radiated Emissions Cable Wanship Upper Site | Microcoax | UFB205A-0-4700-000000 | V033639 | 01/09/2017 | 01/09/2018 |
| 10 Meter Radiated Emissions Cable Wanship Upper Site | VPI Labs | Cable L | V033649 | 01/09/2017 | 01/09/2018 |
| Pre/Power-Amplifier | Hewlett Packard | 8447F | V034218 | 09/07/2016 | 09/07/2017 |
| Test Software (FCC) | VPI Labs | Revision 01 | V035673 | N/A | N/A |

**Table 5: List of equipment used for radiated emissions testing.**

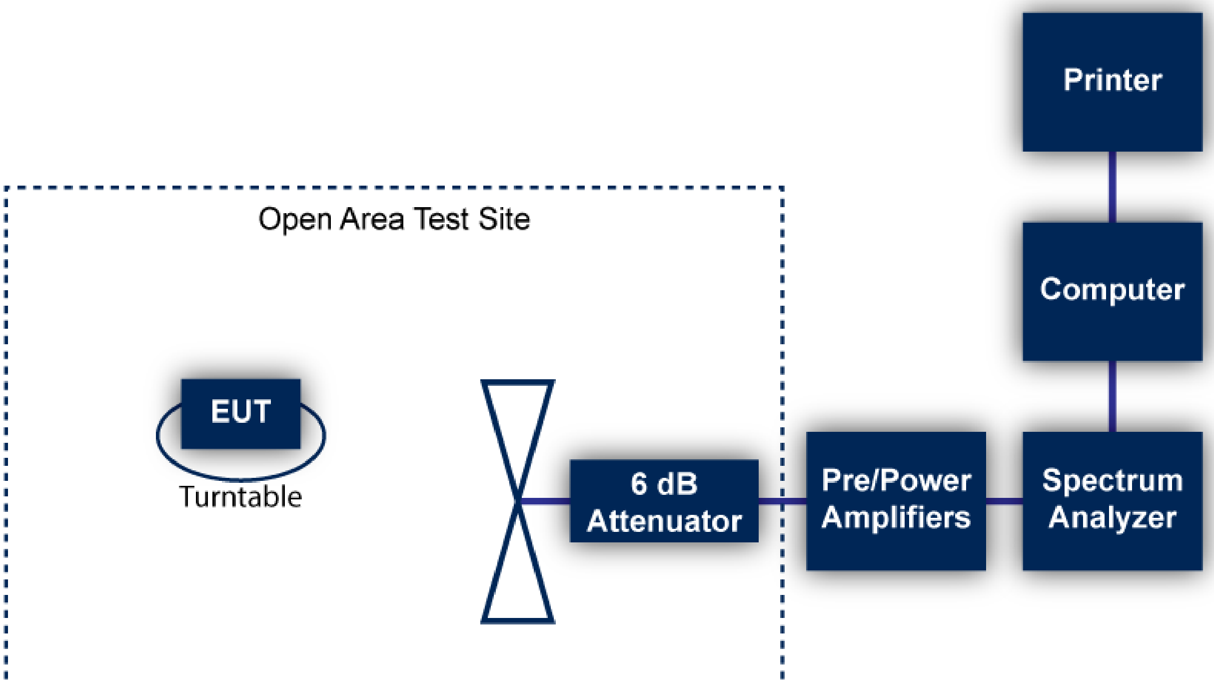



**Figure 2: Radiated Emissions Test**

## 7.3 Equipment Calibration

All applicable equipment is calibrated using either an independent calibration laboratory or VPI Laboratories, Inc. personnel at intervals defined in ANSI C63.4:2014 following outlined calibration procedures. All measurement instrumentation is traceable to the National Institute of Standards and Technology (NIST). Supporting documentation relative to tractability is on file and is available for examination upon request.

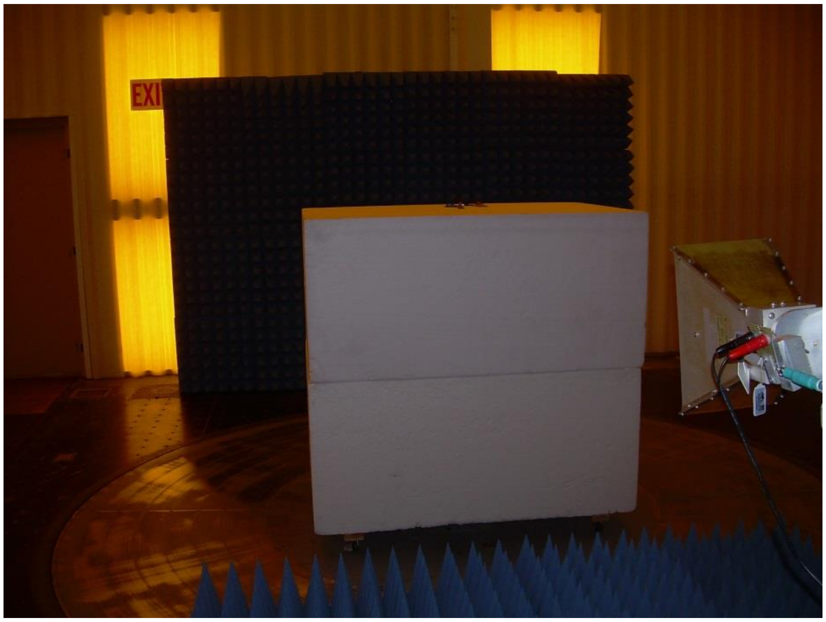
## 7.4 Measurement Uncertainty

| Test | Uncertainty (±dB) | Confidence (%) |
|---|---|---|
| Conducted Emissions | 2.8 | 95 |
| Radiated Emission (9 kHz to 30 MHz) | 3.3 | 95 |
| Radiated Emissions (30 MHz to 1 GHz) | 3.4 | 95 |
| Radiated Emissions (1 GHz to 18 GHz) | 5.0 | 95 |
| Radiated Emissions (18 GHz to 40 GHz) | 4.1 | 95 |

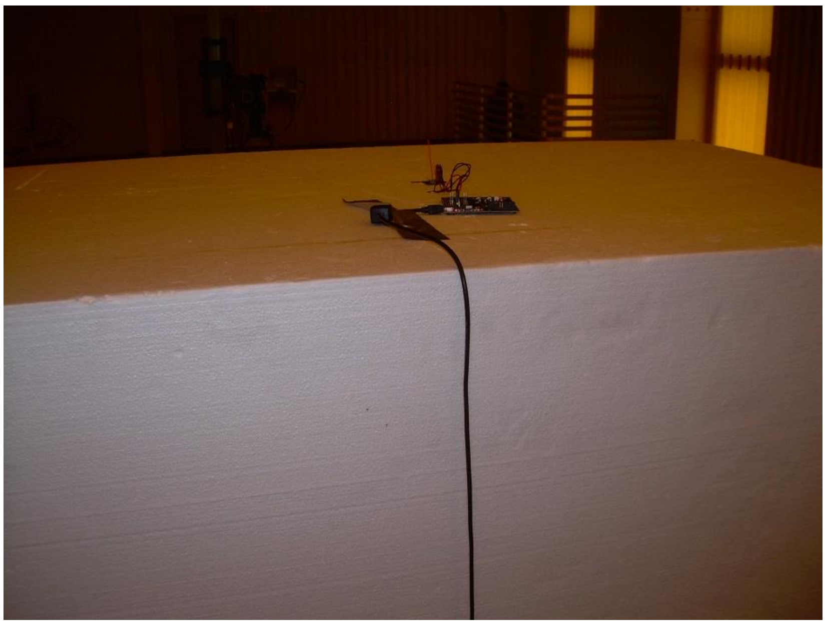
# 8 Photographs

**Photograph 1 – Front View Radiated Emissions Configuration – Whip Antenna – Emissions Below 1000 MHz**

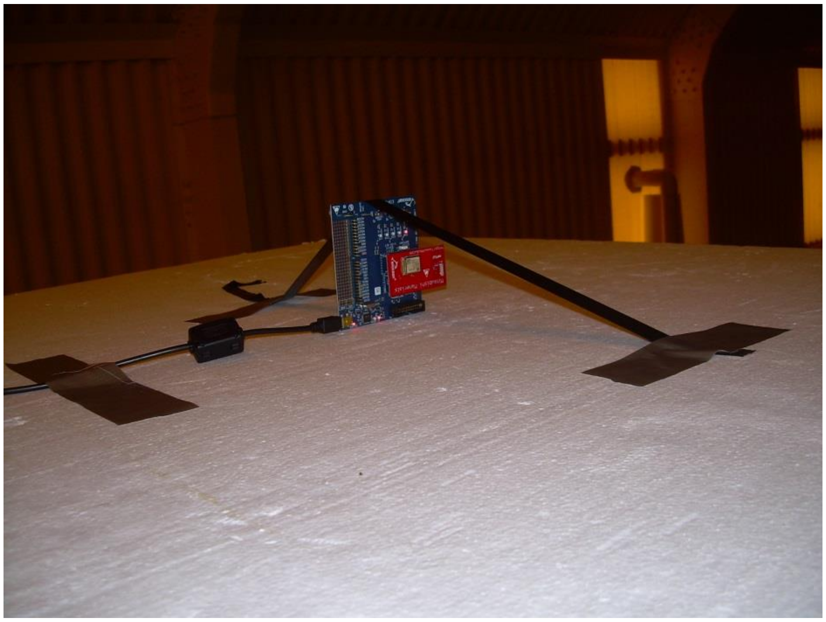
**Photograph 2 – Back View Radiated Emissions Configuration – Emissions 30 – 1000 MHz**



**Photograph 3 – Front View Radiated Emissions Configuration – Whip Antenna – Emissions Above 1000**

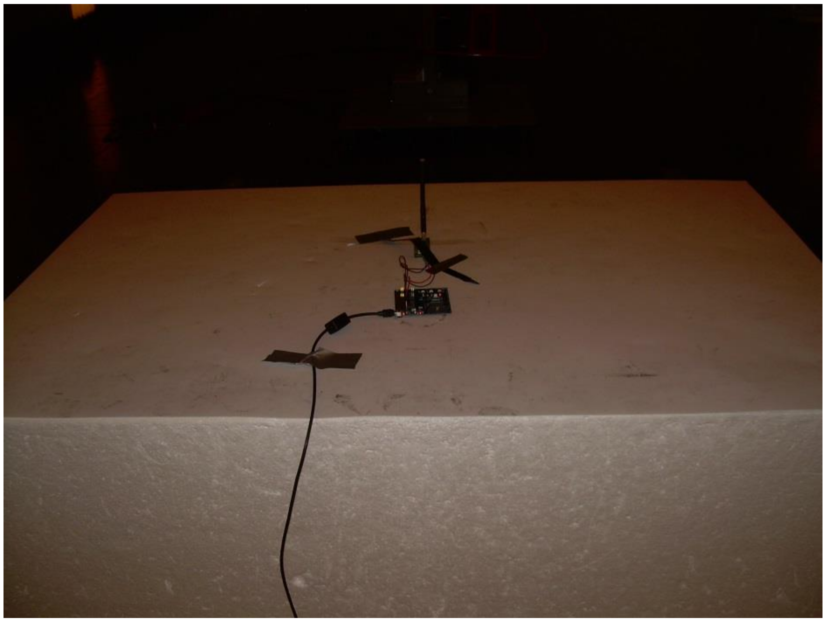


**Photograph 4 – Back View Radiated Emissions Configuration – Whip Antenna – Emissions Above 1000**

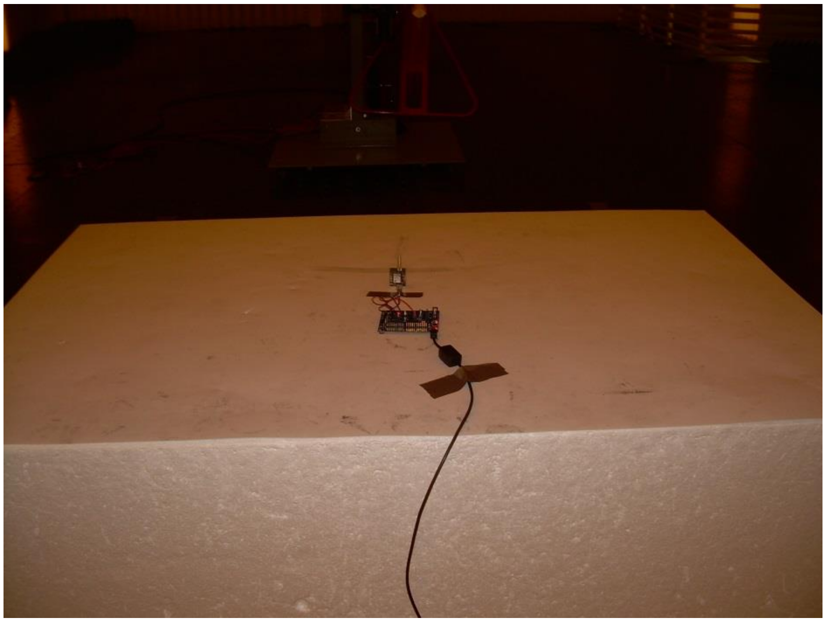


**Photograph 5 – Back View Radiated Emissions Configuration – Chip Antenna On Edge Placement**

**Photograph 6 – Back View Radiated Emissions Configuration – Trace Antenna Vertical Placement**

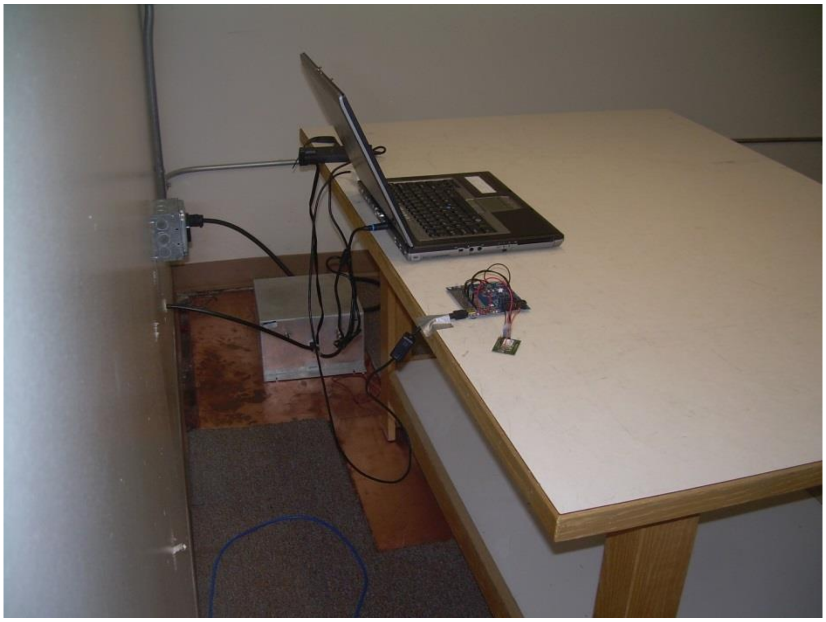


**Photograph 7 – Back View Radiated Emissions Configuration – SMA Antenna Vertical Placement**

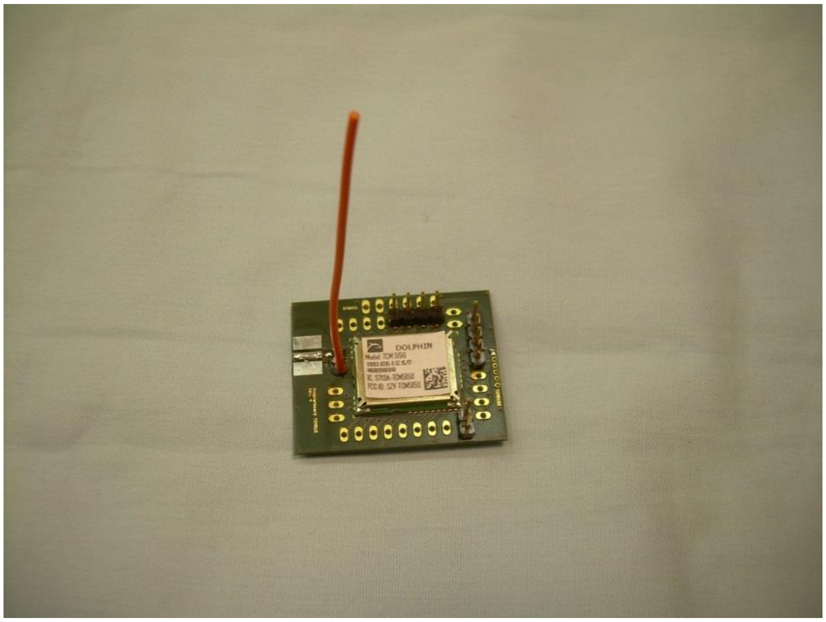


**Photograph 8 – Back View Radiated Emissions Configuration – Helical Antenna Vertical Placement**

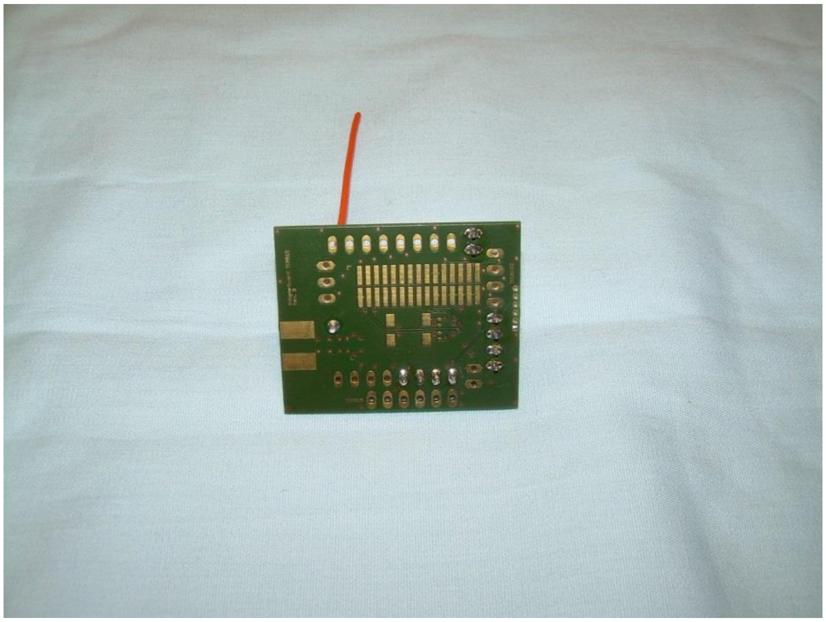
**Photograph 9 - Front View Conducted Emissions Worst Case Configuration**



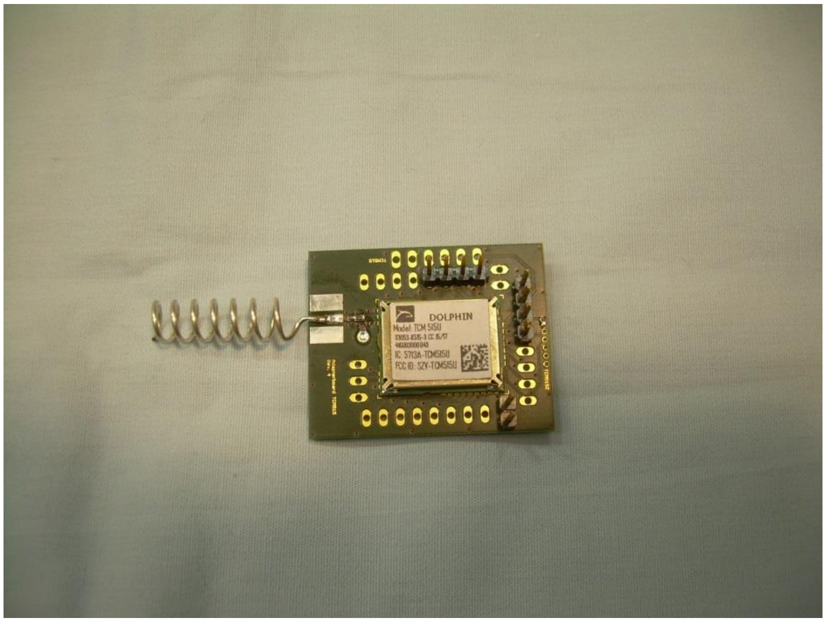
**Photograph 10 - Back View Conducted Emissions Worst Case Configuration**



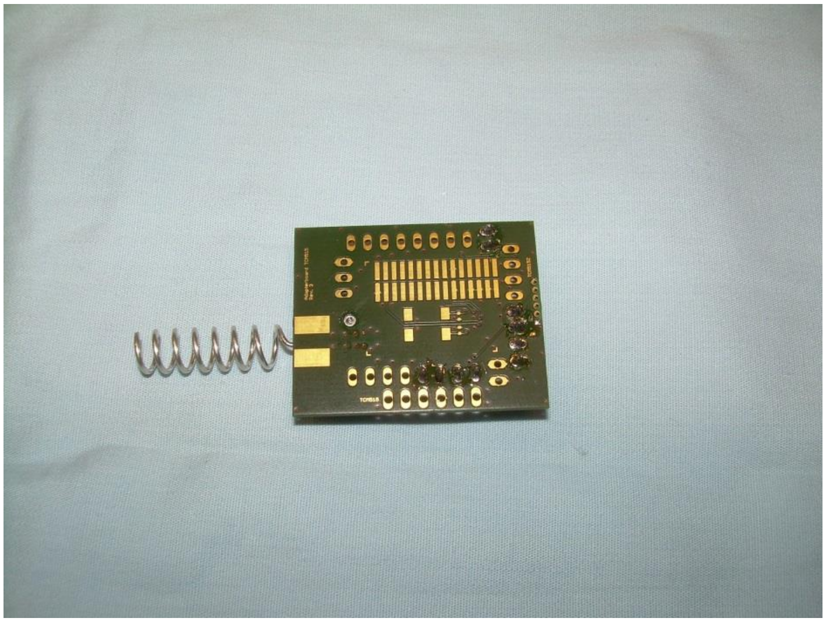

**Photograph 11 - Front View of the EUT – Whip Antenna**



**Photograph 12 - Back View of the EUT – Whip Antenna**

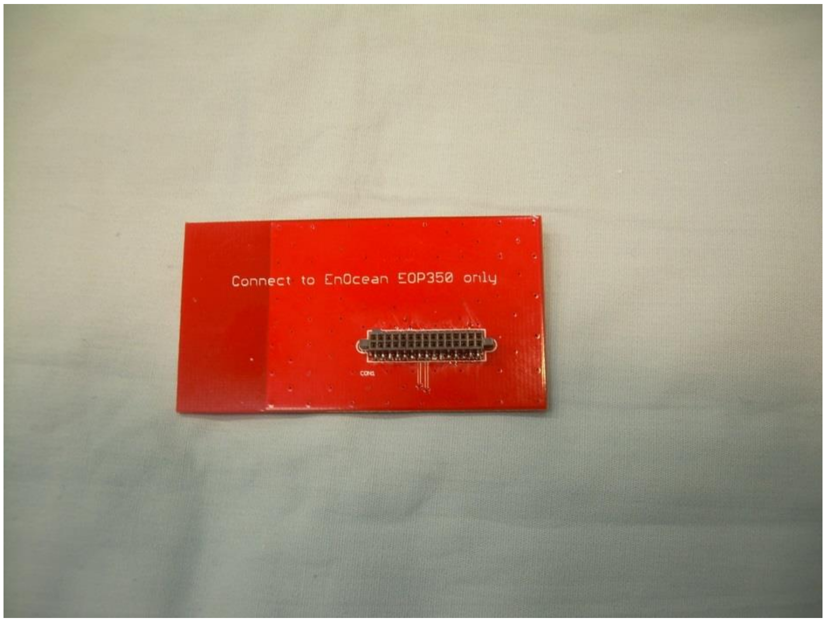



**Photograph 13 - Front View of the EUT – Helical Antenna**

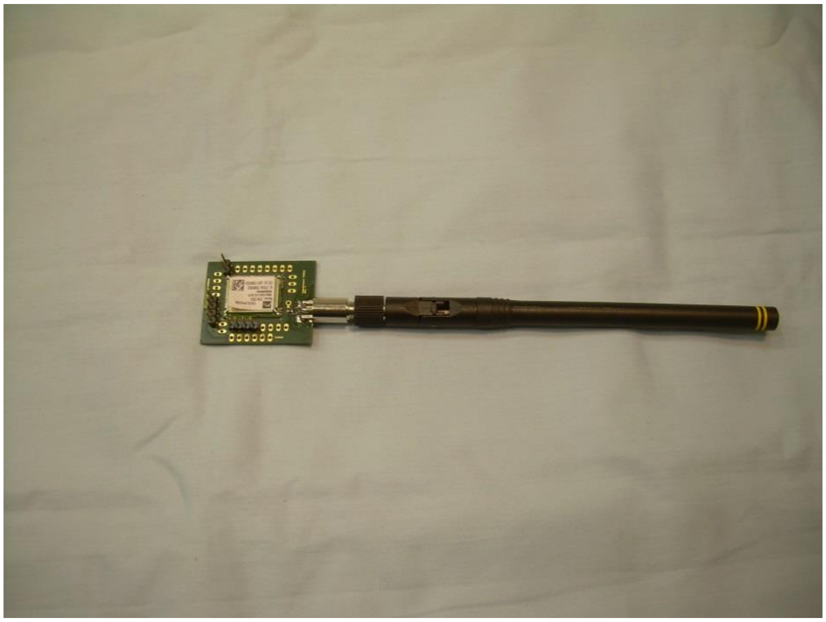


**Photograph 14 - Back View of the EUT – Helical Antenna**

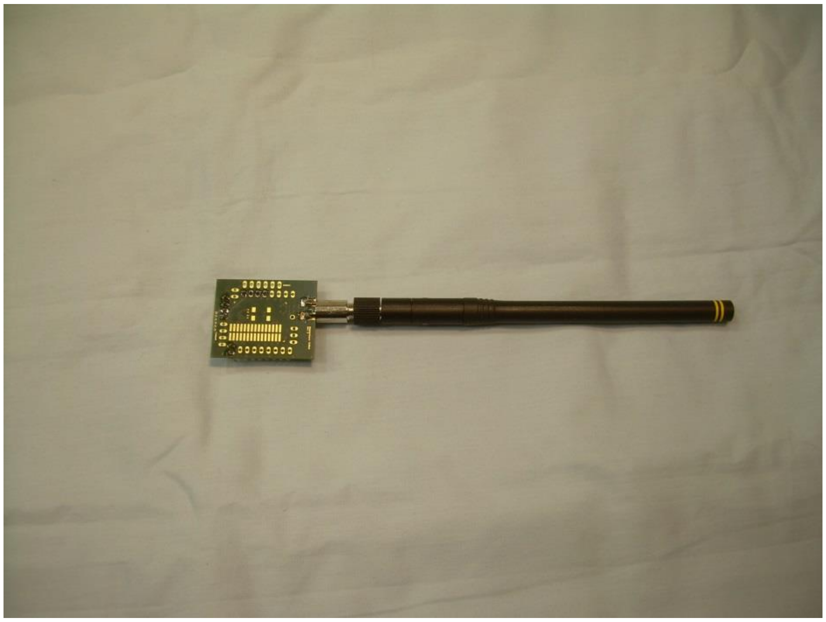

**Photograph 15 - Front View of the EUT – Chip Antenna**



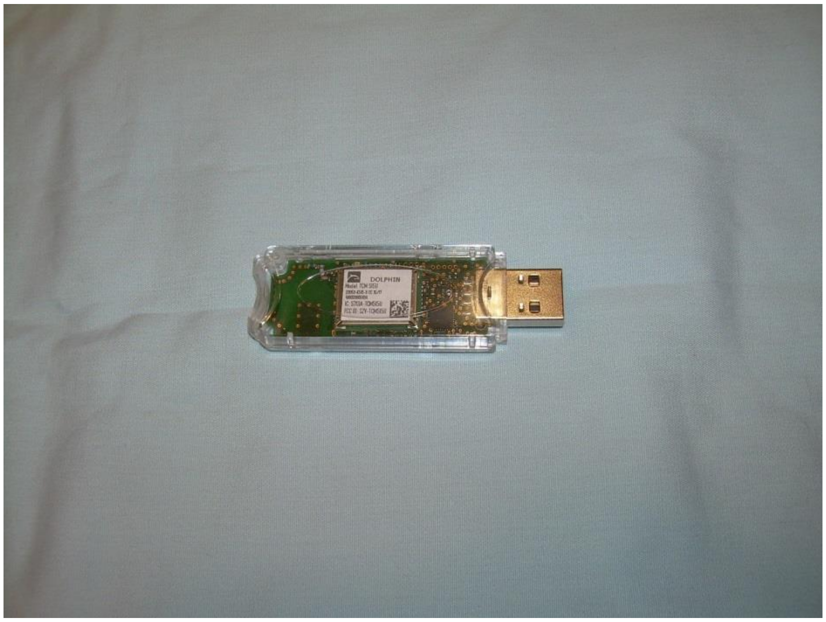

**Photograph 16 - Back View of the EUT – Chip Antenna**



**Photograph 17 - Front View of the EUT – RP-SMA Antenna**

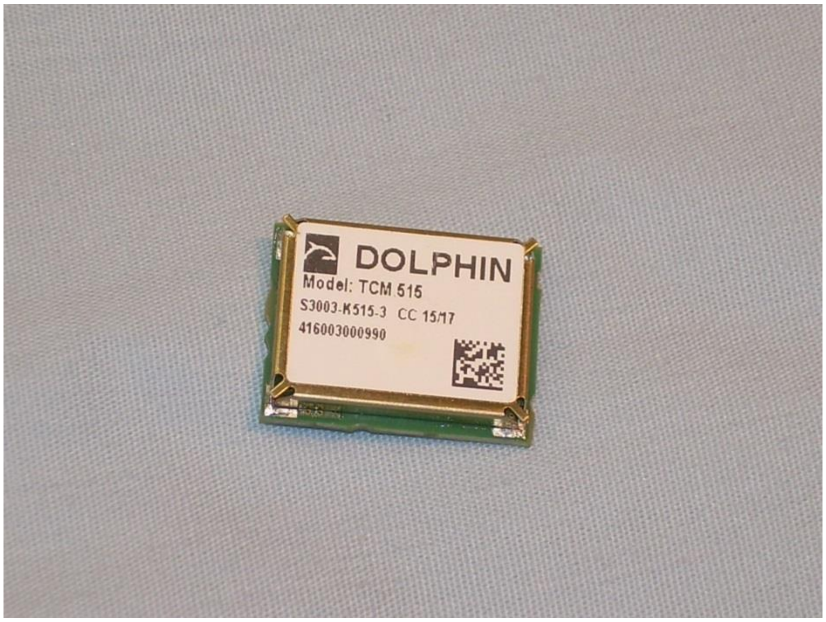


**Photograph 18 - Back View of the EUT – RP-SMA Antenna**

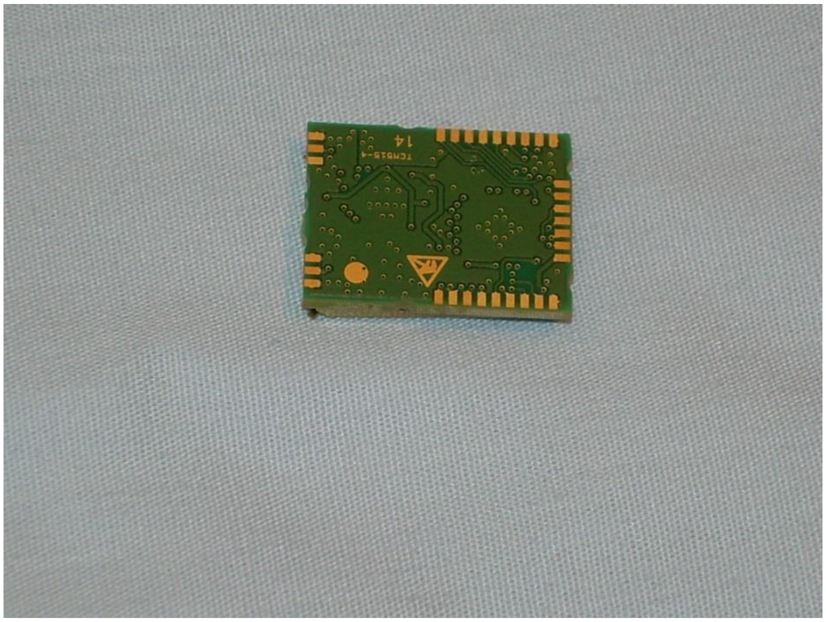


**Photograph 19 - Front View of the EUT – Trace Antenna**

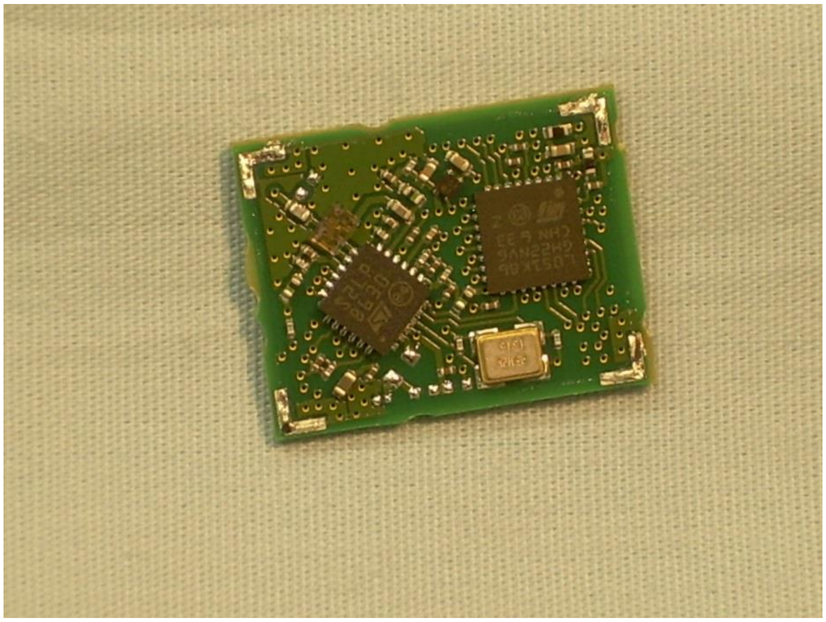
**Photograph 20 - Back View of the EUT – Trace Antenna**




**Photograph 21 – Top View of the Module**

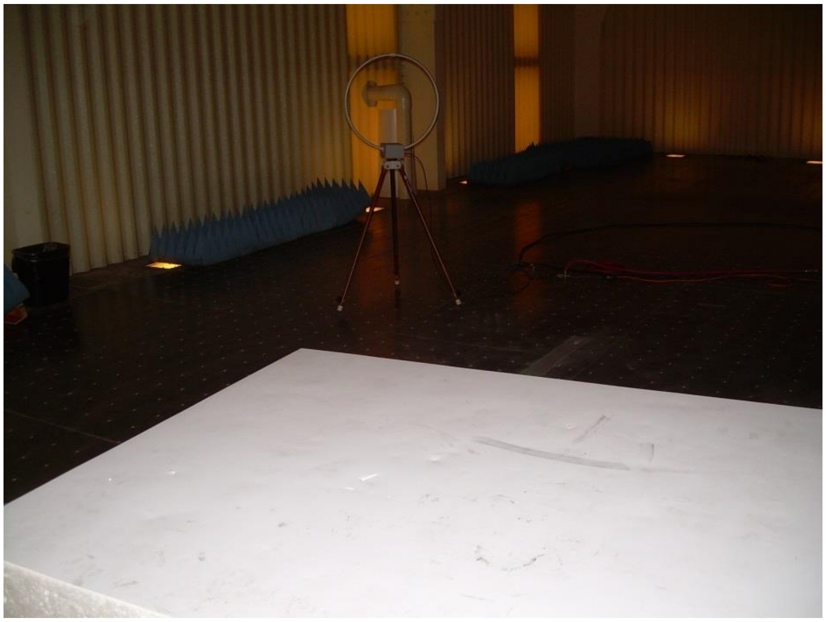


**Photograph 22 – Top View of the Module**

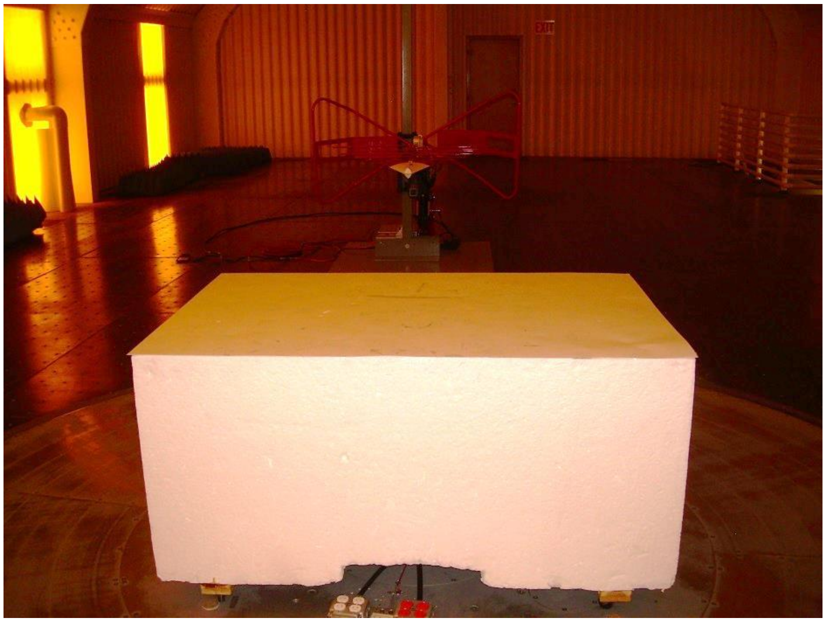


**Photograph 23 – RF Shield Removed Showing Components Underneath**

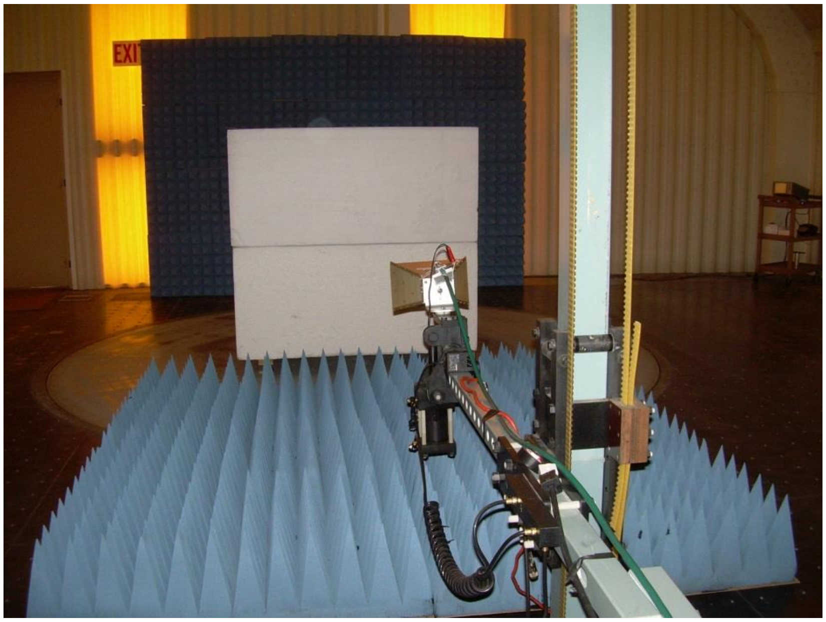
**Reference Test Set Up Photographs**



**Photograph 24: Test Setup for Emissions Below 30 MHz**



**Photograph 25: Test Setup for Emission from 30 MHz to 1000 MHz**



**Photograph 26: Test Setup for Emissions Above 1000 MHz**

**--- End of Report ---**