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Author(s):	Macdonell, Alexander Thomas Meierbachtol, Krista Cruse Evans, James Walter Jr. Mayo, Douglas R.
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EMR Measurements on NDA Equipment

Alexander T. Macdonell Krista C. Meierbachtol James W. Evans Jr.
Douglas R. Mayo

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Abstract

Electromagnetic radiation (EMR) emission strength measurements were performed on a suite of passive non-destructive assay (NDA) radiation detection equipment. Data were collected from 9 kHz up to 6 GHz on each of the assembled systems.

1 Introduction

The electromagnetic radiation (EMR) emission strengths from various passive neutron and γ-ray radiation detection systems were measured in a Gigahertz Transverse Electromagnetic (GTEM) cell. The detector systems measured are described in Table 1. The methodology used by the personnel in A-3 to measure the EMR emissions strengths, electric field calculations, and the results of the measurements are presented in the following sections.

Table 1: Detection Systems Description

Detector Name	**Detection System Description**
Fluke 451B	A COTS, handheld alkaline battery operated (two 9 volt batteries) unit using an ion chamber to measure dose and dose rates for X-/γ-rays and beta particles for radiation protection and health physics measurements. A user reads the measured values from the instrument.

Table 1: Detection Systems Description (continued)

Detector Name	Detection System Description
MC-15	The multiplicity counter - 15 (MC-15) is a joint design of LANL, LLNL, and SNL for a portable neutron multiplicity counter. Onboard high voltage, signal processing, and data analysis and acquisition allow for the combining of two sets of detectors into one data stream. Up to two external inputs, such as a SNAP III may be plugged in and recorded as well. Data may be taken onboard or through a data acquisition laptop (Dell Latitude E7470 Ultrabook) over an ethernet connection. All were operated with 120V AC without the batteries, as they will be operated without internal batteries.
NSpec	The neutron spectrometer (NSpec) is a scintillation detector based upon NE213 (xylene liquid). An external high voltage power supply (CAEN DT5533N) and digitizer (CAEN DT5730) are controlled by a data acquisition laptop (Dell Latitude E7470 Ultrabook) through a USB Extender (USB 2.0 Ranger 2244), which are all powered by 120V AC.
ORTEC Detective	The Ortec Detective is a commercially available detector that utilizes a smaller HPGe crystal. It is considered a handheld system. Data can be transferred from onboard storage or by USB cable and/or USB Extender.
ORTEC HPGe	A high purity germanium (HPGe) detector that is typically cooled by liquid nitrogen. In this application we will be primarily utilizing the commercially available Integrated Cryocooling systeme (ORTEC ICS-P4), with the commercially available XCooler III as a backup to keep the detector at cryogenic temperatures. This system will also include two DSPEC Pros, which provide HV and signal processing for the detector. The DSPEC Pros are connected to a laptop data acquisition system (Dell Latitude E7470 Ultrabook) hrough a USB Extender (USB 2.0 Ranger 2244), which are all powered by 120V AC.
REMBall	A portable neutron dose rate meter that is powered by two 'D' cell alkaline batteries and commercially made by Ludlum. A user reads the measured values from the instrument.
SNAP III	The Shielded Neutron Assay Probe (SNAP) model III is a LANL designed and manufactured portable neutron counter. The SNAP III can either be read out by the operator or is recorded through a shielded cable to the MC-15. In the field these are typically operated on internal Li-ion batteries, but were removed for this application and operated on 120V AC.

2 Test Equipment and Setup

The NDA equipment measured for EMR emissions were performed in the A-3 laboratory at TA-49 utilizing an ETS-Lingren Model 5405 GTEM cell, which allows for valid measurements down to levels of -80 dBm. Background emission spectra were recorded prior to each test. In addition to background measurements, a measurement control reference signal was injected, utilizing a transmitting antenna placed approximately two (2) meters from the end of the GTEM septum. This measurement control served two purposes. The primary was to verify GTEM operation. The second was to provide a reference value for power injected to compare to that measured from devices under test (DUT).

The general test setup is illustrated in Figure 1. The DUT were placed approximately 1.5 meters from the end fo the GTEM septum. The emissions data were collected using the Signal Hound BB60C spectrum analyzer hardware, with configuration parameters listed in Table 2. Please note that data was recorded from 9 kHz up to 6.0 GHz in 100 kHz steps.

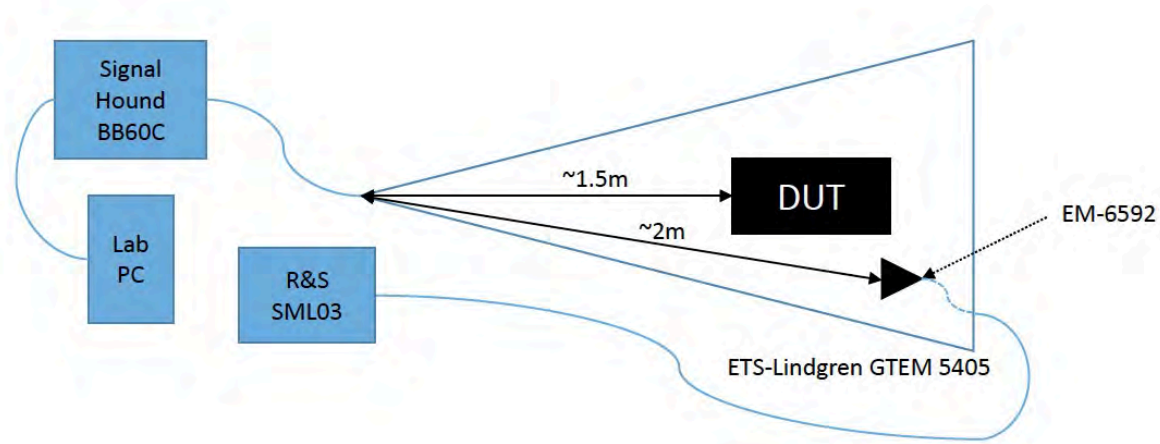


Fig. 1: General Test Setup

Table 2: Spectrum Analyzer Configuration

Specification	Value
Frequency (min)	200 kHz
Frequency (max)	6.0 GHz
Resolution Bandwidth	100 kHz

Although the BB60C is designed to measure below 200 kHz, baseline noise levels were found to be too high for measurements in that region to be valid. At the lower ends (near DC), some spurious noise was noted below 200 kHz. The observed variability in the noise floor at the lower frequencies varied between -25 dBm and -40 dBm. This was equivalent to approximately 2.5 mV/m, which was larger than any of the values seen in the spectrum of the DUT.

The reference signal used for measurement control was injected into the background measurements utilizing an Electro-Metrics EM-6592 log-periodic transmitting antenna. The signal was generated by a Rohde & Schwarz SML03 signal generator. It was set to a level of -30 dBm in the GTEM cell at a frequency of 3.10 GHz.

3 Electric Field Calculations

The data recorded by the spectrum analyzer was in terms of measured power [dBm]. This can be converted to electric field data of millivolts per meter [mV/m] through the parallel plate approximation:

$$\mathbf{E} = \left(\frac{1}{h}\right)(\mathbf{P} \times \mathbf{Z_0})^{1/2} \tag{1}$$

where $\mathbf{E}$ is the electric field in volts per meter [V/m], h is the height of the septum over the GTEM floor at the position of the DUT in meters [m], $\mathbf{P}$ is the radiated power in watts [W], and Z_0 is the characteristic impedance of the GTEM (50 ohms [Ω]). Please note that the calculated electric field strength is valid at h, which is roughly 0.5 m from the receiving antenna in this configuration.

To ensure the accuracy of the measurements taken, the DUT was rotated through 90 degrees in the x-y plane (horizontal plane) and remeasured. A third measurement with the DUT rotated into the z-plane (vertical plane) is theoretically warranted for proper EMR testing, but was impractical for this testing due to the items being measured relative to the size of the chamber. The addition of fixtures would further complicate the measurements.

4 Testing Configurations

From the detector systems listed in Table 1, the following configurations were each tested to reduce the overall number of measurements needed:

- Background + Reference Signal
- Fluke 451B
- MC-15 (x2) + SNAP III + laptop computer
- Neutron Spectrometer - Detectors + HV Powersupply + Digitizer + Laptop
- Ortec Detective + laptop computer
- ORTEC HPGe + DSPEC Pro + XCooler III/ICS-P4+ laptop computer
- REMBall
- Supporting Hardware

5 EMR Emission Strength Results

The following presents the measurement results in terms of radiated power [dBm and nW] and electric field [mV/m]

5.1 Background and Reference Signal Data

Although background data were taken between every set of measurements, it was very consistent measurement to measurement. The background plus reference signal are shown in Figures 2, 3, and 4.

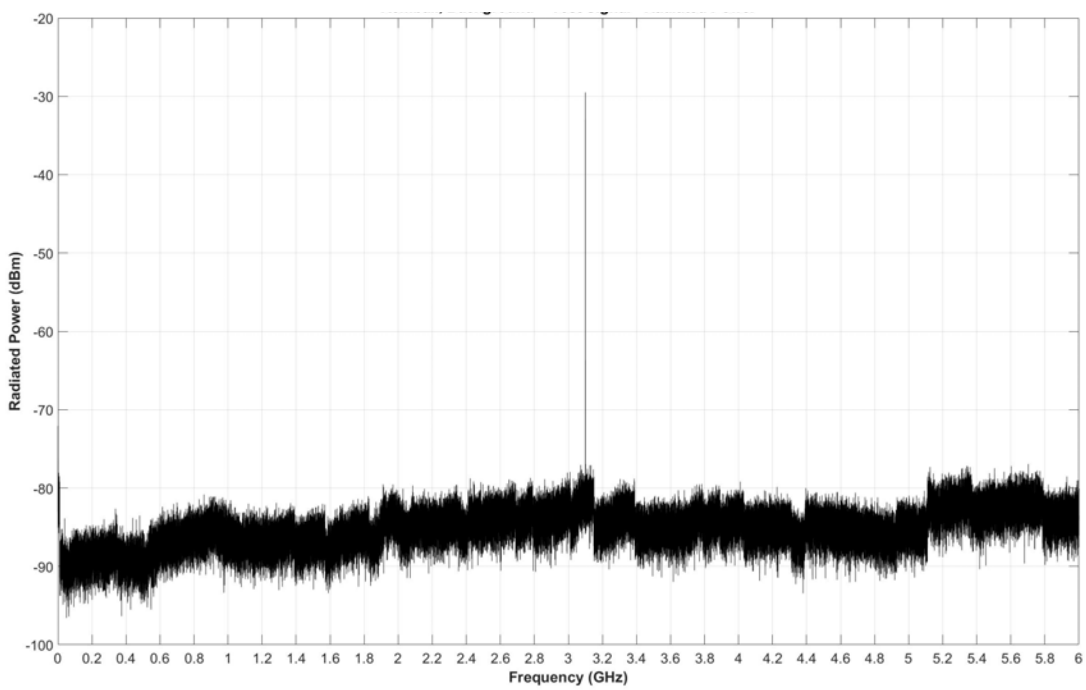


Fig. 2: Background Power Spectrum with Reference Signal [dBm]

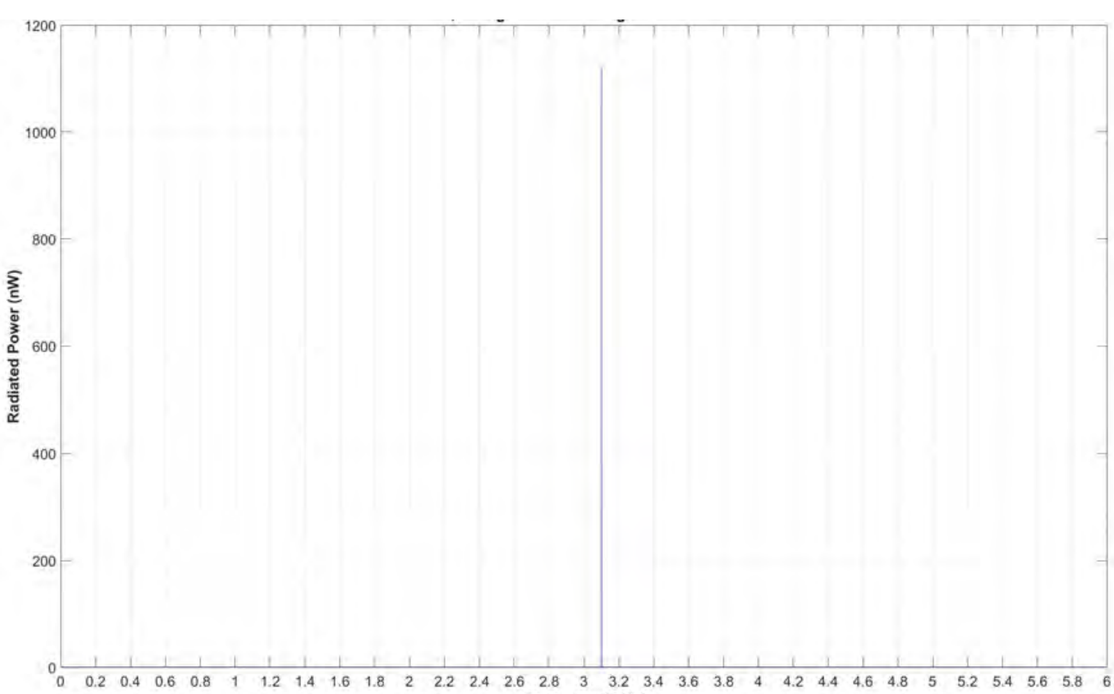


Fig. 3: Background Power Spectrum with Reference Signal [nW]

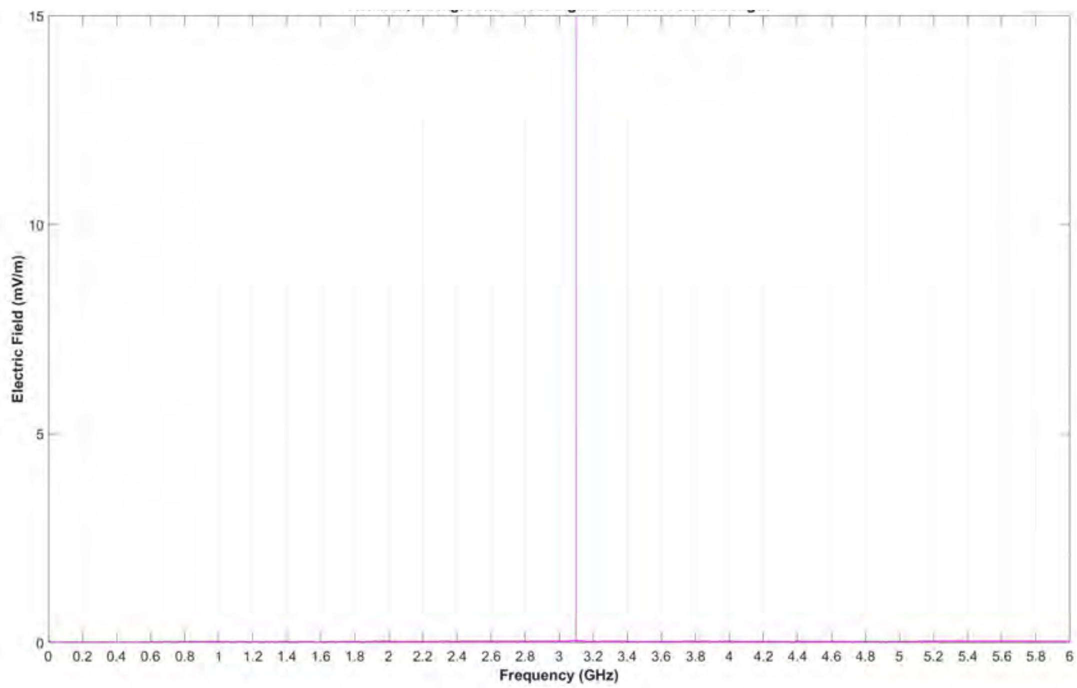


Fig. 4: Background Electric Field Strength with Reference Signal [mV/m]

5.2 Fluke 451B Results

The Fluke 451B detector, shown in Figure 5, was measured while turned on and collecting data using a reference level of -25 dBm. Results are shown below in Figures 6-8 for the initial orientation, and Figures 9-11 for the 90 degree rotation. The largest emission noted was at a power level of -76 dBm, which corresponds to around 0.02 nW and an electric field strength of 0.06 mV/m. These emissions were very close the noise floor and can be considered negligible. The FLUKE 451B meets Directive 2014/30/EU, Electromagnetic Compatibility (EMC).

Fig. 5: Picture of fluke detector

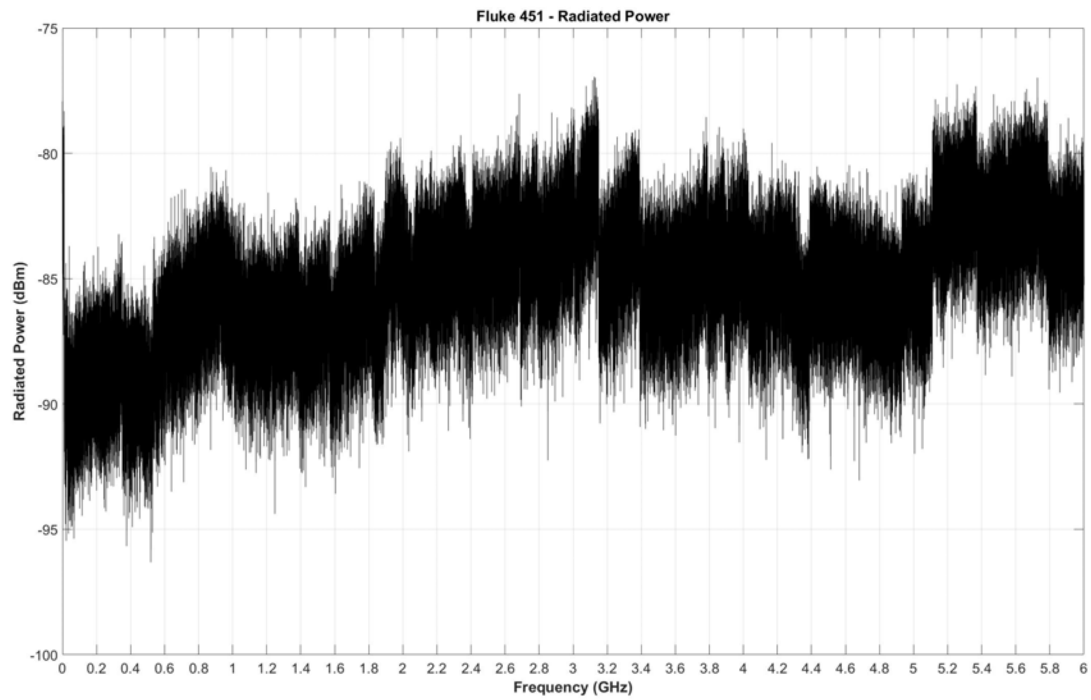


Fig. 6: Fluke Radiated Power [dBm]

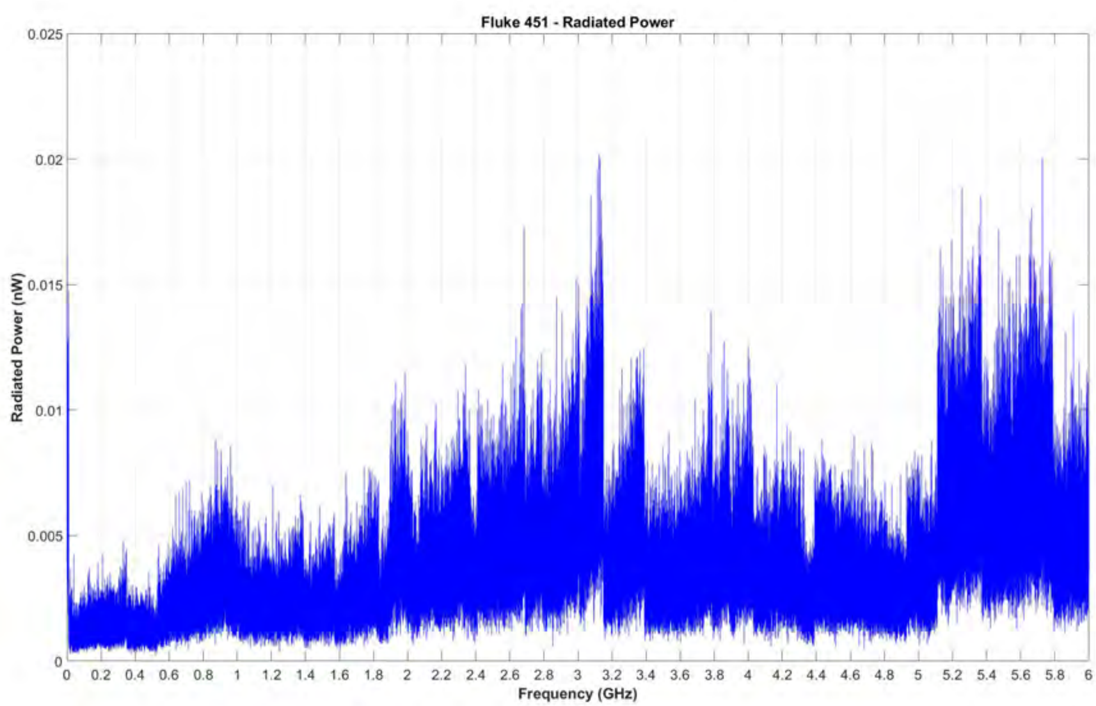


Fig. 7: Fluke Radiated Power [nW]

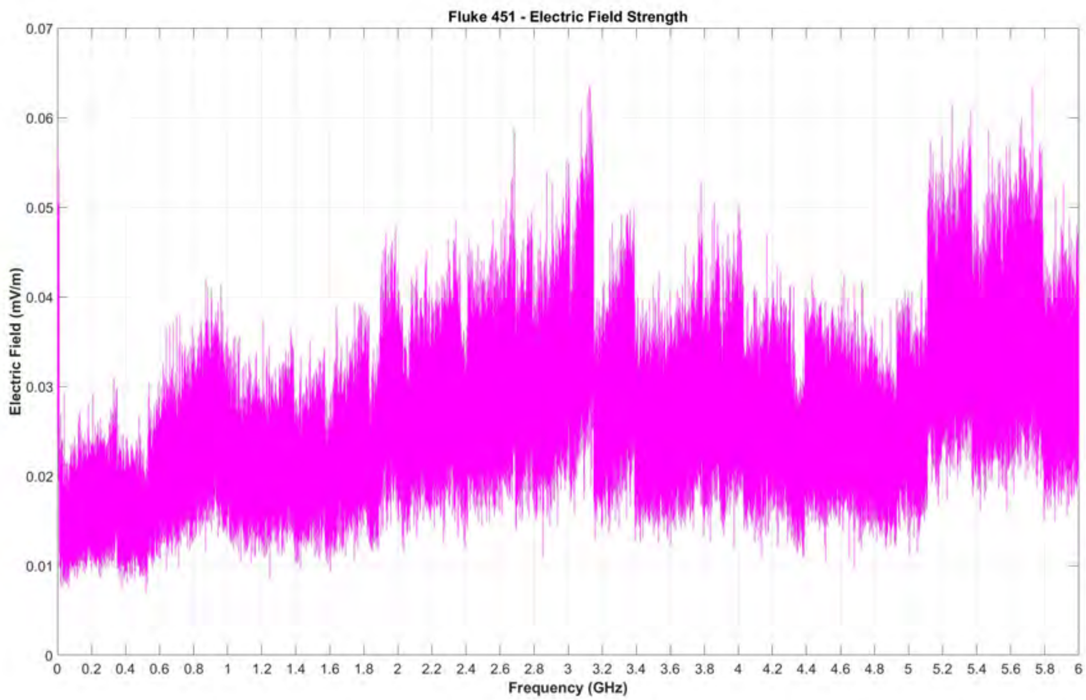


Fig. 8: Fluke Electric Field Stength [mV/m]

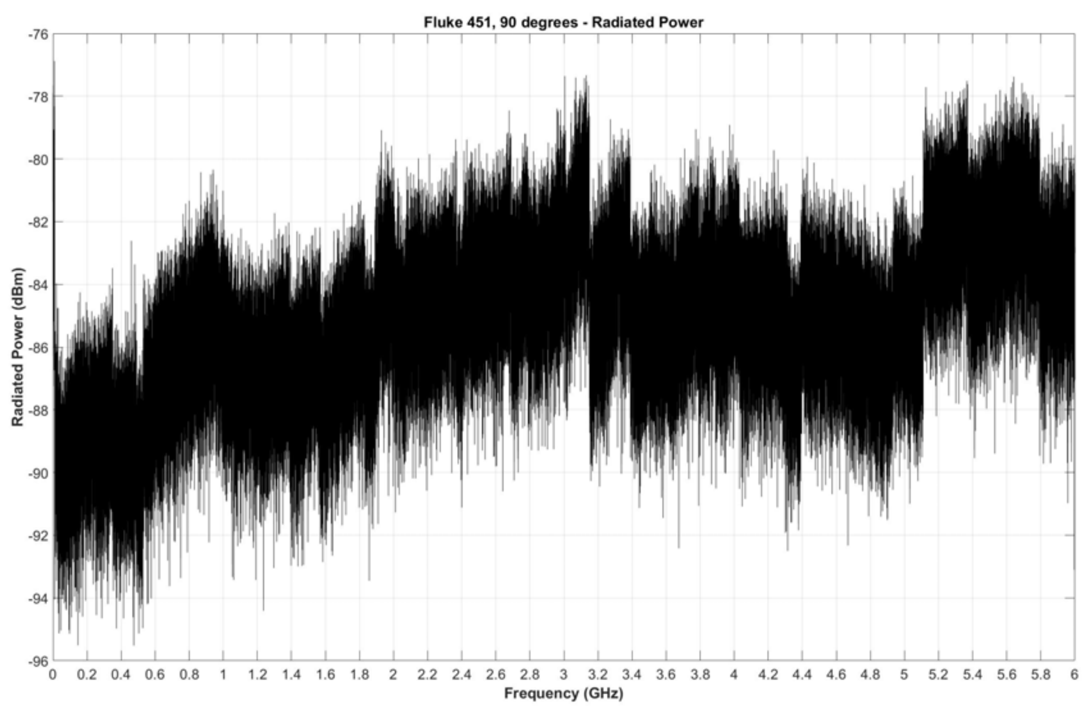


Fig. 9: Fluke Radiated Power [dBm], 90 Degrees

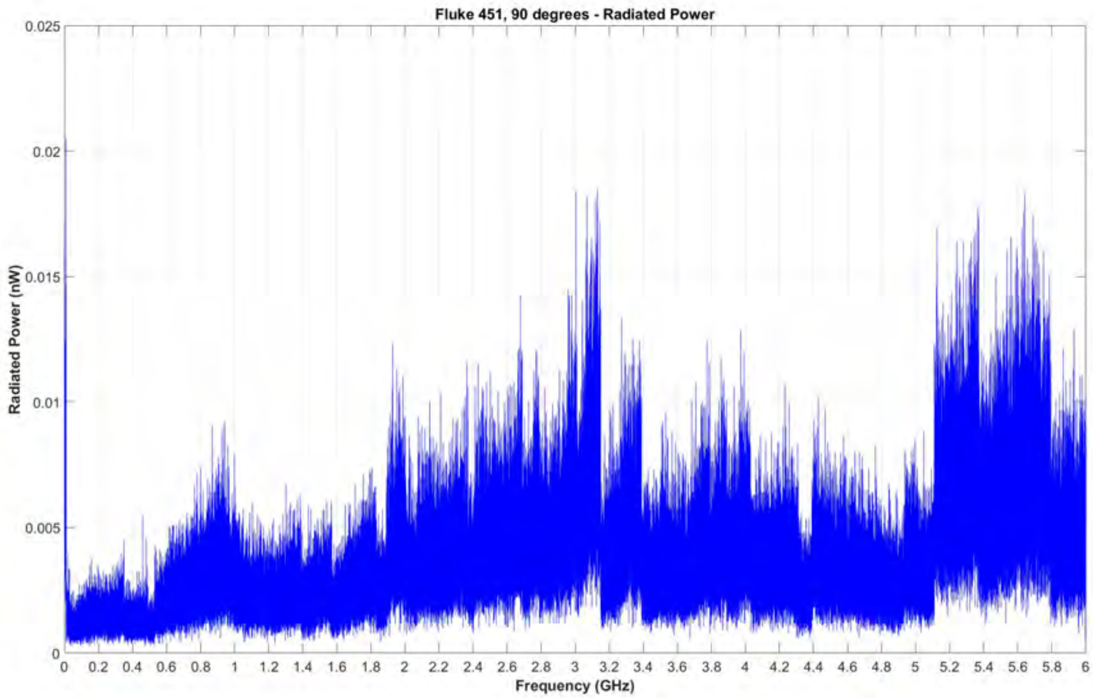


Fig. 10: Fluke Radiated Power [nW], 90 Degrees

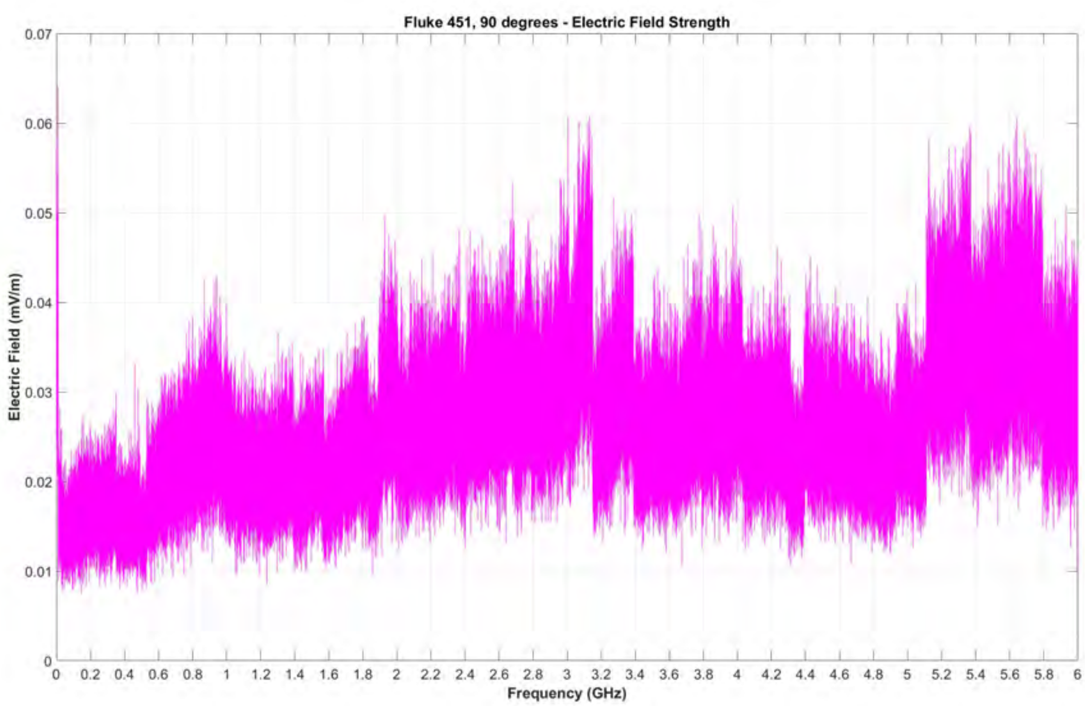


Fig. 11: Fluke Electric Field Stength [mV/m], 90 Degrees

5.3 MC-15 and SNAP III Results

Both MC-15 detectors (Figure 12a) and the SNAP III (Figure 12b) which will be operated together, as shown schematically in Figure 13, were measured while turned on and collecting data using a reference level of -30 dBm. A laptop computer was connected to the system and turned on with the screen open. Results are shown below in Figures 14-16 for the initial orientation, and Figures 17-19 for the 90 degree rotation. The MC-15 detectors were too large to rotate into the 90 degree orientation, so only the SNAP III and the laptop computer were rotated. Emissions from this detector are seen at some frequencies below 600 MHz, with the largest emission noted at a power level of -48 dBm, which corresponds to around 16 nW and an electric field strength of 1.8 mV/m.

(a) (b)

Fig. 12: Pictures of the (a) MC-15 Detectors and (b) SNAP III

Fig. 13: Schematic of MC-15 (x2) and SNAP III Detectors Measurement Setup

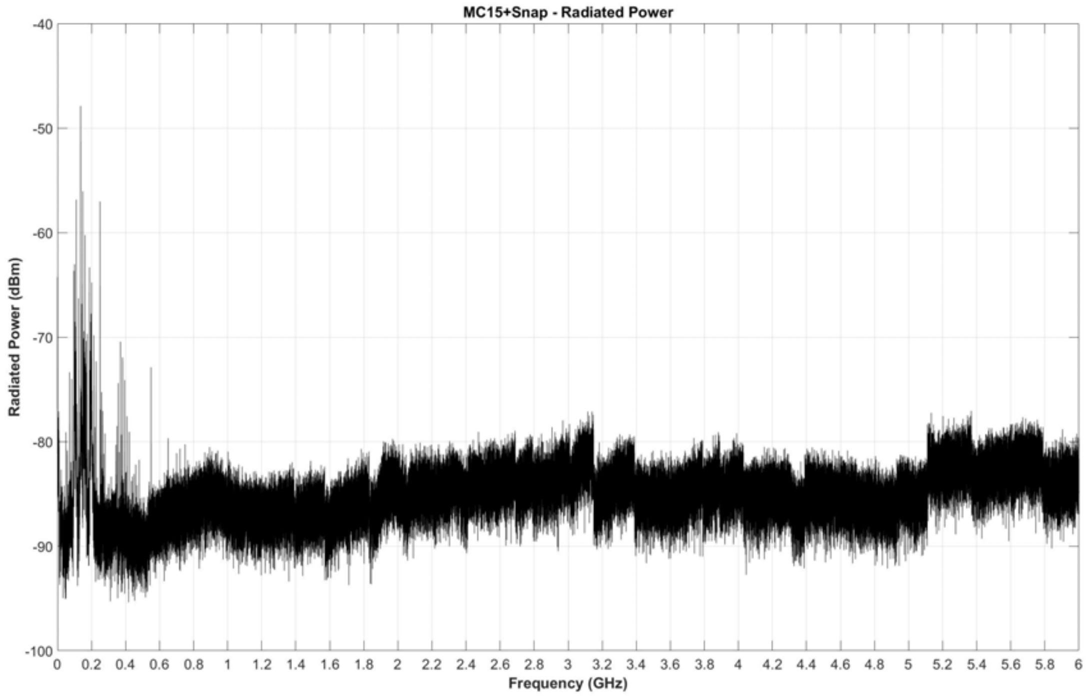


Fig. 14: MC-15 (x2), SNAP III, and Data Acquisition Laptop Radiated Power [dBm]

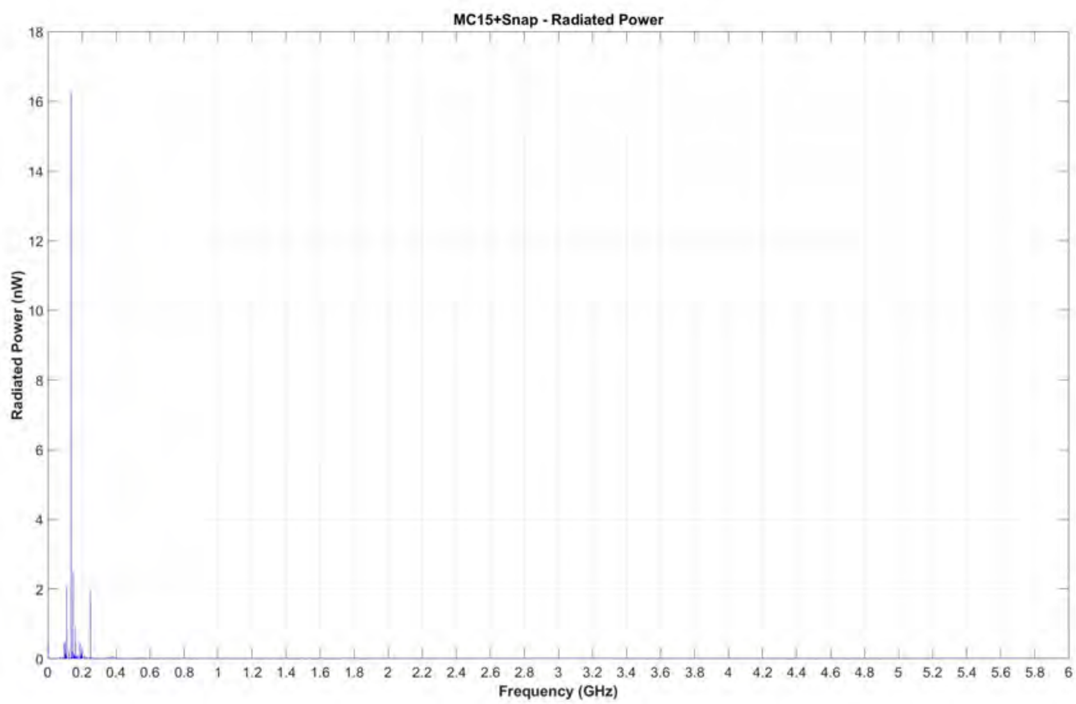


Fig. 15: MC-15 (x2), SNAP III, and Data Acquisition Laptop Radiated Power [nW]

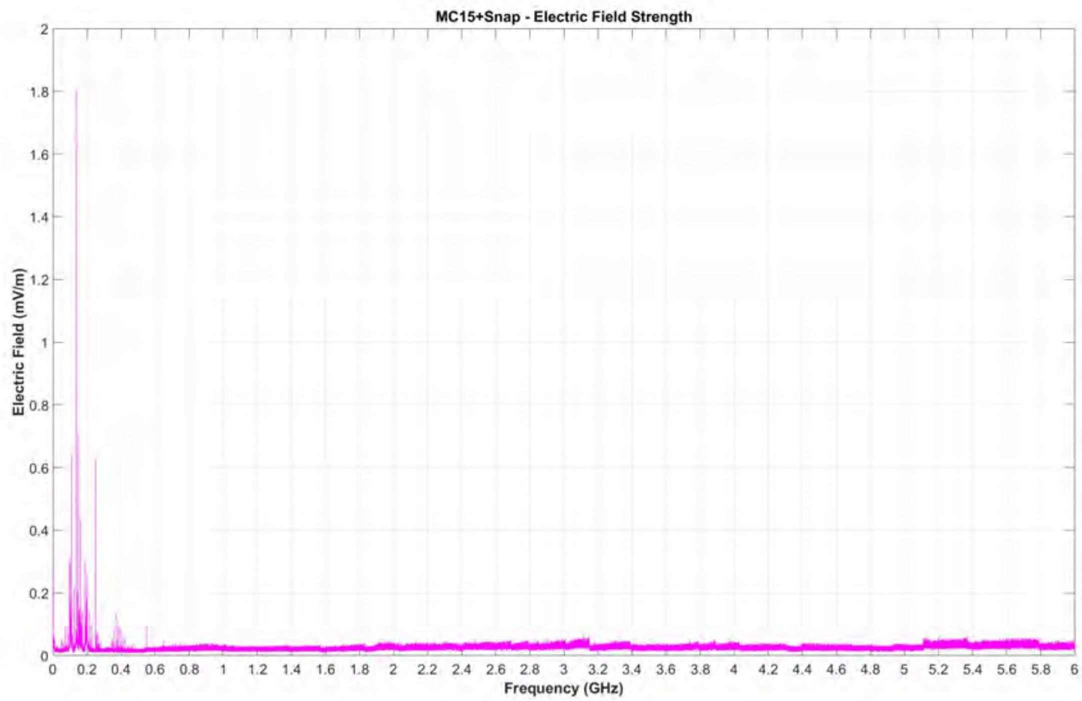


Fig. 16: MC-15 (x2), SNAP III, and Data Acquisition Laptop Electric Field Stength [mV/m]

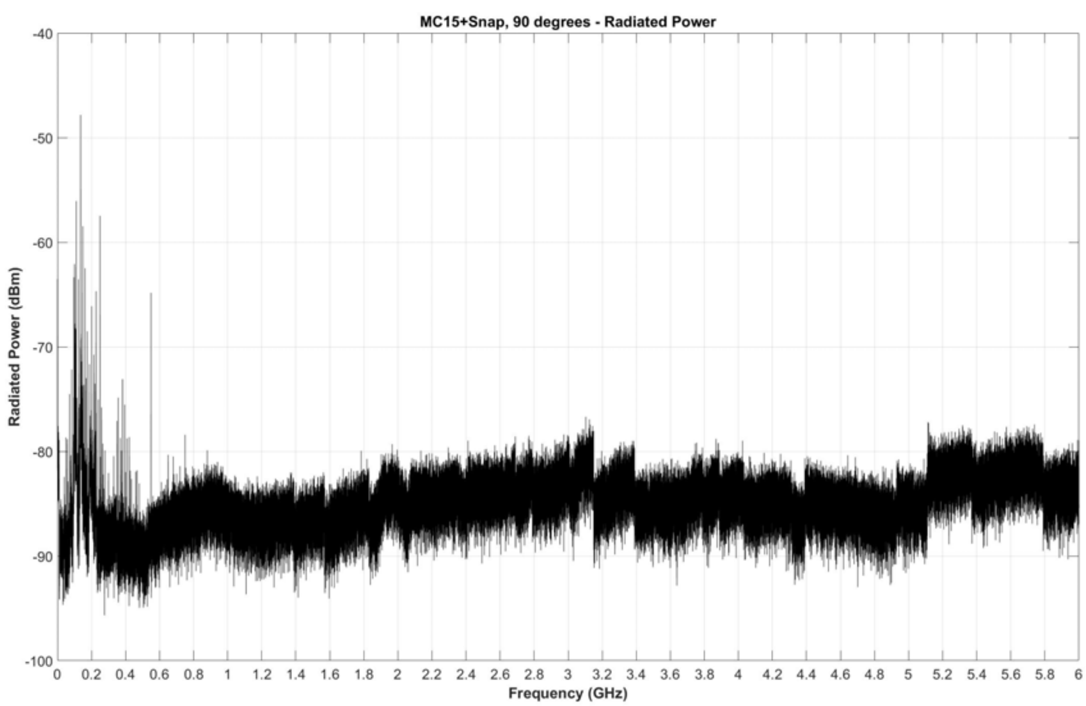


Fig. 17: MC-15 (x2), SNAP III, and Data Acquisition Laptop Radiated Power [dBm], 90 Degrees

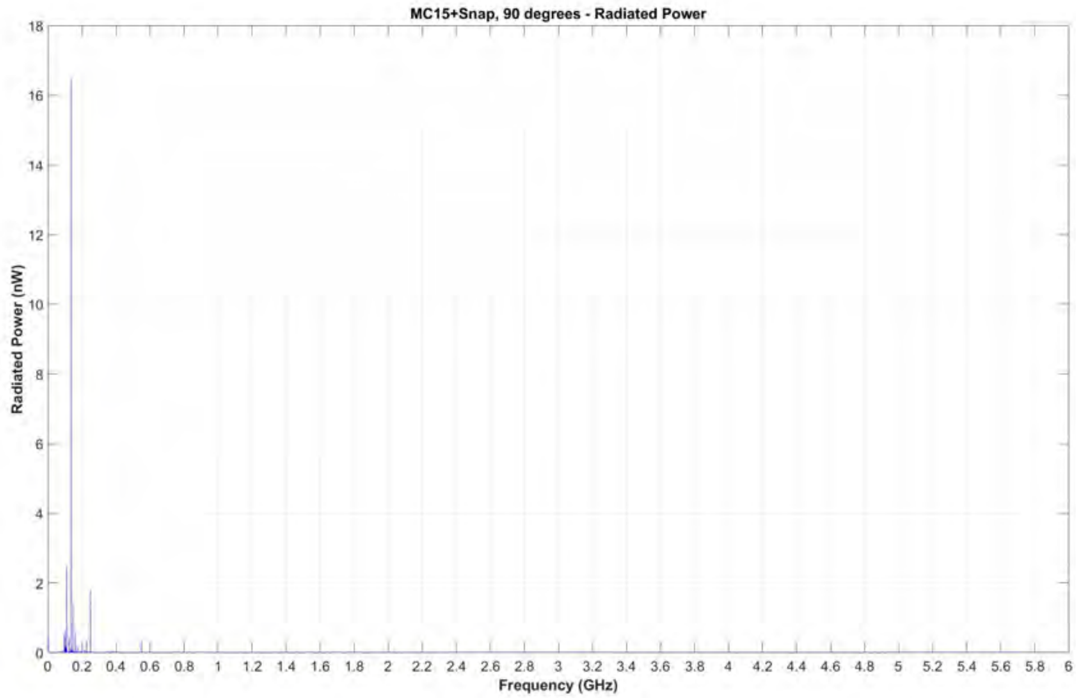


Fig. 18: MC-15 (x2), SNAP III, and Data Acquisition Laptop Radiated Power [nW], 90 Degrees

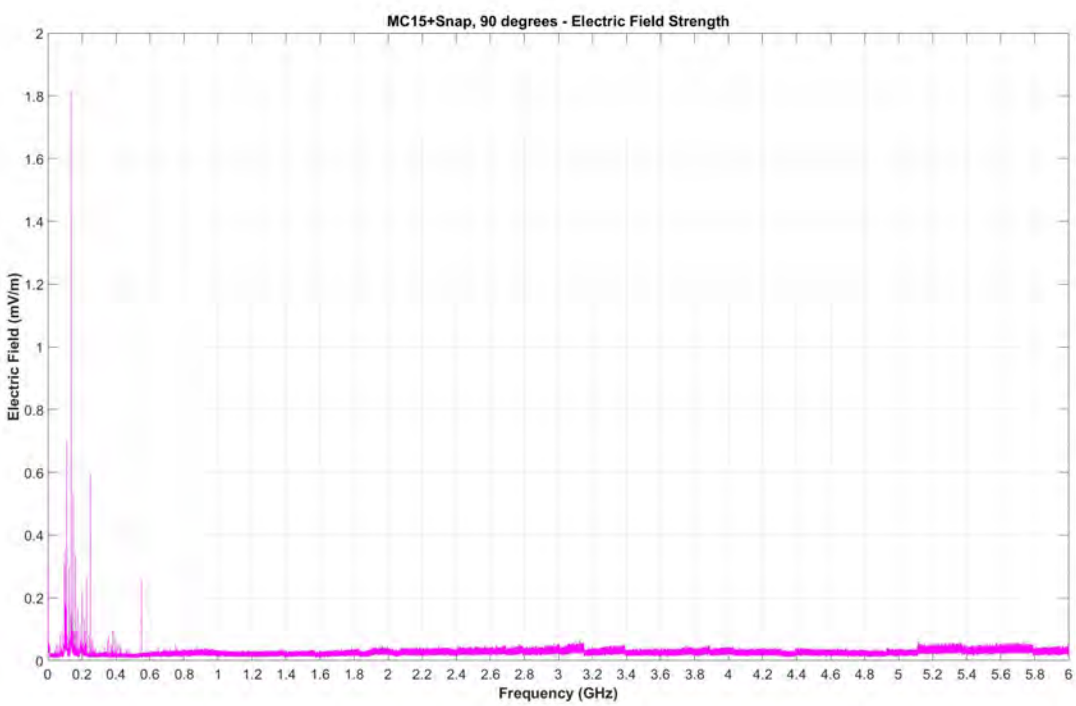


Fig. 19: MC-15 (x2), SNAP III, and Data Acquisition Laptop Electric Field Stength [mV/m], 90 Degrees

5.4 Neutron Spectrometer Results

The neutron spectrometer system, shown schematically in Figure 20, was measured while turned on and collecting data using a reference level of -40 dBm. Results are shown below in Figures 22-24 for the initial orientation, and Figures 25-27 for the 90 degree rotation. Emissions from this detector are seen at some frequencies below 1.5 GHz, with the largest emission noted at a power level of -69 dBm, which corresponds to approximately 0.14 nW and an electric field of strength of 0.16 mV/m. The CAEN HV powersupply passed 47 CFR 15.109 Class A and 15.107 Class B.

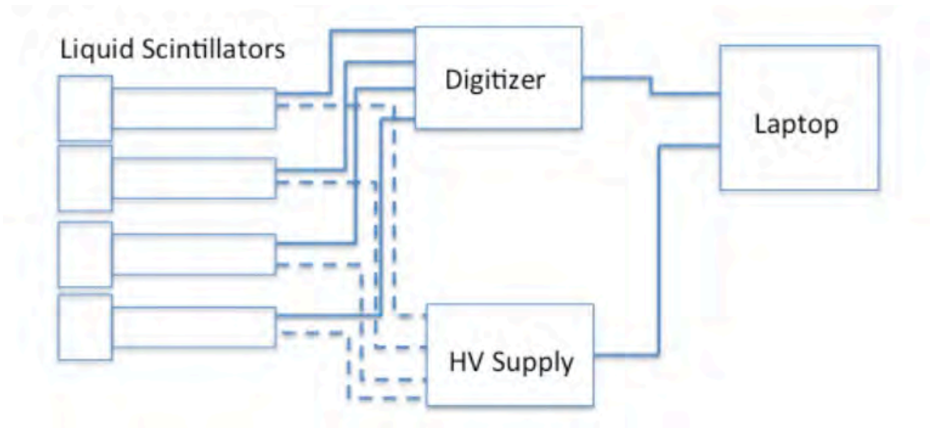
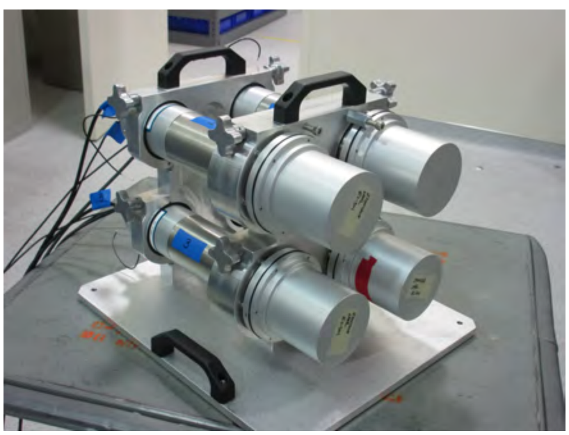
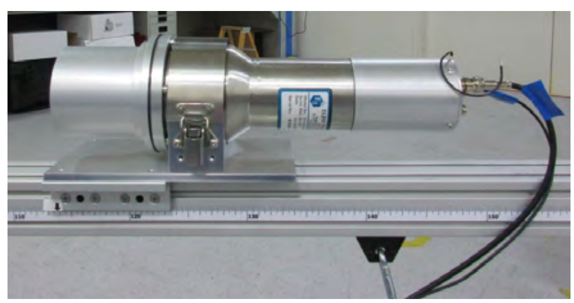


Fig. 20: Schematic of Neutron Spectrometer Measurement Setup



(a)



(b)

Fig. 21: Configuration of the (a) Neutron Spectrometer 4-detectors and (b) Picture of Single Module

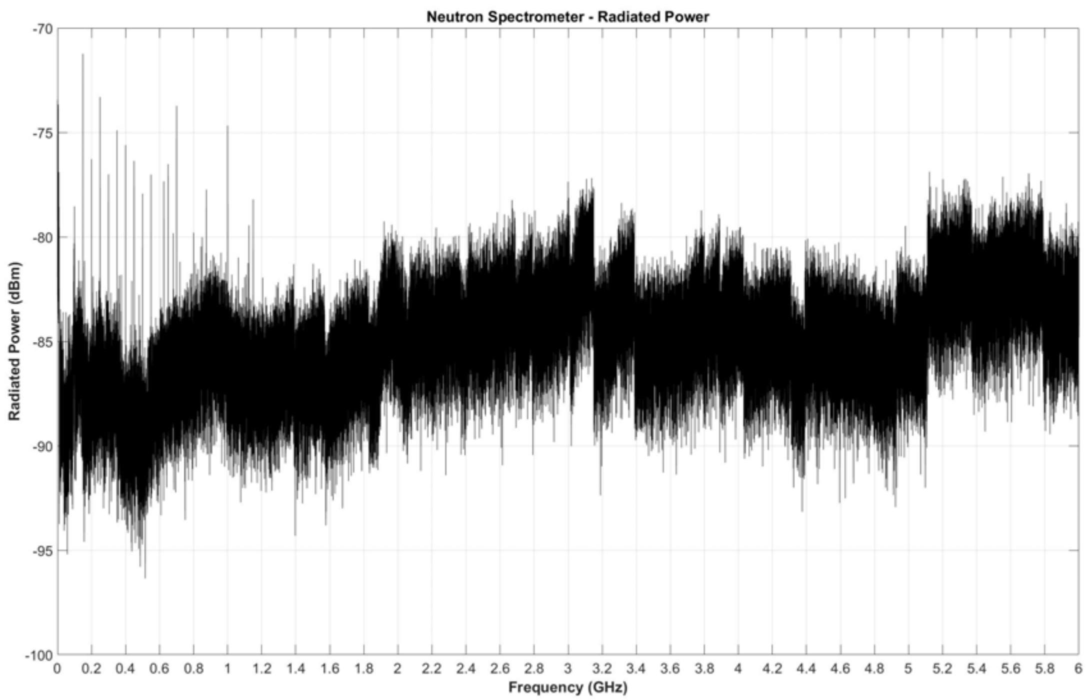


Fig. 22: Neutron Spectrometer Radiated Power [dBm]

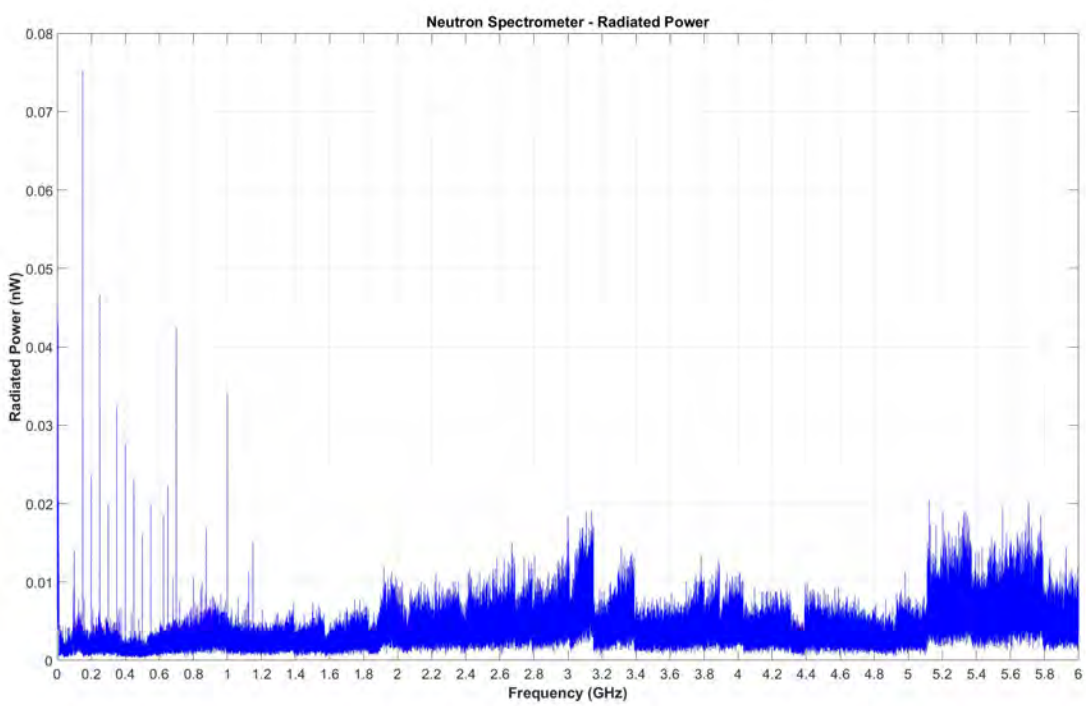


Fig. 23: Neutron Spectrometer Radiated Power [nW]

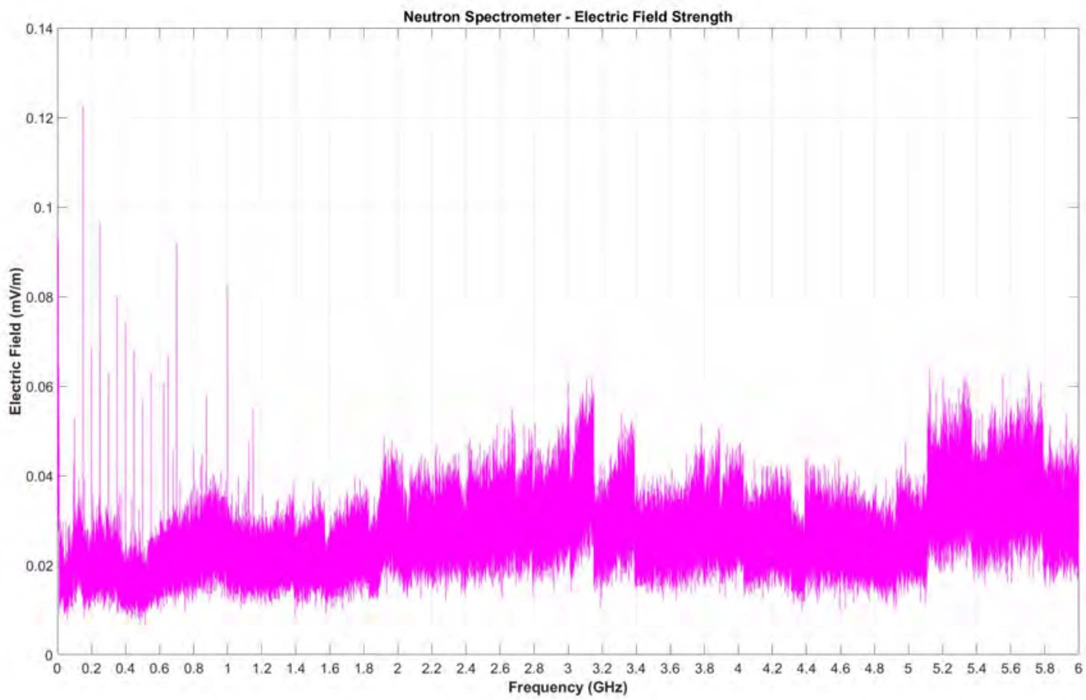


Fig. 24: Neutron Spectrometer Electric Field Stength [mV/m]

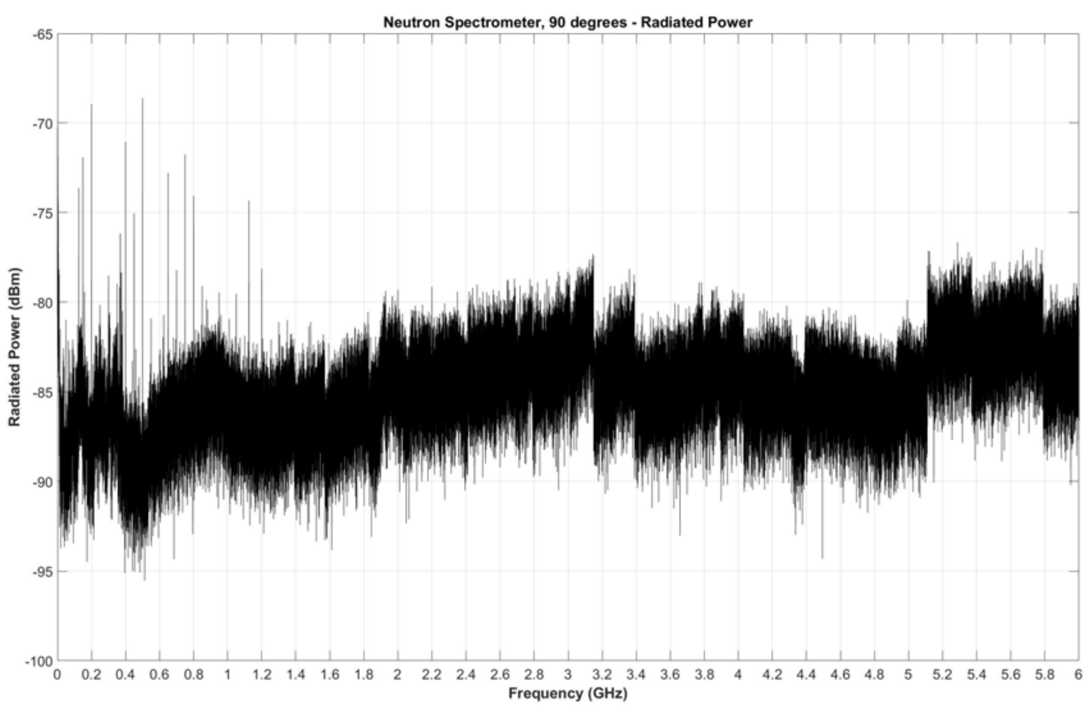


Fig. 25: Neutron Spectrometer Radiated Power [dBm], 90 Degrees

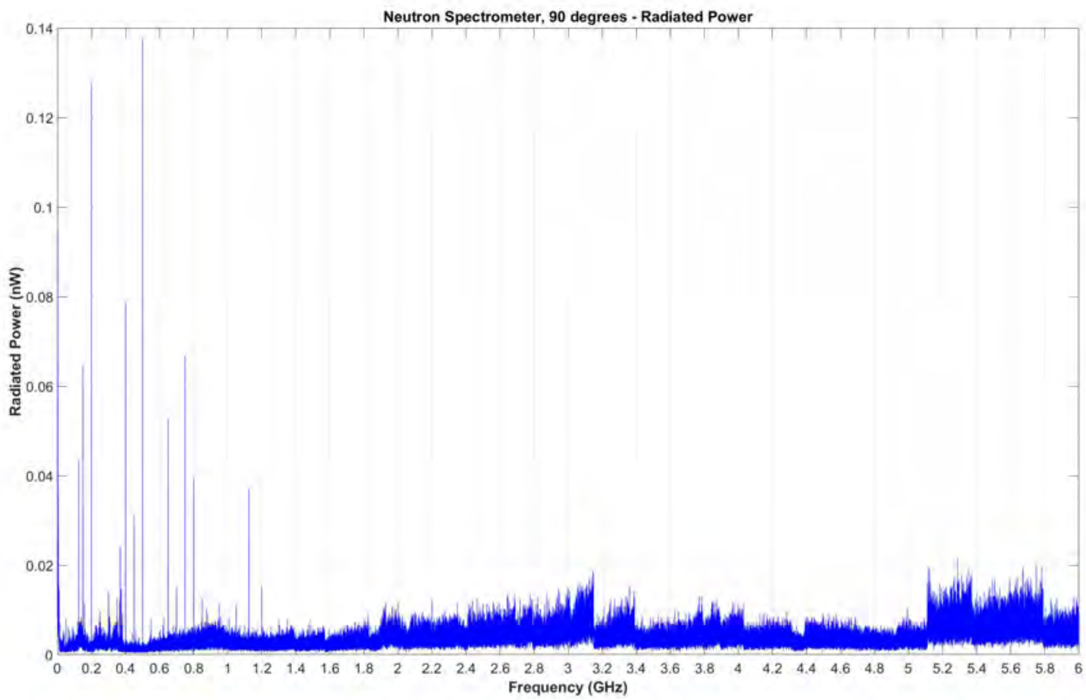


Fig. 26: Neutron Spectrometer Radiated Power [nW], 90 Degrees

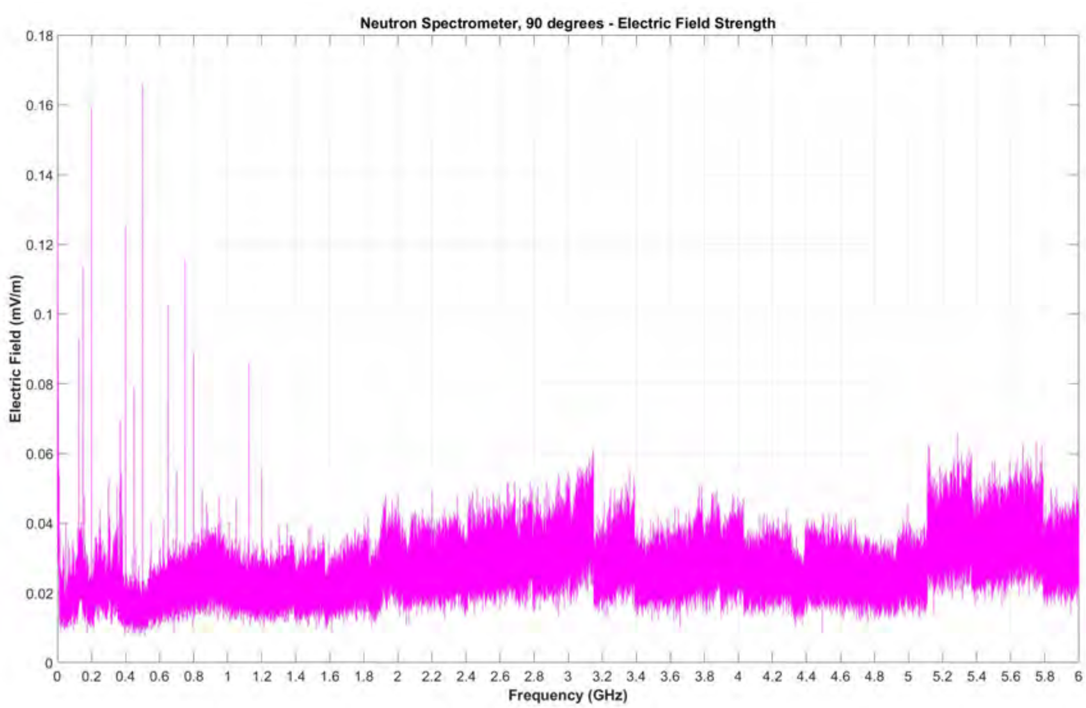


Fig. 27: Neutron Spectrometer Electric Field Stength [mV/m], 90 Degrees

5.5 Ortec Detective Results

The Ortec Detective-EX200, shown in Figure 28, was measured while turned on and collecting data using a reference level of -40 dBm. A laptop computer was connected to the system and turned on with the screen open. Results are shown below in Figures 29-31 for the initial orientation, and Figures 32-34 for the 90 degree rotation. Emissions from this detector are seen at around 1.3 GHz and again at some frequencies below 500 MHz, with the largest emission noted at a power level of -66 dBm, which corresponds to around 0.27 nW and an electric field strength of 0.24 mV/m. In the 90 degree orientation there was some very low frequency power emitted near the 200 kHz lower bound. This may have been a perturbation in the spectrum analyzer noise floor, but the cause was unclear. Even if these were valid emissions from the detector, they resulted in a radiated power level of around -36 dBm or 0.25 μW and an electric field strength of just over 7 mV/m.

Fig. 28: Picture of Detective-EX 200 Measurement Setup

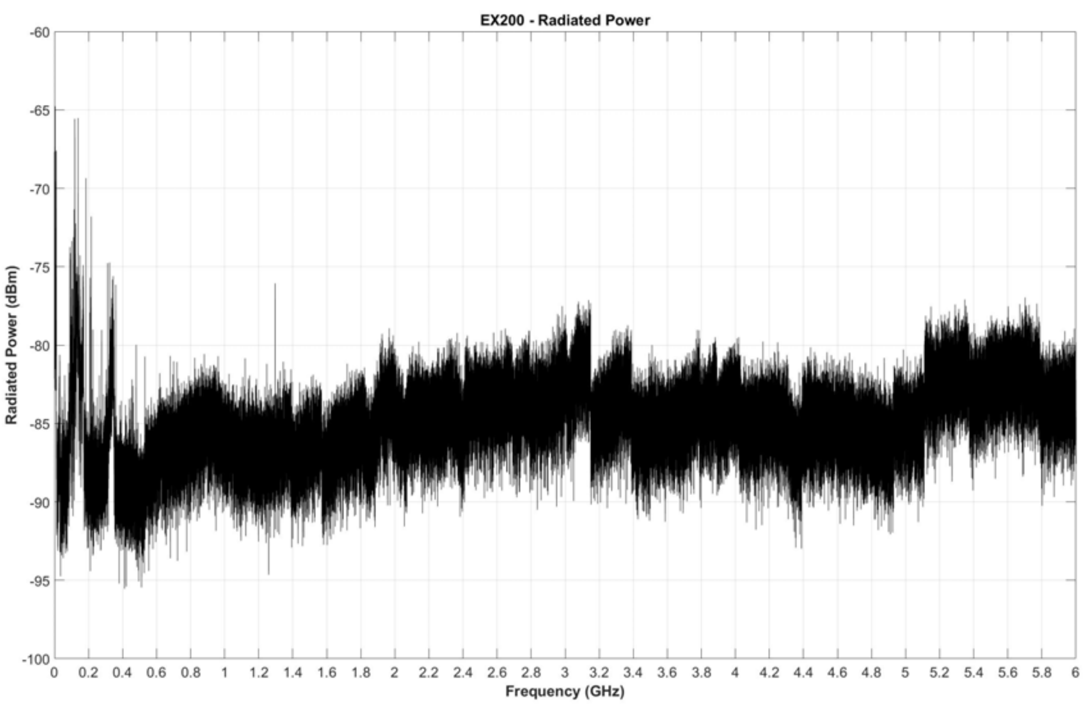


Fig. 29: Detective-EX200 and Data Acquisition Laptop Radiated Power [dBm]

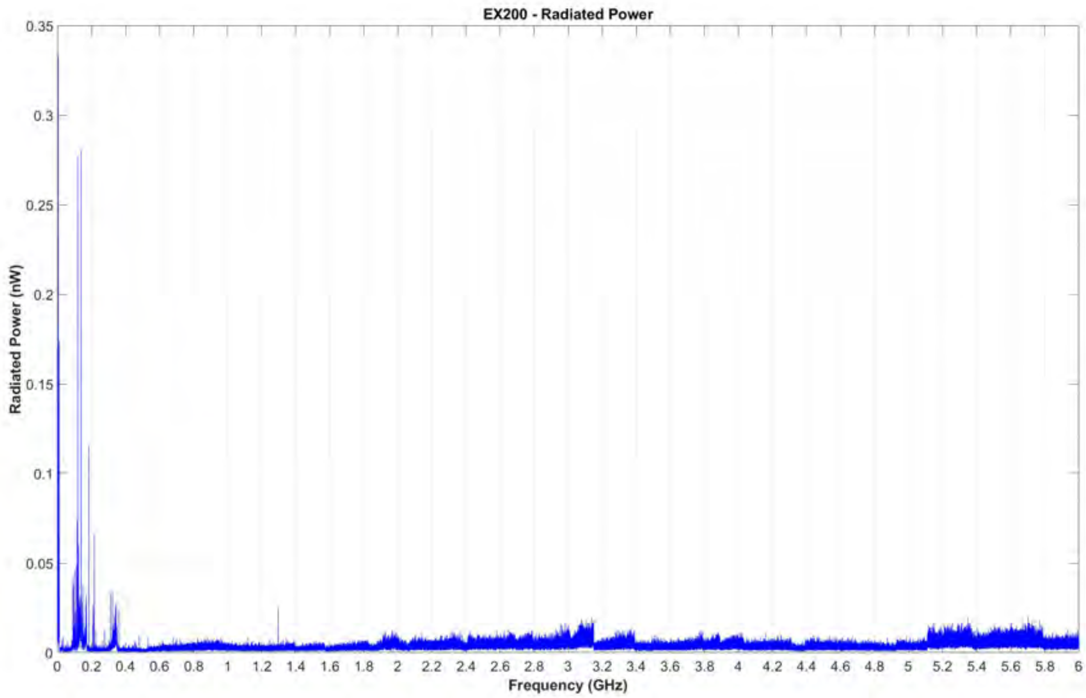


Fig. 30: Detective-EX200 and Data Acquisition Laptop Radiated Power [nW]

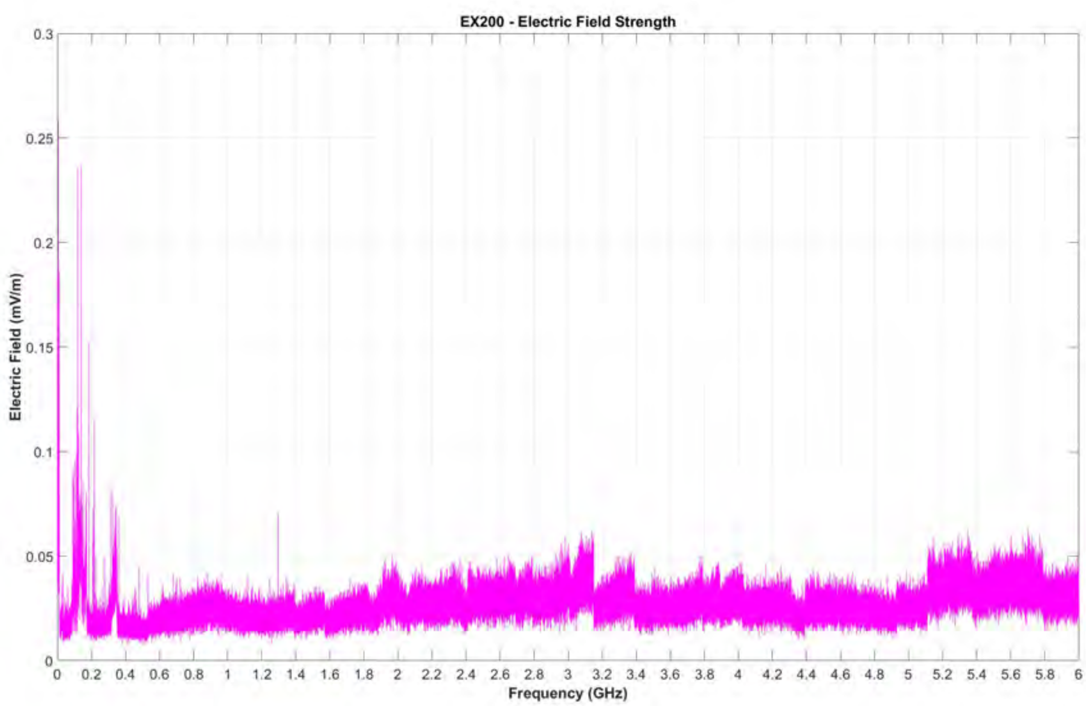


Fig. 31: Detective-EX200 and Data Acquisition Laptop Electric Field Stength [mV/m]

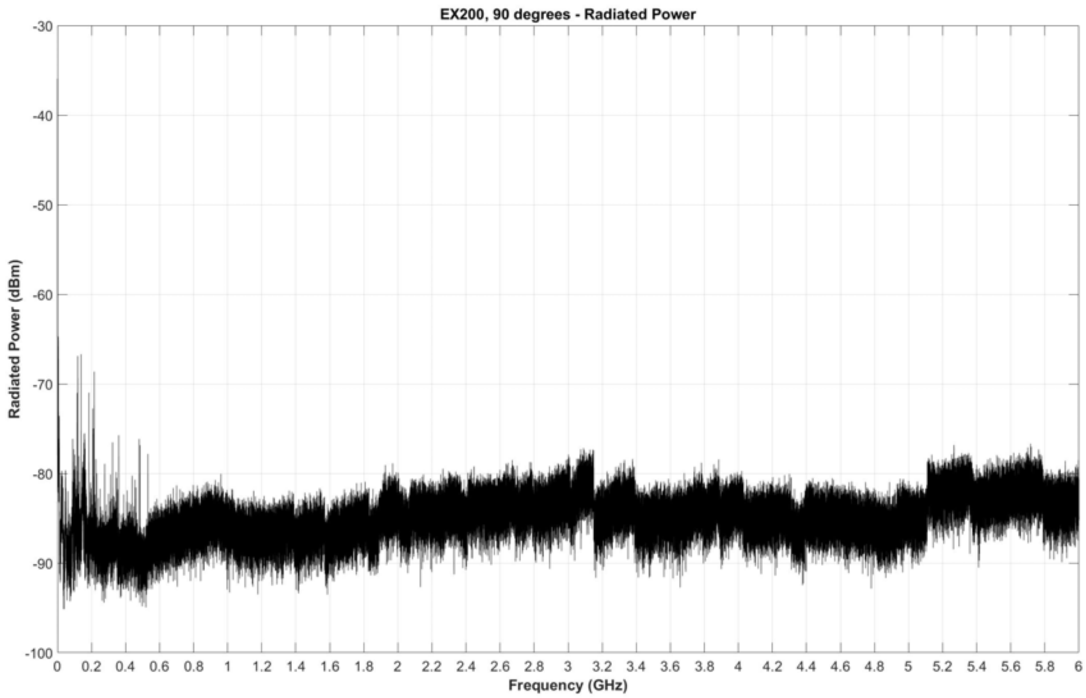


Fig. 32: Detective-EX200 and Data Acquisition Laptop Radiated Power [dBm], 90 Degrees

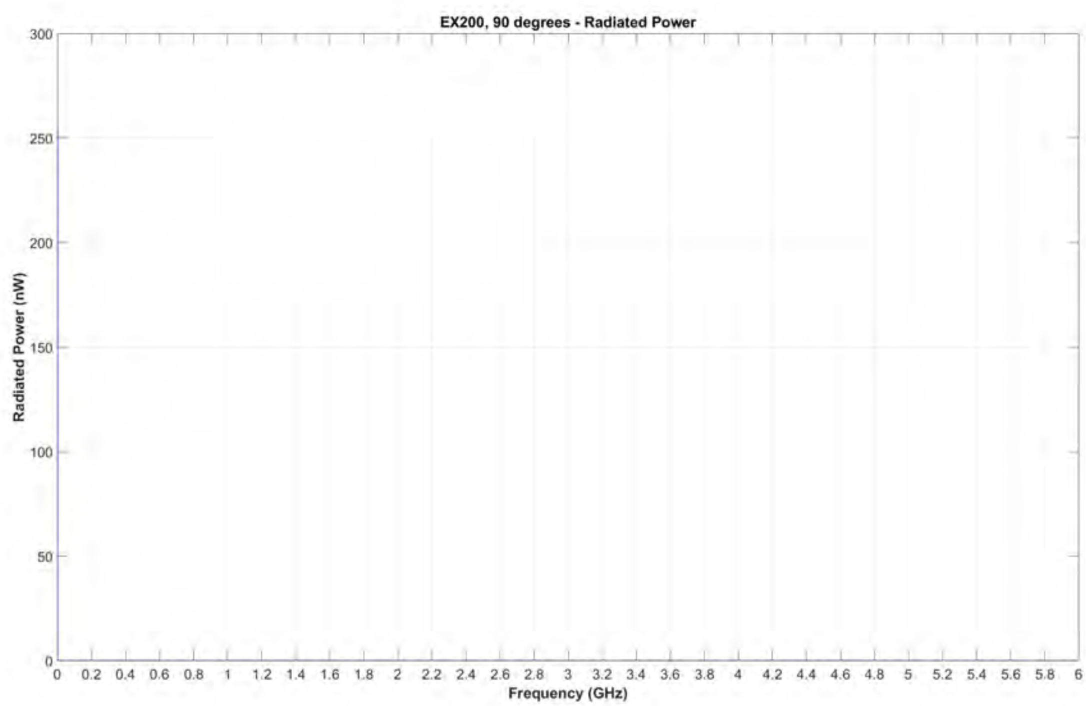


Fig. 33: Detective-EX200 and Data Acquisition Laptop Radiated Power [nW], 90 Degrees

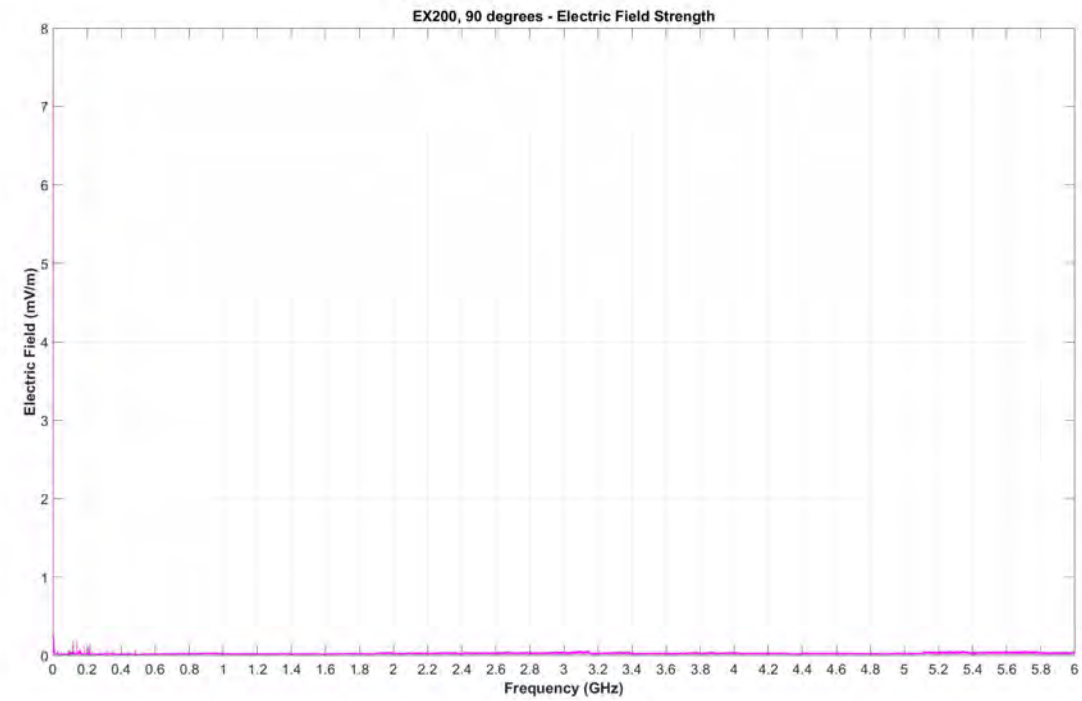


Fig. 34: Detective-EX200 and Data Acquisition Laptop Electric Field Stength [mV/m], 90 Degrees

5.6 ORTEC HPGe Results

The HPGe detector, DSPEC Pro, XCooler-III and data acquisition laptop setup, shown in Figure 35, was measured while turned on and collecting data using a reference level of -40 dBm. The HPGe detector crystal had been chilled by the XCooler for 24 hours prior to being measured. A laptop computer was connected to the system and turned on with the screen open. Results are shown below in Figures 36-38 for the initial orientation, and Figures 39-41 for the 90 degree rotation. Emissions from this detector were minimal, but were dominated by a very low frequency spike resulting in a power level of -55 dBm, which corresponds to around 3.4 nW and an electric field strength of 0.8 mV/m. As this spike was again near the 200 kHz cutoff, it was likely due to a perturbation of the spectrum analyzer noise floor, but is included here for completeness.

Fig. 35: HPGe Detection System Measurement Setup

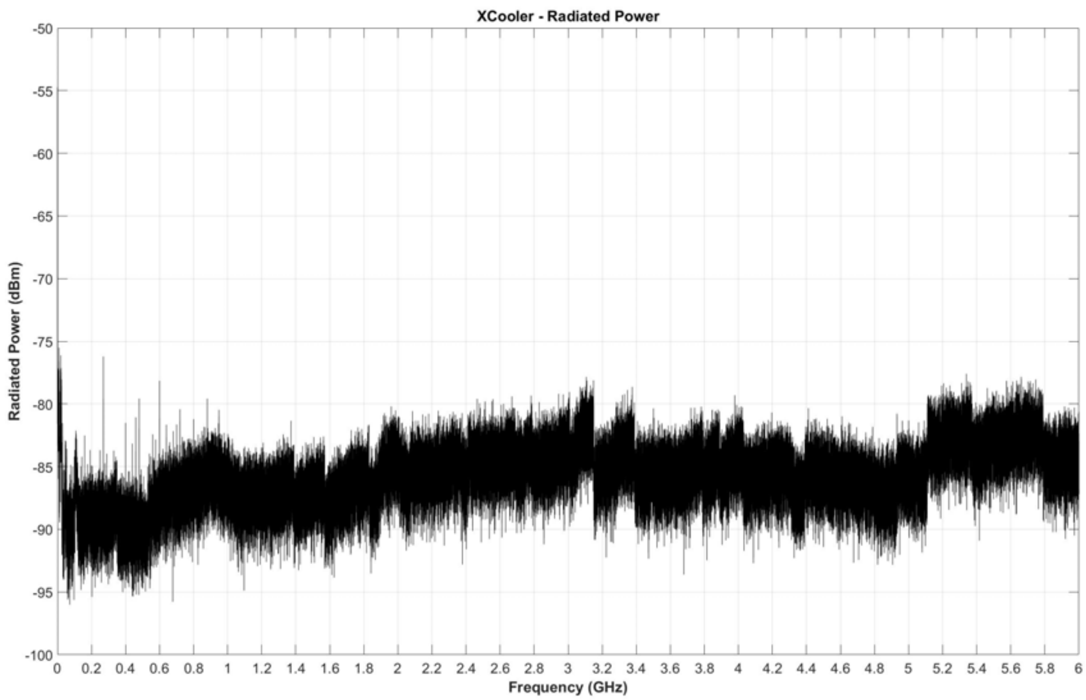


Fig. 36: HPGe Detection System Radiated Power [dBm]

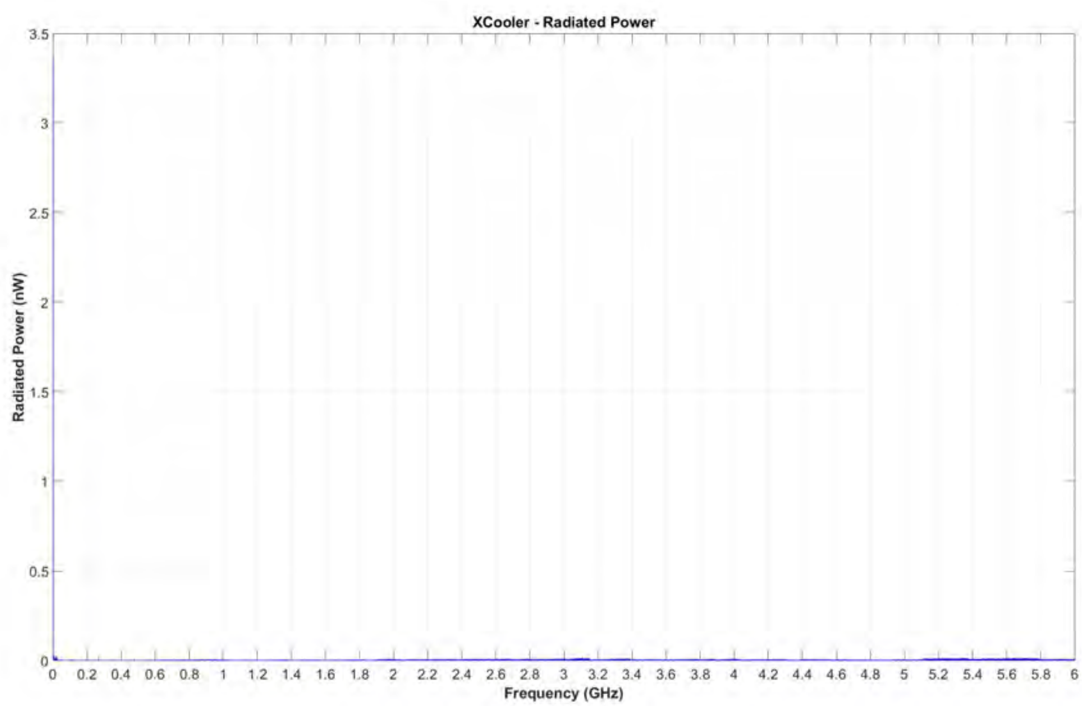


Fig. 37: HPGe Detection System Radiated Power [nW]

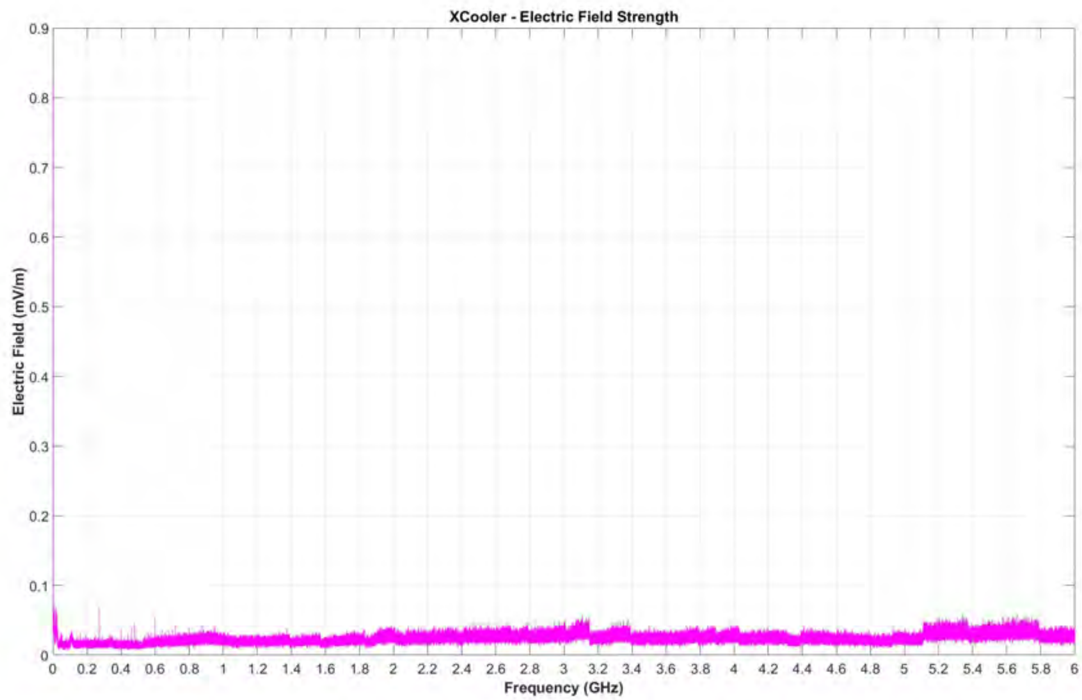


Fig. 38: HPGe Detection System Electric Field Stength [mV/m]

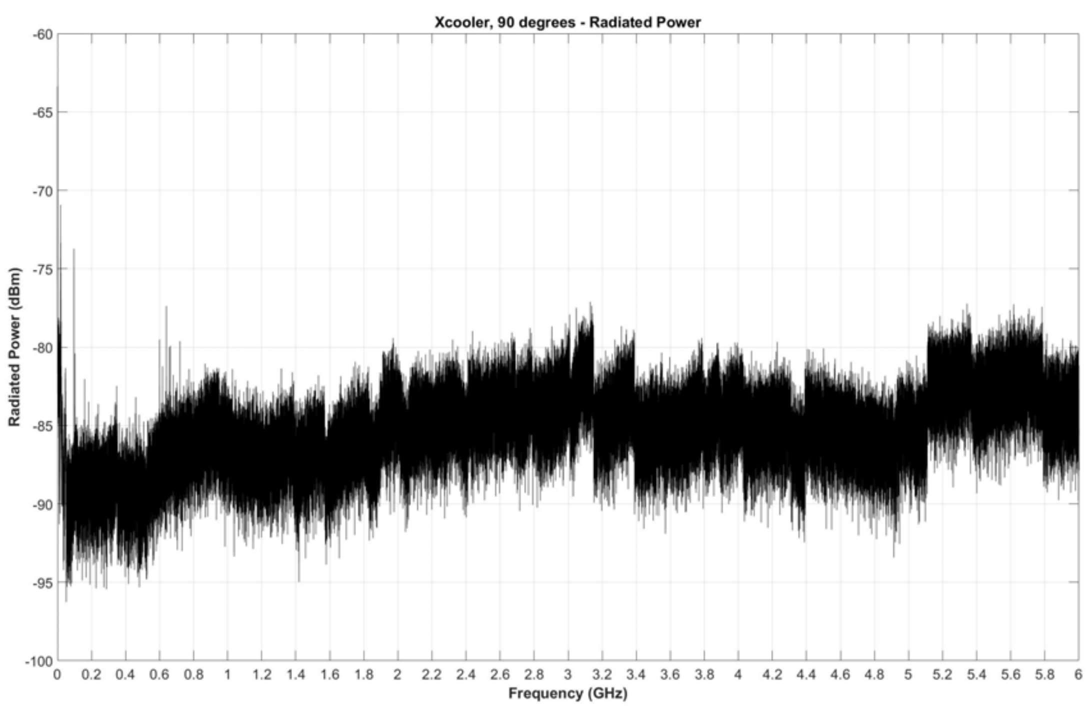


Fig. 39: HPGe Detection System Radiated Power [dBm], 90 Degrees

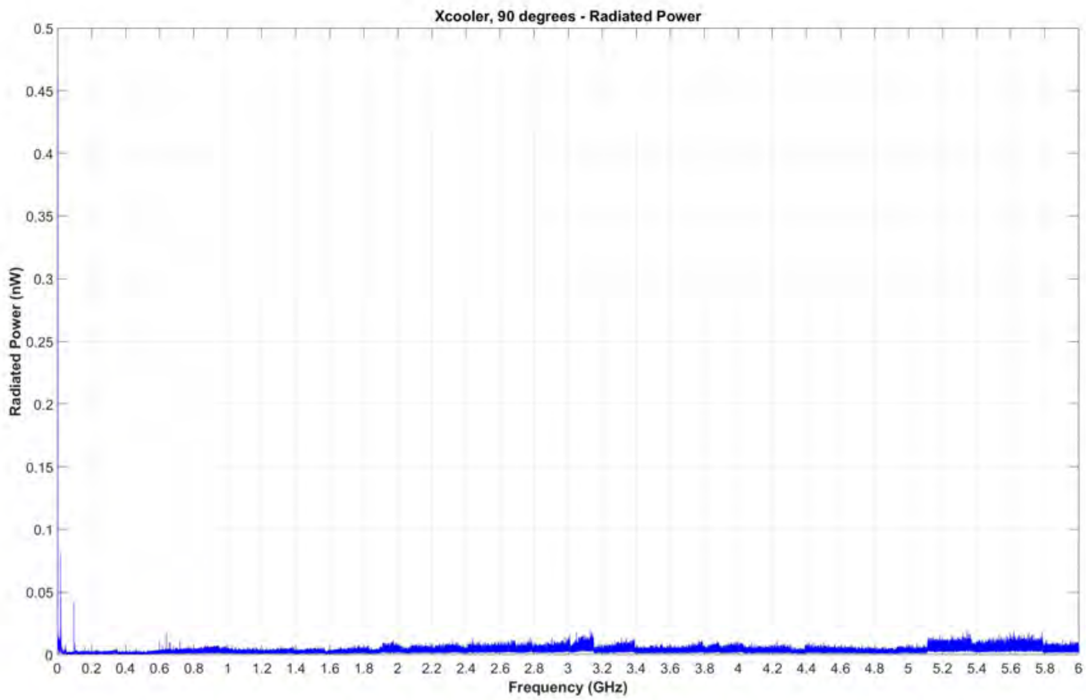


Fig. 40: HPGe Detection System Radiated Power [nW], 90 Degrees

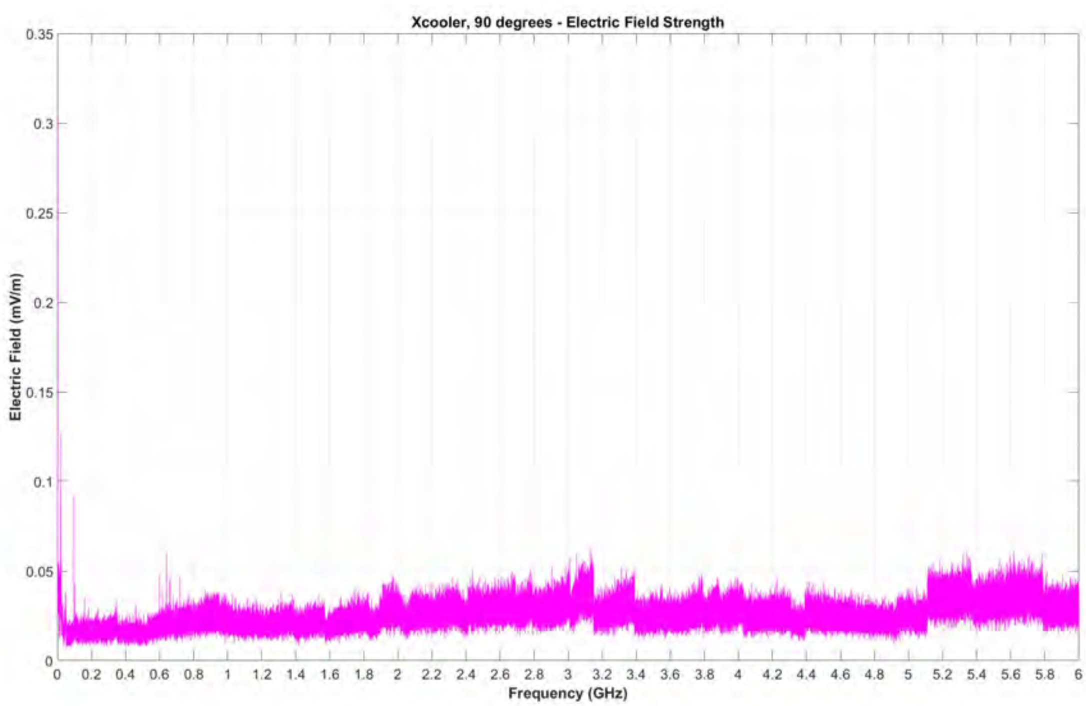


Fig. 41: HPGe Detection System Electric Field Stength [mV/m], 90 Degrees

The preferred option for operation of the HPGe Detector, just recently became available. It is using the ORTEC ICS-P4 (Integrated Cryocooling System for HPGe, PopTop detectors). This system is much preferred over the XCOOLER-III and its issues associated with the refrigerant. As such a separate EMR measurement of the ICS-P4 was performed when it arrived. The HPGe crystal was attached to the ICS-P4 was measured while turned on and operating in the initial cooling phase (highest power consumption) using a reference level of -40 dBm. At maximum a summation of the previous measurement utilizing the XCOOLER-III and ICS-P4 would give the upper limit for any emissions. The results for the ICS-P4 are shown in Figures 42-44. The largest emission noted was at a power level of -77.6 dBm at 118.01 MHz, which corresponds to 0.02 nW and an electric field strength of 0.06 mV/m.

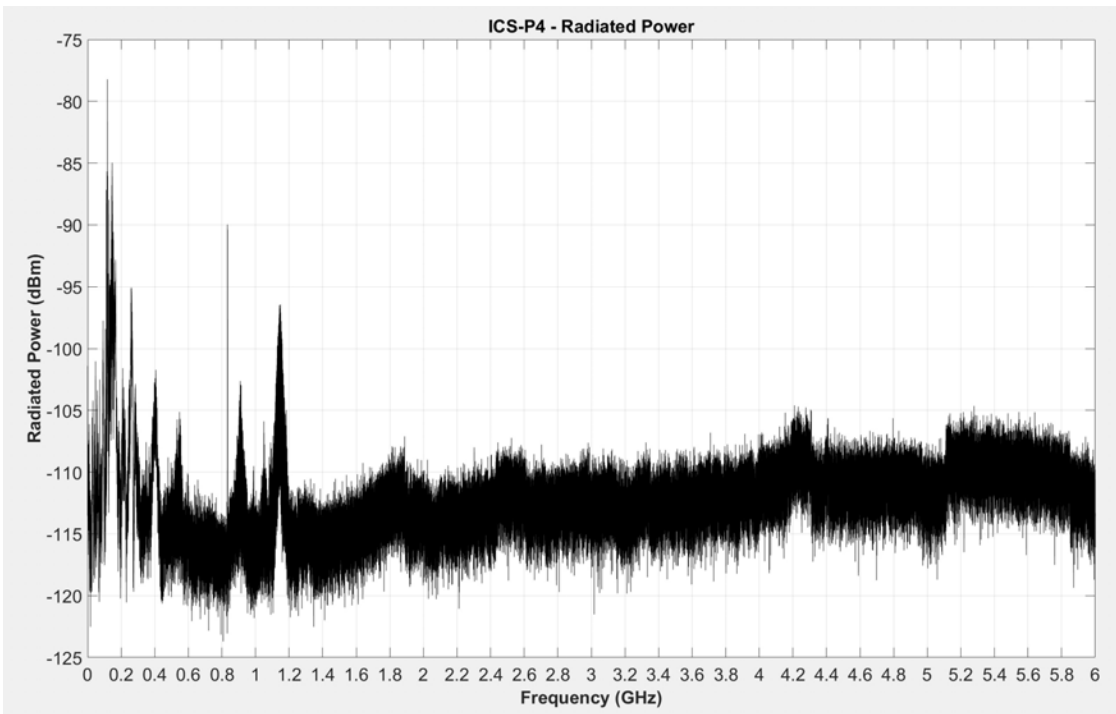


Fig. 42: ICS-P4 Radiated Power [dBm]

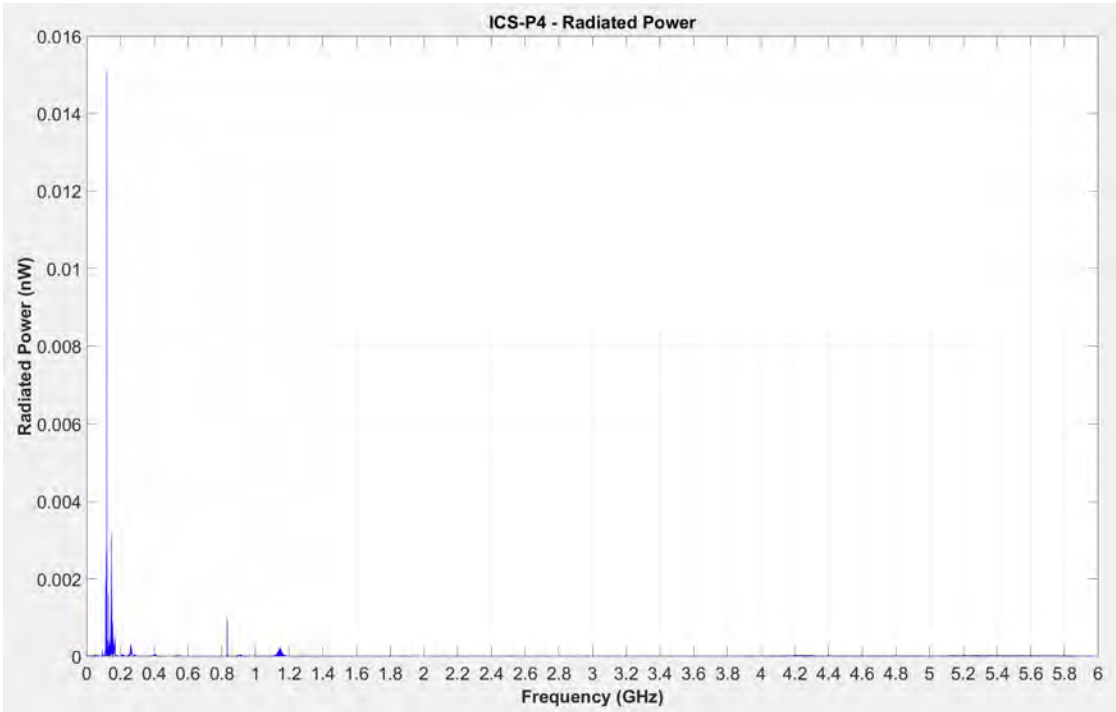


Fig. 43: ICS-P4 Radiated Power [nW]

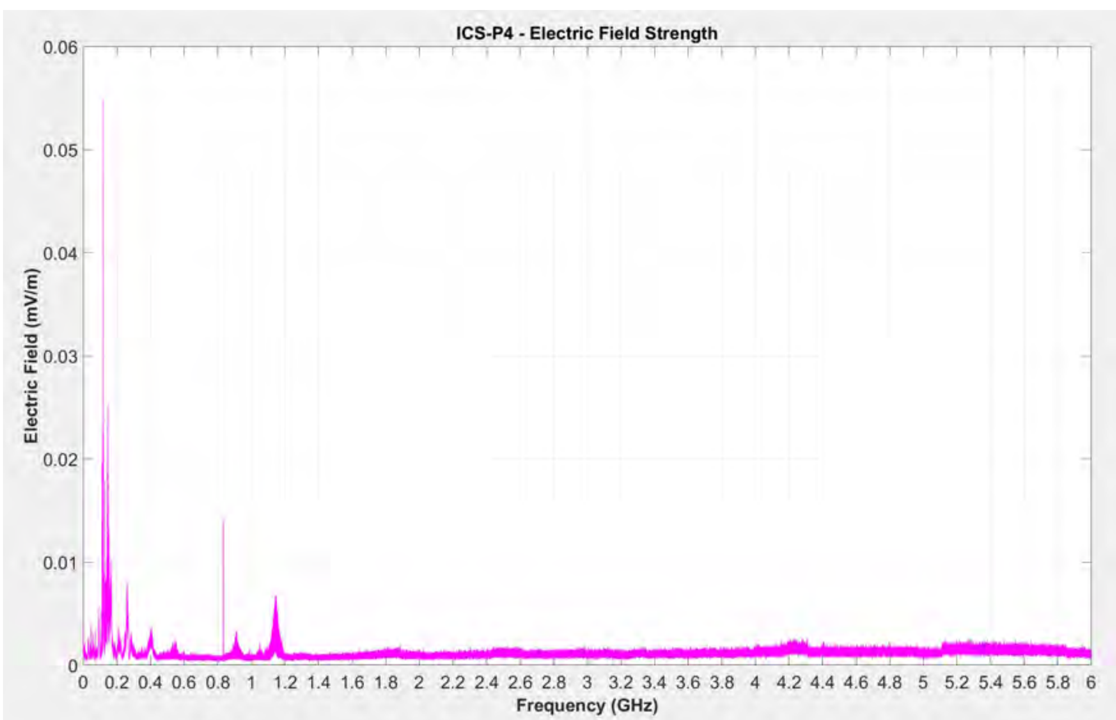


Fig. 44: ICS-P4 Electric Field Stength [mV/m]

5.7 REMBall Results

The REMBall detector, shown in Figure 45, was measured while turned on and collecting data using a reference level of -25 dBm. Results are shown below in Figures 46-48 for the initial orientation, and Figures 49-51 for the 90 degree rotation. The largest emission noted was at a power level of -55 dBm, which corresponds to around 3 nW and an electric field strength of 0.8 mV/m. The spike present at around 100 MHz was a transient emission occurirng at a rate of roughly 2 Hz, successfully captured in this orientation, but not in the 90 degree rotation. Aside from the transient event, emissions were relatively negligible.

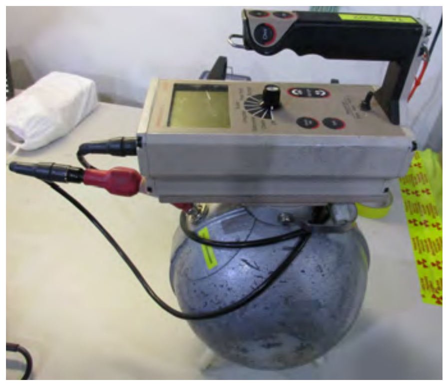


Fig. 45: Picture of REMBall detector

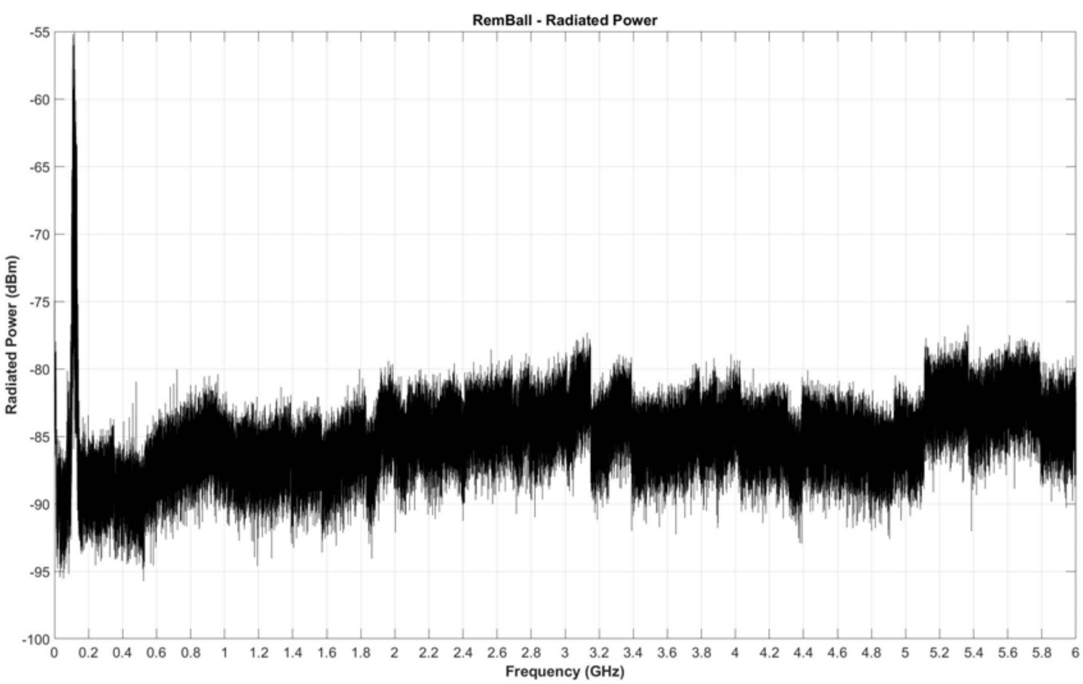


Fig. 46: REMBall Radiated Power [dBm]

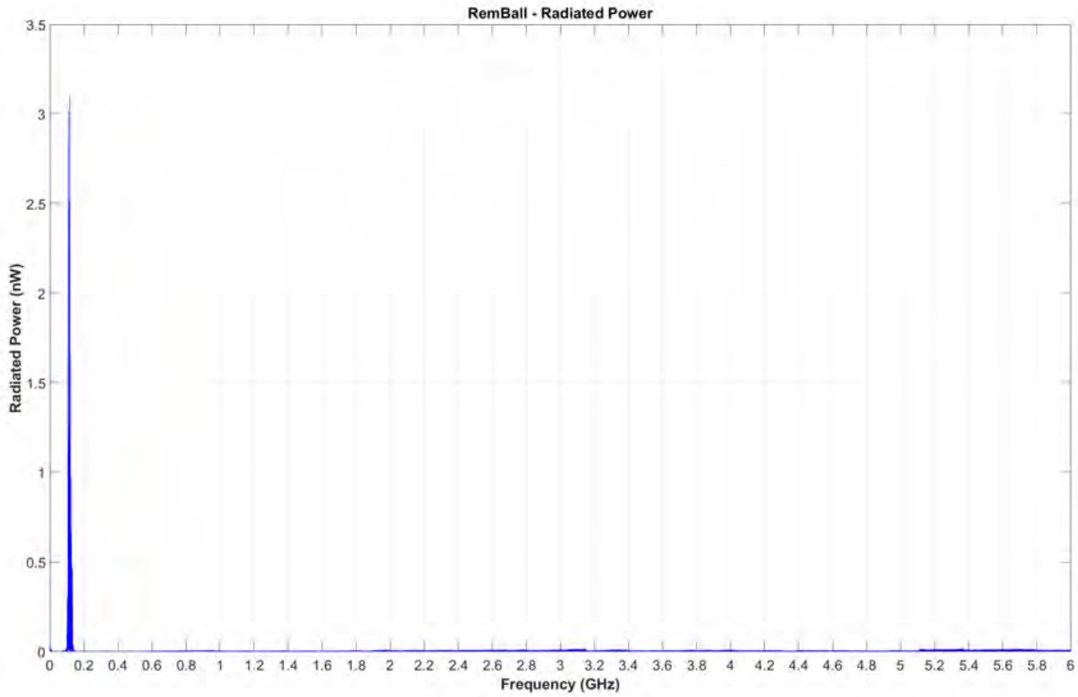


Fig. 47: REMBall Radiated Power [nW]

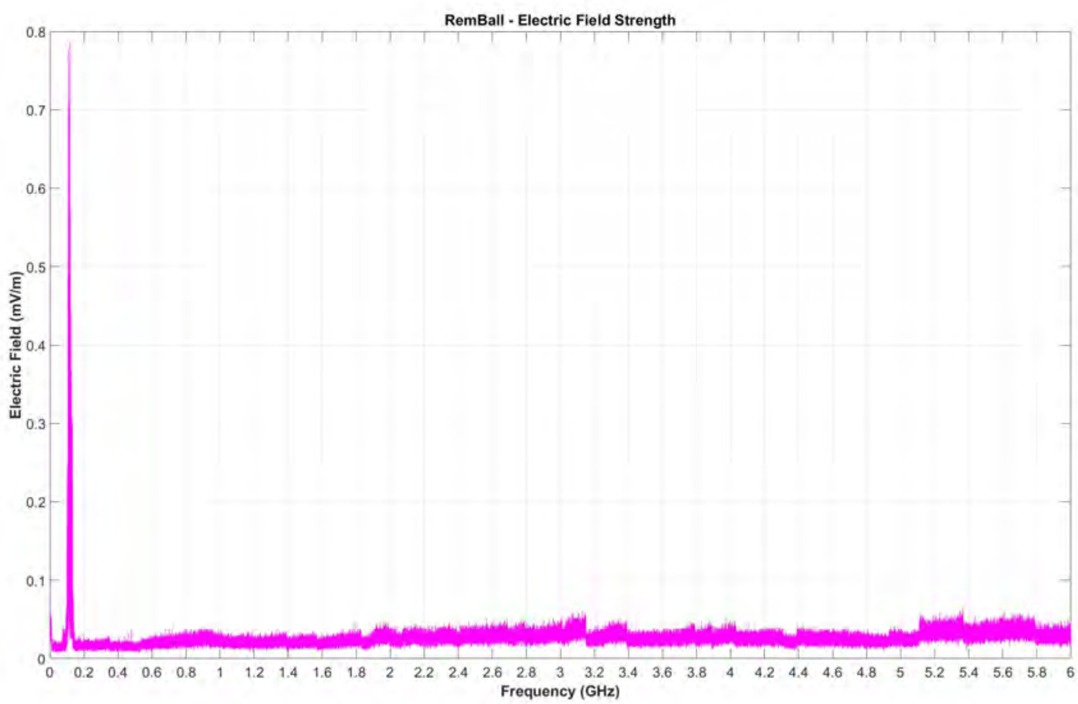


Fig. 48: REMBall Electric Field Strength [mV/m]

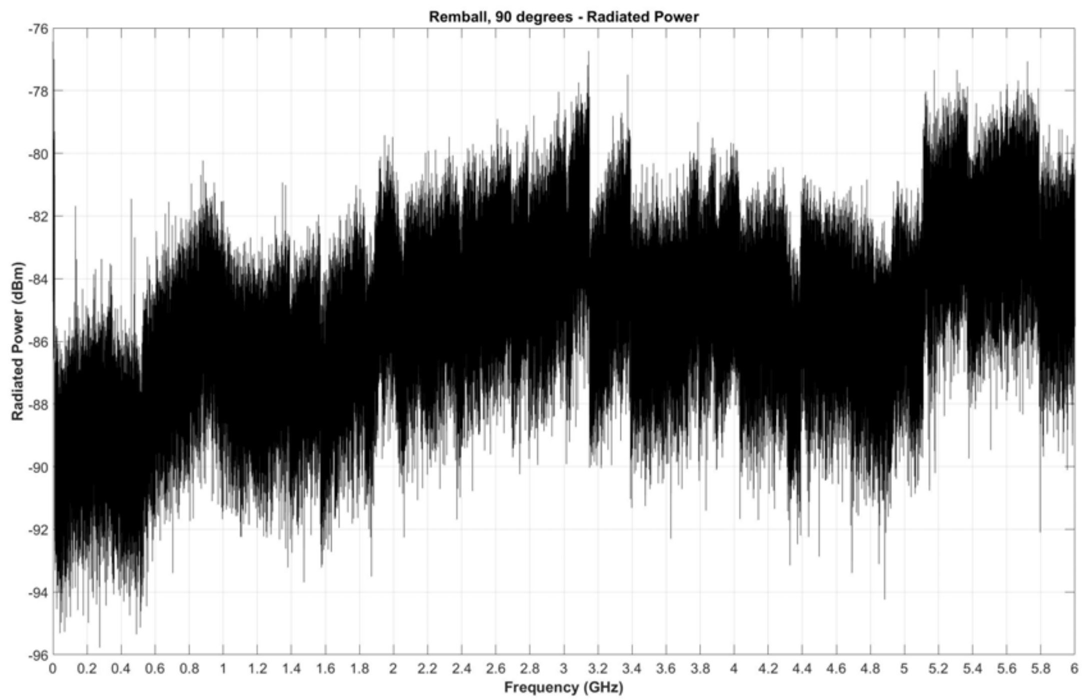


Fig. 49: REMBall Radiated Power [dBm], 90 Degrees

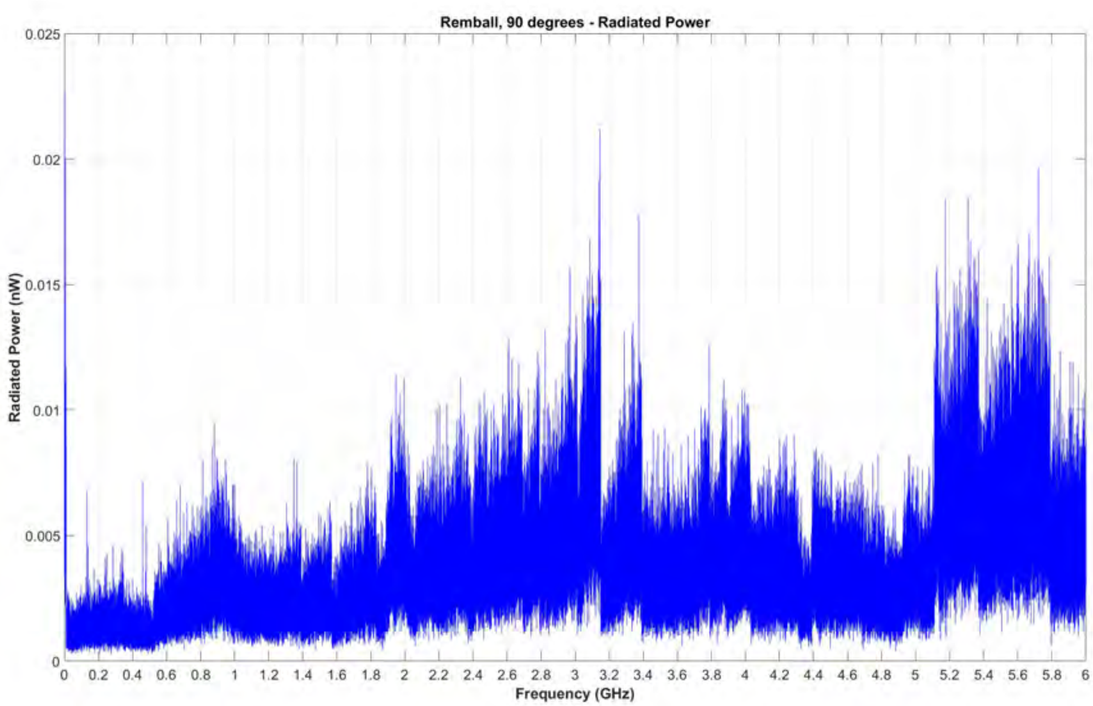


Fig. 50: REMBall Radiated Power [nW], 90 Degrees

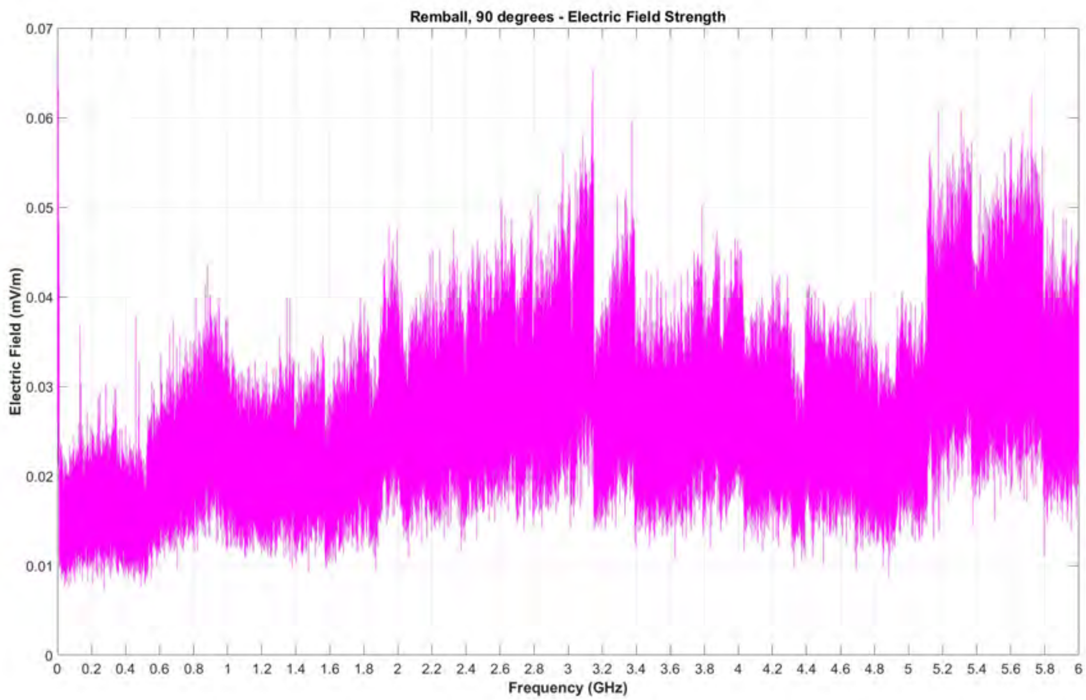


Fig. 51: REMBall Electric Field Stength [mV/m], 90 Degrees

5.8 Supporting Hardware Results

The USB 2.0 Ranger 2244 is a USB extender that encodes/decodes USB over fiber optic cable. The USB extenders will be used with the HPGe system and the NSpec system to control the hardware. The EMR measurements for the USB extender were done using a USB drive on one end and a laptop on the other. The measurements were performed during a very large file transfer between the USB Drive and the laptop. The measurements were performed using a reference level of -25dBm. The largest emission of -74.8 dBm was seen at 0.21 MHz, which corresponds to a radiated power of 0.3 nW and an electric field strength of 0.8 mV/m. The results are shown in Figures 52-54

Three different UPS systems were also checked for EMR for completeness. These were the Tripp Lite OMNI1000ISO, Tripp Lite SMART1200XLHG, and Trip Lite SU1500XL. The SU1500 and OMNI1000 meets FCC Part 15 Category A (EMI). The SMART1200 meets FCC Part 15 Category A (EMI) and is tested to UL60601-1 (medical grade). The systems were not fully charged and were measured while charging. The measurements were performed with a reference level of -25 dBm for the OMNI1000ISO and -40dBm for the other two systems. The OMNI1000 had a maximum radiated power of -44.2 dBm at 12.05 MHz, which corresponds to 38.4 nW and an electric field strength of 2.77 mV/m. The SMART1200 had a maximum radiated power of -73.5 dBm at 0.25 MHz, which corresponds to 0.05 nW and an electric field strength of 0.10 mV/m. The SU1500 had a maximum radiated power of -65.6 dBm at 0.21 MHz, which corresponds to 0.28 nW and an electric field strength of 0.24 mV/m. The results are shown in Figures 55-63.

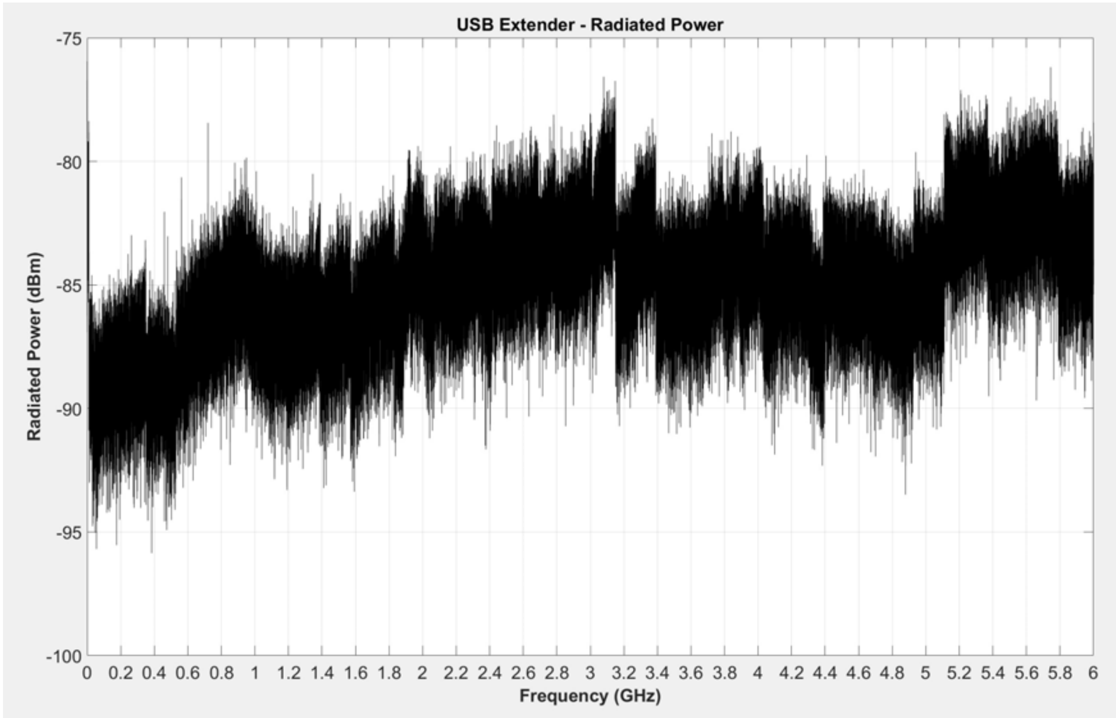


Fig. 52: USB Extender Radiated Power [dBm]

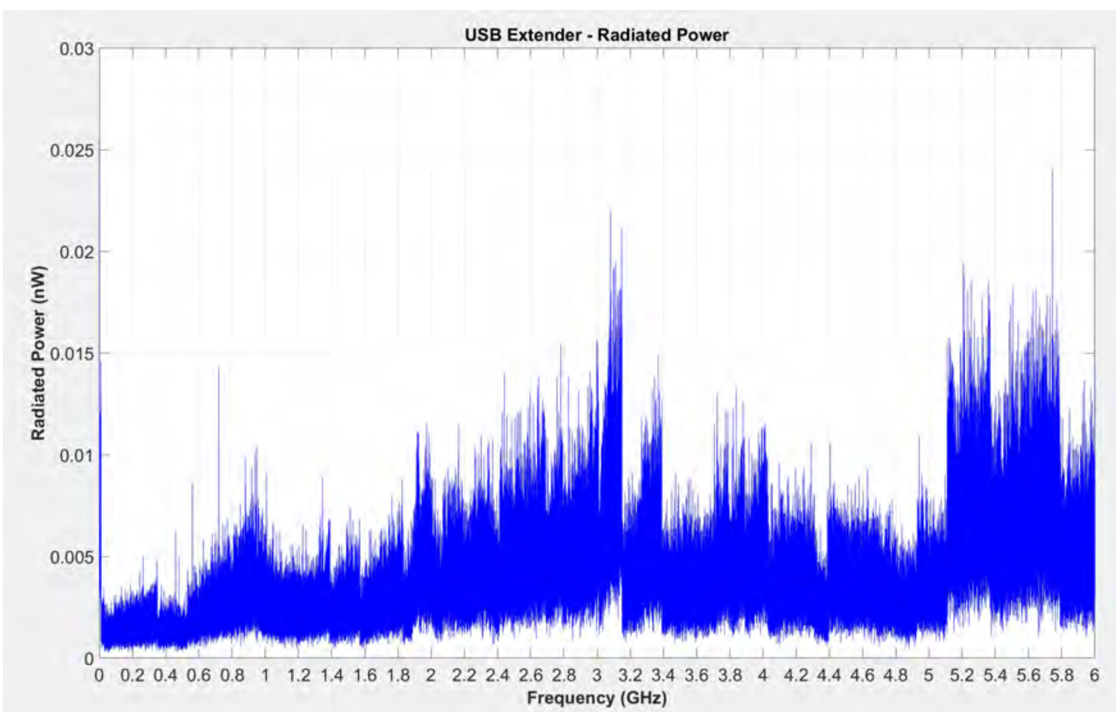


Fig. 53: USB Extender Radiated Power [nW]

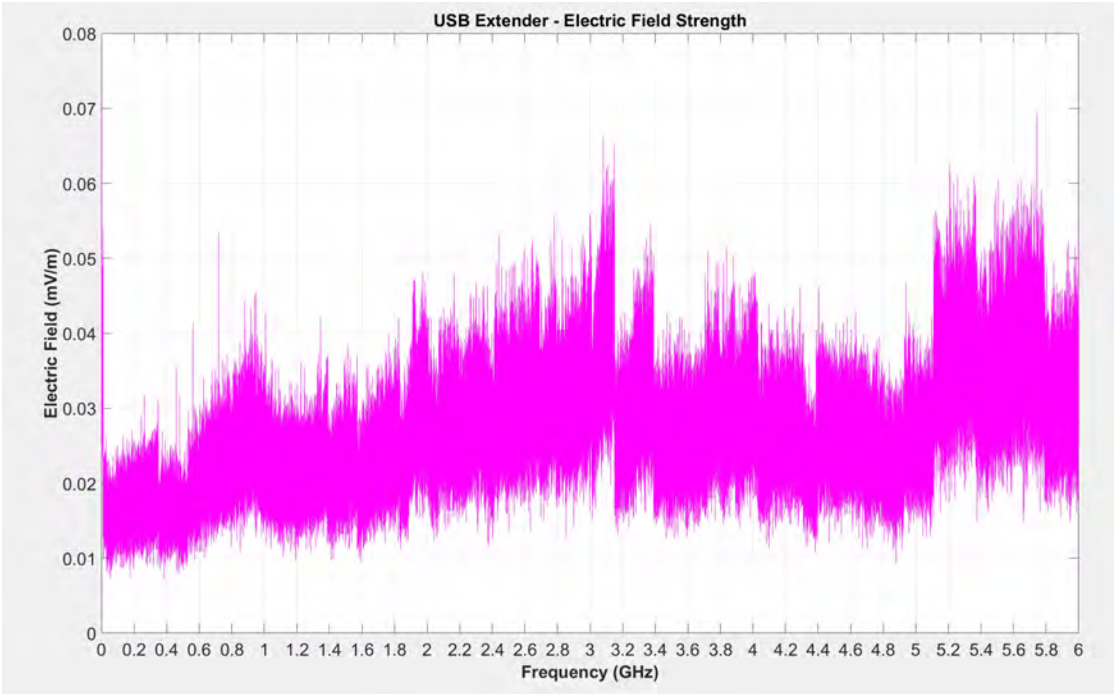


Fig. 54: USB Extender Electric Field Stength [mV/m]

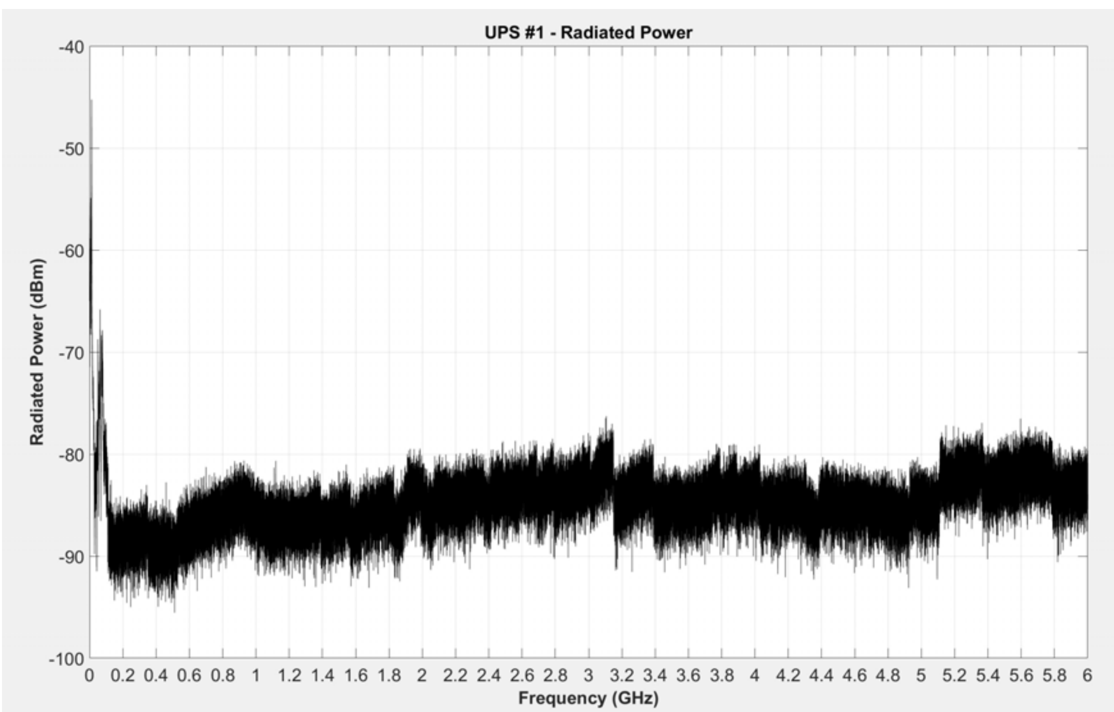


Fig. 55: OMNI100ISO Radiated Power [dBm]

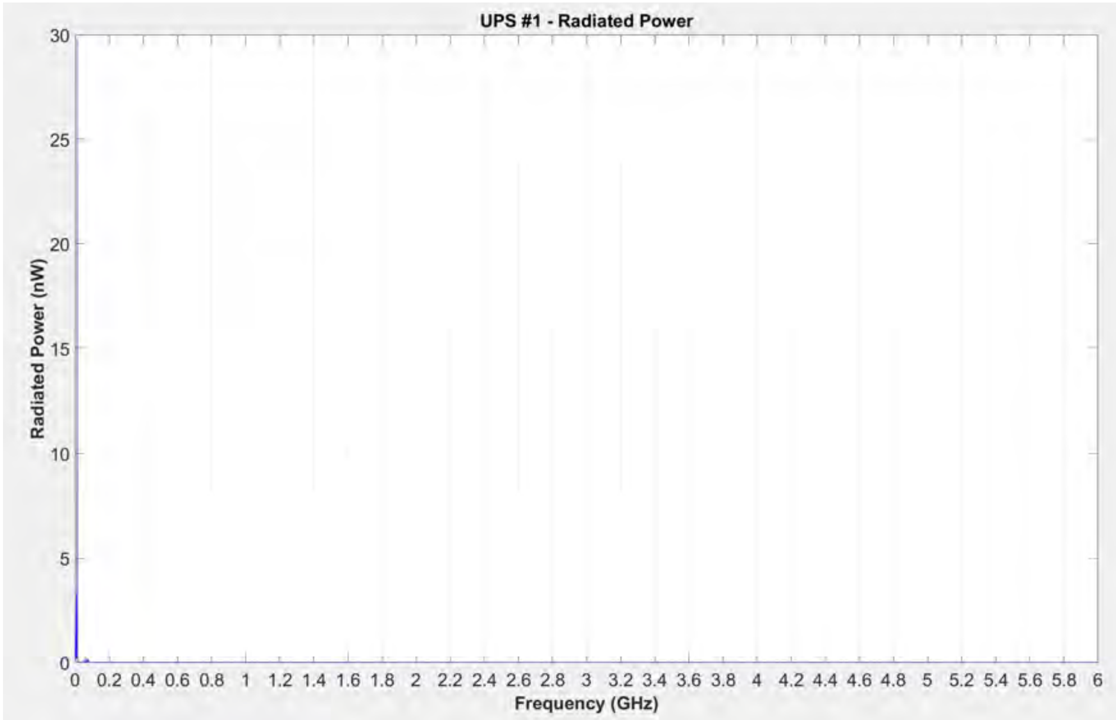


Fig. 56: OMNI100ISO Radiated Power [nW]

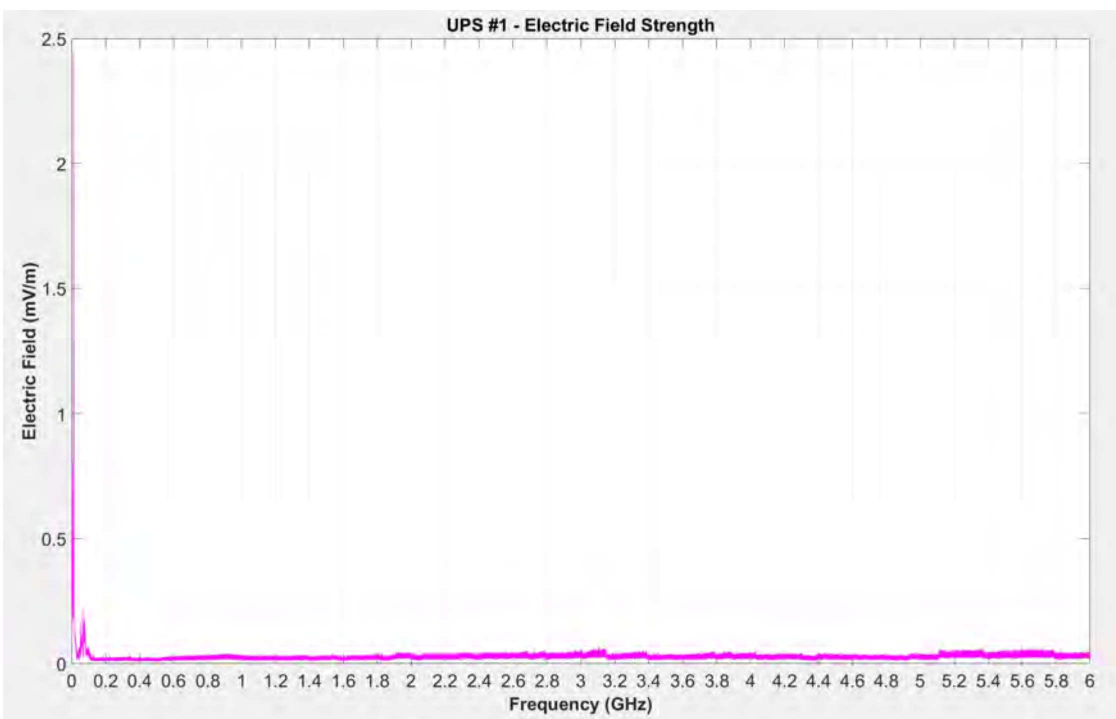


Fig. 57: OMNI100IS Electric Field Stength [mV/m]

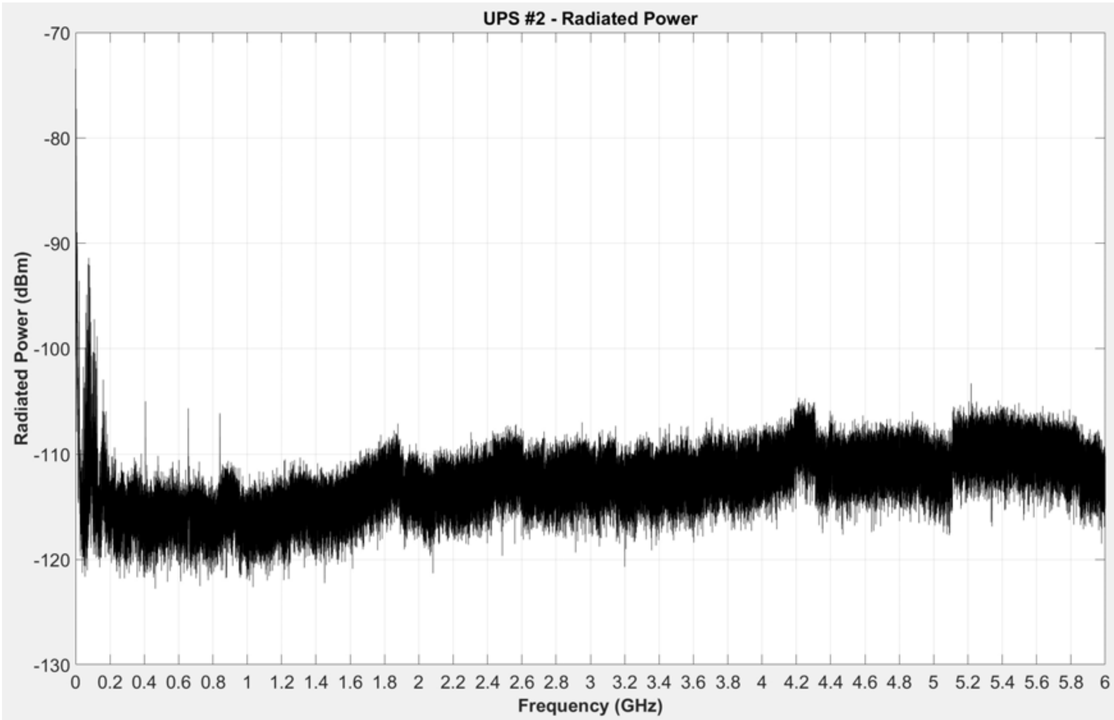


Fig. 58: SMART1200XLHG Radiated Power [dBm]

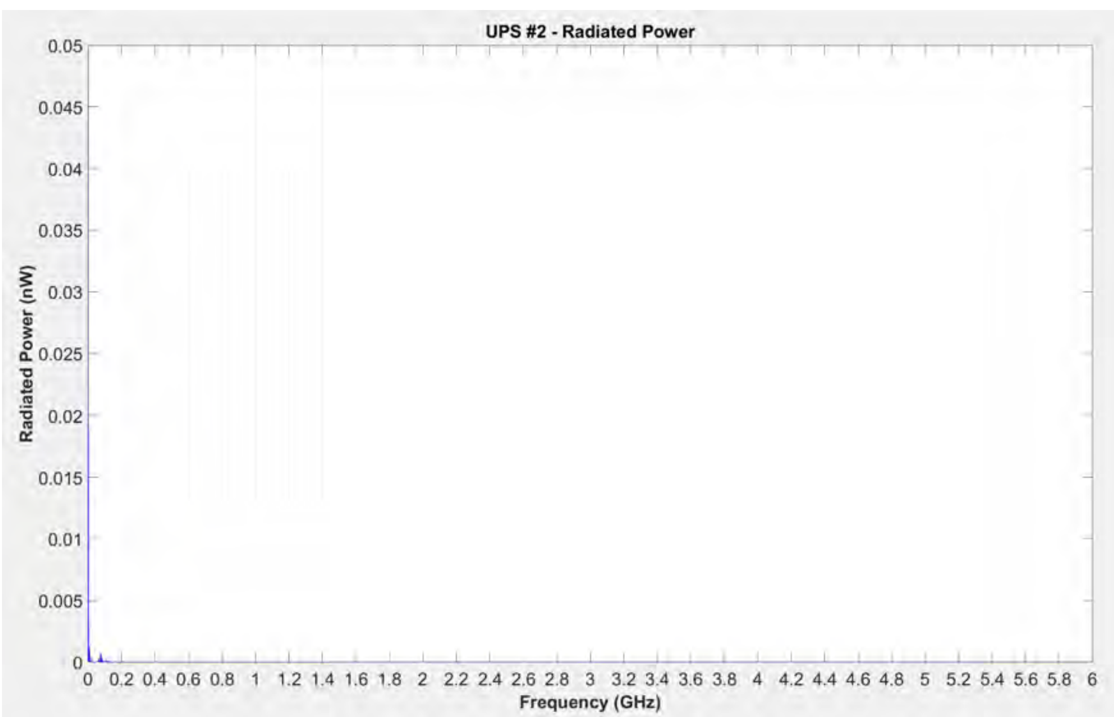


Fig. 59: SMART1200XLHG Radiated Power [nW]

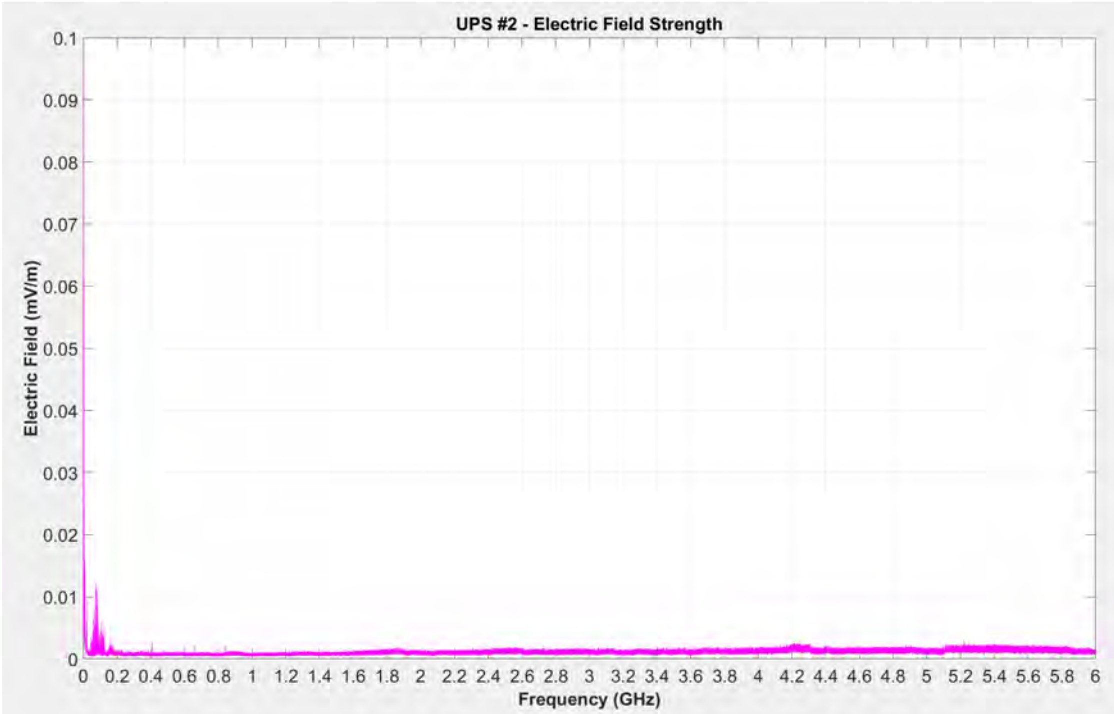


Fig. 60: SMART1200XLHG Electric Field Stength [mV/m]

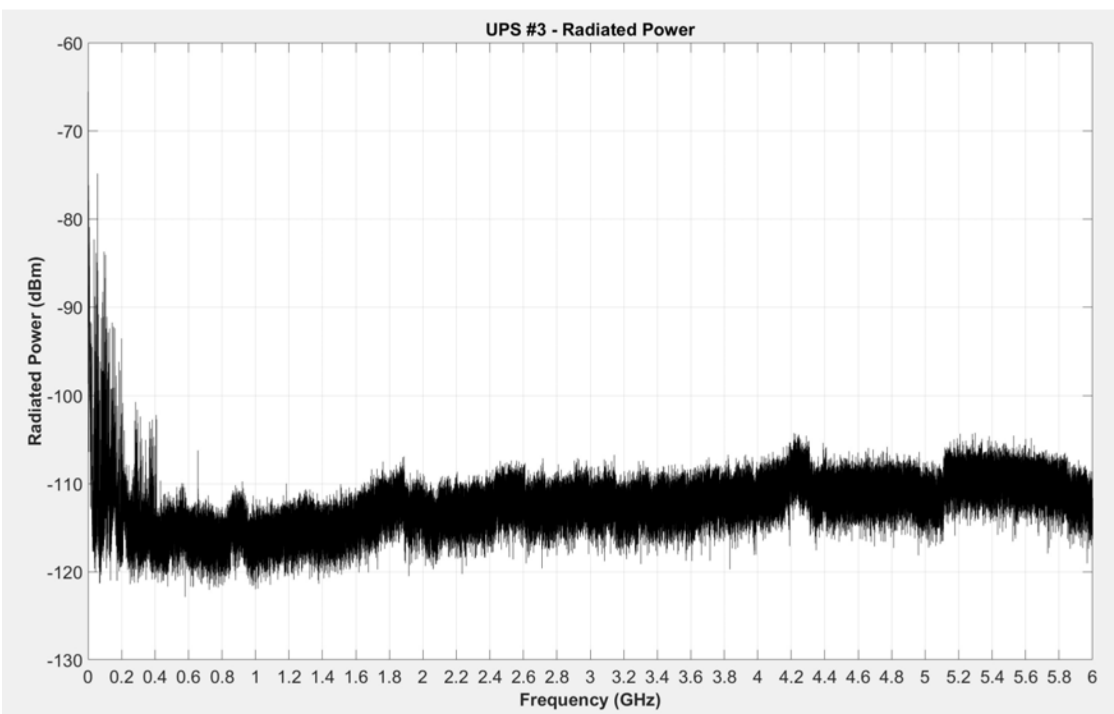


Fig. 61: SU1500XL Radiated Power [dBm]

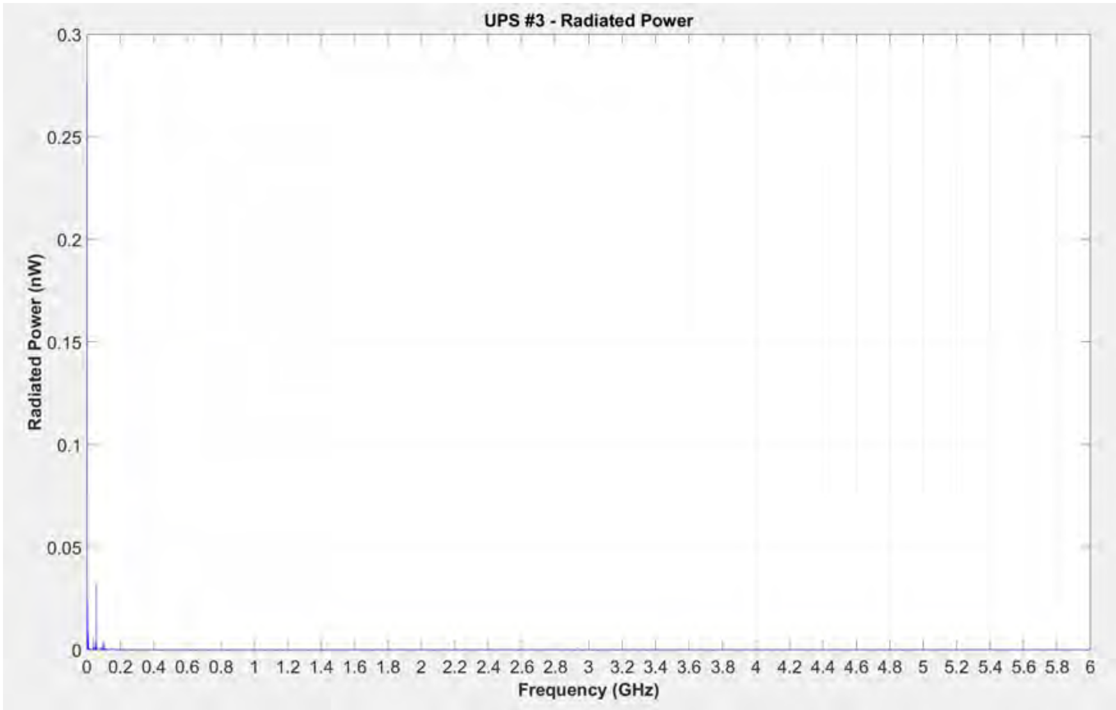


Fig. 62: SU1500XL Radiated Power [nW]

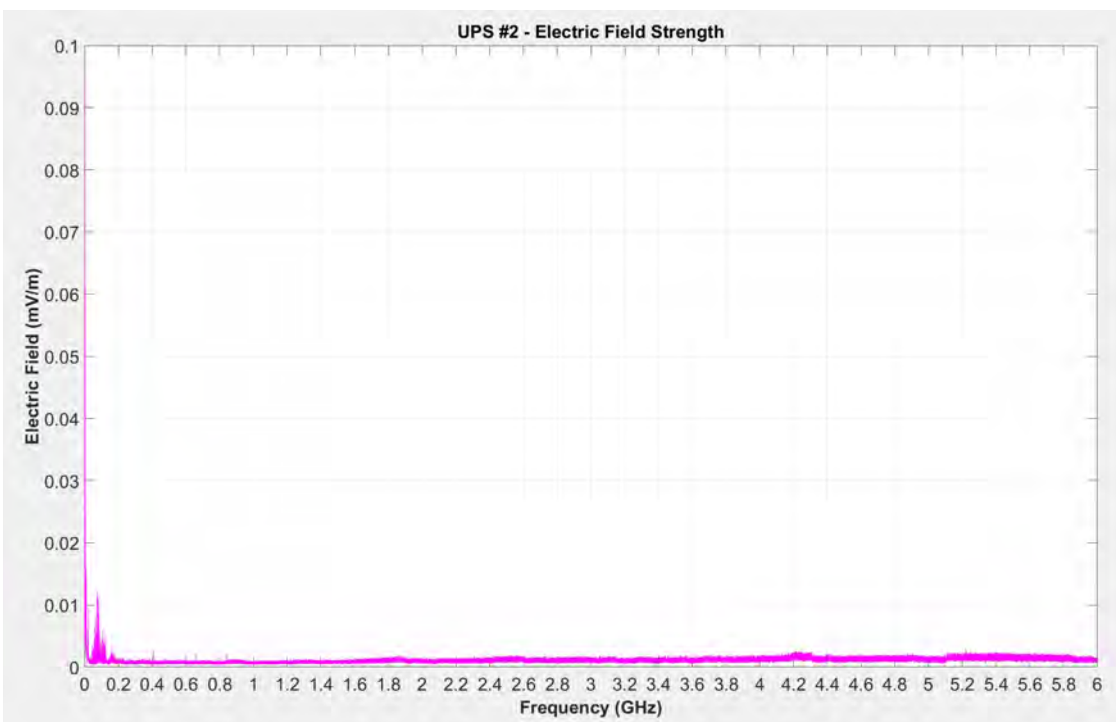


Fig. 63: SU1500XL Electric Field Stength [mV/m]