2018

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, initialisation 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 occurs, but where ESD occurs 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 is designed to look for ESD traces on antenna built for other communication purposes.

II. Coincidence Measurements

Detecting the RF signature of ESD events is common for terrestrial applications [4]. 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 anemeter (100 ppm resolution at 2 Hz acquisition rate) are not as sensitive as the antenna. However, discharges seen by the ammeter temporarily correlate to events seen by the antenna. Larger-amplitude ammeter traces are visible when 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.

III. Spatial Localization Measurements

Having demonstrated that Wi-Fi antennas can identify 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, ∆τRES, the minimum spatial difference detectable is ∆x = c·∆τRES 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 ∆x, 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 (Texas Instruments Freedom Series Super Small Monopole Dual-band 2.4 GHz and 4-9.6 GHz) are 145x50.1 mm and are designed for Wi-Fi or Bluetooth type communications for tablet or smartphone used devices.

As shown in Fig. 4, and in agreement with all 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 [1] with the left antenna at 0 m, the location x of a discharge is x = (1/2)·c·∆τRES, with c = 3·10⁸ m/s and a measured value of 6.7 m for 54 MHz in a vacuum.

IV. Results

For location tests with the 2 GHz 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, 200 ns 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 GHz digital oscilloscope, the Wi-Fi antennas were spaced 15 cm apart with discharges set off at 3, 4, 5, 7, 10, and 12 cm (40.3 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 83 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.

V. 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 interference, intra-spacecraft communications become more common, such systems could be used to monitor ESD events during spacecraft with minimal additional complexity and expense.

VI. References