ADDENDUM
Measurement of voltage level output by magnetic tunneling junction by rectification of RF signals

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Abstract

In this experiment, the DC voltage output of a magnetic tunneling junction (MTJ) was measured. This was accomplished using both a broadband horn ridge antenna as a radio frequency (RF) source. Transmission frequencies ranged from 1 to 6 GHz at varied power levels of 0 to 20 dBm. The signal was received by a coplanar waveguide antenna. A MTJ rectified the RF signal to a DC voltage. Resonance was found at frequencies of 2.1 GHz and 5.6 GHz due to two different MTJ wafers used in manufacturing the detectors. At resonance, rectified voltages levels were approximately 0.3 mV.

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Introduction

The device studied in this experiment operates on the spin of an electron. Microwaves are received by the coplanar waveguide antenna. These signals are passed into a magnetic tunneling junction. These microwaves cause precession of the vector of magnetization in the free layer of the MTJ. Resonance frequency of the free layer is controlled by a tunable external magnet. As the orientation of magnetization of the free layer to fixed layer changes, the generated resistance oscillates with time. A DC voltage results from the changing resistance and spin-polarized current.

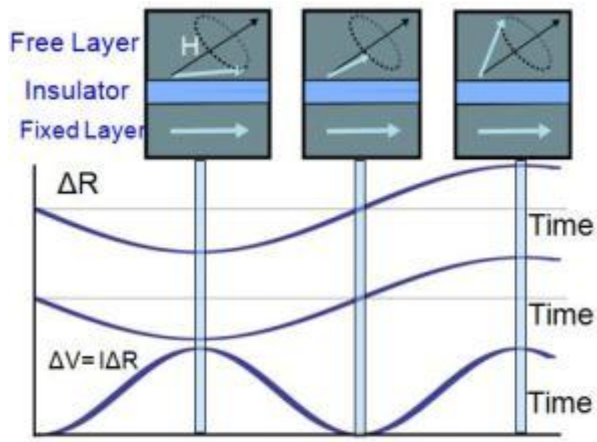

Figure 1 – DC voltage produced by microwave input and changing resistance

The spintronics detector consists of several components and circuit elements. The CPW receives the RF signals. It rests on the brass enclosure for support. The CPW connects to the inputs of the MTJ. The back of the MTJ is grounded to the enclosure. Through wire bonds, it outputs DC voltage to the SMA pin. In the side of the case resides a permanent magnet attached to a set screw. Turning the set screw tunes the magnetic field which changes the sensitivity at the resonance frequency of the MTJ. Electrostatic discharge (ESD) circuit composed of a bias tee and two diodes are also located inside the enclosure. A black Duroid cover, which does not impede microwave transmission, protects the internal components (removed for pictures).

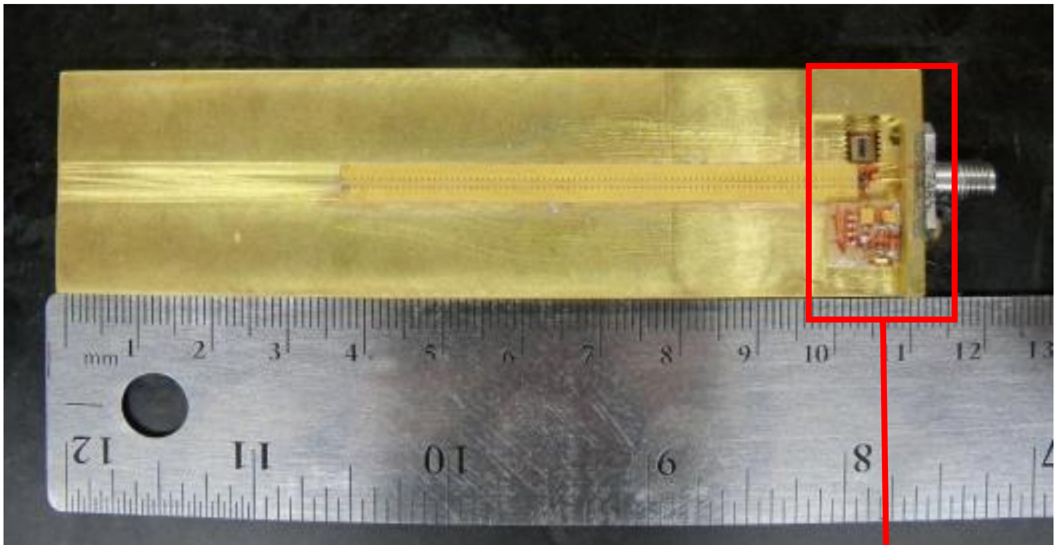

Figure 2 – Spintronics Detector

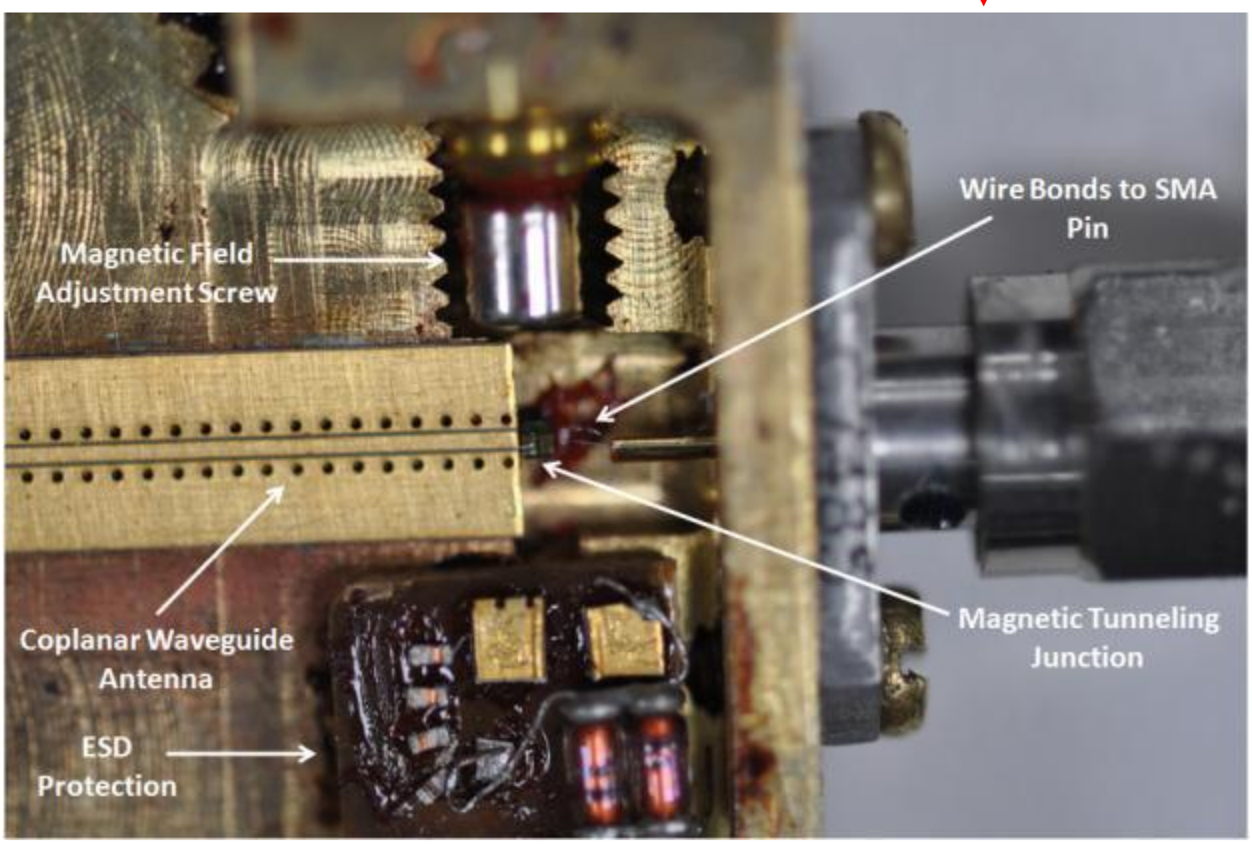

Figure 3 – Spintronics Detector (Exploded View)

The material composition of the MTJ consists of multiple layers. The $Co_{20}Fe_{60}B_{20}$ acts as the free layer and $Co_{40}Fe_{40}B_{20}$ behaves as the fixed or pinned layer. These two layers are separated by a tunneling barrier made of MgO.

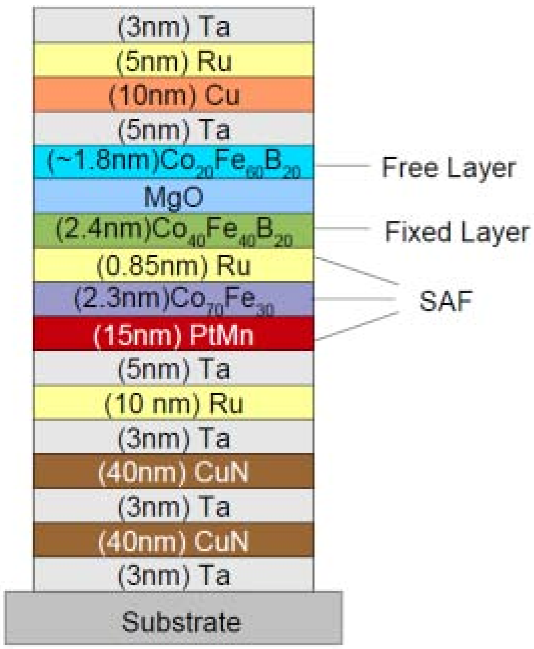

Figure 4 – MTJ Composition

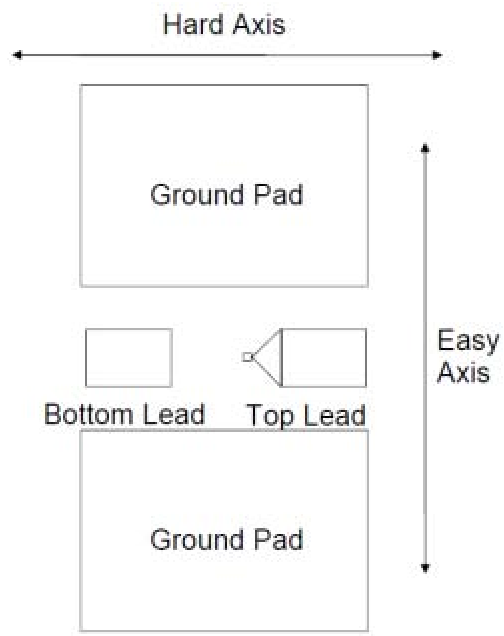

Figure 5 – MTJ electron path

Experimental Setup

Equipment preparation began by testing our antennas. Two different types of antennas were used in this experiment, log periodic and horn ridge. The radiation patterns for each were recorded inside an anechoic chamber encased in a Faraday cage. This was done by using a log periodic antenna to receive signals from another log periodic or the horn ridge antenna. The receive antenna remained stationary while the transmit antenna was rotated.

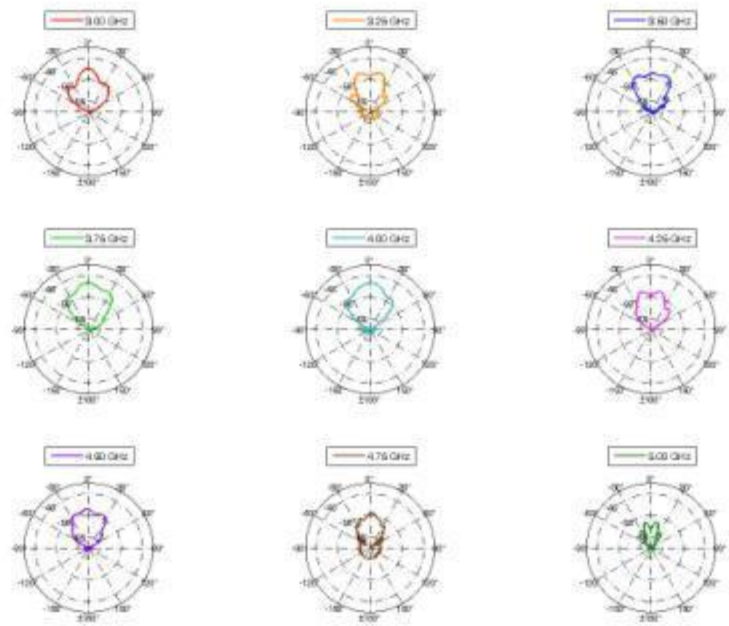

Figure 6 – Log Periodic Antenna Radiation Pattern

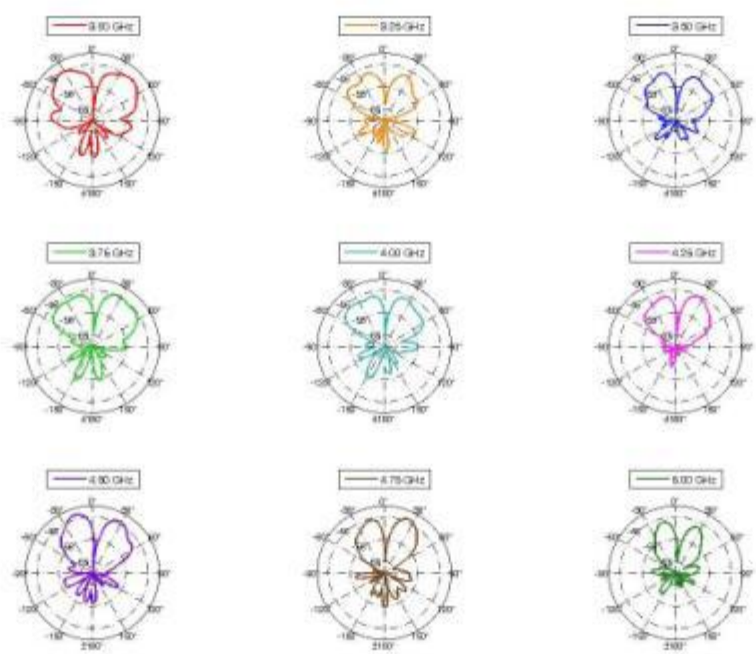

Figure 7 – Horn Ridge Antenna Radiation Pattern

The radiation pattern for the log periodic antenna was as expected. However, the horn ridge antenna radiation pattern was surprising. On the main beam of the antenna (0 degrees), the antenna has zero power. Since this is a directional antenna, maximum power should be achieved at 0 degrees. However, through tests done using the spintronics detector, the horn ridge antenna is fully functional and maximum power is located on the main beam. There is some unknown compatibility between the horn ridge and log periodic antenna.

The complete measuring circuit including the antennas, nanovoltmeter, and function generator was tested using a GaAS microwave detector. The function generator produced a signal to a transmitting antenna. The transmitted signal was received by another antenna and passed to the GaAS detector. The detector rectified the voltage which was read by the nanovoltmeter. The measuring circuit was tested using two different antenna configurations: two log periodic antennas; one log periodic and one horn ridge. Due to the antenna mismatch between the log periodic and horn ridge antennas, no data was recorded for the horn ridge for this test.

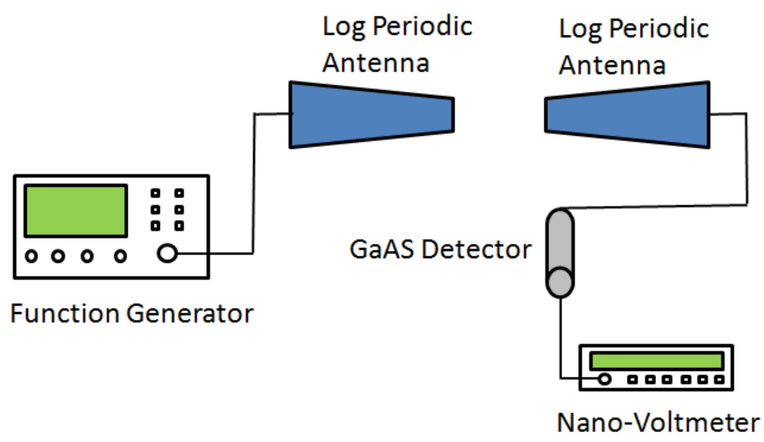

Figure 8 – Log Periodic to Log Periodic measuring test circuit

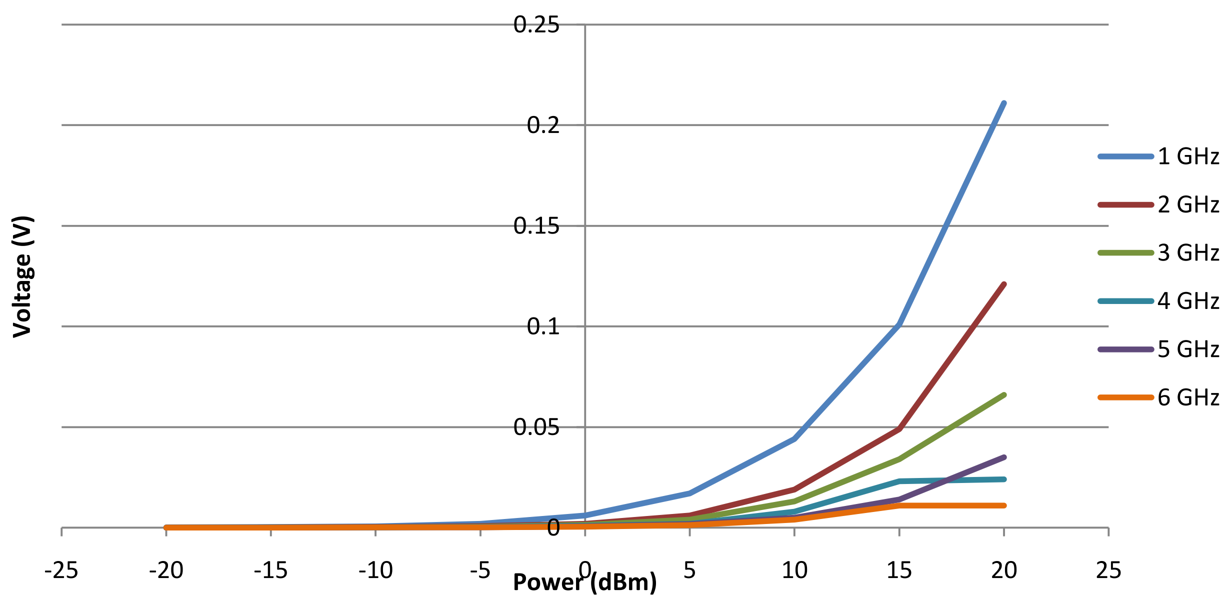

Figure 9 – Log Periodic to Log Periodic GaAS data

Many improvements to the experimental setup were made during the initial testing of the spintronics detectors. To improve transmission clarity, a custom cable was designed and fabricated to connect the nanovoltmeter to the detector. This provided a direct connection from the proprietary nanovoltmeter connector to BNC. The original nanovoltmeter cable had spade terminals. These were attached to a BNC adapter via screw down lugs. The custom cable reduced losses due to the connector conversions. It was tested using the GaAS diode detector for continuity and clarity.

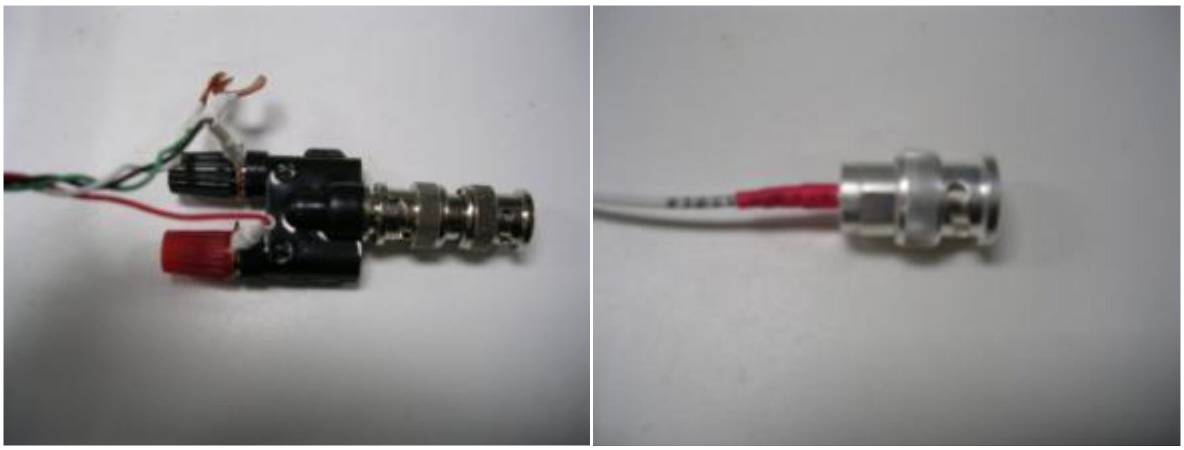

Figure 10 – Left: UCI recommend method. Right: Custom BNC cable

Another improvement was aimed at reducing both internal and external electromagnetic radiation. An anechoic chamber was built from specialized foam to reduce internal reflections. The chamber was wrapped in a Faraday cage and attached to ground to shield external radiation. The chamber was tested by placing a cellular phone inside. The phone would not ring inside the chamber, but immediately received service when removed.

Figure 11 – Left: Anechoic chamber/Faraday cage. Right: Internal view of anechoic chamber

Results

In this experiment, two different MTJ wafers were used. Changing the orientation of the electrodes and grounding pads to the magnetic field produced two different resonance frequencies. Group A exhibited highest sensitivity at approximately 5.6 GHz and Group B at approximately 2.1 GHz. In both configurations, the easy axis (indicated by the arrow) remained perpendicular to the magnetic field.

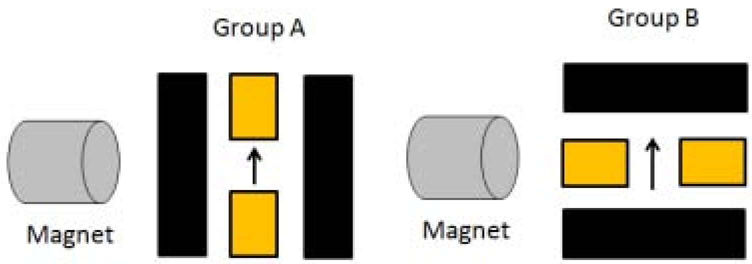

Figure 12 – Internal orientation of MTJ components

Testing was conducted with the horn ridge antenna at minimal distance from the spintronics detector. The detector was oriented parallel to the ridges on the horn antenna.

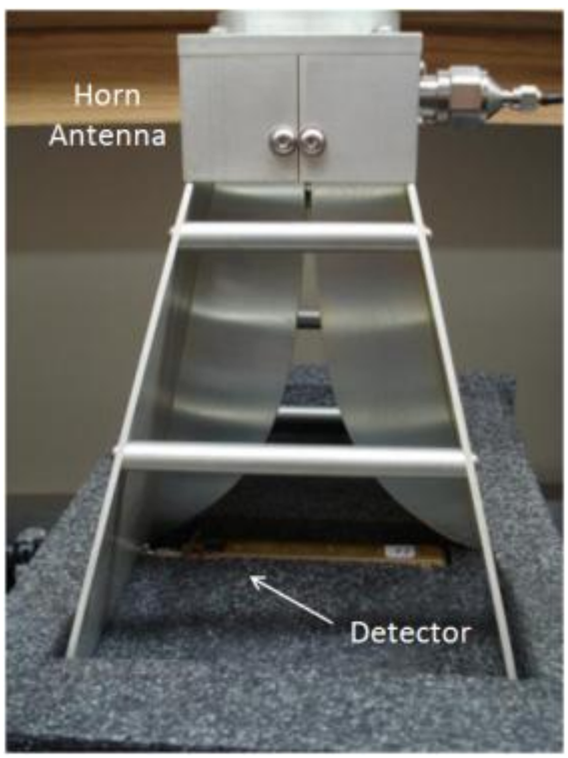

Figure 13 – Horn antenna and detector testing positions

The detectors were scanned from 1- 6 GHz at a power of 15 dBm. Because of the LC circuit located in the bias tee, both group A and B exhibit resonance at around 1 GHz.

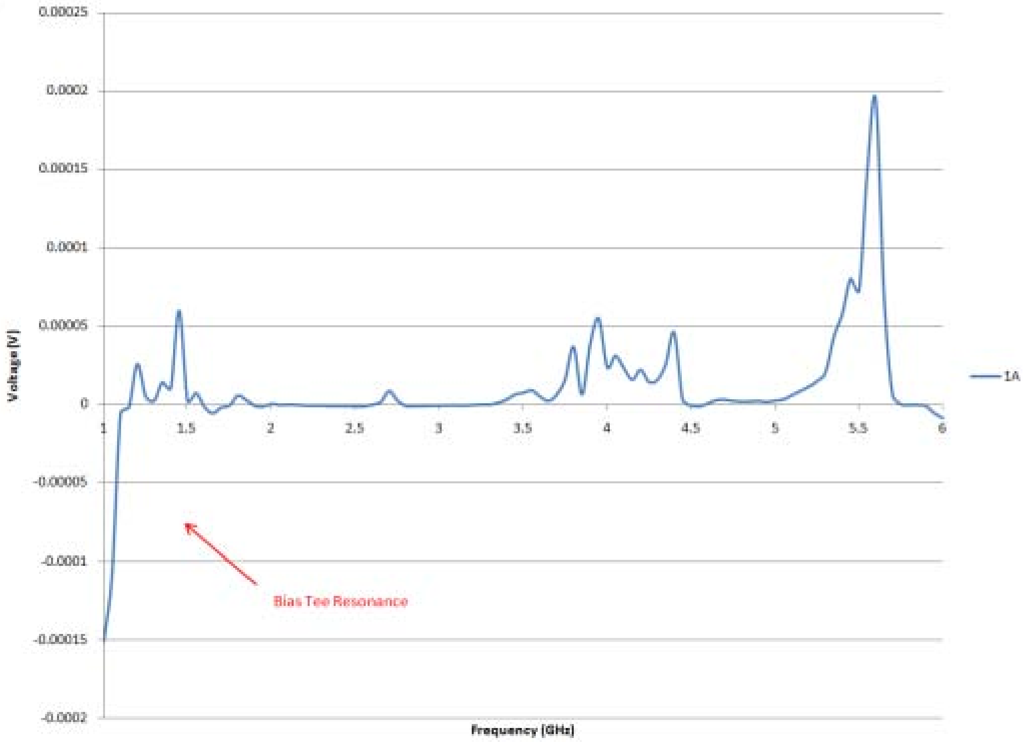

Figure 14 – Detector 1A scan

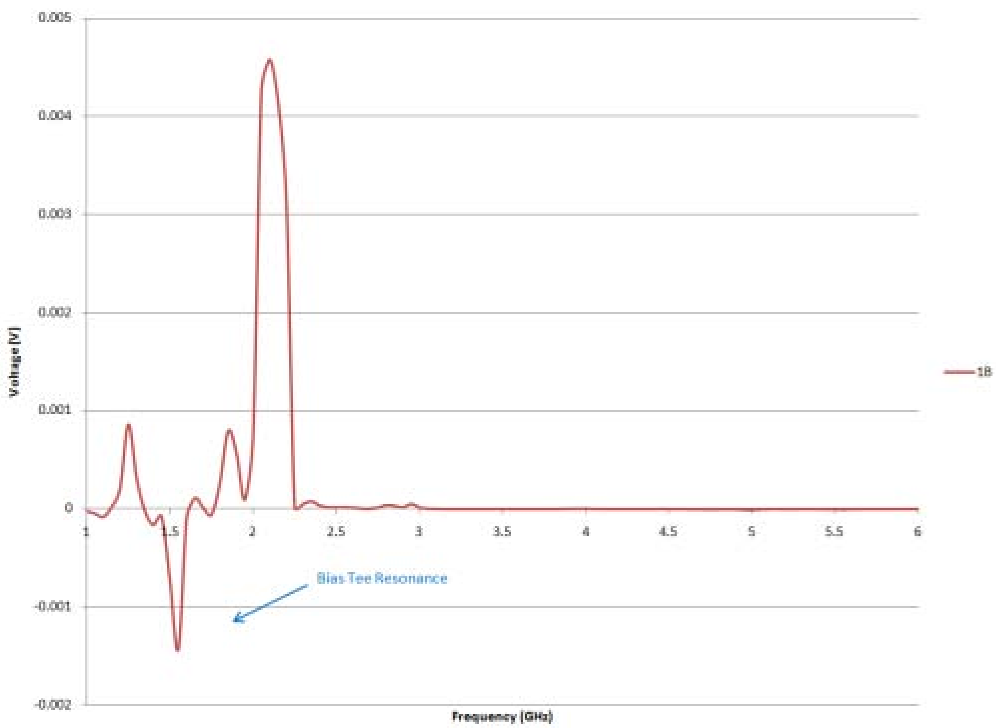

Figure 15 – Detector 1B scan

Optimal sensitivity of the detector was achieved by tuning the magnetic field using the set screw. Each device will have its own characteristic sensitivity. For detector 1A, highest voltage levels of approximately 0.3 mV was found at 1 turn out.

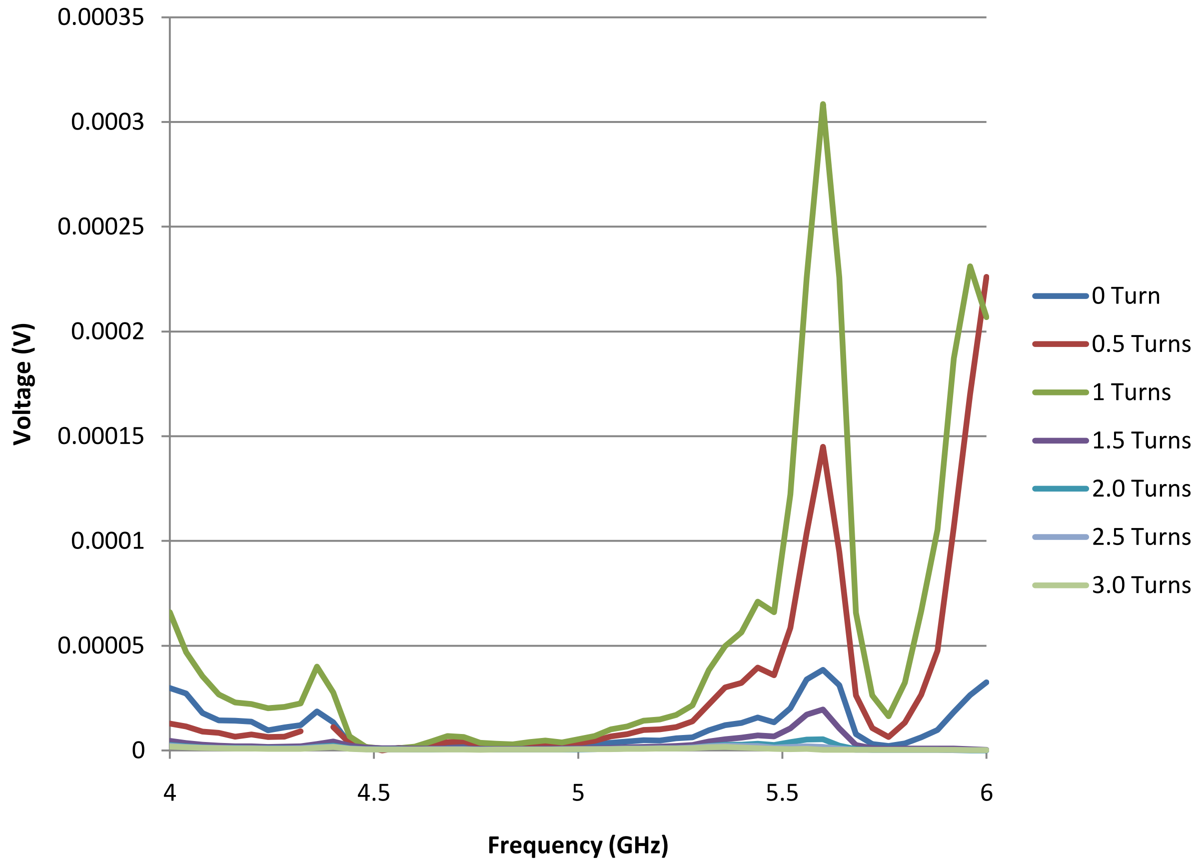

Figure 16 – 1A optimal sensitivity

The results shown above were collected without the protective cover installed. Although Duroid is supposed to be transparent to microwave radiation, it made a significant impact on the voltage level. The Duroid cover may be acting as an extension of the CPW or is causing reflections which amplify the DC voltage. After installing the Duroid cover and metal screws, the following results were produced.

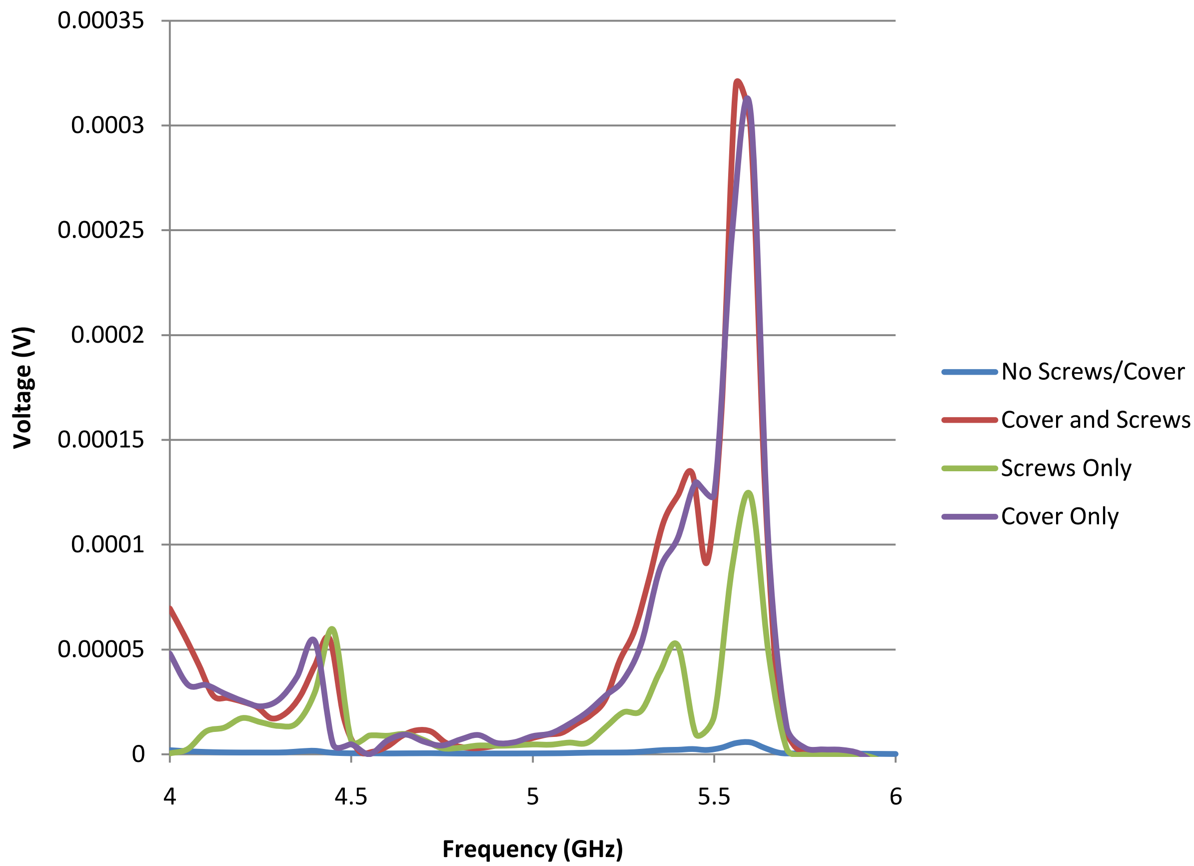

Figure 17 – Effects of Cover and Screws

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