# SMALL UNMANNED AIRCRAFT ELECTROMAGNETIC INTERFERENCE (EMI) INITIAL ASSESSMENT

*Jaewoo Jung, Corey Ippolito, Christopher Rogers, NASA Ames Research Center, Moffett Field, CA*
*Robert Kerczewski, Alan Downey, NASA Glenn Research Center, Cleveland, OH*
*Konstantin Matheou, Zin Technologies, Inc., Brook Park, OH*

## Abstract

As part of NASA's Unmanned Aircraft System Traffic Management Project, flight experiments are planned to characterize the radio frequency environment at altitudes up to 400 ft. to better understand how small unmanned aircraft system command and control links can be expected to perform in the low altitude environment. The flight experiments will use a radio frequency channel sensing payload attached to a small unmanned aircraft. In terms of the payload being capable of measuring relatively low-level signals at altitude, electromagnetic interference emanating from the vehicle itself could potentially complicate the measurement process. For this reason, NASA recognized the importance of identifying and measuring the electromagnetic interference performance of the unmanned aircraft planned for these flight experiments, a Dà-Jiāng Innovations Science and Technology Co., Ltd S1000+ Spreading Wing. This vehicle was measured in a controlled electromagnetic interference test chamber at the NASA Ames Research Center. The S1000 is a carbon fiber based platform with eight rotors. As such, the electromagnetic interference test results represent potential performance of a number of similar small unmanned aircraft types. Unmanned aircraft platforms significantly different from the S1000 may also require electromagnetic interference testing, and the method employed for NASA's S1000 electromagnetic interference tests can be applied to other platforms. In this paper, we describe the Unmanned Aircraft System Traffic Management project, the radio frequency channel sensing payload, the electromagnetic interference testing method and test results for the S1000, and discuss the implications of these results.

## Introduction

With many applications envisioned for small Unmanned Aircraft System (sUAS), and potentially millions of sUAS expected to be in operation in the future, the electromagnetic interference environment associated with the sUAS is of interest to understanding the potential performance impacts on the sUAS command and control communications link as well as the sUAS payload and payload links. As part of NASA's Unmanned Aircraft System Traffic Management (UTM) Project, flight experiments are planned to characterize the radio frequency (RF) environment at altitudes up to 400 ft. to better understand how UAS command and control links can be expected to perform. The flight experiments will use a RF channel sensing payload attached to a small Unmanned Aircraft (UA). In terms of the payload being capable of measuring relatively low-level signals at altitude, electromagnetic interference (EMI) emanating from the small UA itself could potentially complicate the measurement process.

For this reason, NASA recognized the importance of identifying and measuring the EMI performance of the sUAS planned for these flight experiments, a Dà-Jiāng Innovations Science and Technology Co., Ltd S1000+ Spreading Wing (S1000). The S1000 was measured in a controlled EMI test chamber in the RF Test Lab (RTL) at the NASA Ames Research Center. The S1000 is a carbon fiber based platform with eight rotors. As such, the EMI test results represent potential performance of a number of similar small UA types. UA platforms significantly different from the S1000 may also require EMI testing, and the method employed for NASA's S1000 EMI tests can be applied to other platforms. In this paper, we describe the UTM project, the RF channel sensing payload, the EMI testing method and EMI test results for the S1000, and discuss the implications of these results.

## UTM Project Overview

As of December 2016, there are more than 670,000 registered sUAS in the United States, 626,000 as hobbyists and 44,000 as commercial. These

numbers are expected to grow rapidly over the coming years [1]. Operations of these aircraft beyond hobby or recreation in the U.S. is currently regulated by Federal Aviation Regulation (FAR) part 107 (Part 107), and numerous Visual Line-of-Sight (VLOS) applications including aerial photography, real estate, construction, industrial and utility inspection and agriculture are enabled under this regulation [2]. Operations beyond what is allowed under Part 107, such as Beyond Visual Line-of-Sight (BVLOS) operations, operations over people, and night operations, are enabled through the Federal Aviation Administration (FAA)'s waiver process [3], but a limited number of waivers are granted as there is no established infrastructure to safely integrate large-scale, beyond-Part 107 operations into the National Airspace System (NAS).

To safely and efficiently integrate the full gamut of small UAS operations in large-scale at low altitudes, NASA has developed the UTM project [4, 5] to research and develop promising technologies and data exchange protocols to support routine and widespread execution of present and future envisioned applications such as urban area package delivery and BVLOS infrastructure inspection, and also to perform conceptual and technical research that can be transferred to the FAA in the form of airspace integration requirements for further testing. For this transfer, NASA and the FAA formed the UTM Research Transition Team (RTT) with goals to 1) research and mature increasingly complex UTM operational scenarios and technologies; 2) demonstrate those capabilities on the NASA UTM research platform; and 3) deliver to the FAA technology transfer packages that enable NAS service expectations for low-altitude airspace operations by providing insight and capability requirements for critical services [6].

Given the wide technological areas and operating environments that the UTM RTT is addressing, it has been broken into four focus subgroups, 1) Concepts and Use Cases (CWG); 2) Data Exchange and Information Architecture (DWG); 3) Sense and Avoid (SAA); and 4) Communications and Navigation (C&N). The CWG subgroup is providing the conceptual framework, scenarios, and use cases for the other subgroups to explore. The DWG subgroup works to identify, develop, and test expected data exchanges and architectural implications and challenges. The SAA and C&N subgroups work to identify and evaluate key performance and operations challenges and constraints. Outputs from the DWG, SAA, and C&N subgroups in turn inform the CWG subgroup to progressively elaborate the UTM concept of operations. For example, C&N evaluates communications and navigation performance needed for enabling use cases by conducting simulations and flight tests. Findings from these efforts, such as EMI's potential performance impacts on the sUAS command and control communications link as well as the sUAS payload and payload links, is then used to update the concept of operations.

## RF Channel Sensing Payload Overview and Description

To characterize the potential performance of sUAS command and control links, flight experiments are planned to characterize the low altitude environment. To accomplish this, an RF channel sensing payload will be attached to a sUAS. The RF channel sensing payload is intended to allow the measurement of RF Spectrum at altitudes up to about 400 Ft AGL. In particular, it will look for signals in the potential sUAS command and control link bands, either cellular network bands (LTE, 4G) or ISM bands [7]. The payload will be flown at various locations and altitudes to measure the RF spectrum in LTE/4G and ISM frequency bands of interest.. Table 1 shows the LTE bands; the ISM band of interest covers 5725-5825 MHz.

**Table 1. LTE Bands of Interest for sUAS C2 Links**

| Band | Base Station Transmit Bands | User Equipment Transmit Bands |
|---|---|---|
| 700 MHz | 717-768 MHz | 699-716 MHz, 777-798 MHz |
| 800 MHz | 832-869 MHz | 807-824 MHz |
| 850 MHz | 852-894 MHz | 814-849 MHz |
| 1700 MHz | N/A | 1710-1780 MHz |
| 1900 MHz | 1930-1995 MHz | 1850-1915 MHz |
| 2100 MHz | 2110-2170 MHz | 1920-1980 MHz |
| 2300 MHz | 2350-2360 MHz | 2305-2315 MHz |
| 2500 MHz | 2496-2690 MHz | 2496-2690 MHz |

The payload's primary element is the Ettus Research™ E310 and E312 software defined radio

(SDR)[8]. These models possess a broadband transmit/receive capability over 0-6000 MHz bands, programmable via an Ethernet interface. The E312 model includes an internal battery, while the E310 requires an external battery; the E312's internal battery can be supplemented by an external battery to extend operating time if required. Figure 1 shows a configuration applicable to both models.

The RF channel sensing payload analyzes received RF signals via analog-to-digital conversion (ADC) processing to enable post-processing frequency domain spectrum analysis. Signal frequency and amplitude will be observed and related to expected signals from LTE or ISM transmitters within range of the payload.

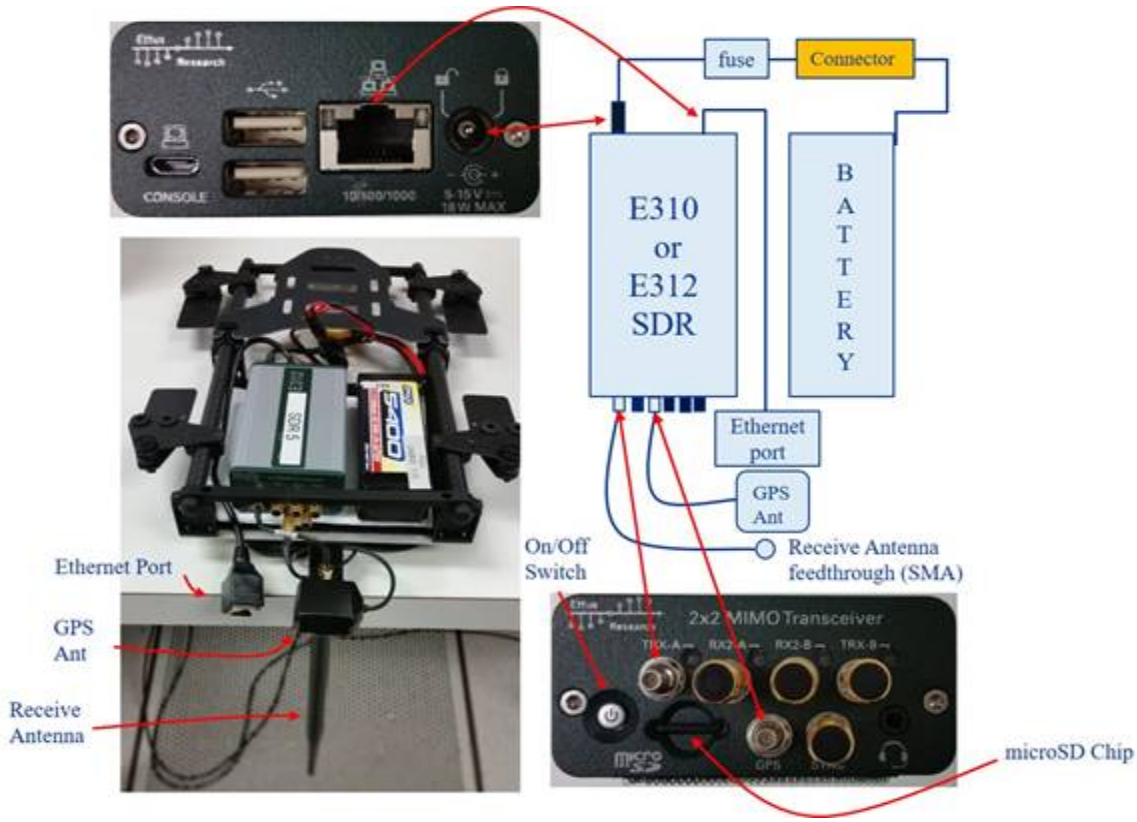


**Figure 1. RF Channel Sensing Payload Configuration**

## DJI S1000 Description

The vehicle intended to carry the RF channel sensing payload is DJI S1000, and it is subjected to the EMI testing. This vehicle has a 40A electronic speed controller (ESC) built into each arm. The 4114 pro motors, high performance 1552 folding propellers, and V-type mixer design combine to give each arm of the S1000 a maximum thrust of 2.5Kg. The vehicle's frame arms and landing gear are made from carbon fiber. Figure 2 is a picture of the vehicle, and additional vehicle details are in Table 2.

**Figure 2. Picture of S1000 (Photo Credit: DJI)**

**Table 2. S1000 Details**

| | |
|---|---|
| Manufacturer/ Model: | Dà-Jiāng Innovations Science and Technology Co., Ltd (DJI)/S-1000+ |
| Configuration: | Octocopter |
| General Characteristics: | |
| Length | 100 cm |
| Height | 48 cm |
| Weight | 4.2 kg |
| Payload Weight | 5 kg |
| Propulsion: | |
| Motor Power | 500 W |
| Motor RPM | 9600 RPM |
| Flight Parameters: | |
| Max Ground Speed | 13.4 m/s (30 MPH) |
| Battery | 6S 16000 mAh LiPo |
| Flight Time | 15 Minutes |

## EMI Assessment Overview

The RF channel sensing payload is intended to capture all signals in the bands of interest, including very low-level signals from distant transmitters that would not be visible at ground level but will be visible at higher altitudes for which radio line-of-sight will be available for much longer distances. It is expected that multiple ground transmitters may be visible for network carriers (e.g., Verizon, AT&T, T-Mobile, Sprint) operating in the same frequency channel.

Any EMI signals originating in the measurement system itself, such as the RF channel sensing payload and the sUAS vehicle carrying the payload, occurring in the bands of interest have the potential to confuse the identification of the signals originating from LTE/4G or ISM transmissions that are the target of the flight measurement campaign, if they can be detected by the RF channel sensing payload receiver. Therefore, the EMI assessment is intended to identify any such signals originating in the measurement system itself. The results of the EMI assessment will enable any in-band EMI signals to be known and subtracted from data captured during resulting RF channel sensing flight tests. It may also be possible to reduce or eliminate EMI sources prior to flight testing if they prove to be particularly problematic.

The S1000 sUAS described in the previous section consists of several electrical and mechanical components potentially capable of creating EMI. Careful measurement of the EMI environment created by the S1000 while in an operating configuration is needed, albeit in a laboratory environment since such measurement in the operational flight environment is impractical. EMI measurement with the payload integrated with the S1000 is preferred in case any interactions alter the EMI performance of either the payload or the S1000.

The RTL at the NASA Ames Research Center was used to conduct the EMI assessment. The following two sections describe the lab and the method employed to conduct EMI measurements.

## NASA Ames RTL Description

### *Background*

High precision RF measurements and full compliance EMC (electromagnetic compatibility) testing can be extremely expensive. Yet they are required for various systems per Mil-STD's (Military Standards), CISPR (International Special Committee on Radio Interference), NPR's (NASA Procedural Requirement), etc. Most of these test campaigns, especially EMC, have very low success rates. More often than not small projects with constrained resources cannot afford the time and money to execute such tests as defined throughout their project lifecycle and are forced to either eliminate or delay testing until later in their project life cycle. While reducing the amount of testing may look beneficial to the budget early on, it carries a high degree of risk. A failure late in the project life cycle can be extremely expensive to fix, and may endanger the mission.

### *Goal*

The RTL was therefore developed to provide a safe, secure, accurate, precise and affordable solution for those resource constrained small-sized projects. Performing pre-compliance level testing earlier in the project development cycle can significantly reduce project risk. Such testing is much less expensive and much quicker than full compliance testing. By performing such testing early in the project life cycle, design problems can

be identified in advance and addressed early in the project life cycle. This early detection enables cheaper and faster solutions. In some cases, projects can further reduce testing costs later in the project lifecycle by leveraging the passing test results performed at the pre-compliance level.

## EMI Test Method

### *General Test Culture*

The RTL aspires to acquire, train and maintain its equipment and personnel to full compliance level standards per MIL-STD-461. Executing pre-compliance level testing with equipment quality that comes with full compliance tests and processes yields test results with high degrees of precision and accuracy. An assortment of electrical integration and RF test equipment also complements the flexibility of the lab to adjust test configurations to better suit the customers' needs and available resources.

As an example of similar types of testing, the RTL performed successful testing on the Astrobee, a free-flying robotic payload bound for the International Space Station [9] and the follow-on to Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) Project [10]. The lab was able to help Astrobee pinpoint precise EMI sources during their hardware development build. Addressing those problems early in the hardware development cycle made them extremely cost-effective to correct. If not for the early pre-compliance testing, Astrobee would surely have failed compliance testing of the flight unit, resulting in cost and schedule overruns that may not be recoverable.

### *Specifics about the S1000 Test*

The S1000 underwent pre-compliance radiated emissions testing in the RTL's RFI/EMI shielded enclosure, shown in Figure 3. This enclosure was designed, built and certified by ETS Lindgren, a leader in the EMC industry. The chamber was designed to provide attenuation for MIL-STD and CISPR tests with performance levels of 56dB at 1KHz and 100dB from 200KHz to 10GHz. This semi-anechoic chamber is also equipped with absorber that completely covers all walls and ceiling adding an additional -15dB to -50dB of attenuation from 450 MHz to 40 GHz. To further guarantee complete environmental isolation for the highest degree of precision and accuracy, the chamber is completely isolated from the facility with the use of a 30A power filter and an independent chamber dedicated ground rod.

**Figure 3. RTL EMI/RFI Shielded Enclosure**

Measurements were conducted with a double ridge guide horn receive antenna specifically designed to meet MIL-STD specifications for frequencies from 700 MHz to 10 GHz. Calibration of the test configuration and emissions measurements were conducted with an Anritsu MS2035B Vector Network Analyzer + Spectrum Analyzer. The test configuration inside the EMI/RFI shielded enclosure is shown in Figure 4.

To improve accuracy, and to better resolve spurious signals, measurements were taken in frequency bands of 700 MHz-930 MHz, 1700 MHz-1800 MHz, 1900 MHz-2700 MHz and 5700 MHz to 5950 MHz. Measuring in smaller frequency bands, as opposed to the full 0-6000 MHz spectrum allowed the use of a decreased resolution bandwidth (RBW) to help resolve otherwise hidden signals without having excessively long measurement periods. This helped decrease the overall test time, allowing extra lab time to look more closely at signals of interest. In a full compliance test lab, additional measurement time would have resulted in additional cost.

## EMI Test Results

### *Test Configuration*

The S1000 was tested in several spectrum ranges at three rotor RPM levels – ambient, slow,

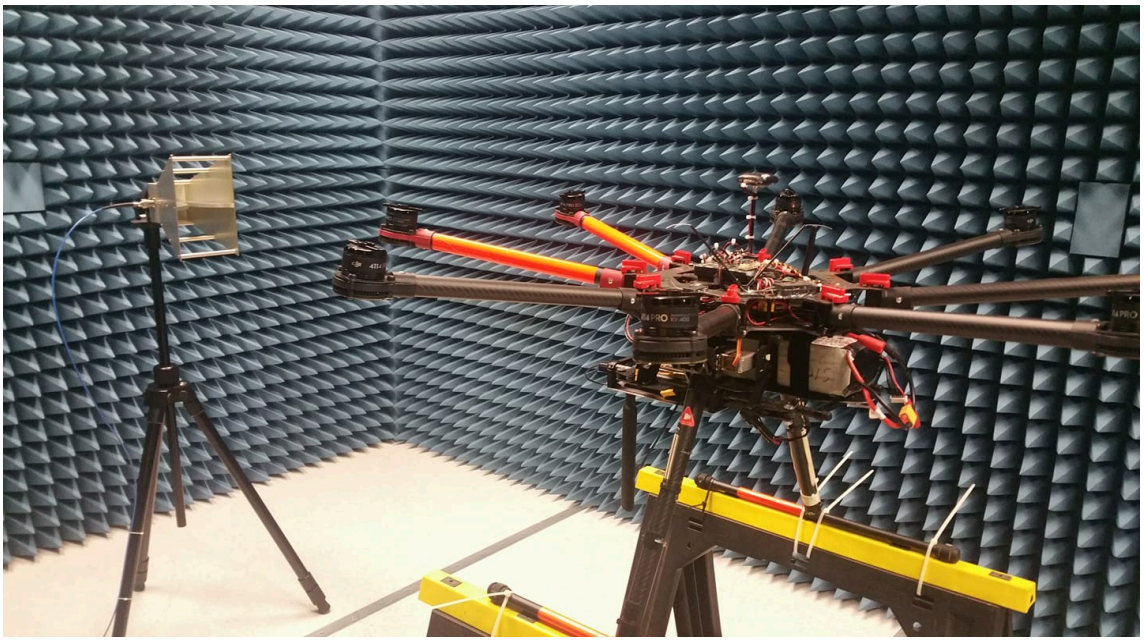

**Figure 4. S1000 and the Receive Horn Antenna**

and fast running, 0, 5500, and 8800 RPMs, respectively. For safety reasons, it was necessary to conduct testing of the S1000 with the propeller portions of the 8 rotors removed, that is, without load to the 8 rotors. Based on previous experiences, this was not expected to impact the presence of EMI signals emanating from the S1000, although the amplitude of EMI might increase under increased load.

During the tests, the RF channel sensing payload is turned off, but physically attached to the S1000 frame in the expected flight test configuration. In addition, six orientations of the S1000 relative to the receive horn antenna were tested – with the S1000 front, left, right, rear, top, and bottom facing the receive horn antenna.

The primary purpose for conducting EMI testing of the S1000 was to understand EMI emissions that might fall into the RF channel sensing payload's frequency bands of interest, corresponding to LTE (Table 1) and ISM band. Therefore, the EMI test was performed in four bands as described in the previous section. Some tests were made covering the full 0-6000 MHz to observe any other signals occurring outside of the primary bands. The spectrum analyzer recording the EMI spectra normally employed RBW of 1 MHz. Some plots were made at lower RBW of 100 Hz in order to obtain a lower noise floor and enable observation of lower level EMI signals. However, at this RBW the measurement took much longer to complete and so it was only employed for the final set of measurements.

### *Ambient Measurements*

With the S1000 rotors turned off, the spectrum was captured for the four frequency bands. Figures 5 through 8 show the recorded EMI spectrum for the four bands. In this configuration, no EMI signals were observed, which indicates that there are no other EMI signals present in the measurement attributable to other sources.

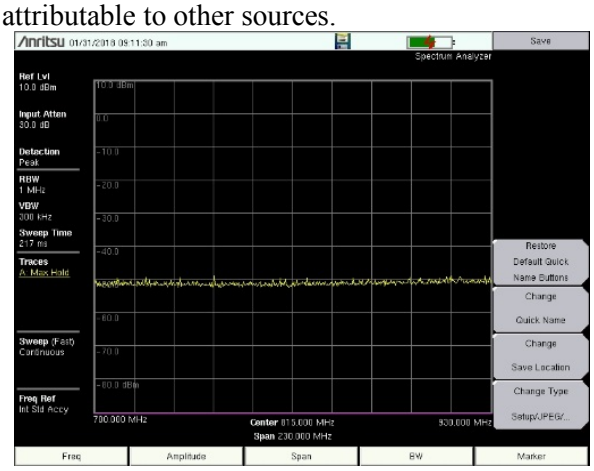


**Figure 5. 700 MHz-930 MHz, Front Orientation, Ambient Condition, 1 MHz RBW**

### *Low RPM Measurements*

With the S1000 rotors at low RPM, a measurement covering 0-6000MHz is shown in Figure 9. The spectrum plot shows 3 signals of interest: 1) the wireless signal from the S1000 control unit to the S1000 which provide operating commands to the S1000 using a frequency hopping transmission at 900MHz; 2) a WiFi signal at 1850 MHz and a 2.8 GHz signal in the 2700-2900 MHz aeronautical radar band likely originating from the nearby Moffett Airfield and 3) a 3.2GHz peak that is in the 3100-3000 MHz band supporting shipborne surface radar and is likely originating from shipborne radars in the vicinity.

In the low RPM condition, EMI signals in the bands of interest were not observed. Figure 10 shows an example of a measurement for the 900 MHz – 2700 MHz range, with the S1000 in rear orientation. In this measurement, signals in the vicinity of 2400 MHz are observed. These signals are attributed to the WiFi network deployed in the building that houses the RF Test Lab. They are not problematic as they are not within the LTE bands.

These WiFi signals which appeared at low levels in the measurement were the only signals observed that varied with the orientation of the S1000. Figure 11 shows the same measurement with the S1000 in top orientation, in which the WiFi signals do not appear. Of the six configurations, the signals do not appear in the top and bottom configurations. This is attributed to the S1000 being at angle compared to the other four orientations as shown in Figure 12. This orientation appears to effectively block the WiFi signal from the receive horn antenna.

### *High RPM Measurements*

In the high RPM condition, EMI signals in the bands of interest were not observed. Figures 13 through 16 provide the spectrum plots for the four frequency ranges measured. In Figure 13 we see, at the upper end of the plot, the S1000 control signal spectrum, as noted above, around 900 MHz. In Figure 15 we see the WiFi signals also noted above. No other signals considered to be EMI are observed.

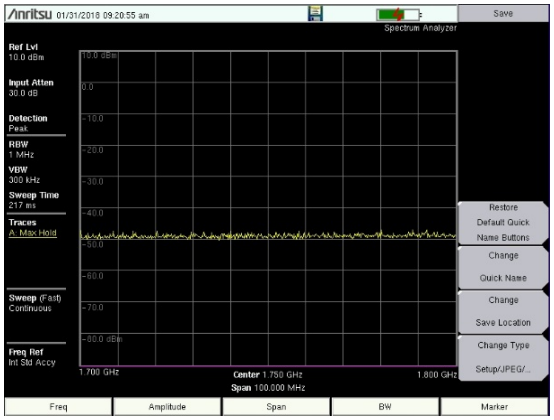


**Figure 6. 1700 MHz-1800 MHz, Front Orientation, Ambient Condition, 1 MHz RBW**

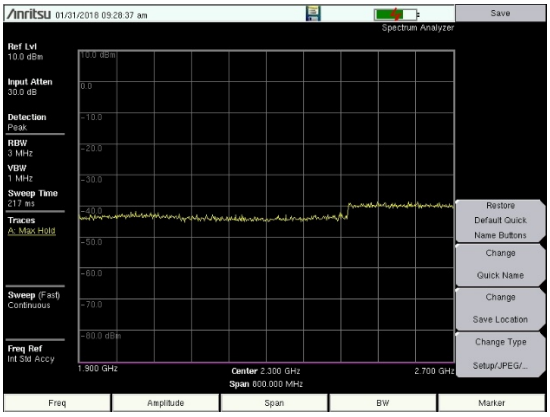


**Figure 7. 1900 MHz-2700 MHz, Front Orientation, Ambient Condition, 1 MHz RBW**

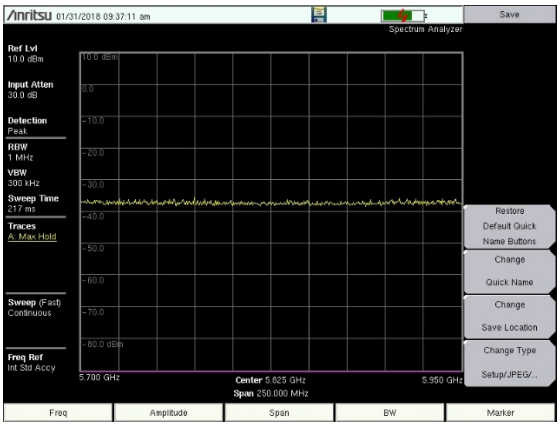


**Figure 8. 5700 MHz-5950 MHz, Front Orientation, Ambient Condition, 1 MHz RBW**

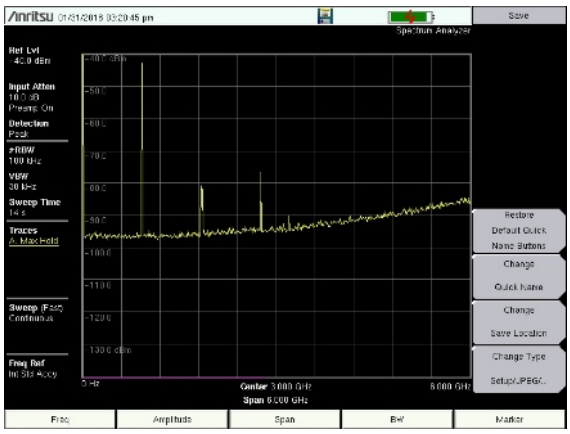


**Figure 9. 0-6000 MHz, Front Orientation, Low RPM, 1 MHz RBW**

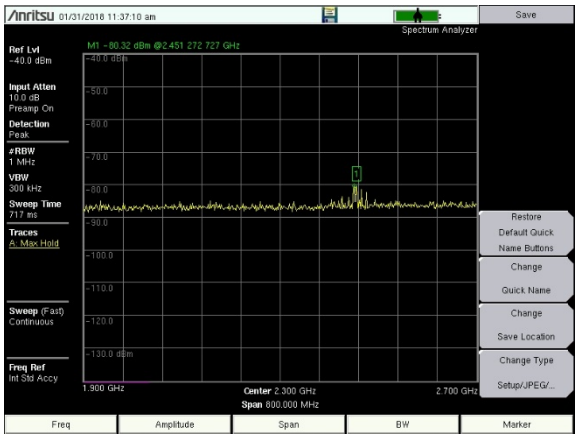


**Figure 10. 1900 MHz-2700 MHz, Rear Orientation, Low RPM, 1 MHz RBW**

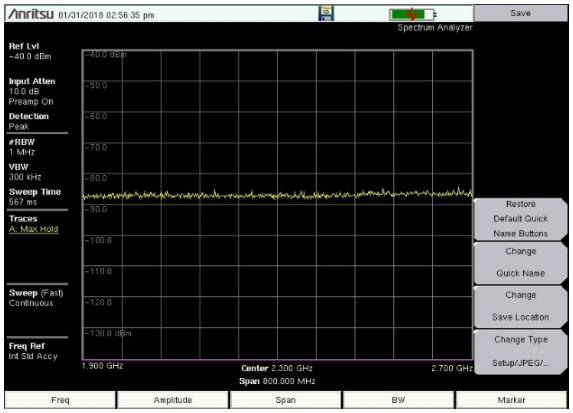


**Figure 11. 1900 MHz-2700 MHz, Top Orientation, Low RPM, 1 MHz RBW**

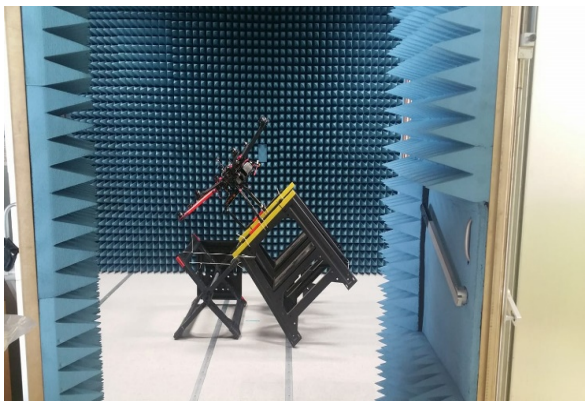

**Figure 12. S1000 in Top Orientation**

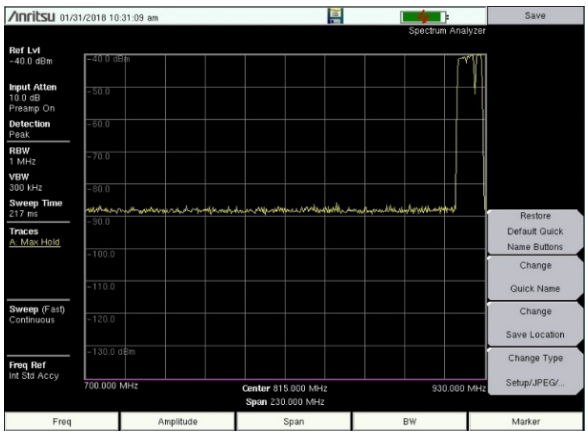


**Figure 13. 700 MHz-930 MHz, Front Orientation, High RPM, 1 MHz RBW**

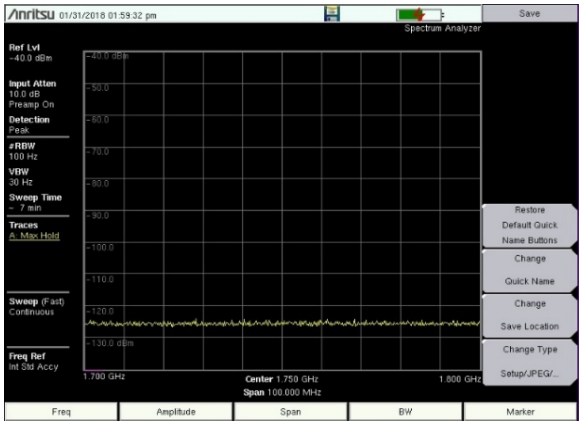


**Figure 14. 1700 MHz-1800 MHz, Front Orientation, High RPM, 100 Hz RBW**

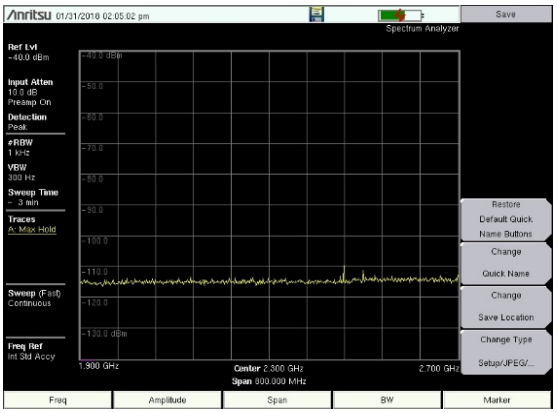


**Figure 15. 1900 MHz-2700 MHz, Front Orientation, High RPM, 100 Hz RBW**

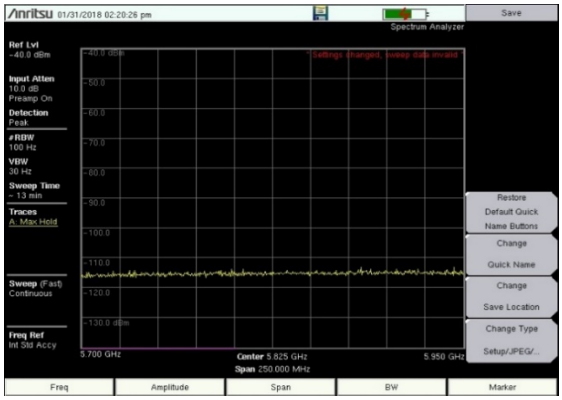


**Figure 16. 5700 MHz-5950 MHz, Front Orientation, High RPM, 100 Hz RBW**

## Summary and Conclusion

Currently there is a lack of clear understanding of EMI from a small UA itself that can impact radio frequency bands of proposed sUAS communications link, such as LTE. The EMI test results show that although there are some emissions associated with the S1000 under low and high rpm operating conditions, these emissions fall outside of the bands of interest for the RF channel sensing payload flight tests. These signals are also traceable to known sources and do not appear to be spurious signals originating from the S1000. Given these results and the main components of the S1000, a carbon fiber frame with eight motors, one can expect EMI from similar small UA types to have negligible impact on the tested LTE and ISM bands. However, small UA platforms significantly different from the S1000 may need EMI testing, especially if the tested bands are to be used for communications. The method employed for NASA's S1000 EMI tests can be applied for these tests, and expanded to investigate additional RF bands of interest beyond the tested LTE and ISM bands.

## Acknowledgements

The authors appreciate support from Sreeja Nag and the UTM project management persons for identification and use of RF test facility.

## References

[1] FAA Aerospace Forecast Fiscal Years 2017-2037, Publication, FAA, Washington, D.C., 2016.

[2] Small Unmanned Aircraft Rule, The Federal Aviation Regulation (FAR) Part 10, FAA, Washington, D.C., 2016.

[3] Request a Part 107 Waiver or Operation in Controlled Airspace [online], URL: https://www.faa.gov/uas/request_waiver/ [accessed 6 March 2018]

[4] Kopardekar, P., Rios, J., Prevot, T., Johnson, M., Jung, J., and Robinson, J. E., "Unmanned Aircraft System Traffic Management (UTM) Concept of Operations," 16th AIAA Aviation Technology, Integration, and Operations Conference, Washington, D.C., 13-17 June 2016.

[5] Kopardekar, P., "Unmanned Aerial System Traffic Management (UTM): Enabling Low-altitude Airspace and UAS Operations," Tech. Rep. NASA TM-2014-21829, 2014.

[6] UAS Traffic Management (UTM) Research Transition Team (RTT) Plan, Publication, FAA, Washington, D.C., 2017.

[7] Kerczewski, R. J., Downey, Apaza, R. A., Downey, A. N., Matheou, K. J., Wang, J., "Assessing C2 Communications for UAS Traffic Management", 2018 ICNS Conference", April 2018.

[8] Ettus Research™ https://www.ettus.com/content/files/USRP_E310_Datasheet.pdf

[9] NASA Astrobee, https://www.nasa.gov/astrobee

[10] NASA SPHERES, https://www.nasa.gov/spheres/home