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Wireless Antenna Detection of Electrostatic Discharge Events

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I. Introduction

Wireless intra-spacecraft communication systems are being developed due to their potential for weight-saving and design flexibility compared to wired systems [1,2]. Such systems are essentially an on-board Wi-Fi network allowing various spacecraft systems to communicate wirelessly.

Electrostatic discharge (ESD) is the primary cause of spacecraft failures and anomalies due to interactions with the space environment [3, 4]. ESD effects include:

- Damage to power systems. See Fig. 1 for an example of a sustained arc resulting from ESD.
- Direct damage to electronics systems.
- On-board electronics and computer anomalies including resets, initiation of safe mode, and failures.
- Signal noise from radiated emissions from ESD. Short time duration of ESD results in a broad frequency spectrum of radiated emissions.

We propose that intra-spacecraft wireless communication antennas are capable of in-flight ESD monitoring and that--if multiple antennas with sufficient time resolution are used--one can detect not only ***if*** and ***when*** ESD occur, but ***where*** ESD occur using time-of-flight calculations.

An increased awareness of ESD, benign or otherwise, will enhance predictions of the risk of problematic ESD for future missions and could result in the identification of ESD prone areas of a spacecraft before anomalies or damage occurs and Could make it possible to identify systems to be put in a protected state in response to observations of increased ESD activity.

Such detection systems may require little, if any, additional hardware on the spacecraft if spacecraft are designed to look for ESD traces on antenna built for other communication purposes.

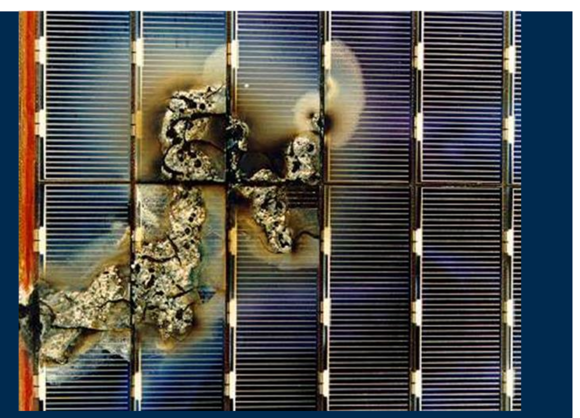

Fig. 1. Sustained arcing damage on a spacecraft solar panel resulting from ESD.

II. Coincidence Measurements

Detecting the RF signature of ESD events is common for terrestrial applications [5-8]. In this research, we demonstrate that these methods are still effective when using cost-effective, standard, off-the-shelf Wi-Fi antennas rather than antennas that are specifically designed for identifying ESD.

Consider a simple example that identifies ESD events with high temporal precision and demonstrates coincidence with other arc detection methods. The USU Materials Physics Group (MPG) measures the likelihood of dielectric breakdown of insulating materials using an *in vacuo* parallel-plate voltage step-up-to-breakdown method [9] adapted from methods recommended in spacecraft charging and ASTM standards [11], described previously [9-13]. Leakage current is measured as applied voltage to the insulating sample is ramped; both transient partial discharges and total dielectric breakdown are observed. A 2.4 GHz Wi-Fi antenna was placed by a vacuum viewport, connected to a 50 Ω load, and monitored with a digital storage oscilloscope.

Results in Fig. 2 of a typical current measurements from an ammeter (100 nA resolution at 2 Hz acquisition rate) are not as sensitive as the antenna. However, discharges seen by the ammeter temporally correlate to events seen by the antenna. Larger-amplitude ammeter traces correspond to current integrated over many fast discharges observed with the antenna, confirming that a typical Wi-Fi antenna is capable of detecting and timing discharges with sub-µs precision.

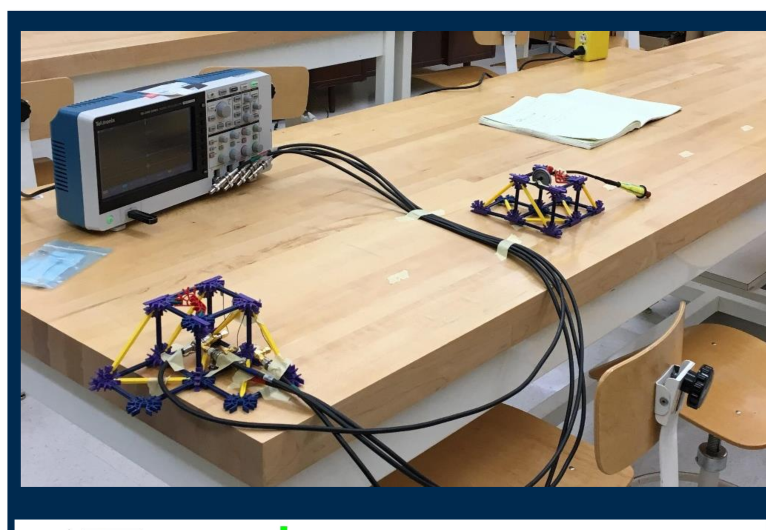

Fig. 2. Wi-Fi antenna characterization setup. Sparks were created at known distances from four Wi-Fi antennas to test their relative response.

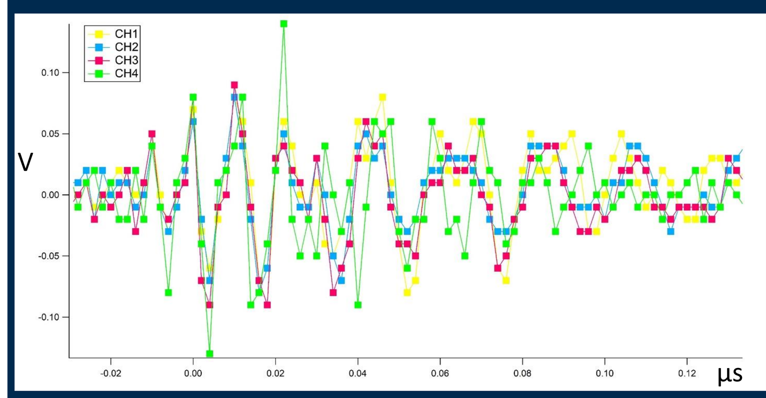

Fig. 3. Traces from antenna characterization test. The first few oscillations in each channel are in phase before a relative phase shift occurs between each pulse.

III. Spatial Localization Measurements

Having demonstrated that Wi-Fi antennas can demonstrate ***if*** and ***when*** ESD occur, we now discuss how to determine ***where*** they occur using differences in time-of flight measurements. The spatial resolution of the calculated ESD location depends on the instrumentation time resolution, Δt_{min}; the minimum spatial difference detectable is $\Delta x_{min} = c\Delta t_{min}$ where c is the speed of light.

Difficulties in matching features in the signals resulting from differences in antenna or cabling response to the ESD signal, polarization effects, etc., may introduce additional uncertainty in Δt_{min} beyond the minimum time resolution of the oscilloscope [8]. The spatial resolution might also be limited by the spatial extent of the antennas or the arc source themselves.

To characterize the relative response of multiple antennas 4 antennas were placed at known distances from a piezoelectric spark source (Fig 3). These antennas (Taoglas FXP840 Freedom Series Super Small Monopole Dual-band 2.4 GHZ and 4.9-6 GHz) are 14x5x0.1 mm and are designed for Wi-Fi or Bluetooth type communications for tablet or smartphone sized devices.

As shown in Fig. 4. and in agreement with other published results, it was observed that the first few oscillations of the signal correlated very well in phase from antenna to antenna, but gradually went out of phase [8]. Therefore, the first peak above the noise was chosen as the feature from which to extract time-of-flight differences in subsequent tests.

The simplest case for localization is the 1D case—simply a discharge between two antennas. A discharge outside the antennas in this geometry would not yield its location, only the separation. Given a known separation between two antennas l with the left antenna at 0 m, the location x of a discharge is $x = \frac{1}{2}[l - c\Delta t]$, with $\Delta t \equiv t_{left} - t_{right}$. It is straightforward to generalize this to 3D. Indeed, such setups have been used in terrestrial applications [8].

Two sets of tests were performed, with:

- 1 GS/s oscilloscope, with an expected $\Delta x_{min} = 0.3$ m (Fig. 2)
- 20 GS/s oscilloscope with an expected $\Delta x_{min} = 0.015$ m (Fig. 4).

A piezoelectric spark generator was used to generate discharges in known locations. Signals from the Wi-Fi antennas were then used to calculated the location based on differences in time-of-flight. With the faster oscilloscope the signals were more sensitive to phase differences between signals; discharges ≲3 cm apart were not distinguishable.

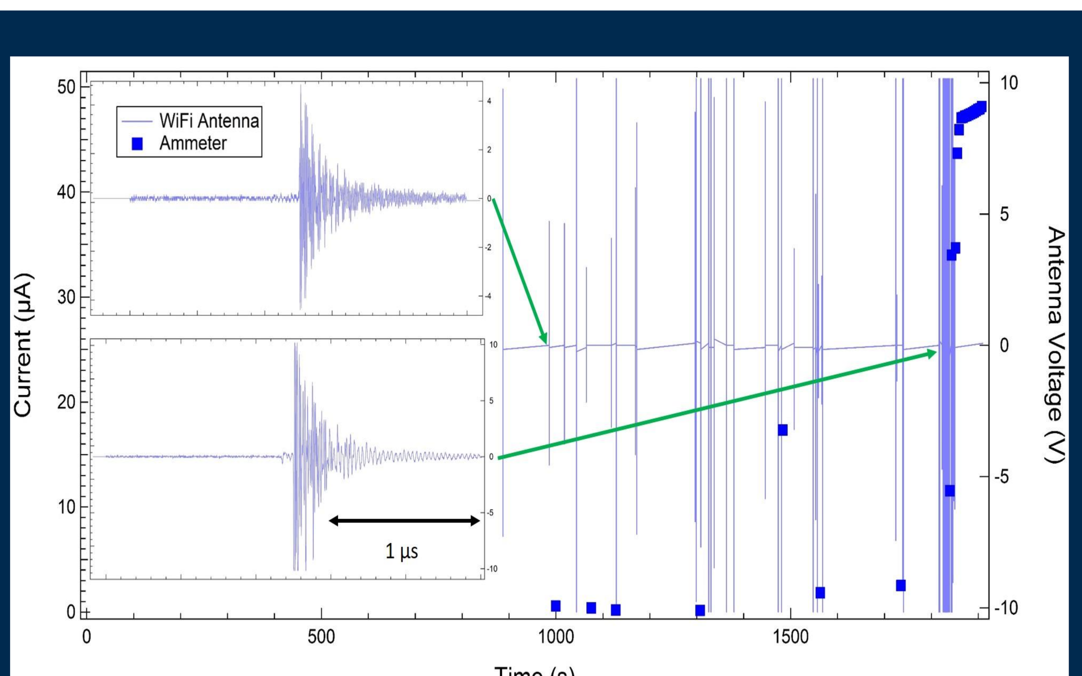

Fig. 2. Partial discharges measured during a voltage step-up test on BOPP by a 2.4 GHz Wi-Fi antenna connected to a 50 Ω load oscilloscope shunt, together with the standard ammeter curve. The inset shows two examples of individual trigger events. Larger amplitude traces from the slower ammeter correspond to multiple DCPD as seen by the antenna [9]..

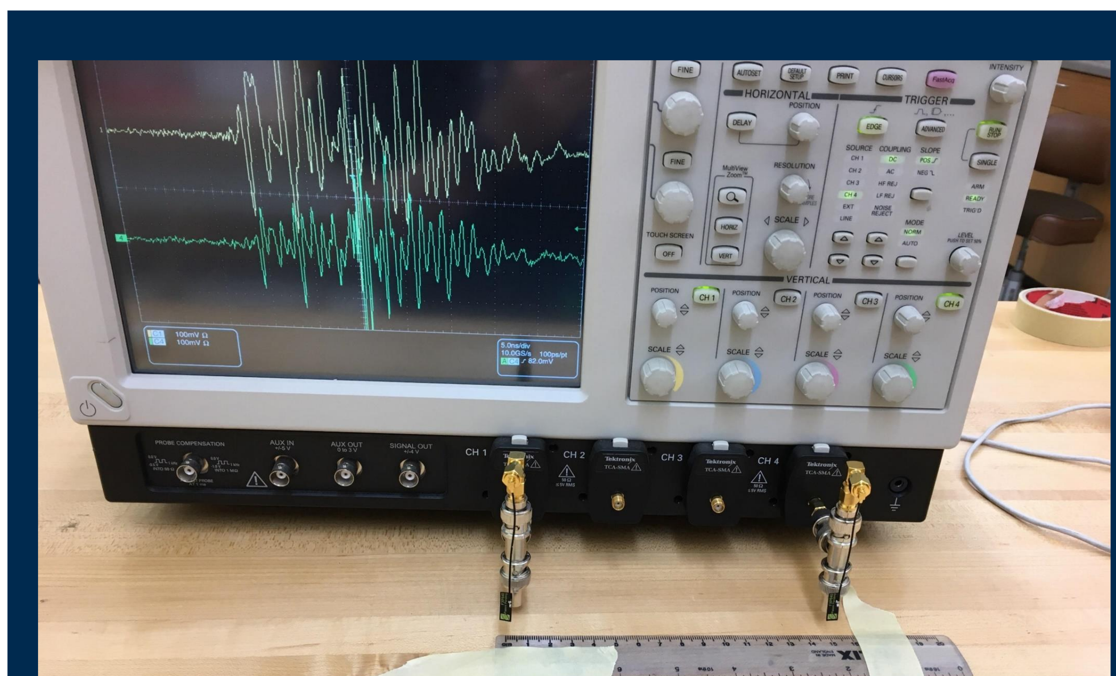

Fig. 4. Difference in time-of-flight table-top setup with 20 GS/s digital phosphor oscilloscope and off-the-shelf mobile device Wi-Fi antennas.

IV. Results

For location tests with the 1 GS/s oscilloscope, pairs of antennas were placed at 2.74 m apart with one discharge at 0.91 m and another at 1.83 m. Given the time resolution of the oscilloscope, ≥0.3 m resolution was expected. Figure 5(a) shows that indeed the setup can locate ESD to within the expected resolution.

For location tests with the faster 20 GS/s digital oscilloscope, the Wi-Fi antennas were spaced 15 cm apart with discharges set off at 3, 4, 5, 7, 10, and 12 (±0.3) cm to determine how well the setup could discriminate between different locations. Signals from the faster oscilloscope were more sensitive to phase differences between signals, and the discharges at 4, 5, 7, and 10 cm were not distinguishable. In this case, the discrepancies of the calculated locations in Fig. 5(b) were on the order of ±3 cm, about twice the expected uncertainty based solely on the oscilloscope resolution. Even without achieving the expected resolution, using the faster oscilloscope resulted in about an order of magnitude improvement in resolution compared to the first measurement

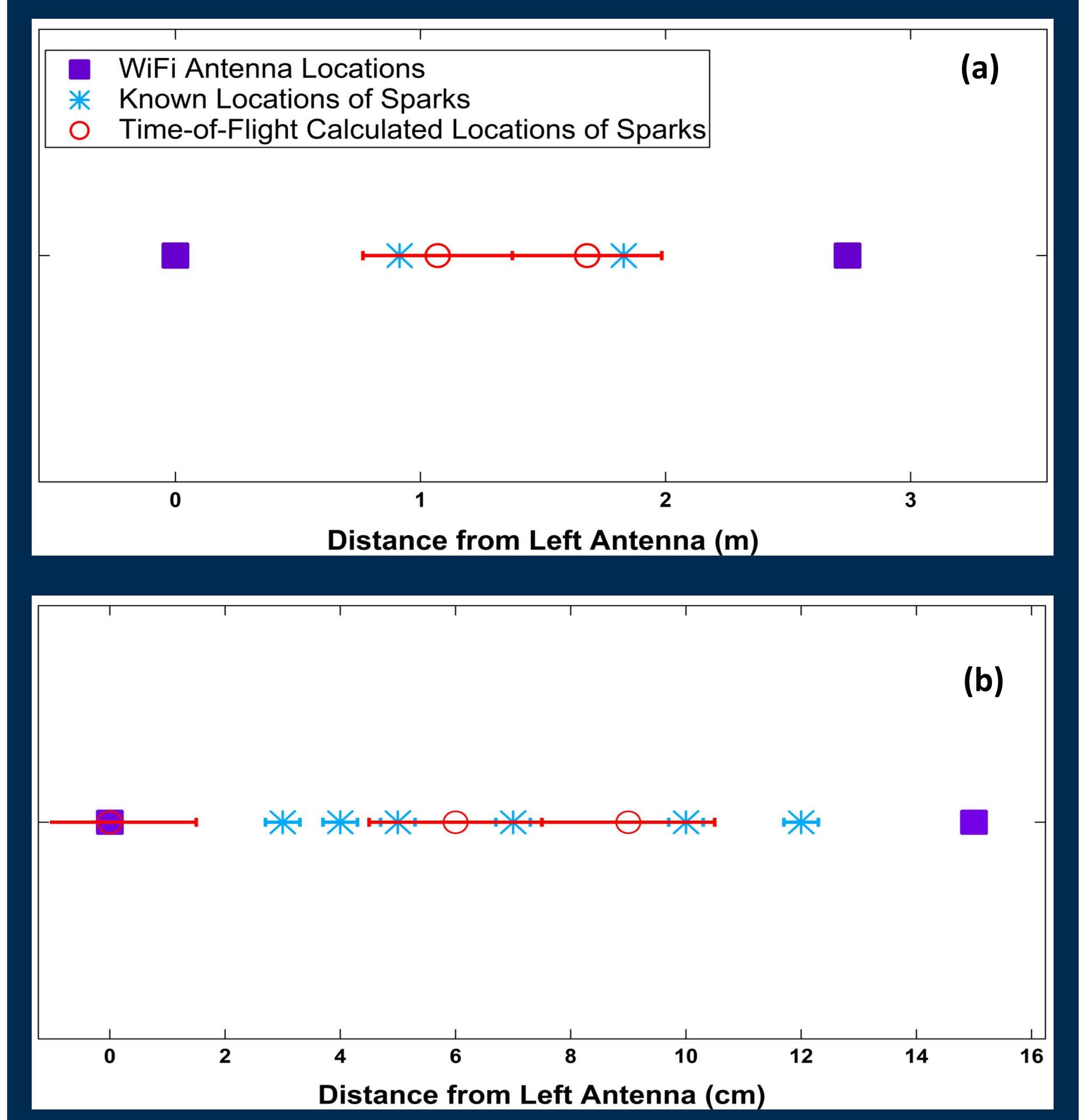

Fig. 5. Time of flight difference calculated locations of ESD compared to known locations and Wi-Fi antenna locations with a 1 GS/s oscilloscope (a) and a 20 GS/s scope (b). Error bars are estimated uncertainties based on the expected best resolution for each oscilloscope.

VI. Conclusions

The ground based tests presented here demonstrate that standard, cost-effective, off-the-shelf Wi-Fi antennas are well suited for detecting ESD events and precisely timing their occurrence, and that when multiple antennas at known locations are used time-of-flight measurements can be used to locate discharges spatially with sufficient resolution. As Wi-Fi-like intra-spacecraft communications become more common, such systems could be used to monitor ESD events during spaceflight with minimal additional complexity and expense.

VII. References

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