

PV Arc Fault Detector Challenges due to Module Frequency Response Variability

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Introduction

PV system arc faults have led to a number of rooftop fires which have caused significant property damage and threatened the safety of building occupants. In response, Article 690.11 was approved for the **2011 National Electrical Code** which **requires new PV systems on or penetrating a building to include a listed arc fault protection device**. Sandia National Labs is researching the electromagnetic phenomena of PV arcs and the propagation characteristics of arcing signals through PV arrays in order to inform arc fault detector designers of frequency-dependant PV attenuation, electromagnetic noise, and radio frequency effects within PV systems.



Arcing at the combiner box [1]. PV arc fault-initiated fire on a warehouse in Buerstadt Germany. Discoloration indicating arcing at the busbar and collector ribbon.

Purpose

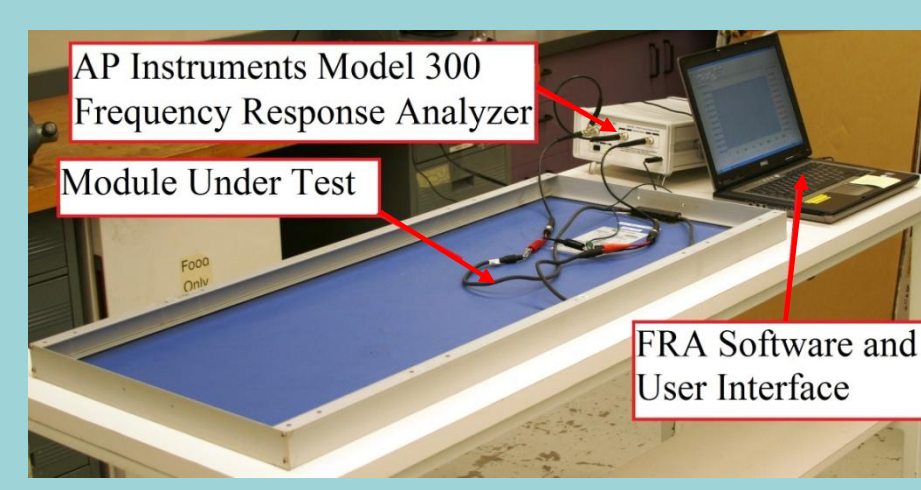
In order to prevent arc faults and fires in PV systems, Sandia National Laboratories is researching electrical signal propagation through PV modules to help design robust Arc Fault Circuit Interrupters (AFCIs).

Research Goal

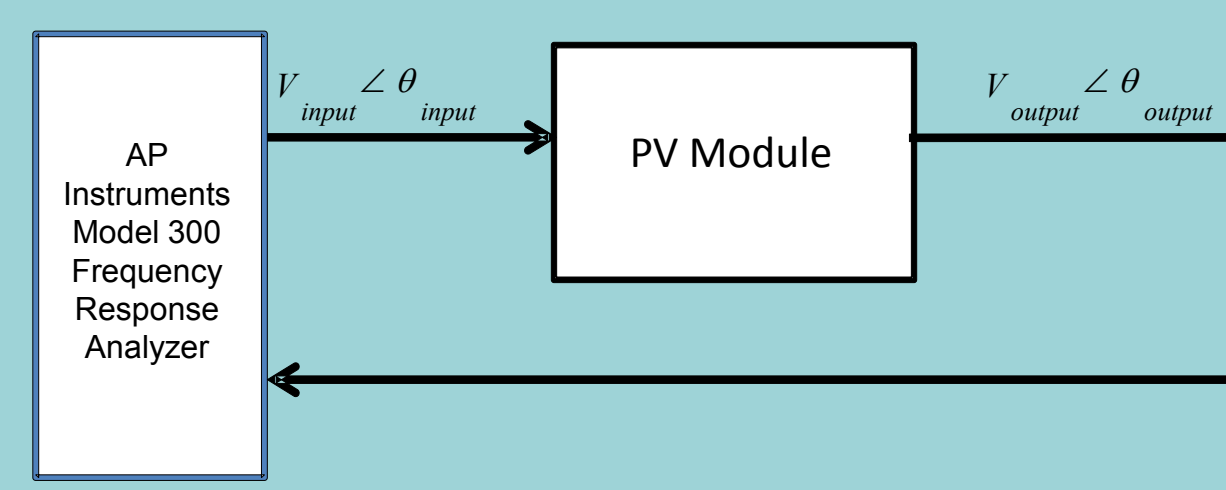
Arc fault detectors utilize frequency content on the string to determine if an arc is occurring. Due to filtering in PV components (e.g., modules, connectors, bypass diodes) and noise in the form of inverter switching, electromagnetic coupling (crosstalk), and other radio frequency (RF) effects, it is possible that arcing could go undetected. To better ascertain the potential for missing a faulting condition, Sandia National Labs is investigating if module degradation alters arcing frequency content measured by a remotely located detector.

Setup

Experimental Procedure: A frequency response analyzer was used to measure the AC response of an intermittent module from 1 Hz to 10 MHz. The attenuation of the AC signal is determined by the magnitude of the output voltage.

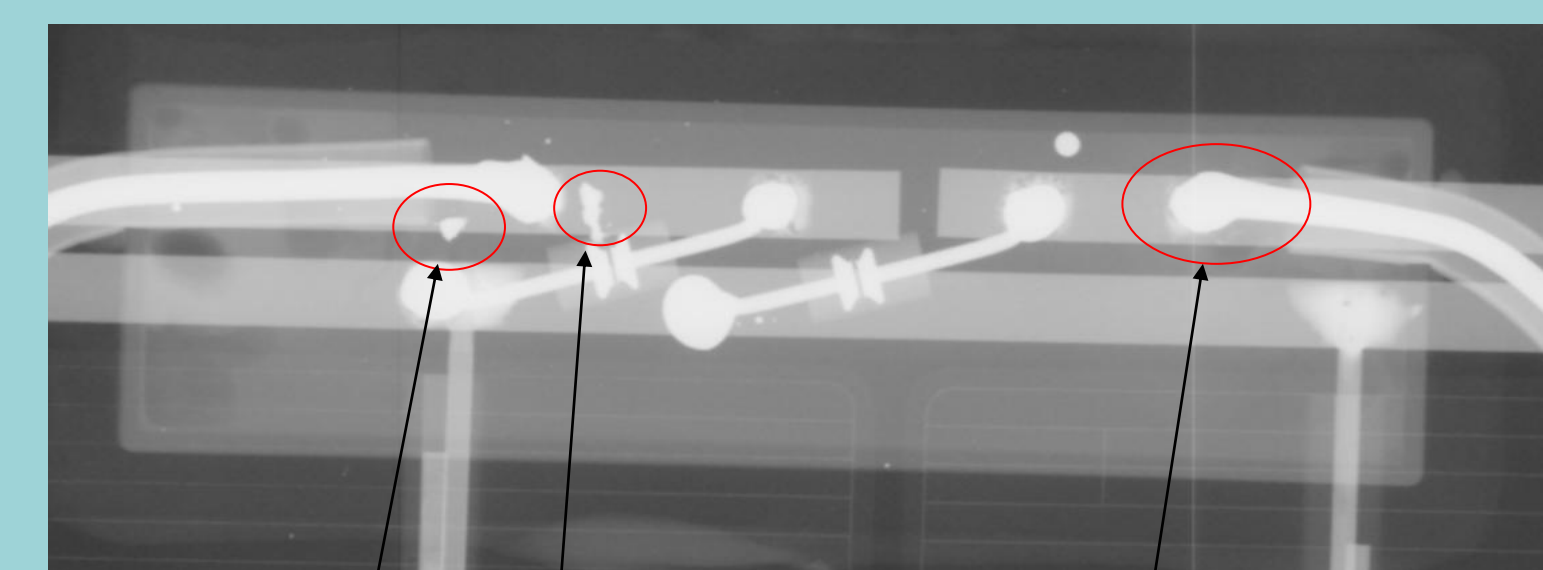


The experimental setup for the module scans. The scans were performed without irradiance.



Sinusoidal AC input voltage signal is driven into the PV module and the Frequency Response Analyzer calculates the attenuation from the output magnitude.

Test Module: An intermittent 80 W polycrystalline module had conductivity issues depending on the angle the external line made with the junction box. The continuity of the soldered junction box connection could be manipulated by twisting the line. The junction box is shown in the x-ray image below.



High Density Particles Failed Bond

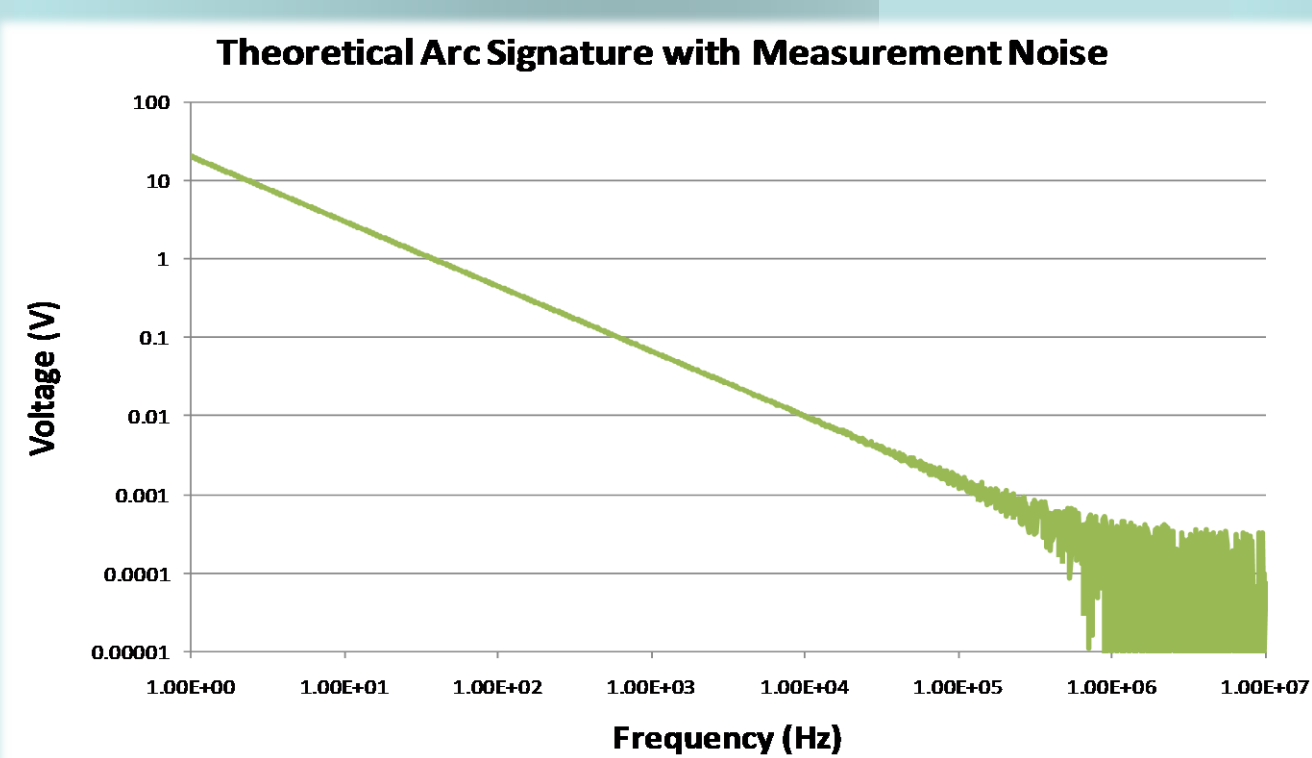
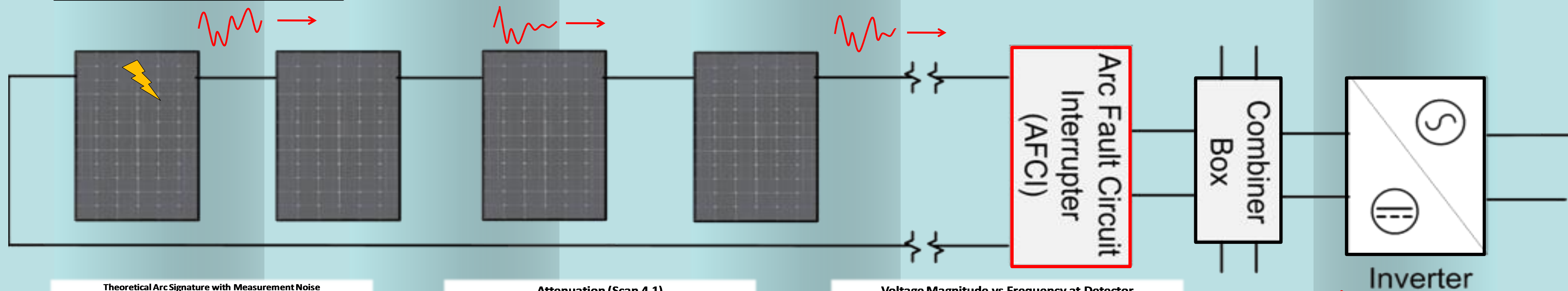
Arc Fault Signal Propagation and Remote Detection Challenges

1. An arc fault initiates at a connector, junction box, or within a module and generates pink AC noise on top of the DC current. This signal travels down the line through the system.

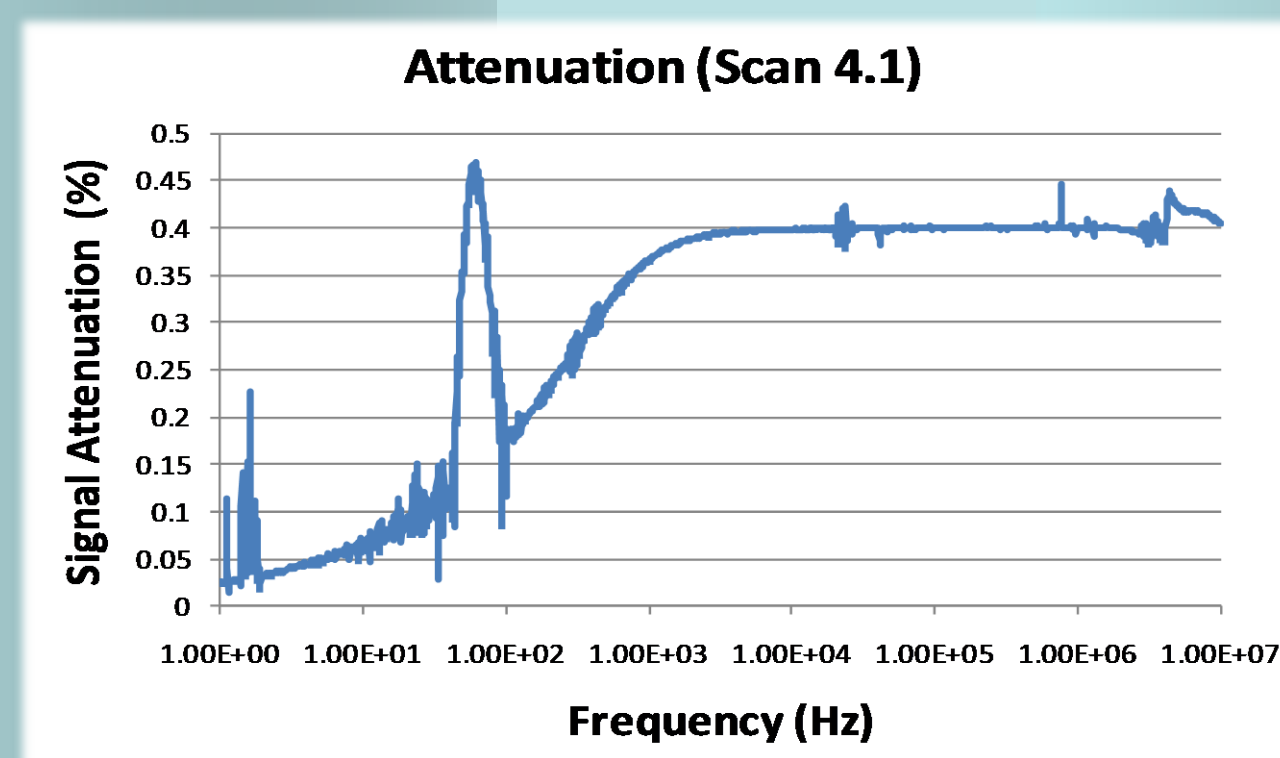
2. As the signal passes through the modules and connectors, some of the frequency content of the electrical AC arc noise is attenuated (or potentially amplified).

3. Depending on the system line lengths and antenna effects, RF phenomena can change the signal characteristics further. In some cases, crosstalk in the system will amplify certain frequency content.

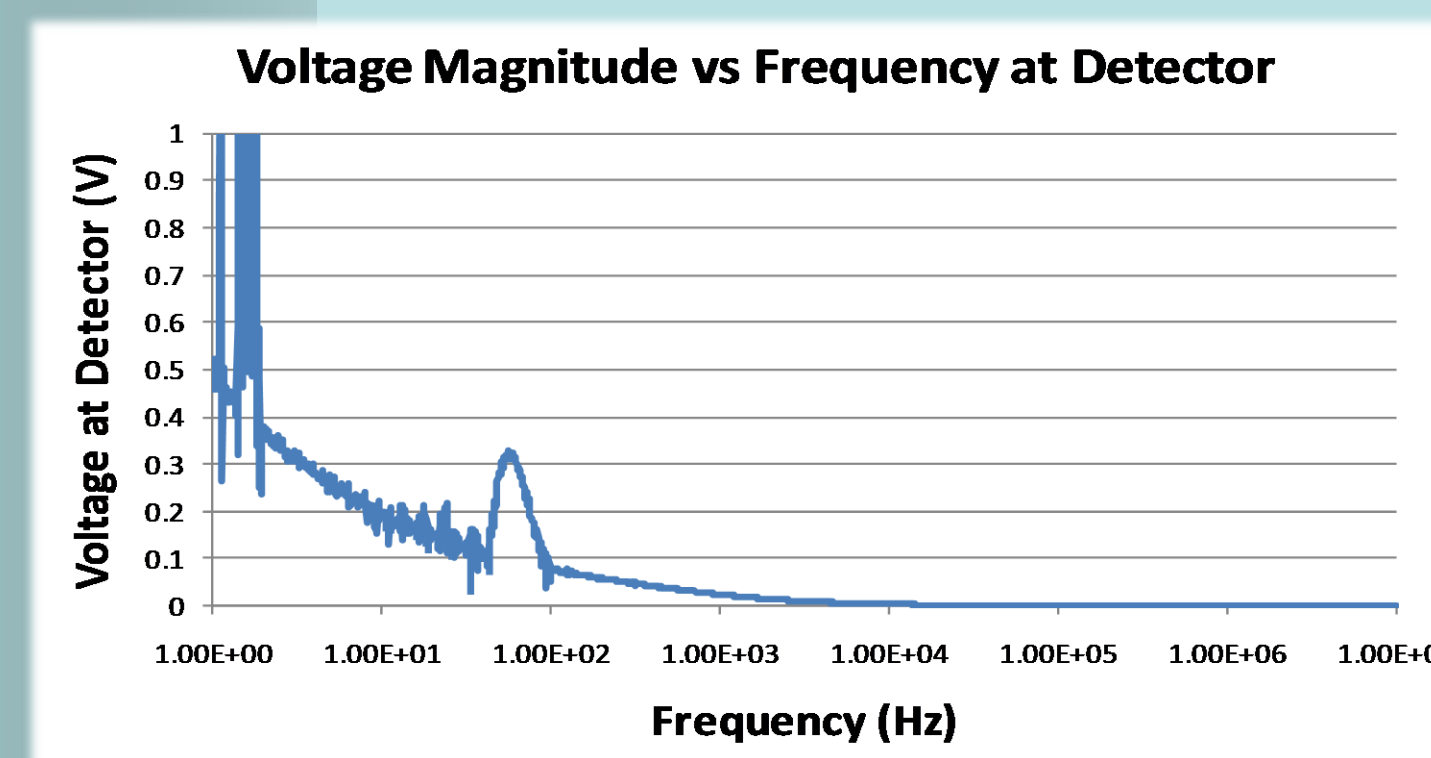
4. The modified arcing signal reaches the arc fault detector within the AFCI. Depending on the cell technology, system topology, meteorological conditions, and health of the modules, the signal reaching the AFCI will be significantly different than the original arcing signal—possibly allowing an arcing condition to go undetected.



1/f noise is produced when the arc event occurs. The noise floor is reached at higher frequencies.



The signal is attenuated as it passes through an intermittent module.

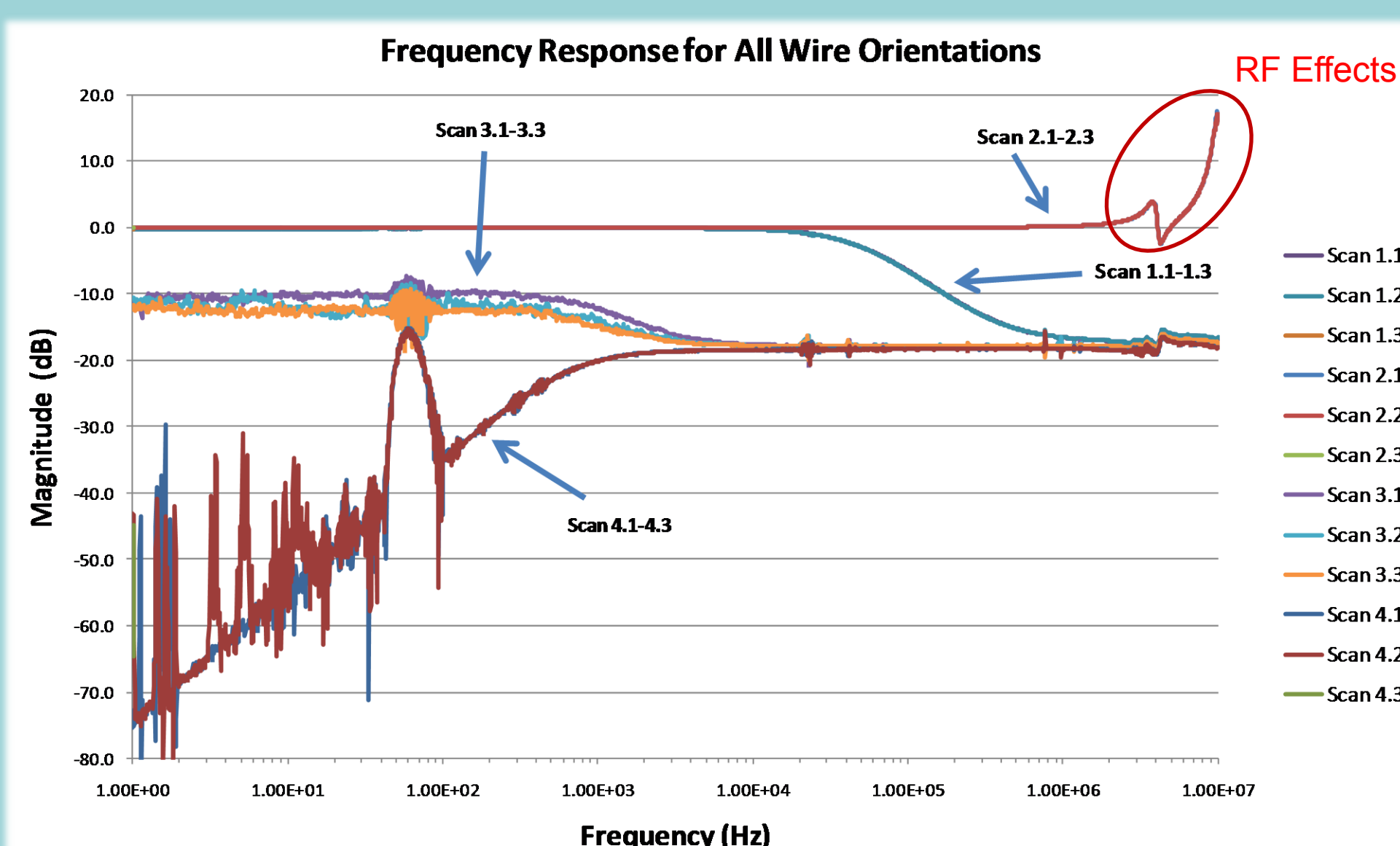


Although this model ignores RF effects and crosstalk, the frequency content of the arc reaching the detector is affected by the intermittent module.

5. Inverter switching generates additional noise in the system at a few kHz to 100 kHz.

Results

The intermittent module was scanned three times with the loose connection in four different orientations. The 2nd orientation (Scans 2.1-2.3) made a good connection in the junction box. The odd behavior above 300 kHz is from RF effects in the line and the connections. Scans for the 1st and 3rd orientations show the module behaving as a low pass filter, whereas orientation 4 strongly attenuates low frequencies. The **variation in the frequency responses implies that conditions which cause arcs (i.e. an electrical discontinuity), could also cause detectors to miss the arc.**



Frequency response of a single intermittent module configured with a loose junction box wire held in four different orientations.

Conclusions

Sandia National Labs is testing electrical propagation through PV strings by characterizing different filtering and RF effects in individual components. Frequency analysis showed RF effects were present at higher frequencies and modules could act as filters on the line. **One intermittent module was capable of acting as either a high pass or low pass filter** depending on the orientation of the junction box wire. This could have grave implications for a remotely located arc fault interrupter because if the AFCI uses sufficiently filtered frequencies for detection, **the AFCI would not trip and the arcing event would not be extinguished.**