A40 – Validation ASTM Remote Identification Standards

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16. Abstract

This document serves as the final test report for the validation of ASTM remote identification standards. This report will aid future research and standards involving remote identification technology.

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ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
ASTM	American Society for Testing and Materials
BT	Bluetooth
FAA	Federal Aviation Administration
FRIA	FAA-Recognized Identification Area
LTE	Long-Term Evolution
NAN	Neighborhood Aware Networking
NAS	National Airspace System
PIC	Pilot in Command
RF	Radio Frequency
RID	Remote Identification
RPIC	Remote Pilot in Command
UAS	Unmanned Aircraft System
VO	Visual Observer

EXECUTIVE SUMMARY

As the use of Uncrewed Aircraft Systems (UAS) rises, innovative technologies are needed to safely integrate UAS into the National Airspace System (NAS). The Federal Aviation Administration (FAA) has turned to Remote Identification (RID) as a means to satisfy security stakeholder needs. It also has potential as one method to increase the safety of UAS and other aircraft in the national airspace. Remote ID enables UAS to self-disclose and broadcast information for the awareness of other pilots, emergency personnel, or anyone with access to an RID receiver. The FAA has instituted a rule requiring RID capabilities on all UAS in the near future, furthering the need to understand the application of this technology. Following the establishment of the FAA RID rule, a standard was developed by the American Society for Testing and Materials (ASTM) for the performance of remote ID devices, along with test methods to do so. This standard sets performance minimums for RID systems, including the data required to be broadcasted, that enable users to be compliant with the FAA's rule. The objective of the A40 research effort was to validate the ASTM remote identification standard through a series of performance tests. RID messages can be broadcasted through Bluetooth (BT) 4.0 or 5.0, Wi-Fi Beacon, and Wi-Fi Neighborhood Aware Networking (NAN). Two Bluetooth systems, the Dronetag Mini and the Aerobits idME, were assessed. Additionally, the Parrot ANAFI USA, a UAS with internal Wi-Fi Beacon system, and another undisclosed UAS Wi-Fi NAN system were assessed. The testing provided an idea of the baseline performance of these systems to determine if the minimum broadcast rates and power levels present in the ASTM standard are adequate for practical use. A series of range tests to determine reasonable operation ranges were performed, along with directionality tests, varied RF environment tests, and proof of concept tests for the use of RID receivers in a crewed aircraft. The number of RID messages sent and the average receival rate were collected among other parameters to assess the performance of the RID systems. Comparison between Bluetooth and Wi-Fi systems showed that Wi-Fi systems may have had increased ranges up to 3000m, however this is with a broadcast rate of 28 dBm, much higher than the standard's minimum of 11 dBm. Typical operations with a Wi-Fi system may not exhibit performance on par with results obtained from testing due to this difference in broadcast power level. Bluetooth systems did not exhibit ranges as large as Wi-Fi, however, the receival rates were more consistent with the broadcast rates. There were consistent decreases in performance of BT devices at ranges of 500m and 700m, however, maximum ranges for BT devices frequently went above 1000m. The practical range for a BT receiver typically extended to approximately 700m from the receiver, and ranges past 700m revealed unreliability. Results from encounters testing showed a drastic decrease in the performance of the RID devices when compared to other range tests conducted. The receival rate for the BT device was severely limited when using BT4 and BT5, to the point that an RID device is not practical to use in such scenarios, although it will still work fine for 'normal' RID operations like a UAS pilot on the ground. Likewise, the Wi-Fi Beacon system struggled to transmit messages to the receiver during encounters testing, and the receiver did not receive a single message throughout all air encounter test points. Future research related to RID can consider the integration of these devices into more complex systems and technologies, such as exploring the usefulness of RIDs for detect and avoid systems. As commercial RID modules and RID-equipped UAS become more prevalent, additional range testing on these devices can begin to paint a picture illustrating the typical performance of RID across a wider variety of devices. Furthermore, repeating tests from this effort, such as encounters testing, with higher power levels and broadcast rates or with the addition of antennas could be beneficial in determining if RID technology is a feasible application for crewed aircraft awareness scenarios. Although further understanding of the

performance of RID systems is needed, RID technology has the potential to aid in the creation a safer national airspace.

1 INTRODUCTION & BACKGROUND

The use of Uncrewed Aircraft Systems (UAS) has increased considerably over recent years, leading to an influx of recreational and commercial drones in low-altitude airspace. The safety and security of the National Airspace System (NAS) is paramount to the Federal Aviation Administration (FAA) and is at the forefront of considerations for integrating uncrewed aircraft systems into the NAS. The FAA's effort to increase the safety of the NAS while working to integrate uncrewed aircraft systems has included the implementation of a Remote Identification (RID) rule for UAS users and manufacturers. This technology works by enabling UAS to self-disclose pertinent information regarding its operation for the awareness of other users in the surrounding area. The American Society for Testing and Materials (ASTM) International has developed a standard for RID performance clarifying the means of compliance for UAS in relation to the FAA's RID rule. The A40 project focused on analyzing the performance of various RID systems in different test settings to develop a baseline of RID behavior in relation to UAS operations. The performance data acquired throughout the A40 project can be used in conjunction with the ASTM RID performance standards to gain an idea of the capabilities of existing commercial off-the-shelf RID products. Understanding the capabilities of RID systems ultimately helps to inform their role in maintaining and improving the safety and security of the NAS as UAS integration continues to progress.

1.1 Remote Identification in UAS

RID can best be described as a "digital license plate" for UAS that allows for easy identification and tracking. Remote identification systems enable an in-flight UAS to broadcast specific identification and location information that can be received by other parties in the surrounding area of the broadcasting system. The information broadcasted by the RID can contain various operation characteristics, such as position, altitude, serial numbers associated with the FAA registration process, and more. This technology has potentially useful applications to law enforcement and other public safety stakeholders by reducing the risk of interference or collision with other aircraft in flight or property surrounding the operation. Furthermore, the ability to obtain location information of an in-flight UAS informs other users flying UAS and can promote safe interaction between operations. Previous methods for identification during UAS operations have presented challenges due to the small size of UAS and the lack of an on-board operator (Federal Aviation Administration, 2021). With the implementation of the RID rule, the process by which UAS are identified provides the FAA and law enforcement with increased efficiency to oversee UAS operations and maintain the safety and security of the NAS.

1.2 Remote Identification Rule

Per the FAA's final RID rule, all users and manufacturers of UAS must possess the capability to utilize RID during operations, with three main ways that users can do so. RID systems can be implemented with UAS in one of two configurations. An FAA-registered UAS can be equipped with a built-in RID system, or a RID module can be mounted or affixed to a noncompliant aircraft to provide RID capabilities. If a UAS does not contain RID capabilities through one of these configurations, then the user is able to be compliant in conducting operations only in an FAA-Recognized Identification Area (FRIA). FRIAs are flight areas the FAA has dedicated specifically for users to fly without RID and are requested by community-based organizations and educational institutions (Remote Identification of Unmanned Aircraft, 14 C.F.R § 89 , 2022). Figure 1 (Federal Aviation Administration, 2021) Figure 1summarizes the three ways in which UAS users can conduct operations while complying with the final remote ID rule.

Figure 1. The three methods to comply with the FAA's RID rule.

In addition to requiring UAS to have RID capability, the FAA's rule also provides requirements for the minimum message elements that must be present in the actual RID broadcasts. Table 1 displays these requirements (Remote Identification of Unmanned Aircraft, 14 C.F.R. §§ 89.305-89.315, 2022).

Table 1. Required RID broadcast information.

Standard RID UAS	**RID Module UAS**
Identity - Serial Number - Session ID	Identity - Serial Number - Session ID
UAS - Latitude - Longitude - Geometric Altitude - Velocity	UAS - Latitude - Longitude - Altitude - Velocity
GCS - Latitude - Longitude - Geometric Altitude	Take off location - Latitude - Longitude - Altitude
UTC Time Mark	UTC Time Mark
Emergency Status Indicator	

The required message elements must broadcast the entire time the UAS is powered on. An operator of a standard RID UAS may opt to broadcast either their drone's serial number or their session ID, though they are not required to do both. The data elements shown above are sent in message blocks in which a specific type of information is contained. Six message types are shown in Table 2 with optional messages marked by an asterisk. These elements are not required to be sent in the RID message unless specified by a local regulation.

Table 2. RID message types and their elements.

Message Type	*Message Elements*
0x0	UAS ID
	UAS Type
0x1	Operational Status*
	Aircraft Latitude & Longitude
	Geodetic Altitude
	Height Above Takeoff*
	Pressure Altitude*
	Vertical Accuracy
	Horizontal Accuracy
	Speed Accuracy
	Speed
	Direction
	Vertical Speed
	Timestamp
0x2	Authentication Info*
0x3	Operation Description*
0x4	Operator Latitude & Longitude*
	Operator Altitude
	Group Count*
	Group Radius/Height*
0x5	Operator ID*
0xF	Message Pack

1.3 ASTM Remote Identification Standard

The ASTM standard for RID "defines message formats, transmission methods, and minimum performance standards for two forms of Remote ID: broadcast and network (ASTM International, 2020). Additionally, this standard addresses communications and test requirements for these two forms of RID. The ASTM standard explicitly refers to UAS that meet the requirements of Part 89.

> *"This specification is applicable to UAS that operate at very low level (VLL) airspace over diverse environments including but not limited to rural, urban, networked, network degraded, and network denied environments, regardless of airspace class." (ASTM International, 2020)*

The test methods and data collected from the A40 project effort informed the verification of test methods and aided the FAA in acceptance of the ASTM standard. Following the FAA's acceptance of the ASTM standard, testing was conducted throughout the remainder of the project period of performance to acquire more data to inform future potential uses.

2 TESTING

2.1 Test Objectives

The objective of the A40 research effort was to establish a baseline performance for RID devices operating at the minimum requirements designated in the ASTM RID standard. To do this, the tests focused on collecting RID data at different ranges, altitudes, orientations, different RF environments, and more. Performance differences in the different communication protocols, Bluetooth, and Wi-Fi, were determined by testing commercially available RID components. The applicability of RID use by pilots in crewed aircraft was also explored during testing to establish the feasibility of crewed RID use.

2.2 Equipment

Four different RID devices were used throughout the testing effort for this project. Two of these devices used Bluetooth technology, one used Wi-Fi Beacon, and one used Wi-Fi Neighborhood Awareness Networking (NAN). Two of the devices used in this research were standard RID UAS (UAS with integrated RID) and two were RID modules. In addition to the RID devices, a Tektronix RSA306B RF Spectrum Analyzer was also used to capture Radio Frequency (RF) noise floor measurements during the tests.

2.2.1 Dronetag Mini

The Dronetag Mini is an external Bluetooth RID module. When used, this module was securely attached to the aircraft via hook and loop fasteners. The Dronetag module is accompanied by a companion phone application that allows its power level and broadcast rates to be customized along with other settings. Additionally, the module uses internal antennas to broadcast its signal but has ports for external Bluetooth and Long-Term Evolution (LTE) antennas. The Dronetag module was the primary testing mechanism due to its ease of use and predicted future use by UAS pilots. Table 3 details specifications of the Dronetag Mini Module.

Figure 2. Dronetag Mini external RID module (Dronetag, n.d.).

Table 3. Dronetag Mini external module specifications.

Parameter	Description
Manufacturer	Dronetag
Model	Mini
Cellular	LTE-M and Narrowband IoT (NB-IoT)
Cellular Bands	2, 4, 12 (US)
Short-Range Radio	Bluetooth 2.4GHz
Sensors	GNSS, Barometer, Accelerometer
Positioning	GPS L1, GLONASS L1, Galileo E1, SBAS
SIM Card	Chip SIM soldered on mainboard
Built-in Antennas	Internal LTE, Bluetooth, and GNSS
Optional Antennas	External LTE, Bluetooth via MMCX plugs
External Ports	3.3V extension connector and 5V Micro USB
Battery	LiPo 3.7V 500mAh
Battery Life	8-14 Hours depending on configuration
Charging	5V Micro USB
Charging Time	2 hours from discharged state
Average current consumption	50mA
Maximum current consumption	1A
Enclosure	Plastic
Fastening Mechanism	3M Dual-lock SJ4570
IP Rating	IP43
Operating Temperature	-5ºC to +40ºC (23°F to 104°F)
Dimensions	54x35x15mm (2.1x1.3x0.6in)
Weight	32 grams (1.1oz)

2.2.2 Parrot ANAFI USA

The Parrot ANAFI USA drone uses an internal Wi-Fi Beacon RID system. The RID settings, such as broadcast channel and rate, can be changed in Parrot's FreeFlight 6 phone application.

Figure 3. Parrot ANAFI USA with built in Wi-Fi Beacon RID system (Parrot, n.d.).

Table 4. Parrot ANAFI USA specifications.

Parameter	Description
Manufacturer	Parrot
Aircraft Model	ANAFI USA
Aircraft Type	Quadrotor
Takeoff Weight	320 g
Length (Unfolded)	175 mm
Width (Unfolded)	240 mm
Height (Unfolded)	65 mm
Diagonal Distance	279.4 mm
Max Ascent Speed	4 m/s
Max Descent Speed	4 m/s
Max Speed	15 m/s (55km/h)
Maximum Takeoff Altitude	4800 m
Max Flight Time	25 min
Max Hovering Time	30 min (no wind)
Max Distance	14 km at 11.5 m/s
Max Wind Speed Resistance	27 knots (50 km/h)
Max Tilt Angle	35° with remote controller or 25° (flight mode dependent)
Max Angular Velocity	200°/s
Hovering Accuracy (Vertical)	1.5 cm radius sphere @ 1m height
Hovering Accuracy (Horizontal)	1.5 cm radius sphere @ 1m height
Operating Frequency (Remote Controller)	2.40 - 5.80 GHz
Static Broadcast Rate	0.5 Hz
Dynamic Broadcast Rate	1 Hz

2.2.3 Aerobits idME

The Aerobits idME is an external Bluetooth module designed to be used with a Pixhawk controller via a Japan Solderless Terminal connector. The settings of the module can be customized with the Aerobits Micro Automatic Dependent Surveillance-Broadcast (ADS-B) software. The idME does not have an internal battery and must be powered by an external source. This lack of onboard power necessitated the use of an external battery pack as seen in Figure 4. Table 5 presents additional specifications for the Aerobits idME module.

Figure 4. Testing configuration of idME module on Autel Evo II.

Table 5. Aerobits idME specifications.

Parameter	Description
Manufacturer	Aerobits
Model	idME
Frequency	Bluetooth 2.402-2.480GHz
Max Output Power	+8dBm
Power Supply	5V
ESD Protection	All connectors
Interface baud	Configuration or MAVLink 115200bps
Main Connector	SM06B-GHS-TB(LF)(SN)
Antenna Connector	2x RF-IPX125-1G-AU
Dimensions	32.0x16.7x7.5mm
Weight (with antenna)	4 grams

2.2.4 Vendor 1 Aircraft

The manufacturer of the following aircraft has requested to remain anonymous. Therefore, the aircraft was referred to as “Vendor 1 Aircraft”. This UAS is equipped with an integrated Wi-Fi NAN RID system enabled through firmware installations. The firmware installations may be changed to alter the power levels and broadcast rates. Table 6 contains the specifications for the aircraft.

Table 6. Vendor 1 aircraft specifications.

Parameter	Description
Aircraft Manufacturer	Vendor 1
Aircraft Model	Vendor 1 Aircraft

Aircraft Type	Quadcopter
Takeoff Weight	905 g (max: 1100 g)
Length (Unfolded)	322 mm
Width (Unfolded)	242 mm
Height (Unfolded)	84 mm
Diagonal Distance	354 mm
Max Ascent Speed	5 m/s or 4 m/s (dependent on flight mode)
Max Descent Speed	3 m/s
Max Speed	72 kph (flight mode dependent, near sea-level, no wind)
Maximum Takeoff Altitude	6000 m
Max Flight Time	31 min (@ 25 kph, no wind)
Max Hovering Time	29 min (no wind)
Max Flight Distance	18 km (no wind)
Max Wind Speed Resistance	29-38 kph (15-20 knots)
Max Tilt Angle	35° with remote controller or 25° (flight mode dependent)
Max Angular Velocity	200°/s (flight mode dependent)
Hovering Accuracy (Vertical)	± 0.1 m (with visual positioning) ± 0.5 m (with GPS positioning)
Hovering Accuracy (Horizontal)	± 0.4 m (with visual positioning) ± 1.5 m (with GPS positioning)
Operating Frequency (Remote Controller)	2.400 – 2.483 GHz; 5.725 – 5.850 GHz
Broadcast Power Level	28 dBm
Broadcast Rate	Configurable

2.2.5 Autel EVO II

The Autel EVO II was the primary UAS for testing external RID modules due to its lack of internal RID systems. The modules would typically be fitted to the top of the aircraft above the camera, due to this being the only suitable mounting location on this specific drone. Manufacturers such as Dronetag state that their module can be mounted on either the top or bottom of the drone, with the placement depending on the user's preference.

Figure 5. Autel Evo II (Robotics, n.d.).

Table 7. Autel EVO II specifications.

Parameter	Description
Aircraft Manufacturer	Autel Robotics
Aircraft Model	EVO II
Aircraft Type	Quadcopter
Takeoff Weight	1150 g (max: 1999 g)
Length (Unfolded)	424 mm
Width (Unfolded)	354 mm
Height (Unfolded)	110 mm
Diagonal Distance	397 mm
Max Ascent Speed	8 m/s (Ludicrous mode)
Max Descent Speed	4 m/s (Ludicrous mode)
Max Speed	20 m/s (Ludicrous mode)
Maximum Takeoff Altitude	7000 m
Max Flight Time	40 min
Max Hovering Time	35 min
Max Distance	25 km
Max Wind Speed Resistance	Force 8 wind (34-40 KTS)
Max Tilt Angle	-
Max Angular Velocity	-
Hovering Accuracy (Vertical)	±0.02m (with visual positioning) ±0.20m (with GPS positioning)
Hovering Accuracy (Horizontal)	±0.02m (with visual positioning) ±0.20m (with GPS positioning)
Operating Frequency (Remote Controller)	2.4000-2.4838 GHz

2.2.6 Samsung Galaxy S20 FE 5G

A Samsung Galaxy smartphone was chosen as the receiver for all testing due to its representative nature of the most common devices for receiving RID messages. The phone was mounted on a tripod at a height of 140 cm ± 10 cm in accordance with ASTM International test methods and pointed in the direction of the RID transmitter.

2.2.7 Open Drone ID

The Open Drone ID application was installed on the Samsung Galaxy smartphone, enabling message receipt and data collection for all tests. Open Drone ID is an open-source application developed by Intel that continuously scans for the advertised broadcast signals sent by both BT and Wi-Fi devices and displays their location on a map. Data collection was achieved simply by opening the application, which initiates a data log for the session until the application is closed. Once closed, the collected data is stored in a .csv file and saved to the phone’s storage, allowing the user to analyze at a later time. Figure 6 shows an example image of the map screen and detailed information page. Additionally, the Open Drone ID application creates a list of detected devices in the surrounding area. This allows the user to select a specific device in proximity and acquire more detailed information regarding the device and/or drone of interest.

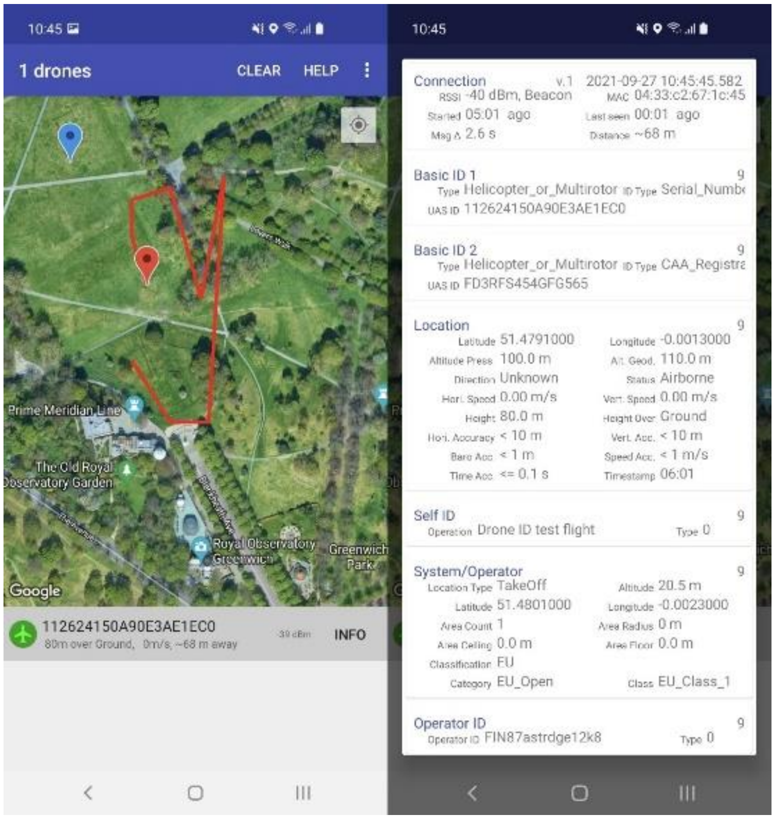

Figure 6. Example images of the Open Drone ID application (Friis, 2022).

2.2.8 Tektronix RSA306B Signal/Spectrum Analyzer and SignalVu Software

The RSA306B Signal/Spectrum Analyzer, shown in Figure 7, was used to capture measurements of the RF noise floor at multiple testing areas. This provided the research team with supplemental data to determine if the RF environment for the test area may have impacted the performance of the RID modules. These measurements also provided a comparison between the rural test environments and the more populated test environments. The frequency range of the analyzer used is 9kHz to 6.2 GHz. This is a wide range which covered both the Bluetooth and Wi-Fi operating frequency ranges used during testing. This device was paired with Tektronix's SignalVu-PC software, allowing the team to observe the noise floor measurements in real time and save the RF environment measurements for later use.

Figure 7. Tektronix RSA306B spectrum/signal analyzer used for noise floor measurements (Tektronix, n.d.).

2.3 Personnel

The following personnel were designated for all or some of the test events accomplished for this research.

Test Director

The Test Director was responsible for ensuring the flight test was completed in accordance with the flight test plan. The Test Director was responsible for termination of flight test maneuvers due to safety or technical issues. Their primary communication interface was with the Pilot-in-Command. They participated in the Flight Readiness Review meeting where the flight test plan, flight test cards, and hazard identification forms are discussed and finalized. In addition, they chaired the preflight briefing and debrief; ensured the test flights were conducted in a safe manner and in compliance with the flight test cards with accepted deviations and approved flight test plans and flight test report.

Test Conductor

The Test Conductor was responsible for coordinating personnel, aircraft, and equipment to meet the objectives of the Test Cards during a test flight. This was the lead role for generating the flight test plans and flight test cards. The Test Conductor chaired the Flight Readiness Review meeting where the flight test plan, flight test cards, and hazard identification forms are discussed and finalized. They oversee the conduct of the flight test.

Test Engineer

The Test Engineer was responsible for monitoring the status of the aircraft and/or operating the system(s) during the flight test. The Test Engineer was tasked with data recording, equipment emplacement, and data analysis.

Pilot-in-Command

The Pilot-in-Command (PIC) was responsible for the safe operation of the aircraft. The PIC was the final decision-making authority on the safety of flight for the aircraft during a flight test.

Visual Observer

The Visual Observer (VO) was responsible for maintaining positive visual control of the aircraft under test. The VO was in constant communication with the PIC to ensure separation from other air traffic and that Visual Flight Rule weather minimums were maintained.

2.4 Test Methods and Procedures

Four distinct categories of tests were completed during the A40 research effort: range testing, directionality testing, encounters testing, and RF environment testing. For some test categories, multiple iterations were conducted with varying test parameters. Additionally, not all devices were utilized in each test. A sizable portion of the data collected pertained to the range tests of the RIDs, as the range capability of these devices is of particular importance. The other tests, such as directionality, RF environment, and encounters testing provided supplemental situational context to the range test data. Unless specified otherwise, testing was generally performed at the minimum broadcast rate of 1 Hz and power level of 5dBm for Bluetooth devices. Wi-Fi devices did not have a set broadcast rate but did have set power levels of 28 dBm. Horizontal range tests were conducted with the aircraft and module facing away from the receiver.

2.4.1 Range Testing

Range tests were the primary method the A40 research team utilized to collect data on the performance of RID systems. The objective of these tests was to acquire data to be able to compare RID systems operating at different broadcast rates, power levels, and horizontal and vertical distances from the receiver. Four total range tests were conducted at Mississippi State University's North Research Farm with varying test points, procedures, and locations. The first range test conducted was referred to as the preliminary range test and consisted of collecting data at vertical and horizontal test points, shown in Figure 8. The vertical test points were located at altitudes of 100 ft, 200 ft, 300 ft, and 400 ft above the receiver.

Figure 8. Test point locations for the preliminary range test.

For the horizontal data collection, the UAS hovered at an altitude of 300ft Above Ground Level (AGL) at each of four test points, which were located every 500m. During horizontal testing, the UAS was prescribed to hover at 300 ft AGL. Data was collected for approximately 60 seconds at each horizontal and vertical test point. The Vendor 1 aircraft and the Dronetag Mini module were the designated RID systems used for the preliminary range test. Throughout this range test, the broadcast rates of the two systems were varied in the configurations detailed in Table 8. The power level for the BT system was also varied between 5 dBm and 8 dBm

Table 8. Preliminary range testing configurations.

Bluetooth 4 & 5 Configurations	
Broadcast Rate (Hz)	Power Level (dBm)
1	5
3	5
6	5
1	8
Wi-Fi NAN Configurations	
Broadcast Rate (Hz)	Power Level (dBm)
1	28
3	28
5	28
1	28

After performing the preliminary range test, the research team noticed a change in performance of the RID systems at the 500m and 700m test points. A second range test was conducted with the Parrot ANAFI and Dronetag module to determine if the presence of nearby high voltage transmission lines were affecting the RID data but results were inconclusive. The location of the test points for the second range test were moved to a different area of the North Research Farm to avoid potential interference with the transmission lines. Figure 9 shows the horizontal test points every 500 meters at 300 ft AGL along with the vertical test points directly above the receiver.

Figure 9. Test points for Parrot ANAFI Wi-Fi beacon and Dronetag range testing.

The broadcast rate and power level of the ANAFI was not customizable and operated based on the French RID standard (Legifrance, 2019), as the UAS is a French platform. The power level of the ANAFI was set at 28 dBm and an RID message would be sent every three seconds at a minimum. Additionally, the Parrot ANAFI utilized Channel 6 (2.4 GHz) and Channel 149 (5 GHz), as shown in Figure 10. The Dronetag module broadcasted at 1 Hz and 5 dBm for this test.

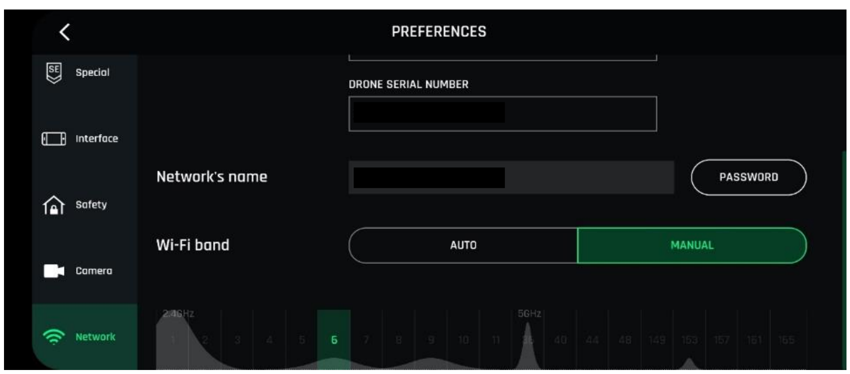

Figure 10. Parrot Freeflight 6 application and Wi-Fi band selection.

The final range test consisted of testing the Aerobits idME Bluetooth module and the Dronetag Mini module in an extended range scenario. Horizontal range data was collected at test points up to 1500m in increments of 100m. These test points can be seen in Figure 11. After the 1500m test point was reached, the UAS was then flown to test points in increments of 500m. To achieve the extended test points past the 1500m mark, the receiver location had to be moved to allow for the further distance, which can be seen in Figure 12.

Figure 11. Testing locations for the Aerobits idME and Dronetag Bluetooth modules.

Figure 12. Testing locations for extended horizontal test points.

The fourth and final range test was conducted using the Dronetag module. This test and consisted of flying the UAS to different horizontal test points with a smaller increment than the previous range tests. The test points were located 100m to 700m away from the receiver and differed in 100m increments, as shown in Figure 13. Additionally, data was collected at altitudes of 100ft, 200ft, 300ft, and 400ft AGL at horizontal distances of 500m and 700m. Retrieving data at 500m and 700m specifically was important as the research team found that the RID devices were performing differently at these horizontal distances, and additional data was needed to determine the reason for the performance difference.

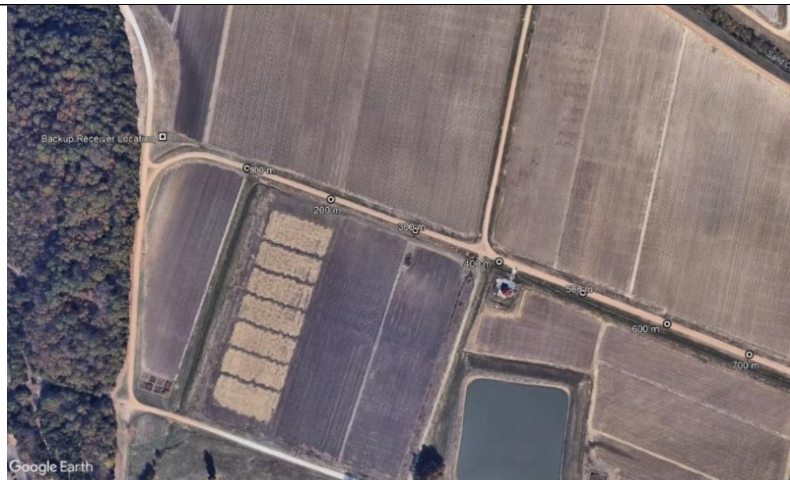

Figure 13. Test points for shortened range test.

2.4.2 Directionality

Directionality testing was performed using with the primary objective being to determine if the orientation of the RID module relative to the receiver affected the device's performance. The RID module used for this testing was the Dronetag Mini affixed to the Autel Evo II aircraft. The receiver that corresponded with this module was the Samsung Galaxy SE companion phone equipped with the Open Drone ID app. This test was initially performed on the ground with the receiver placed 100m away from the module. The UAS rested on a tripod, shown in Figure 14, that was rotated to each desired orientation. Measurements were taken by opening the Dronetag app to "initiate" the data collection by the module. A total of 40 measurements were taken during the test from 0° - 360° in 9° increments. Data was collected for approximately 15 seconds for each test point.

Figure 14. Autel EVO II with mounted Dronetag module during initial directionality test.

To provide additional value to the directionality data, a similar test was performed with an airborne model. For airborne testing, the UAS hovered at distances of 500m and 700m at an altitude of 300ft. Data was collected in four different orientations relative to the receiver: 0°, 90°, 180°, 270°. These distances were chosen for testing due to increased interest in the performance of the device at these ranges because of degradation in previous tests.

Figure 15. Orientation testing locations at ranges of 500m and 700m.

2.4.3 Ground Encounters Testing

Ground encounters testing was one of two test configurations designed to analyze the interaction between a UAS RID module and a receiver in a crewed aircraft. A Grumman Tiger was the designated crewed aircraft for this testing, along with both the Dronetag Mini module mounted on the Autel Evo II, and the Parrot ANAFI USA with build in RID capability. The Grumman Tiger was parked south of a hangar located at the George M. Bryan Airfield (KSTF). The Test Conductor was located in the cockpit of the aircraft with the receiver to record data for each test point while the drone maneuvered on the paths shown in Figure 16. The aircraft was completely powered off and the canopy closed.

Figure 16. Crewed aircraft ground encounters test plan.

The Remote Pilot in Command (RPIC) flew each aircraft on the flight paths marked in red at an altitude of 400 ft AGL. It was pre-determined that if receival from either RID module was difficult at the designated altitude, the RPIC would decrease the altitude of the UAS by 50 ft until receival improved. The RPIC flew each aircraft at its maximum speed throughout the duration of the test. The designated flight paths were 300 m long and ran directly north and south. The center path was located directly over the center of the crewed aircraft, while the west and east paths were 150 m away from the aircraft on either side. Each path was flown ten times by each UAS, with each aircraft completing the flight test separately.

2.4.4 Air Encounters Testing

The reverse of the ground encounters test was also conducted, with the crewed aircraft maneuvering above the UAS as opposed to below. For this test, the Grumman Tiger was the designated crewed aircraft, and Autel EVO II with mounted Dronetag Mini and the Parrot ANAFI USA were the designated drones for this test. The Test Director and RPIC were collocated at Mississippi State’s North Research Farm. The Test Conductor and crewed aircraft PIC performed preflight and takeoff procedures while the ground-based team situated the UAS at 400 ft AGL with a heading of 305°. The UAS hovered at this location, maintaining the position as closely as possible. The drone hovered at the designated location for the duration of the test unless a battery replacement was needed. Once the drone was in place at the correct location, the crewed aircraft began flying passes on the paths marked in red in Figure 17. While flying passes, the test conductor collected data through the receiver. There were six passes made by the crewed aircraft on each pass – three in each direction.

Figure 17. Flight paths for crewed aircraft during RID encounters testing.

Each path was 3 km in length, and data collection took place the entire time the aircraft flew on each path, ending when the pilot began to turn around.

2.4.5 RF Environment

The A40 research performers had the opportunity to perform range testing in an altered RF environment, providing additional value to RID performance data. This testing took place throughout the course of a local event in Starkville, MS, which historically draws a crowd of approximately 40,000 people. To accommodate this large crowd, a 5G cellular tower was emplaced near the event location. To gather data on the performance of RID in an altered RF environment, the Autel EVO II with attached Dronetag Mini module hovered at three separate locations at three different times of the event. The RPIC, Test Conductor, and Test Director were stationed on top of a building approximately 30ft tall. From this location, the UAS was flown to distances of 100m, 300m, and 430m away and collected data for one minute at each location. The designated distances the UAS was flown to was dictated by the security needs of the event and reflect locations that local law enforcement allowed the research to be conducted. This process was repeated at 2:00pm, 4:00pm, and 5:30pm as crowds were expected to increase throughout the evening. These times were hypothesized to be low, medium, and high RF noise environments, respectively. Before each set of testing began, an engineer used an RF Scanner to take readings of the RF environment, providing additional context for the data collected. Figure 18 below shows and the receiver location in blue as well as the data collection points where the aircraft hovered in red.

Figure 18. Test point locations for UAS during RF testing.

3 DATA ANALYSIS

3.1 Method of Analysis

The method of analysis for this project focused on interpreting the information contained in the data packets provided by the RID devices. The goal for the analysis was to validate the contents of the RID packages the RID systems were transmitting, the receival rate, and determine the range performance of the various transport methods tested. The analysis approach lends to the ability to draw comparisons from the actual performance of RID modules in the test environments with the manufacturer performance specifications. Test environment data was interpreted alongside packet information to give additional context to the RID data when drawing conclusions or identifying trends. Packet information can be classified as either static information or dynamic information. Static information characterized the system itself, such as the UAS's identification type or identification number. Dynamic data referred to the flight characteristics of the UAS operation, such as the UAS's latitude and longitude vector or speed vector. The data categories and information that were considered pertinent for data analysis in these spreadsheets are detailed in Table 9. Static information is followed by a "+" symbol, while dynamic information is specified using the "-" symbol.

Table 9. Parameters utilized for data analysis.

Parameter	Information Included
Timestamp -	Numerical time value automatically listed in nanoseconds, converted manually to seconds
Transport Type +	Qualitative Entry Stating BT4, BT5, Beacon, or NAN
ID Type +	Numerical value of "1" or blank entry
UA Type +	Numerical value of "0" or blank entry
Status -	Numerical value of "2" or blank entry

Though there is additional static or dynamic information given in the data packets, only a few parameters were necessary to analyze. Packets that had an ID Type value of "1" or UA Type value of "0" also contained additional static information. Packets that contained a Status value of "2" also contained dynamic information. The presence of these numbers in these fields allowed the team to recognize and sort the static and dynamic messages transmitted by the RID devices although their true purpose is to provide information on how the UAS identifies itself i.e., through a serial number or some other means, or what type of aircraft the RID device is attached to. The values themselves were not important for data analysis. Therefore, these three parameters were used to identify the amount of static and dynamic packets. Additionally, each data set was filtered to remove "empty" or nonpertinent data. Empty data was characterized by packets in which required RID information was not received (no static or dynamic information).

3.2 Calculations

From the filtered data, calculations were derived from collected RID data to produce graphs and charts to identify trends in the test data. These calculations included receival rates, transport type percentages, total time of collection, number of packets, and transport type rates.

3.2.1 Total Collection Time

The total collection time was calculated by subtracting the last timestamp value in the data set from the last timestamp value. A conversion factor was performed to convert the time value from nanoseconds to seconds.

$$Total\ Collection\ Time = (t_{end} - t_{start}) * 1e^{-9}$$

3.2.2 Number and Type of Packets

Number of static packets, dynamic packets, and total number of packets were computed for each data set. The number of static and dynamic packets were acquired by summing the parameter column characterizing the data entry as either static or dynamic. For static packets, the sum was applied to the ID Type or UA Type column. For dynamic packets, the sum was applied to the Status data column. Similarly, the number of BT4 and BT5 entries in the Transport Type data column was also summed. This was not done for Wi-Fi RID systems as all messages would be sent by the same communication protocol of Wi-Fi NAN or Wi-Fi Beacon.

3.2.3 Receival Rates

Receival rates were calculated for static, dynamic, and total packets received. The following calculations were used:

$$Static\ Receival\ Rate = \frac{\#\ Static\ Packets}{Total\ Collection\ Time}$$

$$Dynamic\ Receival\ Rate = \frac{\#\ Dynamic\ Packets}{Total\ Collection\ Time}$$

$$Average\ Receival\ Rate = \frac{(Static\ Receival\ Rate + Dynamic\ Receival\ Rate)}{2}$$

3.2.4 Transport Type Percentages and Rates

The percentage of transport methods was calculated using the information in the "Transport Type" data column. Additionally, transport method rates were calculated with this information.

$$\%BT4\ Transmissions\ Received = \left(\frac{\#\ BT4\ Packets}{Total\ Number\ of\ Packets}\right) * 100$$

$$\%BT5\ Transmissions\ Received = \left(\frac{\#\ BT5\ Packets}{Total\ Number\ of\ Packets}\right) * 100$$

$$BT4\ Rate = \frac{\#\ BT4\ Packets}{Total\ Collection\ Time}$$

$$BT5\ Rate = \frac{\#\ BT5\ Packets}{Total\ Collection\ Time}$$

3.3 Raw Data Summaries

The calculations listed above were computed for each data set for each test performed. The values from these calculations served as the basis for the development of charts and relations that led to the identification of data trends. The following tables show a summary of each test and its data. The averages calculated in the following tables include test points where no messages were received and therefore have values of 0 that lower the averages. If these values were at the range limit of the device they were not included, only those that did not receive messages at a test point but did at the next test point with a higher range. These tables are meant to provide a brief view of the testing and its results overall. More detailed analysis can be found in section 4.

The following tables present summaries of the data collected during the three range tests of the Dronetag Mini. Table 10 contains results from the vertical range test and Table 11 from the horizontal tests. All testing with the Dronetag was performed at the ASTM International RID performance minimum of 1 Hz and 5 dBm.

Table 10. Dronetag Mini vertical testing data summary.

	External Antenna	Internal Antenna
Average # of packets received	99	77
Average collection time (s)	61.25	62.25
Average # static packets received	21.75	15.25
Average # dynamic packets received	77.5	61.75
Average receival rate (Hz)	0.81	0.62
Average % BT4 transmissions	81.68	67.23
Average % BT5 transmissions	18.32	32.77

Table 11. Dronetag Mini horizontal testing data summary.

	Data Set 1	Data Set 2	Data Set 3

Broadcast Power Level (dBm)	5					
Broadcast Rate (Hz)	1					
Testing Distances	500m – 2000m 500m increments		500m - 2000m 100m increments		100m – 700m 100m increments	
Antenna Configuration	External Antenna	Internal Antenna	External Antenna	Internal Antenna	External Antenna	Internal Antenna
Average # of packets received	26.17	13.82	9	18.27	42.71	65.86
Average collection time (s)	40.8	41.9	50.18	33	61.71	65.43
Average # static packets received	10.83	4.82	2.45	3.27	10.71	15.43
Average # dynamic packets received	15.33	9	6.55	14.91	32	50.43
Average receival rate (Hz)	0.21	0.12	0.07	0.15	0.34	0.50

Table 12 is a summary of the data collected during the range test of the Aerobits idME external Bluetooth module.

Table 12. Aerobits idME range test data summary.

Aerobits idME (BT)		
Broadcast Power Level (dBm)	5 dBm	
Dynamic Rate (Hz)	1	
Static Rate (Hz)	0.5	
	Vertical Testing	Horizontal Testing
Testing Distances	0ft – 100ft 100ft increments	100m – 2500m 100m increments
Average # of packets received	384.75	138.56
Average collection time (s)	62.25	65.61
Average # static packets received	100.25	43.22

Average # dynamic packets received	95.75	43.61
Average receival rate (Hz)	1.57	0.64

Table 13 shows a summary of the results of directionality testing. The averages presented were calculated by using all four orientations at each distance.

Table 13. Directionality test data summary.

Dronetag Mini (BT)			
Broadcast Power Level (dBm)	5		
Horizontal Distance (m)	100	500	700
Average # of packets received	28.13	28	21.5
Average collection time (s)	14	62.5	62.5
Average # static packets received	5.5	4.25	4.5
Average # dynamic packets received	23.25	23.75	17
Average receival rate (Hz)	1.02	0.23	0.16

The ground encounters summary shown in Table 14 reflects the data acquired from the Dronetag Mini RID module and the Parrot ANAFI internal RID module at various distances. The values provided in the table are averages across the three different paths the UAS flew during the ground encounter test.

Table 14. Ground encounters test data summary.

	Dronetag Mini			Parrot ANAFI		
Broadcast Method	Bluetooth			Wi-Fi Beacon		
UAS Altitude (ft AGL)	400					
Broadcast Power Level (dBm)	5			28		
Flight Path	Center	West	East	Center	West	East
Average # of packets received per pass	35	46	28	1	2.7	2.6
Average # static packets received	16.8	21	13.5	0.2	0.8	0.38

Average # dynamic packets received	18.3	25	14.6	0.8	1.8	2.25
Average receival rate (Hz)	0.36	0.4	0.21	0.02	0.04	0.02

The air encounters summary shown in Table 15 reflects the data acquired from the Dronetag Mini RID module and the Parrot ANAFI internal RID module at various distances. The values provided in the table are averages across the three different paths the crewed aircraft flew.

Table 15. Air encounters test data summary.

	Dronetag Mini	Parrot ANAFI
Broadcast Method	Bluetooth	Wi-Fi Beacon
UAS Altitude (ft AGL)	400	
Airplane Altitude (ft AGL)	1000	
Broadcast Power Level (dBm)	5	28
Average # of packets received per pass	2	0
Average collection time (s)	3	0
Average # static packets received	1	0
Average # dynamic packets received	1	0
Average receival rate (Hz)	0.013	0

The RF environment summary shown in Table 16 reflects the data acquired by the Dronetag Mini RID module at various distances and in various RF environments. These environments are categorized as low RF noise, medium RF noise, and high RF noise. The amount of noise in the three instances matches closely with the RF noise in rural, suburban, and urban environments.

Table 16. RF Environment test data summary.

	Low Noise	Medium Noise	High Noise
Average # of packets received per pass	37	25	49
Average collection time (s)	61	41	52
Average # static packets received	16	12	24

Average # dynamic packets received	20	13	26
Average receival rate (Hz)	0.30	0.26	0.41

4 RESULTS

4.1 Range Testing Results

Each range test consisted of two parts: the vertical test points and horizontal test points. Vertical test points were located directly above the receiver at altitudes of 100ft, 200ft, 300ft, and 400ft. The horizontal test points varied from 100m to 3000m in varying increments.

4.1.1 Vertical Testing Results

4.1.1.1 Dronetag Mini Vertical Range Test Results

The Dronetag Mini was evaluated three separate times – once in the preliminary range test at multiple broadcast rates and power levels, with an external antenna, and finally with its internal antenna. Figure 19 shows the results at all four altitudes at the minimum broadcast rate and power level. As can be seen in the figure, there was little to no degradation in performance, which was the expected result.

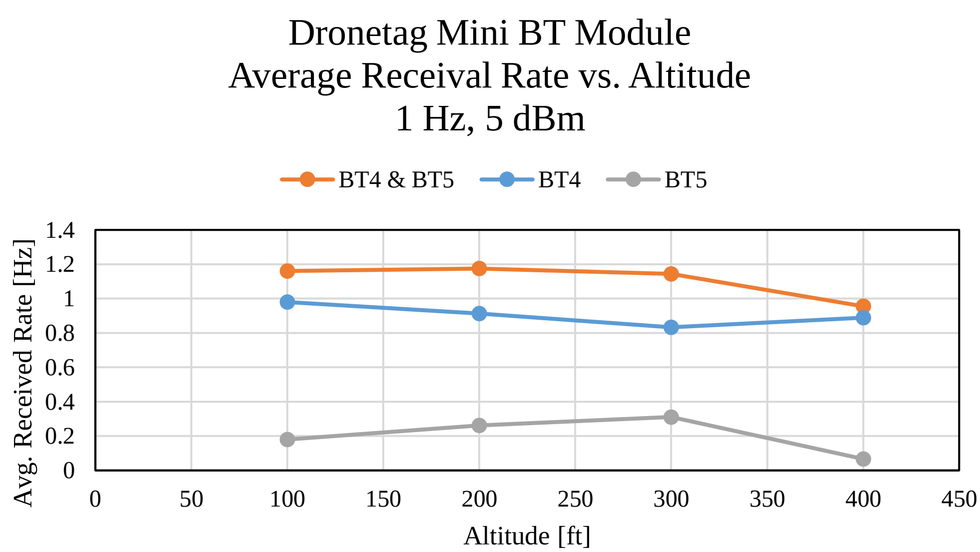

Figure 19. Average receival rate vs. altitude per transport type for Dronetag module.

Likewise, Figure 20 shows the received rate for the four different configurations the device was tested in. All show similar results with the received rate matching closely to the broadcast rate. A change in power level did not correlate to a change in the received rate for the Bluetooth test points in the preliminary test.

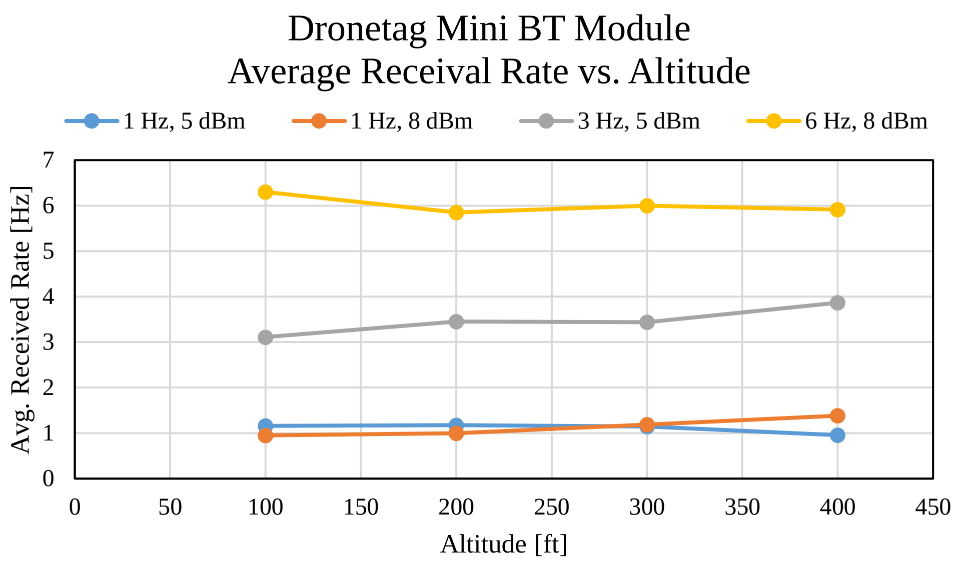

Figure 20. Average receival rate vs. altitude per broadcast configuration for Dronetag module.

The final vertical test conducted with the Dronetag was a comparison between the internal and external antenna with identical broadcast rates and power levels for all tests. The external antenna performed in an analogous manner to the internal antenna in the preliminary vertical test. However, the internal antenna experienced degradation in the received rate as its altitude increased. This culminated in an extremely low received rate at 400ft AGL, especially when compared to previous testing where there was no degradation even at the maximum altitude.

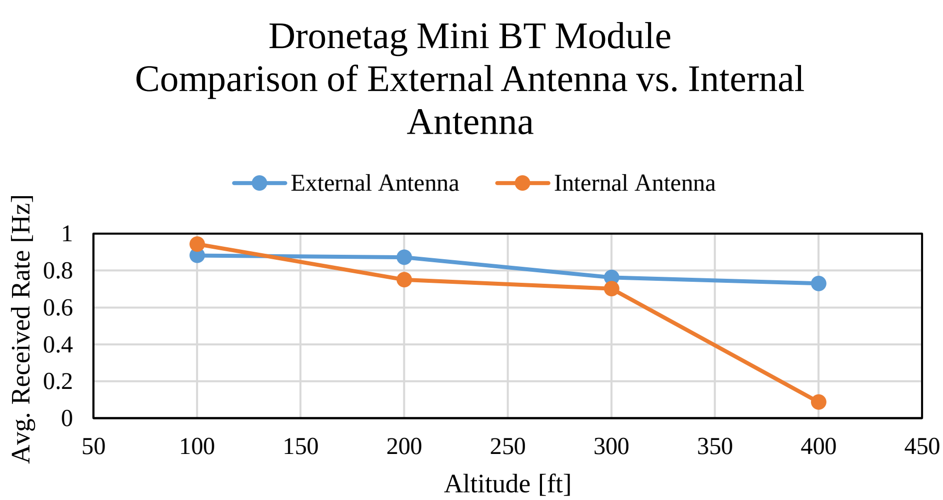

Figure 21. Comparison of average receival rate vs. height for Dronetag internal and external antenna.

The above results are not consistent with findings at 500m and 700m where the altitude was varied from 100ft up to 400ft AGL. Shown in Figure 22 and Figure 23, the internal antenna had increased reception rates compared to the external antenna. Both configurations followed similar trends, however, increasing and decreasing in similar ways but with different intensities.

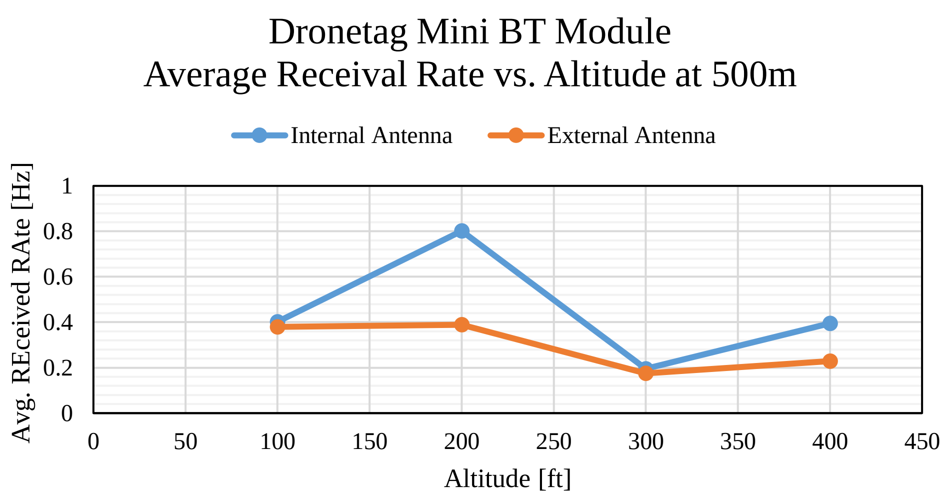

Figure 22. Average receival rate vs. altitude at 500m range for Dronetag module.

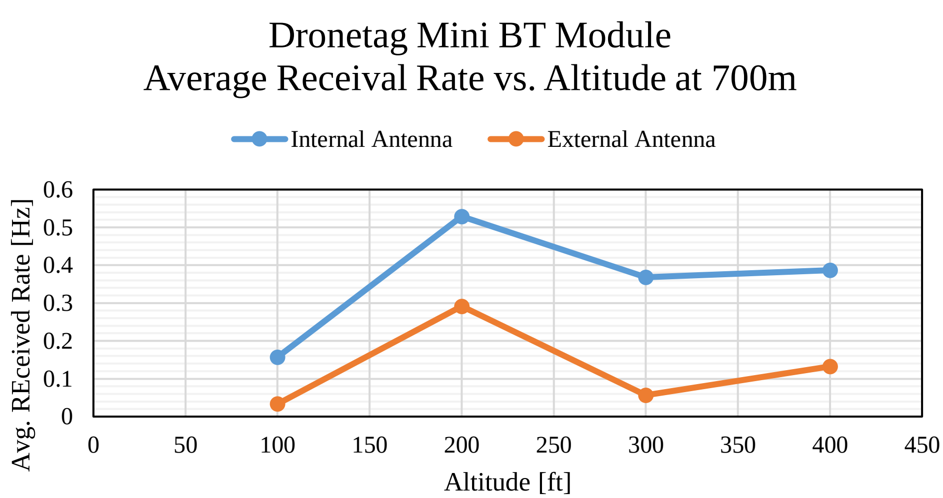

Figure 23. Average receival rate vs. altitude at 700m range for Dronetag module.

4.1.1.2 Aerobits idME Vertical Range Test Results

The Aerobits idME, also a Bluetooth RID module, was evaluated similarly to the Dronetag. The idME module results reflected a decrease in the rate as altitude increases, though not to the extent seen in Figure 24.

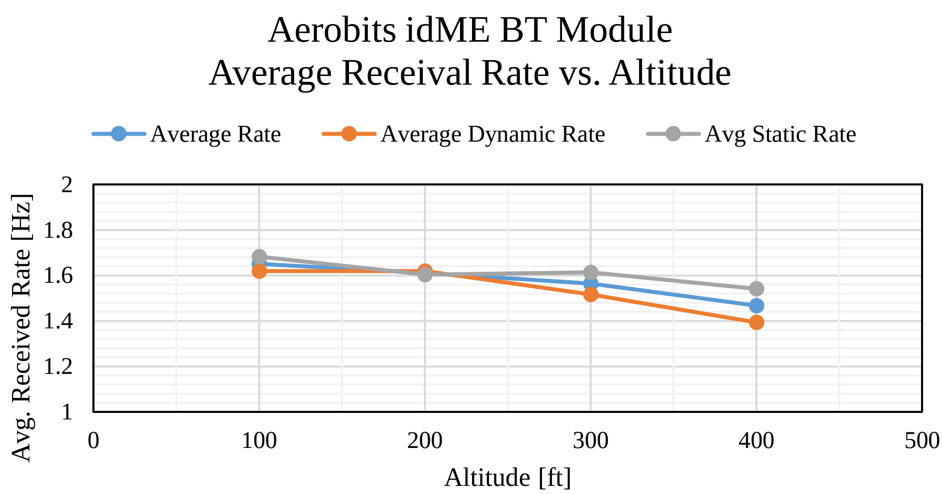

Figure 24. Average receival rate vs. altitude for Aerobits idME module.

4.1.1.3 Vendor 1 Aircraft Vertical Range Test Results

The Vendor 1 Wi-Fi NAN system had a drastically reduced received rate as altitude increased, only managing to achieve 1 Hz when it was broadcasting at a rate of 5 Hz. However, even though the actual broadcast rate was never achieved, the received rate did remain consistent, with little to no degradation in performance as the vertical distance between the receiver and transmitter increased.

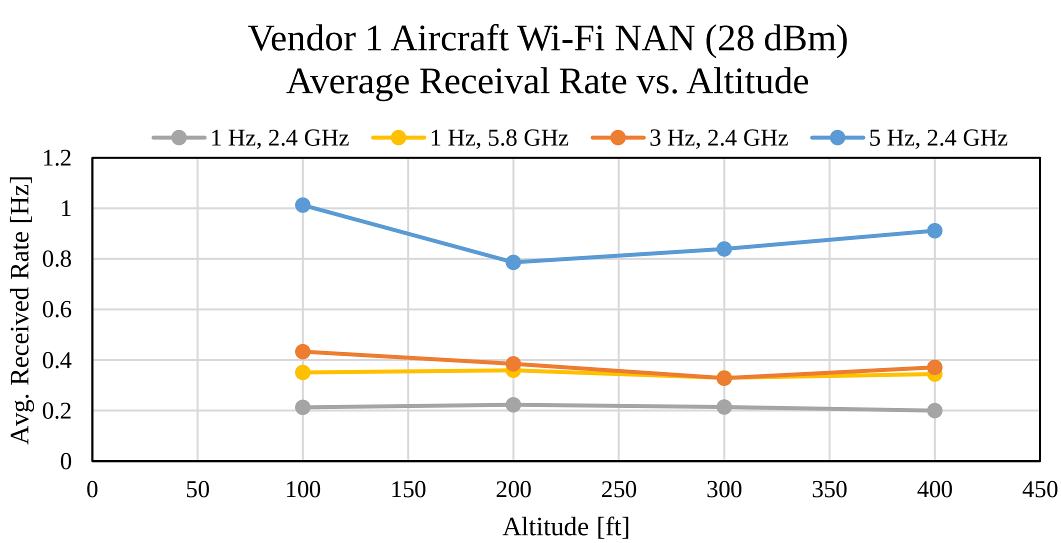

Figure 25. Average receival rate vs. altitude per broadcast configuration for Vendor 1 aircraft.

4.1.1.4 Parrot ANAFI Vertical Test Results

The Wi-Fi Beacon system on the Parrot ANAFI was tested on the 2.4 GHz and 5 GHz frequencies. At its time of testing, this UAS did not have a way to configure its broadcast rate and thus the device broadcasted at the minimum set by France's RID standard. This standard sets a minimum broadcast rate of 0.5 Hz. The broadcast power level was 28 dBm, higher than the minimum set in the ASTM standard. As seen in Figure 26, the received rate matches closely with this broadcast rate and the performance of the two frequencies is similar.

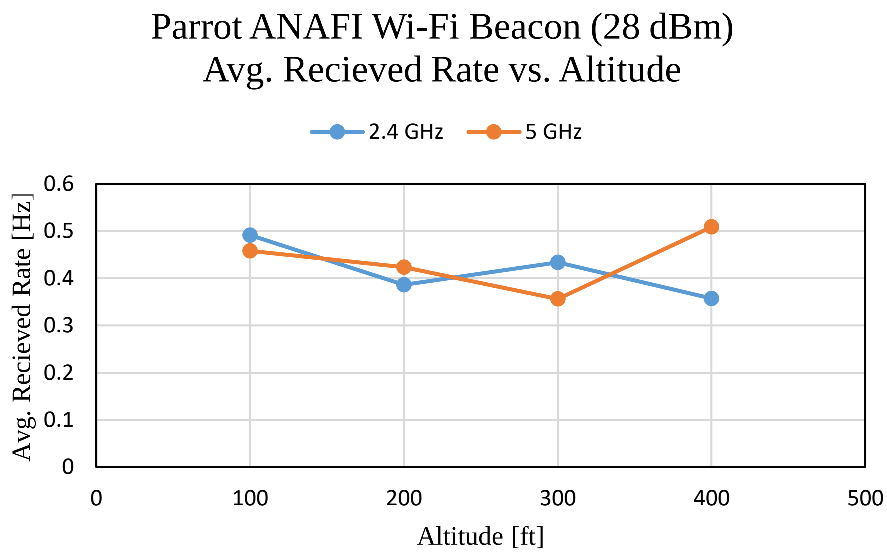

Figure 26. Average receival rate vs. altitude per broadcast configuration for Parrot ANAFI.

4.1.2 Horizontal Testing Results

4.1.2.1 Preliminary Horizontal Range Test Results

Broadcasting at a rate of 1 Hz and a power level of 5 dBm, the Dronetag Mini experienced a significant decrease in the average received rate at a horizontal distance of 500m from the receiver. Bluetooth 4.0. and Bluetooth 5.0 remained at a constant rate. The average rate decreased to 0.3 Hz at this range and gradually decreased to 0.14 Hz at its maximum range of 1800m.

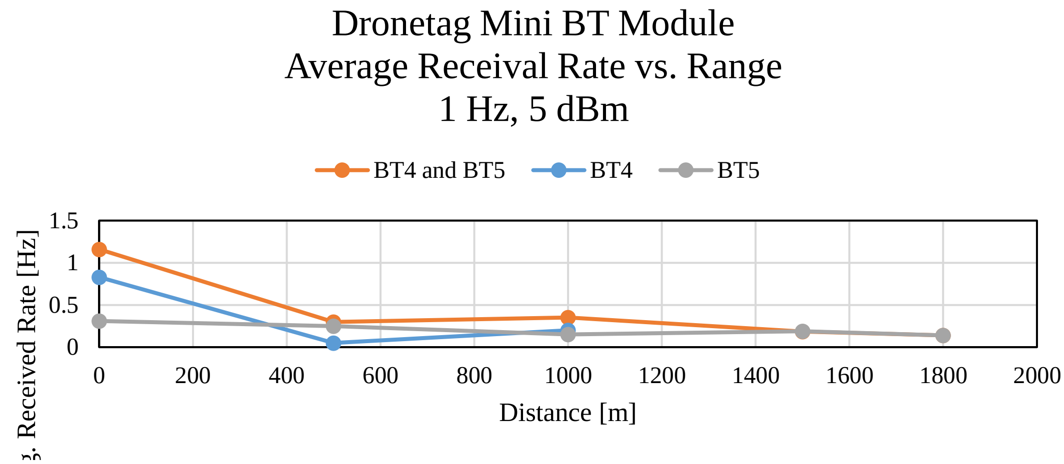

Figure 27. Average receival rate vs. range at 1 Hz, 5 dBm for Dronetag module.

When broadcasting at the same rate of 1 Hz but a power level of 8 dBm, there was a marginal improvement in the range of the device, reaching the furthest distance recorded for the Bluetooth system at 1900m. The received rates were slightly higher compared to the power level of 5 dBm. At this power level Bluetooth 5.0 had a decrease in performance compared to Bluetooth 4.0 at 1000 m.

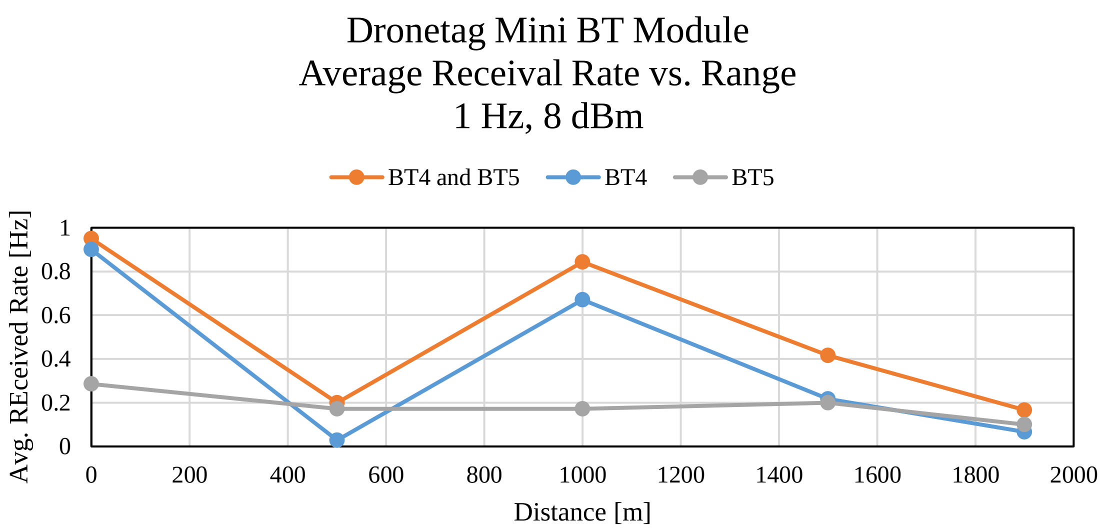

Figure 28. Average receival rate vs. range at 1 Hz, 8 dBm for Dronetag module.

Overall, Bluetooth 4.0 exhibited a decrease in the received rate for the test points past 500m and 1000m. At these larger distances, this behavior is expected since Bluetooth 5.0 has increased range over Bluetooth 4.0. The results reflect that a significantly higher percentage of messages received at further ranges were transported by Bluetooth 5.0 The difference in transmissions between the two Bluetooth protocols does not affect the quality of the data as the information is still being sent. The packets are simply being received by a different transport method. The received rates for all horizontal Bluetooth test points were consistently less than the broadcast rate, and many times this rate was less than half the broadcast rate at any range. Figure 29 contains the average rate for all four broadcast and power configurations. The performance of the Bluetooth device is similar for each configuration; however, it can be determined by the results that the broadcast rate had the biggest impact on reception range.

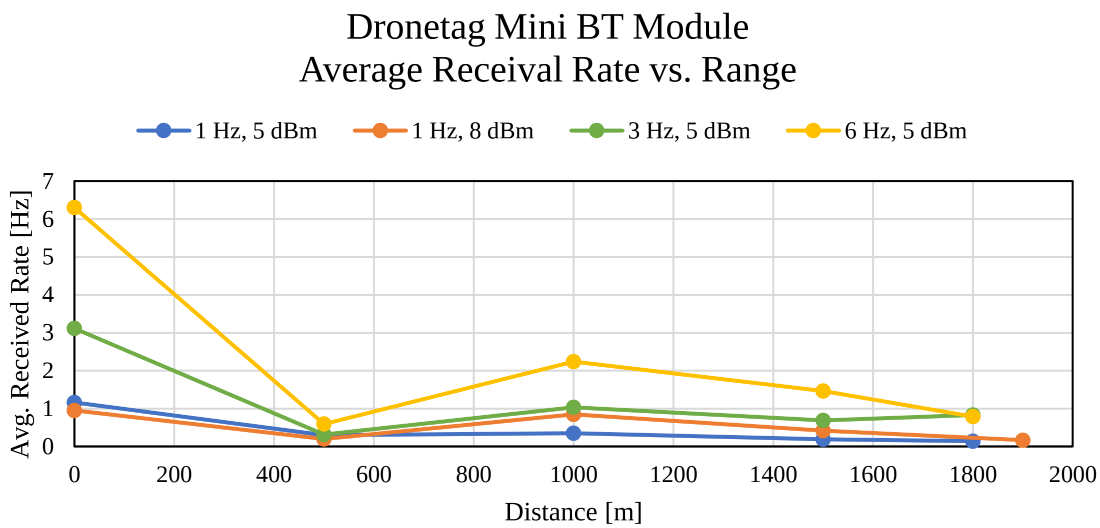

Figure 29. Comparison of average receival rate of per range for all Dronetag Bluetooth broadcast configurations.

Horizontal range testing of the Vendor 1 aircraft Wi-Fi system did not produce a noticeable difference in the range for 2.4 GHz and 5.8 GHz frequencies. The broadcast rate played a larger role in performance differences. Specifically, increasing the rate to 3 Hz and 6 Hz increased the range capability. The range increased from 1000 m to 2800 m for the 3 Hz broadcast rate and from 1000 m to 3000 m for the 5 Hz broadcast rate. The average received rate and broadcast rate were never matched for all four broadcast configurations. For broadcast rates of 5 Hz, the true rate only approached 1 Hz.

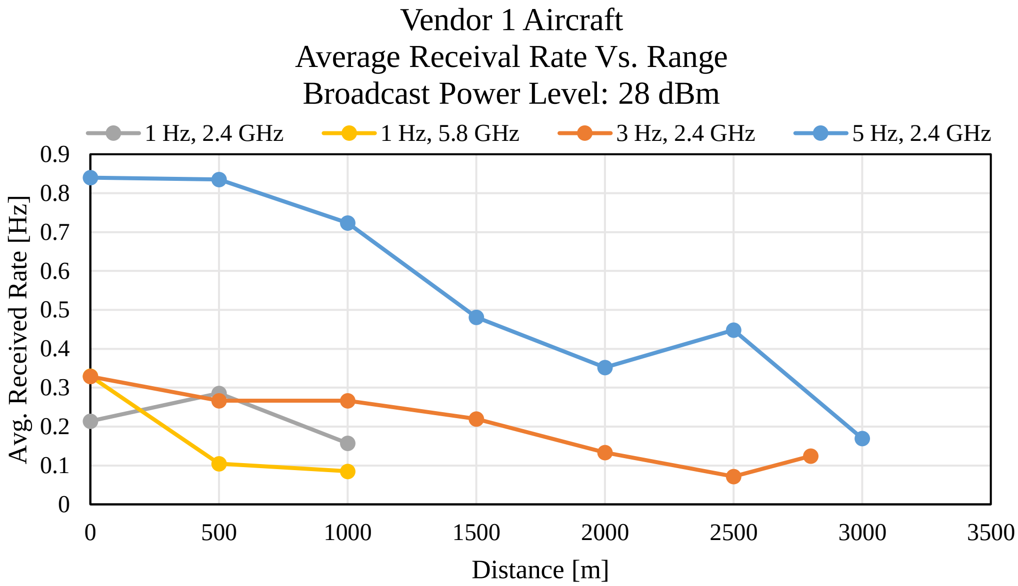

Figure 30. Average receival rates for four different configurations for Parrot ANAFI.

Comparison between the highest broadcast rates for the Wi-Fi and Bluetooth systems shows that while the Wi-Fi system has greater range, the Bluetooth system has a consistently higher received rate. Notably, for 1 Hz broadcast rates the Bluetooth system has a much higher range while the average received rate at this broadcast rate is similar between the two. The full preliminary report containing all data and charts from this testing can be found in the appendix.

4.1.2.2 Dronetag Mini Range Test Results

The internal and external antennas of the Dronetag Mini were evaluated at distances from 100m to 700m, with two tests conducted for each antenna. Lower range distances were chosen due to a lack of performance data at lower distances. As seen in Figure 31, the internal antenna received more messages than the external antenna, although at the 500m test point the receival rates for the antennas was within 0.2 Hz of each other. The internal antenna's rate increased at 700m, while the external antenna maintained a downward trend at this point. The external antenna experienced a significant decrease in its rate at the 700m test point, experiencing a rate of 0.4 Hz compared to 0.8 Hz at the 100m test point.

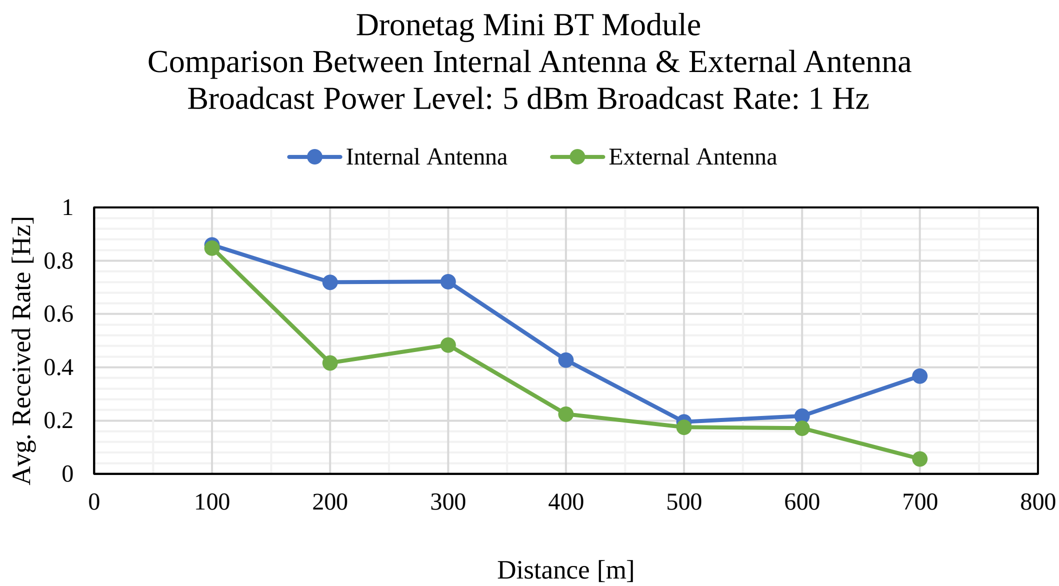

Figure 31. Comparison of Dronetag internal and external antennas for 'low' range testing.

Two range tests were conducted with the external antenna starting at 500m up to the maximum operational range, typically around 1000m. Figure 32 shows a drastic decrease in received rate at the low range location of 500m. Over the course of an entire minute the 900m and 1500m test points only received 2 and 3 messages, respectively. These messages were all dynamic, and none contained identifying information sent with the basic message type.

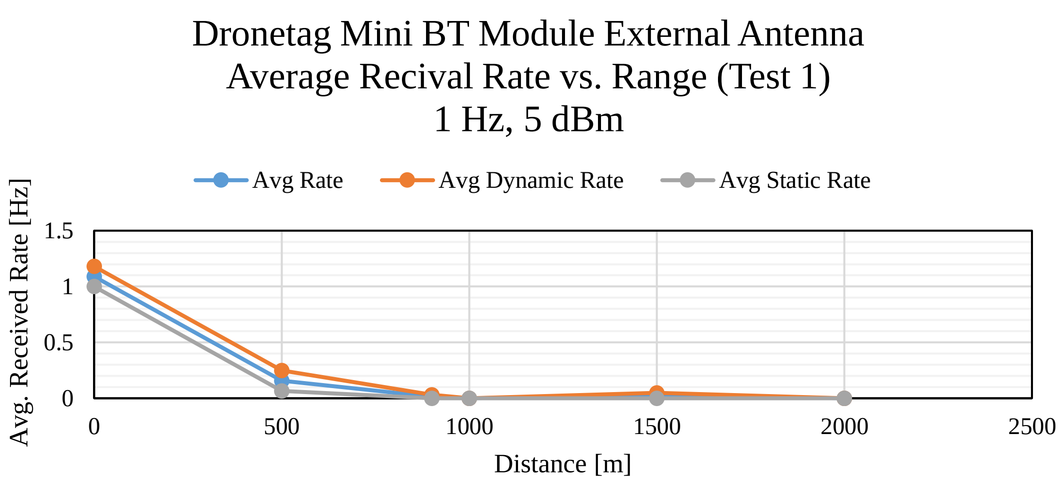

Figure 32. Average receival rate for Range Test 1 with Dronetag external antenna.

Figure 33 displays data from a second range test where data was collected in increments of 100m. The received rate achieved a maximum of only 0.3 Hz at 600m. Due to the low receival rate during testing, the 700m test point had a data collection period of 116 seconds, as opposed to the typical 60 seconds. This was to determine if the system would see an increase in rate with a longer collection time. However, over the period of 116 seconds only 10 messages were received. Additionally, only one message was received over the course of 60 seconds for distances of 1100m and 1500m.

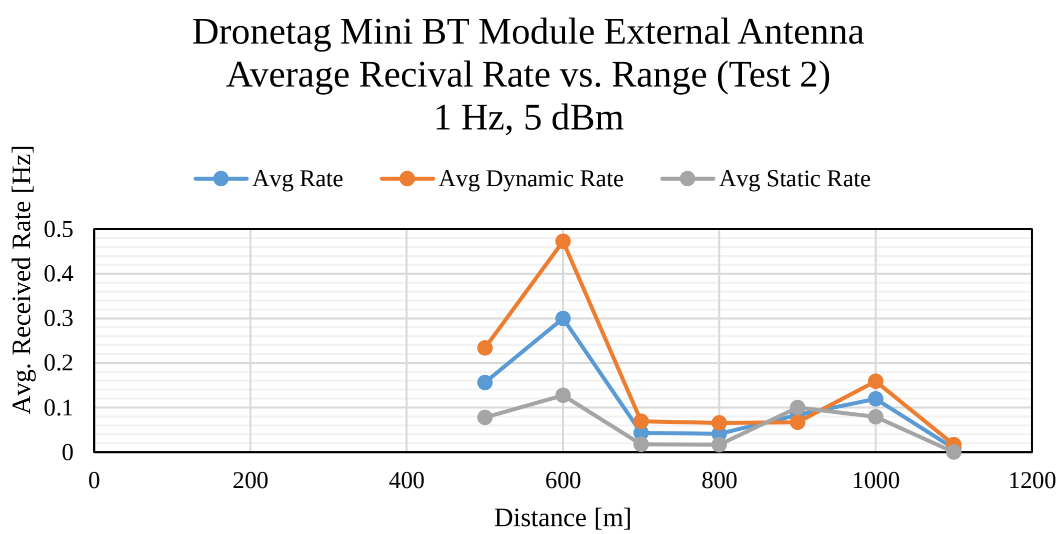

Figure 33. Average receival rate for Range Test 2 with Dronetag external antenna.

As can be seen in Figure 34, the majority of the Dronetag range test points saw transportation of the RID messages with Bluetooth 5.0, with some solely receiving all messages through Bluetooth 5.0.

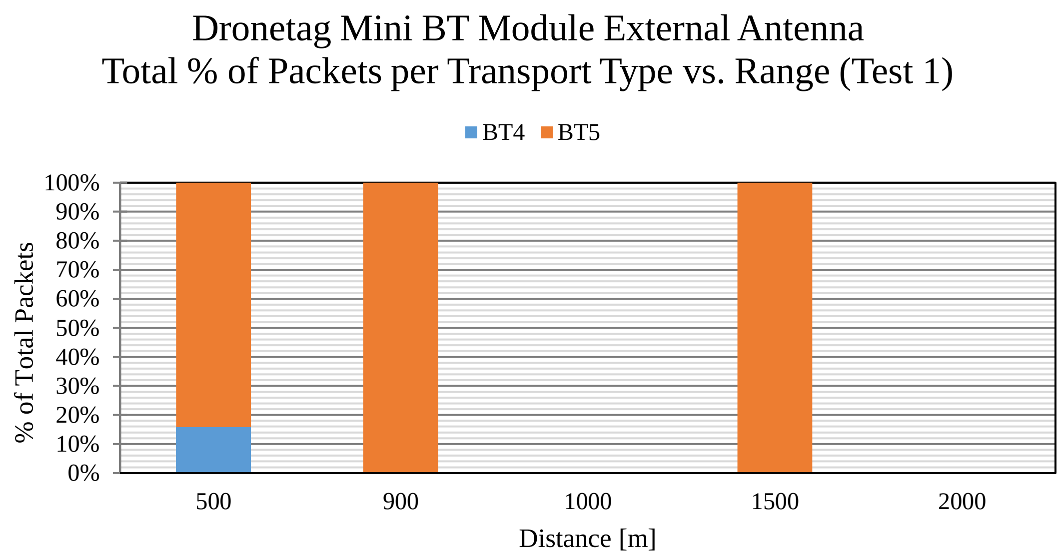

Figure 34. Total percentage of packets per transport type vs. range by Dronetag in Range Test 1.

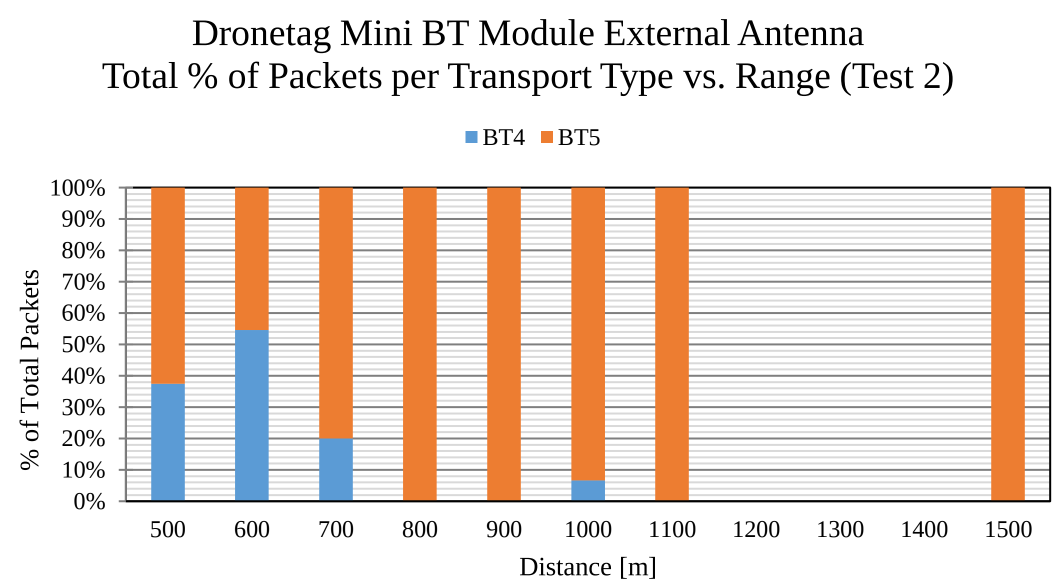

Figure 35. Total percentage of packets per transport type vs. range by Dronetag in Range Test 2.

These tests were repeated with the internal antenna, which showed marginally improved performance, especially in the 800m to 1000m range. However, the received rates were still less than half of the broadcast rate and performed around 0.1 Hz as seen in Figure 36. A similar rise in rate at 600m and then drastic decline at 700m was also observed in this test similar to the performance of the external antenna in the second test.

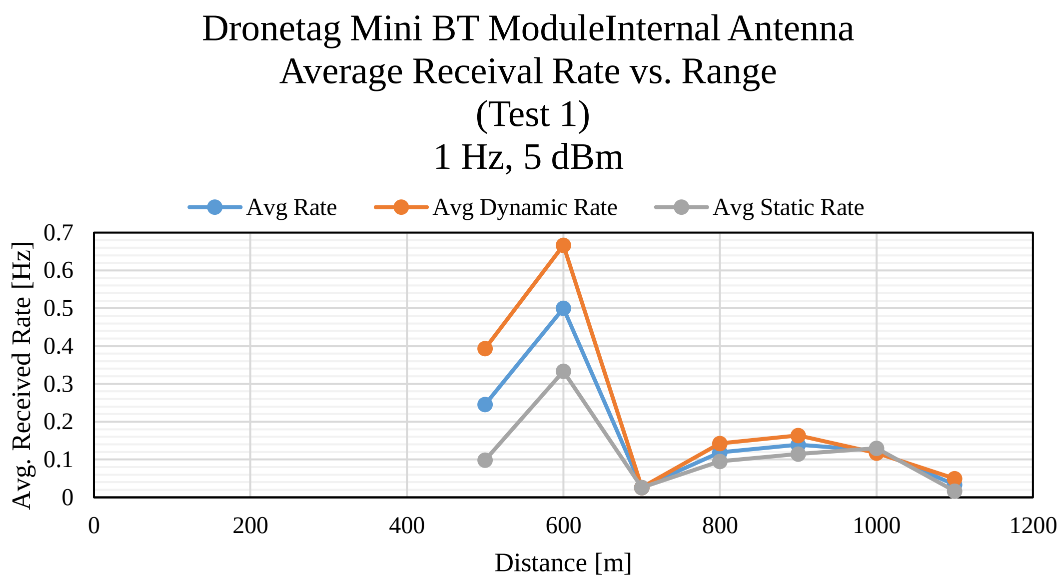

Figure 36. Average receival rate vs. range with Dronetag internal antenna for Range Test 1.

The subsequent internal antenna range test exhibited comparable results to the first test, with a major difference being an improved receival rate at 500m of 0.9 Hz. This contrasts with the other range tests that had decreased rates (less than 0.5 Hz). This dip in performance at 500m relates to findings from the preliminary range test.

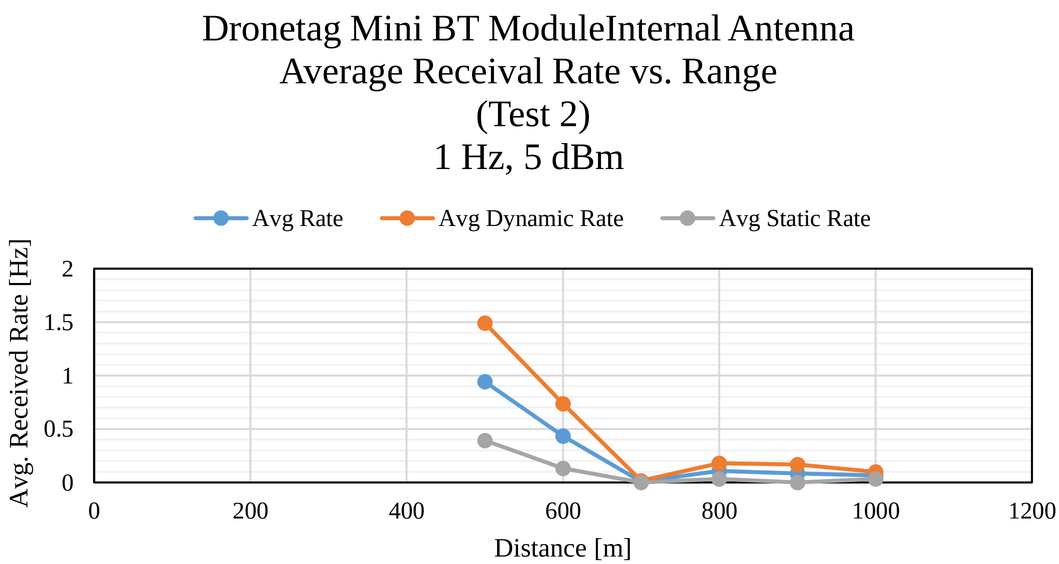

Figure 37. Average receival rate vs. range with Dronetag internal antenna for Range Test 1.

Plotting the average rate of the internal and external antennas across both trials in Figure 38 illustrates the significant difference in performance at 500m but shows nearly identical rates for all other test points.

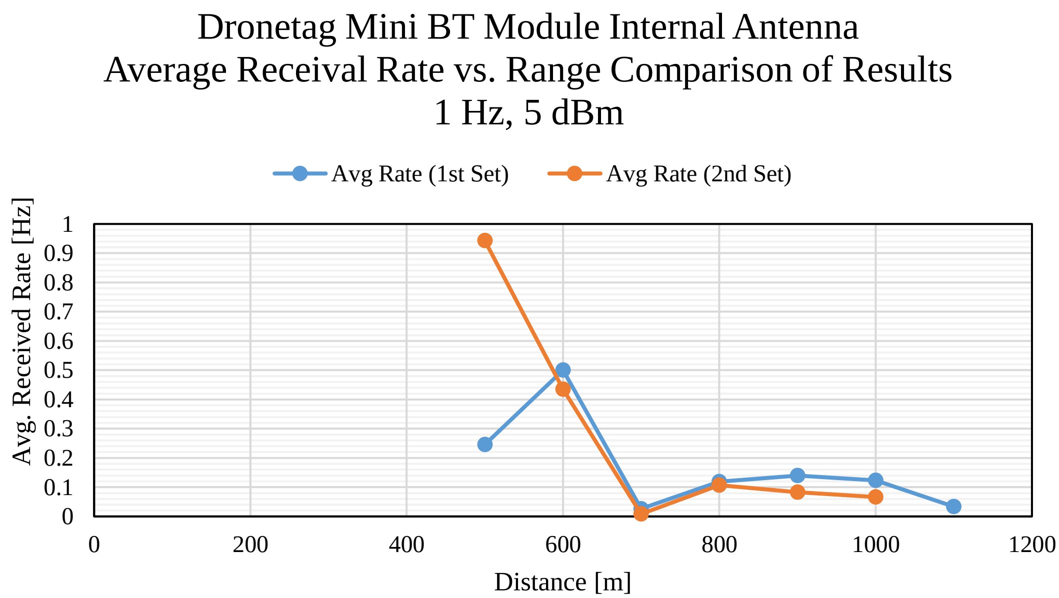

Figure 38. Comparison of average received rate for range tests with internal antenna.

The internal antenna, like the external configuration, received most of its messages through Bluetooth 5.0, especially at ranges above 600m. This is demonstrated in Figures 39 and 40.

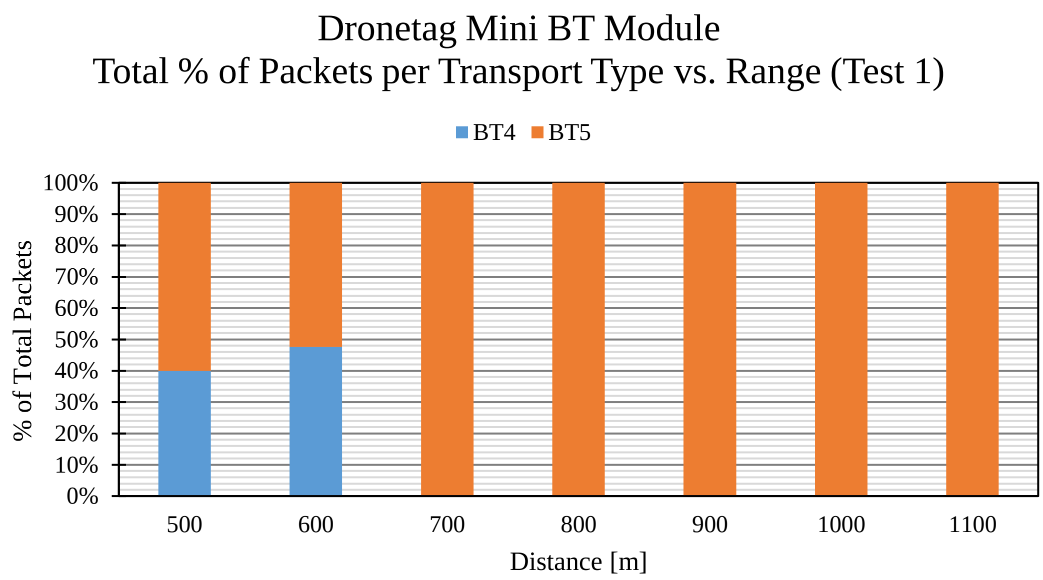

Figure 39. Total percentage of messages per Dronetag transport type vs. range for Range Test 1.

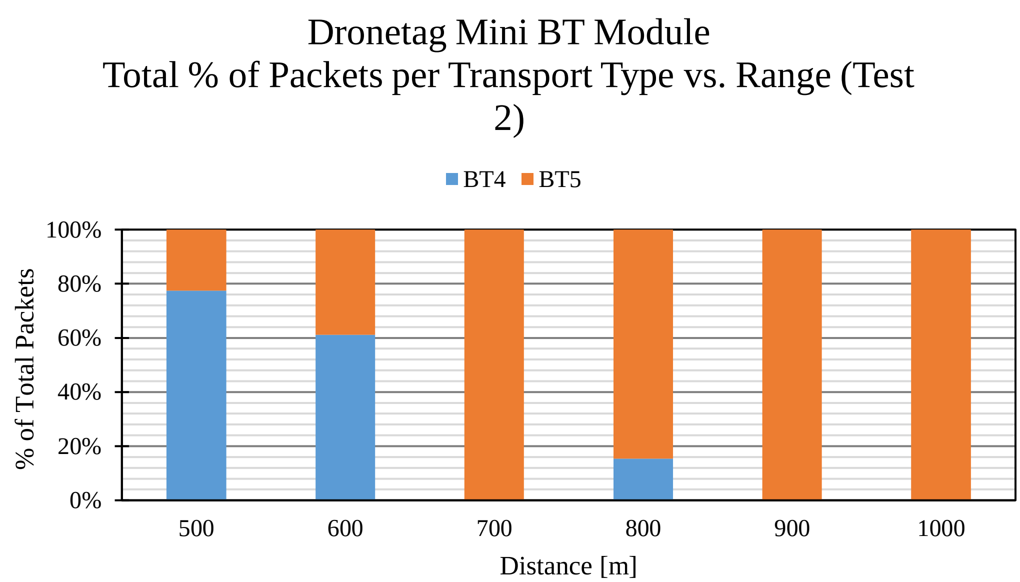

Figure 40. Total percentage of messages per Dronetag transport type vs. range for Range Test 1.

General trends emerged throughout the lower range tests that can be seen in Figure 41, where all data is plotted together. All tests reflected a decline in performance to around 0.2 Hz, with one outlier at 500m. The 700m test point repeatedly showed rates less than 0.1 Hz. Some test points saw a rise in received rates at larger distances. These rates, while improved, were still virtually zero.

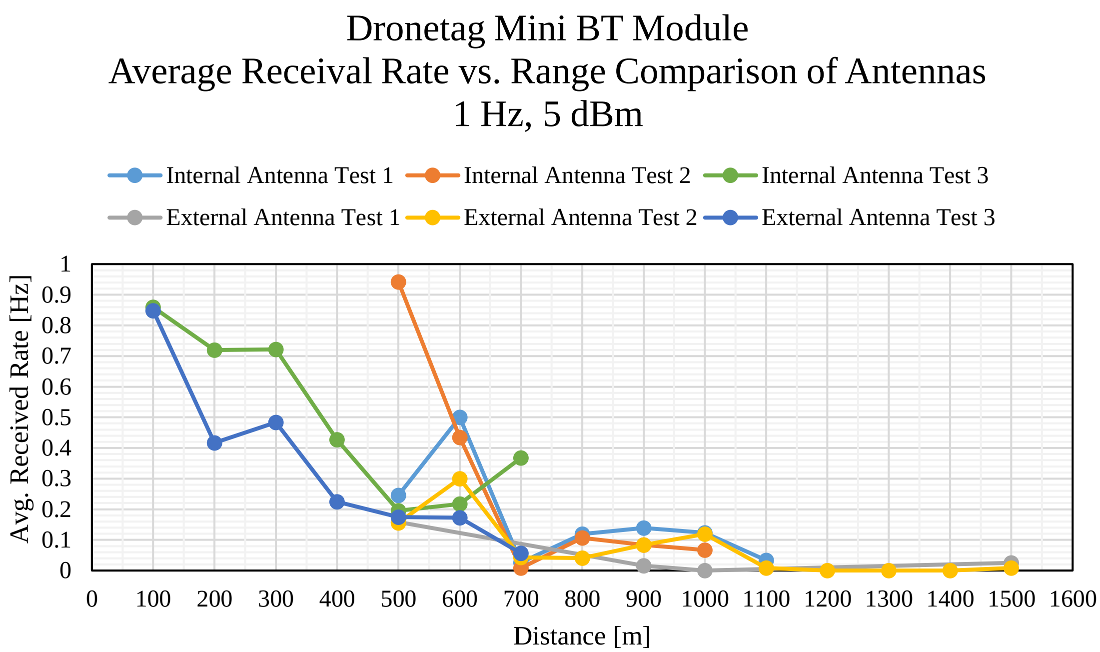

Figure 41. Comparison of range testing data for the Dronetag Mini Bluetooth module.

4.1.2.3 Parrot ANAFI Range Test Results

The ANAFI's 2.4 GHz configuration reached a maximum horizontal distance of 1725m while the 5 GHz configuration only reached 1000m after multiple attempts. This can be seen in Figure 42. The research team initially backed up and collected data at a test point of 850m due to the smartphone not receiving any signal during the first 1000m test point. Eventually the device did connect and provided a receive rate that closely matched the broadcast rate, making the 1000m point the furthest range reached by the device. These results match closely with those from the Vendor 1 Wi-Fi NAN system, with the ANAFI RID outperforming at the 2.4 GHz configuration. When operating at the 2.4 GHz frequency messages can typically travel further. The opposite is true for the 5 GHz frequency where messages may not be sent as far but have better connectivity at lower ranges. This is reflected in the data shown in Figure 42.

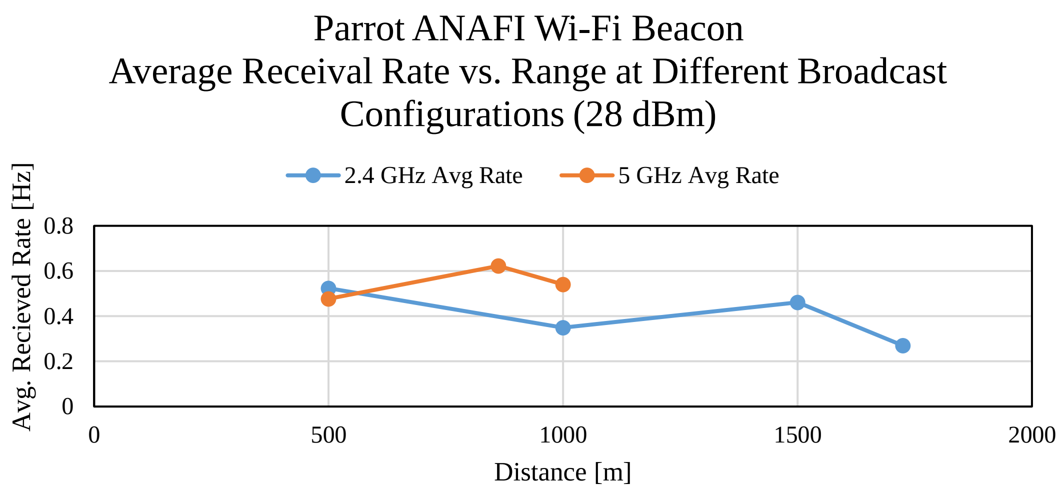

Figure 42. Range test results for the Parrot ANAFI Wi-Fi Beacon system.

4.1.2.4 Aerobits idME Range Test Results

The Aerobits idME module's configurable broadcast rate was set to send both a dynamic and static rate of a message once per second. The received rate trended downwards as the horizontal distance increased, reaching its lowest rate of 0.1 Hz at a range of 2400m. The Bluetooth module experienced similar decreases in received rate at 500m and 700m, although not as severe. Overall, the idME outperformed the Dronetag, with higher average receival rates and longer ranges.

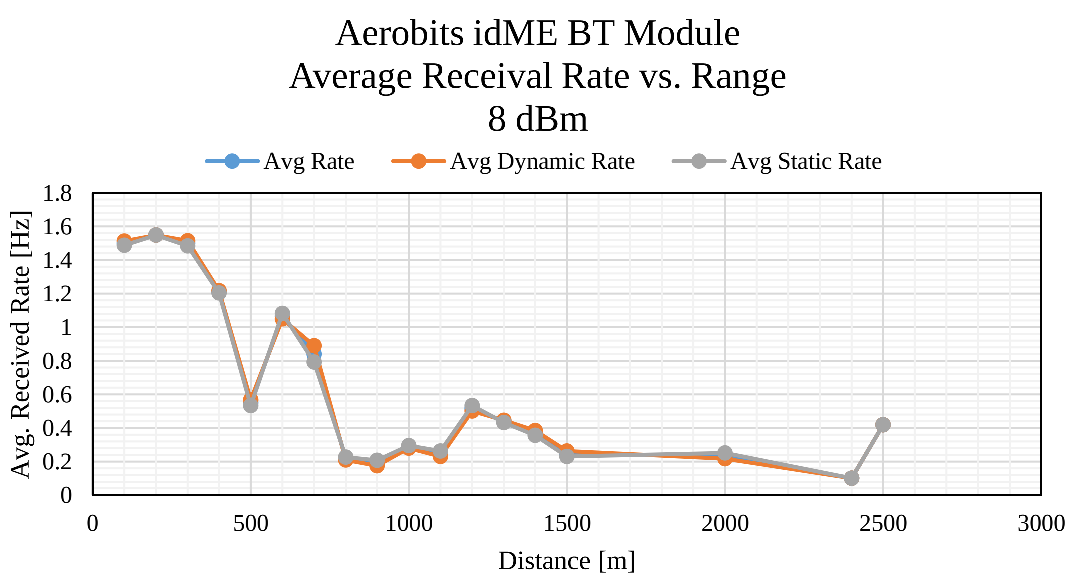

Figure 43. Average received rate for the Aerobits idME vs. range.

Figure 43 illustrates that some of the received rates are higher than 1 Hz even though 1 Hz was the set broadcast rate. This is due to the module sending two messages per a second for some messages, which can be seen in the example test data in Figure 44. Over the course of a second there were two static messages sent, shown in blue, and two dynamic messages sent, shown in orange.

timestamp	seconds	transportT	rssi	idType	uaType	uasId	status	heightType	EWDirecti	speedMult	direction
1.8E+15	1796791.59	BT4	-86	1	0	26-0000097					
1.8E+15	1796791.59	BT4	-88				0	0	1	1	181
1.8E+15	1796791.59	BT4	-88								
1.8E+15	1796791.6	BT4	-86								
1.8E+15	1796791.6	BT4	-87								
1.8E+15	1796791.64	BT5	-97	1	0	26-000009	0	0	1	1	181

Figure 44. Example of two messages being sent within a single second.

4.2 Directionality Test Results

The initial directionality test performed at ground level, shown in Figure 45, showed no discernable performance differences in the orientations of the Dronetag Mini when using its external antenna. The drone and module facing away from the receiver is the 0° test point, 90° is to the right, 180° towards the receiver, and 270° to the left of the receiver. The internal antenna shows a slight increase in its received rate at 90° and 180° and a decrease at 270°. These differences in performance were largely unnoticeable during testing as the rate only fluctuates ±0.2 Hz.

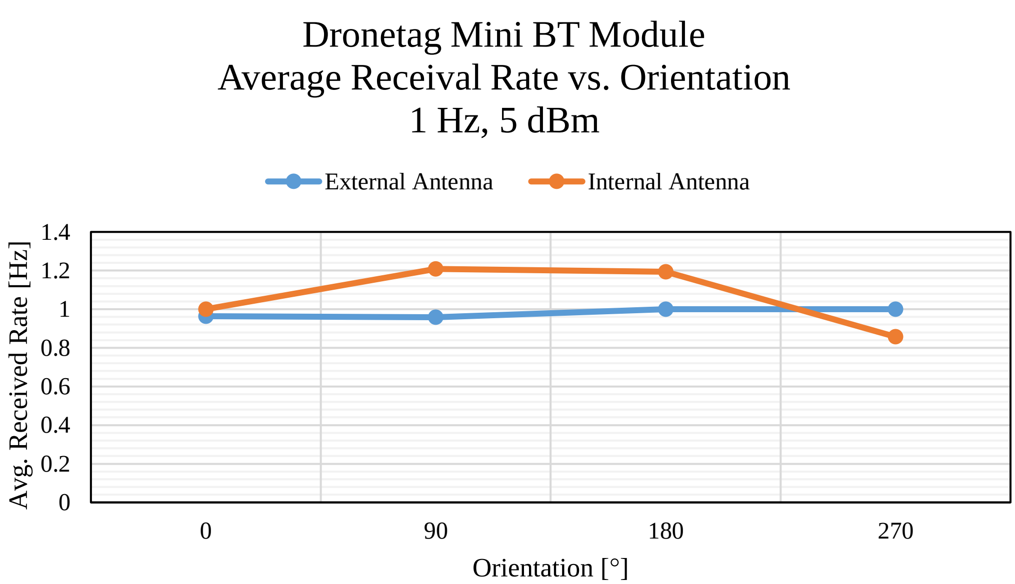

Figure 45. Average receival rate at different orientations for the Dronetag Mini.

Figures 46 and 47 show data from a similar directionality test; however, the aircraft was located at an altitude of 300ft to match the standard altitude used for all range testing in the research effort. In comparing the two figures, the performance does not appear to change drastically between the two distances. However, there are noticeable performance differences in the internal and external antennas. The internal antenna had a higher received rate than the external antenna at the 500m test point. At 700m, the external antenna had a higher received rate in every orientation except for the 0° test point.

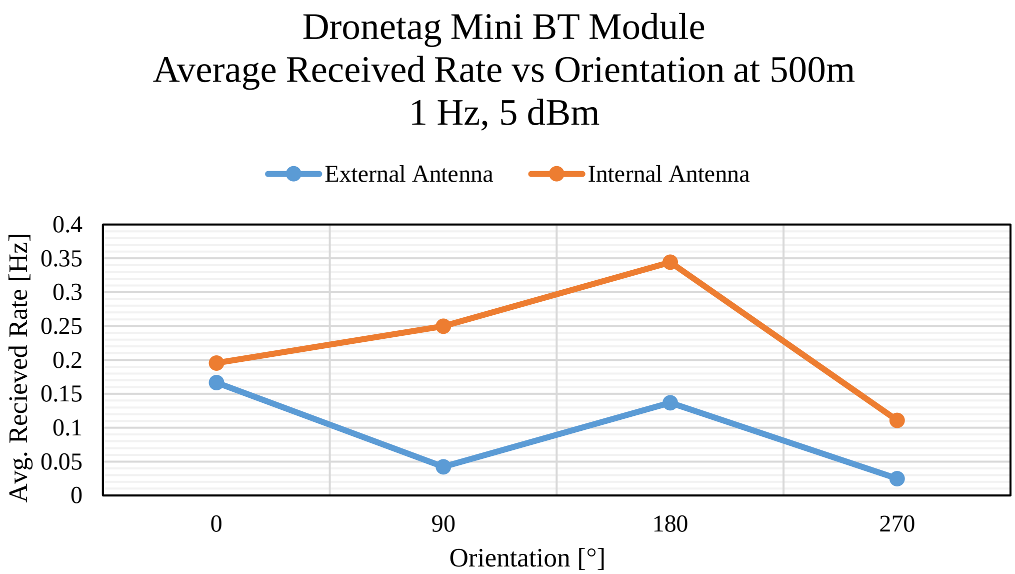

Figure 46. Average received rate from the Dronetag at 500m.

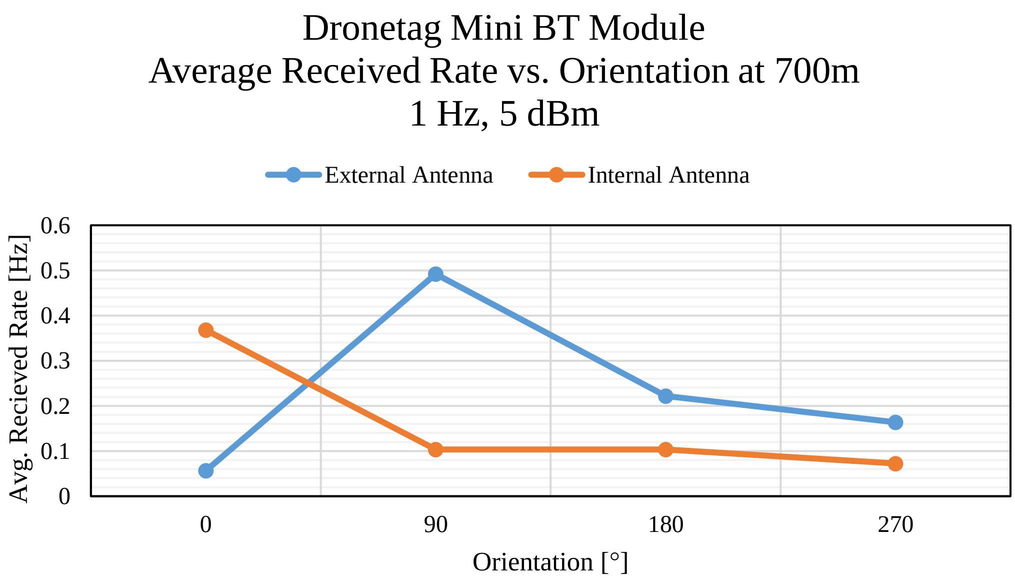

Figure 47. Average received rate from the Dronetag at 700m.

Overall, there does not seem to be a significant correlation between the orientation of the device relative to the receiver and performance. Both antennas had reduced reception rates in the orientation tests than the broadcast rate of 1 Hz. It is concluded by the research team that this could be due to the distance between the receiver and transmitter, and this behavior is similar to previous range test results.

4.3 Ground Encounters Test Results

Encounters testing between a crewed aircraft and either the Dronetag Mini Bluetooth module or Parrot ANAFI Wi-Fi Beacon system revealed decreased performance as compared to other range tests. The receiver was placed within the closed cockpit of the Grumman Tiger and the OpenDroneID application open for the full minute it would take the UAS to maneuver from one end of the flight path to the other. The crewed aircraft faced south, meaning that the west path was to the right of the aircraft and researcher and the east path was to the left. The maximum range allowable during testing was 193m, which has been shown in previous testing to be well within the operational bounds of both devices. Typical average received rates at 200m were above 0.4 Hz, but in encounters testing this value was the maximum rate for the Dronetag, occurring on the west path. The Parrot ANAFI exhibited additionally decreased performance, with its received rate being virtually zero. This received rate is significantly lower than what was observed in vertical testing and range testing for the device. The Dronetag Mini saw a decline in average received rates on the east path, likely due to obstruction from buildings in the area, although the aircraft was always in line of sight of the research team.

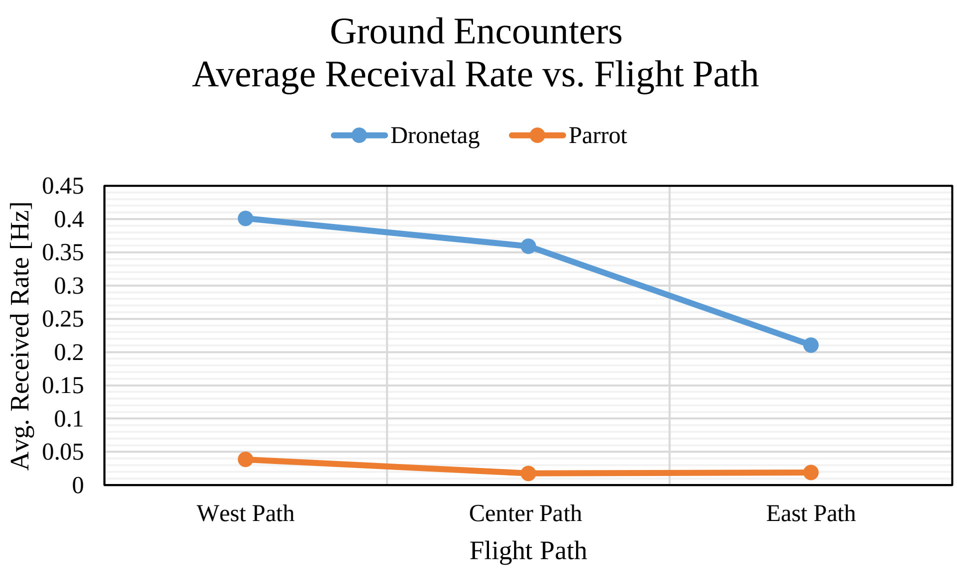

Figure 48. Average receival rate during ground encounters.

It should be noted that the values represented in Figure 48 are averages of the received rates for all passes the UAS made. The average rates for each path can be found in Tables 17 through 19.

Table 17. Average receival rates for each pass made by UAS on center path.

Dronetag Mini		Parrot ANAFI	
Pass #	Average Receival Rate (Hz)	Pass #	Average Receival Rate (Hz)
Center Pass 1	0.5	Center Pass 1	0.14
Center Pass 2	0.46	Center Pass 2	0
Center Pass 3	0.47	Center Pass 3	0
Center Pass 4	0.25	Center Pass 4	0.02
Center Pass 5	0.34	Center Pass 5	0
Center Pass 6	0.23	Center Pass 6	0
Center Pass 7	0.3	Center Pass 7	0
Center Pass 8	0.2	Center Pass 8	0
Center Pass 9	0.27	Center Pass 9	0.01
Center Pass 10	0.83	Center Pass 10	0.008

Table 18. Average receival rates for each pass made by UAS on east path.

Dronetag Mini		Parrot ANAFI	
Pass #	Average Receival Rate (Hz)	Pass #	Average Receival Rate (Hz)
East Pass 1	0.2	East Pass 1	0.012
East Pass 2	0.13	East Pass 2	0
East Pass 3	0.22	East Pass 3	0.025
East Pass 4	0.18	East Pass 4	0.03
East Pass 5	0.17	East Pass 5	0.02
East Pass 6	0.11	East Pass 6	0
East Pass 7	0.16	East Pass 7	0.02
East Pass 8	0.18	East Pass 8	0.03
East Pass 9	0.14	East Pass 9	-
East Pass 10	0.75	East Pass 10	-

Table 19. Average receival rates for each pass made by UAS on west flight path.

Dronetag Mini		Parrot ANAFI	
Pass #	Average Receival Rate (Hz)	Pass #	Average Receival Rate (Hz)
West Pass 1	0.52	West Pass 1	0
West Pass 2	0.35	West Pass 2	0
West Pass 3	0.59	West Pass 3	0.07
West Pass 4	0.13	West Pass 4	0.05
West Pass 5	0.36	West Pass 5	0.03
West Pass 6	0.32	West Pass 6	0.04
West Pass 7	0.19	West Pass 7	0.04
West Pass 8	0.76	West Pass 8	0.025
West Pass 9	-	West Pass 9	0.008
West Pass 10	-	West Pass 10	0.06

The Parrot ANAFI struggled to receive any messages throughout the ground encounters testing, reaching a maximum of only 5 messages received across all test points. Figure 49 shows the stark contrast in the average number of messages received from each RID device for each path.

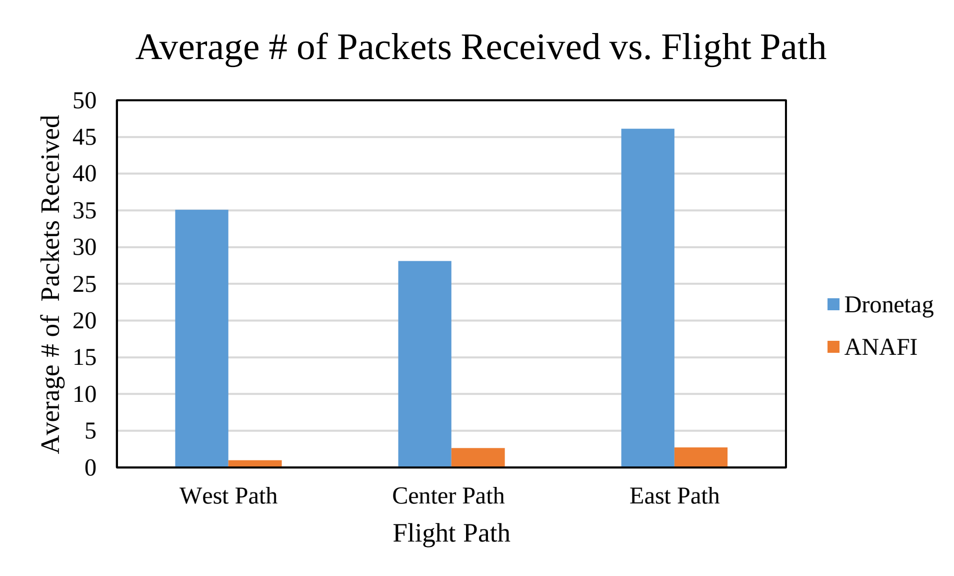

Figure 49. Average number of packets received by Dronetag and Parrot by path during ground encounters.

Figures 50 through 52 show the number of messages received from the Dronetag Mini BT module during each individual pass. Likewise, figures 53 through 55 show the Wi-Fi Beacon systems results. The results are rather consistent with the only anomaly occurring on the aforementioned east path where on the last pass there was a spike in the number of received messages. The first 9 passes on this path were at or below 20 packets received with the tenth pass receiving 150 packets. This is much higher than any other test point with the second highest pass having only 68 packets received in comparison.

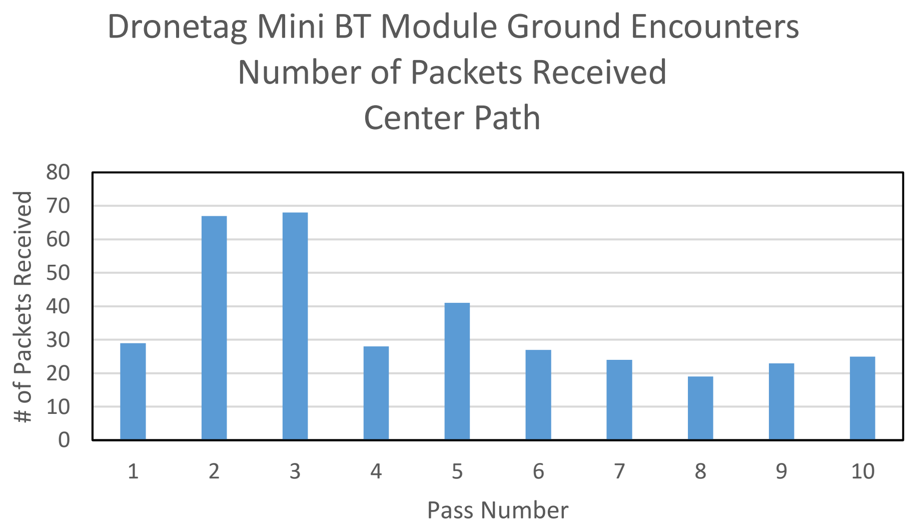

Figure 50. The number of packets received from the Dronetag Mini for each center pass made by the UAS.

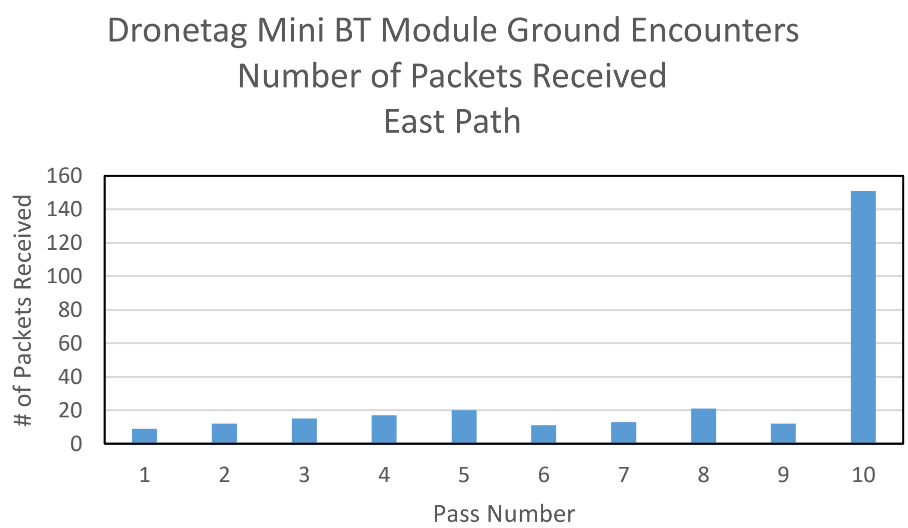

Figure 51. The number of packets received from the Dronetag Mini for each east pass made by the UAS.

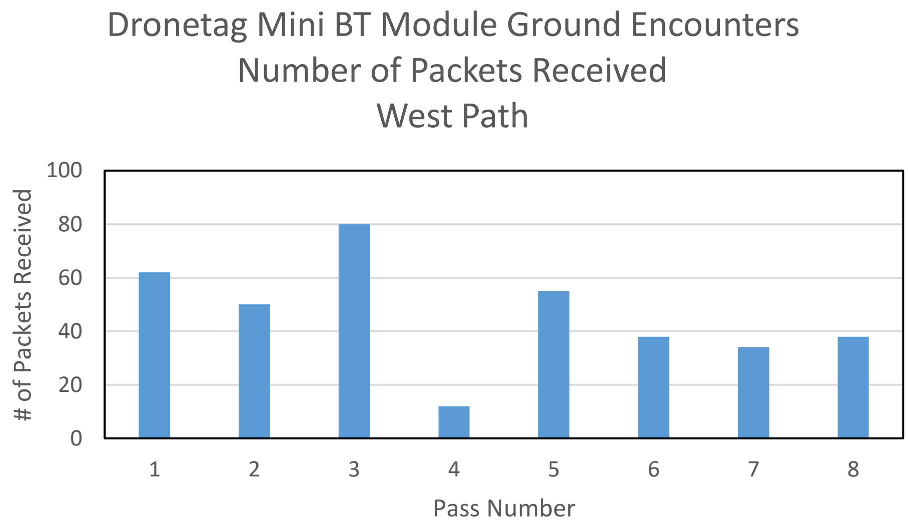

Figure 52. The number of packets received from the Dronetag Mini for each west pass made by the UAS.

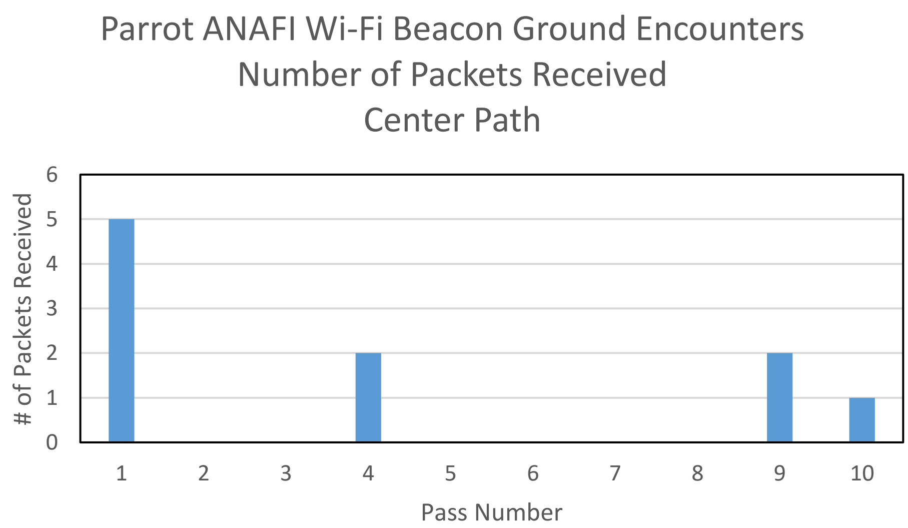

Figure 53. The number of packets received from the Parrot ANAFI for each center pass made by the UAS.

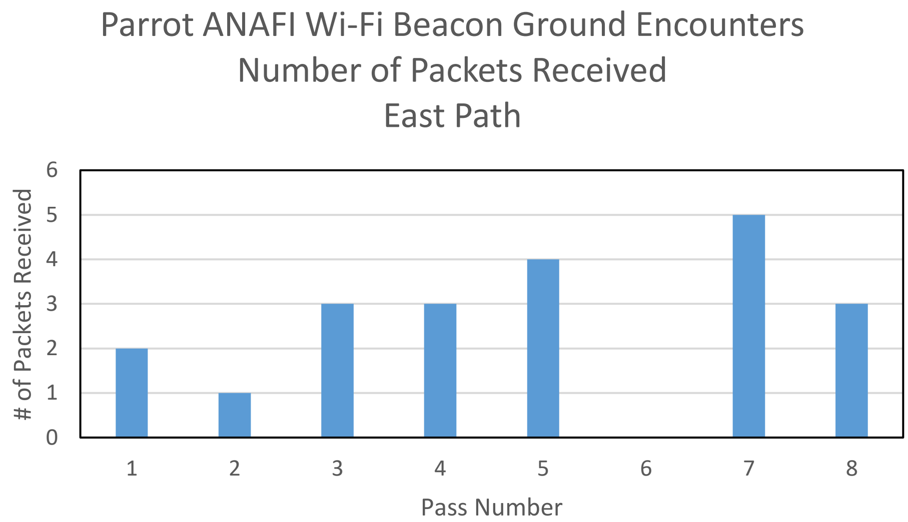

Figure 54. The number of packets received from the Parrot ANAFI for each east pass made by the UAS.

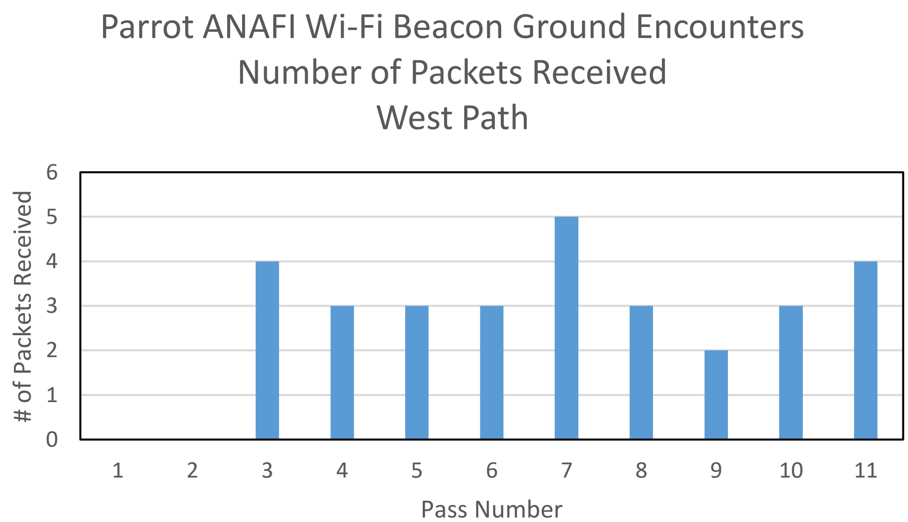

Figure 55. The number of packets received from the Parrot ANAFI for each west pass made by the UAS.

4.4 Air Encounters Test Results

The air encounters testing saw further diminished performance compared to all other tests ,with both devices struggling to send packets over the 90 second test period. Contrary to most other tests, no messages were received by the Parrot ANAFI throughout the entirety of the test. Figures ## through ## show the number of packets received from the Dronetag Mini BT module during each pass made by the crewed aircraft.

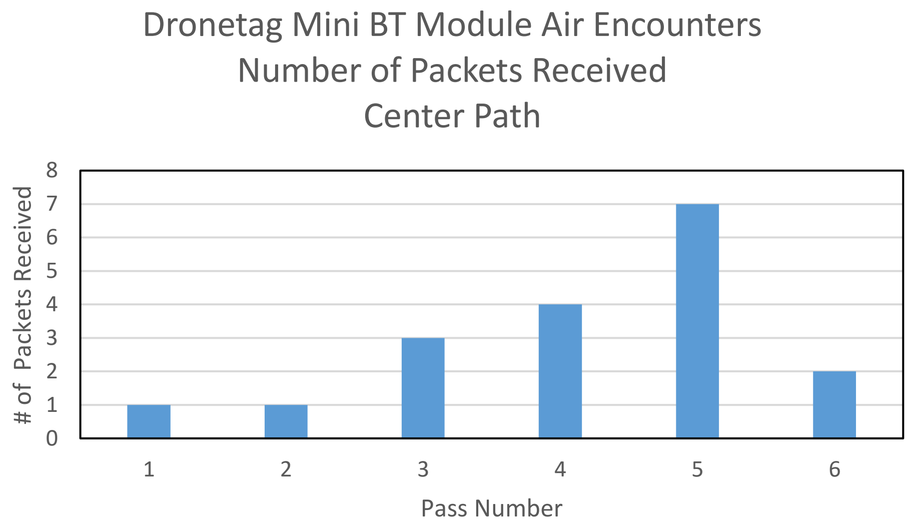

Figure 56. The number of packets received from the Dronetag Mini BT module for each center pass made by the crewed aircraft.

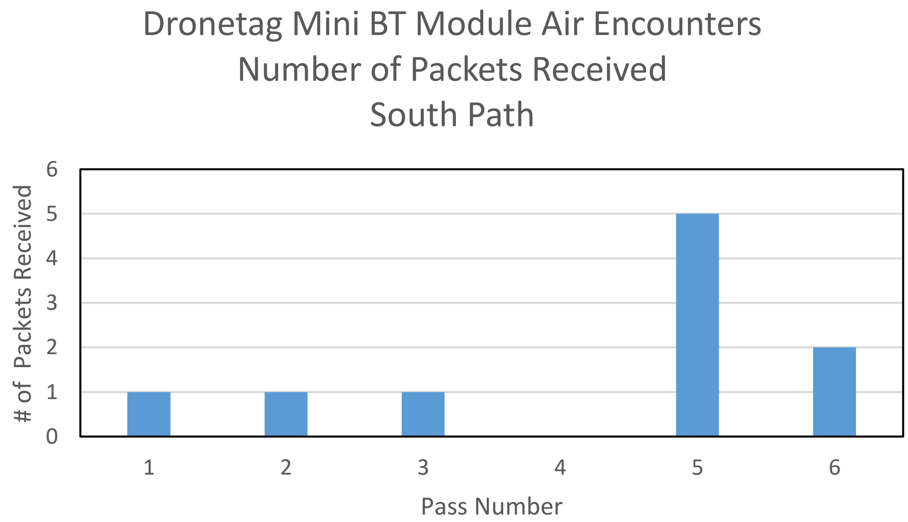

Figure 57. The number of packets received from the Dronetag Mini BT module for each south pass made by the crewed aircraft.

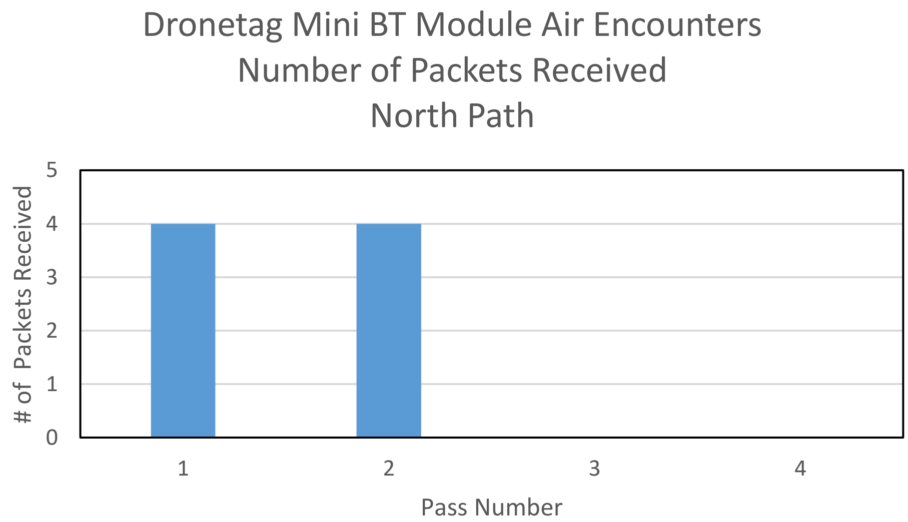

Figure 58. The number of packets received from the Dronetag Mini BT module for each north pass made by the crewed aircraft.

The Dronetag's received rates were also extremely low, only reaching 0.016 Hz at its highest as shown in Figure 59.

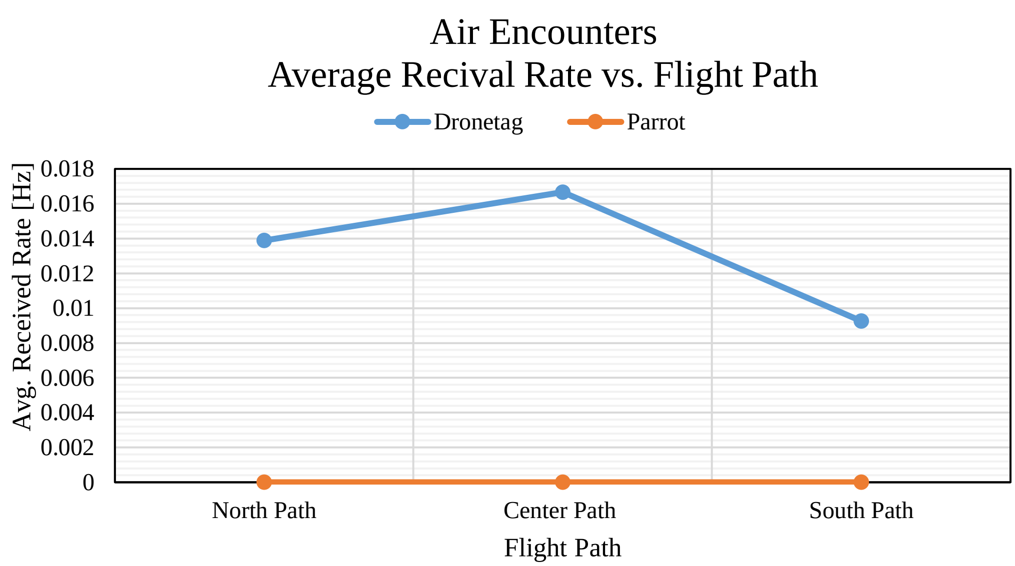

Figure 59. Comparison of average receival rates for Dronetag and Parrot during air encounters.

The small number of messages received from the Dronetag were transmitted predominantly through Bluetooth 5.0. This is expected due considering the decreased performance and difficulty receiving any messages from the device.

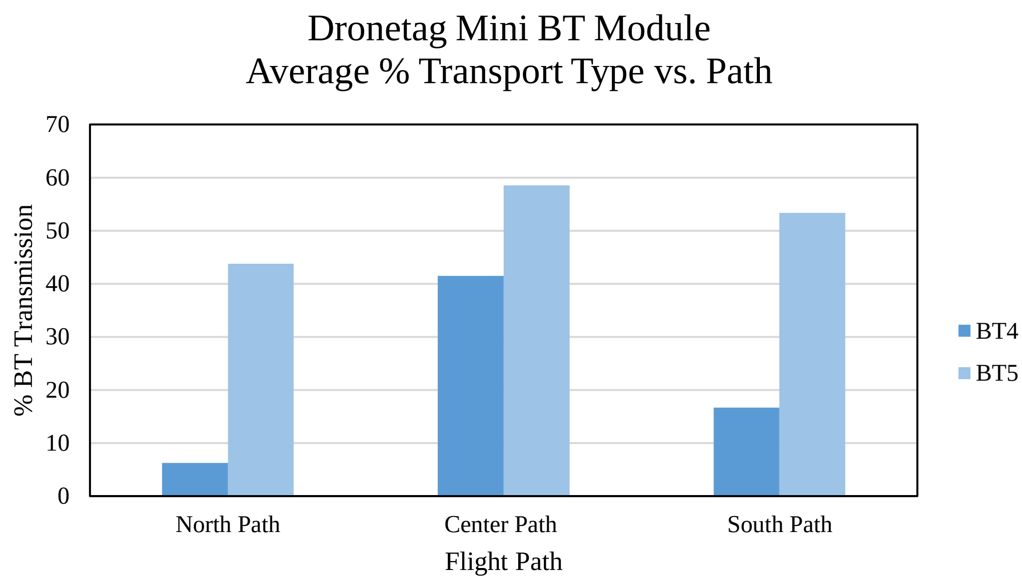

Figure 60. Average percentage of Bluetooth type transmission by Dronetag module vs. flight path.

The research team predicted that both devices would struggle in the air encounters test after examination of ground test results. This led to the team designing flight passes with lower speeds and altitudes to aid in data collection if the devices did struggle. The received rates remained low enough to be considered ineffective or useless messages, especially in the scenario of crewed encounters where pilots would have heightened workload in the cockpit by checking for RID packets. Another performance weakness in the devices was the time taken to establish the initial connection between the devices and receiver. In the encounter testing it was typical for the device to take up to 10 seconds before the RID device would appear on the Open Drone ID application, even for test points that had higher received rates or were at shorter ranges. When considering the practical application of a crewed aircraft and UAS encounter, this short amount of time could lead to the receiver entering and exiting the range of the transmitter before there is a chance for any messages to be sent. The research team analyzed the location data for the air encounters testing and determined the orientation of the UAS in relation to the crewed aircraft for each packet sent and received. A direction classification of either SE or NW was designated to each packet to associate the packets with an "approaching" or "departing" flight pattern. This aided the analysis in terms of understanding the probability of receiving useful packet information upon approach of an encounter. Due to the severity of the performance decline in the air encounters testing, the probability of receiving a packet upon approach of a crewed aircraft was virtually zero across all passes.

4.5 RF Environment Test Results

Most of the testing for the A40 research effort was performed in rural environments where the RF noise floor was between -110 dBm and -100 dBm. Suburban and urban environments typically range from -100 dBm to -90 dBm and -90 dBm to -80 dBm, respectively. The RF environment test aimed to acquire results in an environment with a different noise floor than the majority of tests conducted. As mentioned in the test procedures section, RF measurements were taken, and tests were conducted at three separate times throughout an evening with increasing population. These three test time environments were referred to as low, medium, and high noise environments for simplicity. The researchers hypothesized that the noise floor would increase with each test time, though the RF noise floors do not necessarily follow this progression. Figures 61 through 63 show the readings collected by the SignalVu-PC software and corresponding RF reader and illustrate the RF noise floor measurements at each test time. The Bluetooth advertisement channels 37 (2402 MHz), 38 (2426 MHz), and 39 (2480MHz) have been highlighted. These are the channels that RID messages are sent and received on. Figure 61 shows the 'low' noise environment, which averaged around -110 dBm.

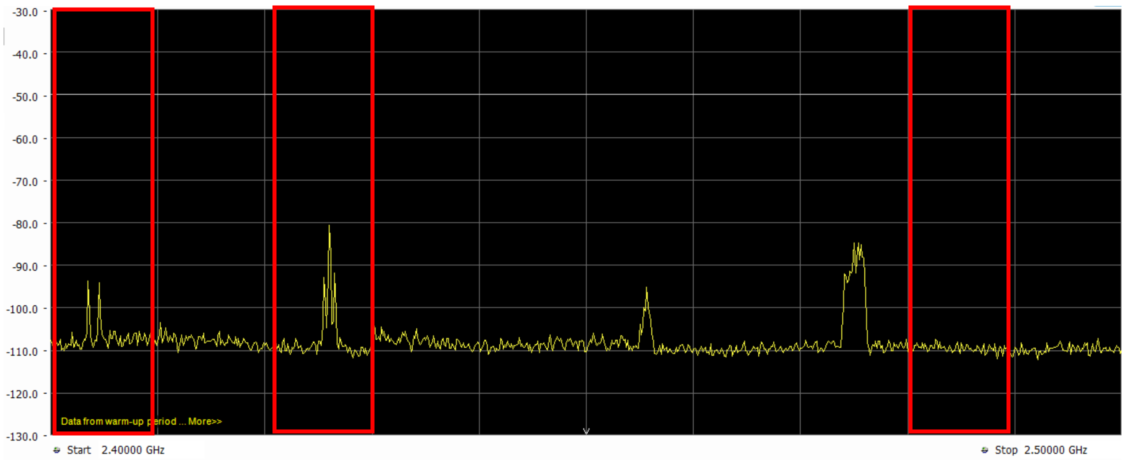

Figure 61. RF noise floor for a 'low' noise environment.

Figure 62 shows the 'medium' RF noise measurement, which ranged from around -100 dBm to -90 dBm.

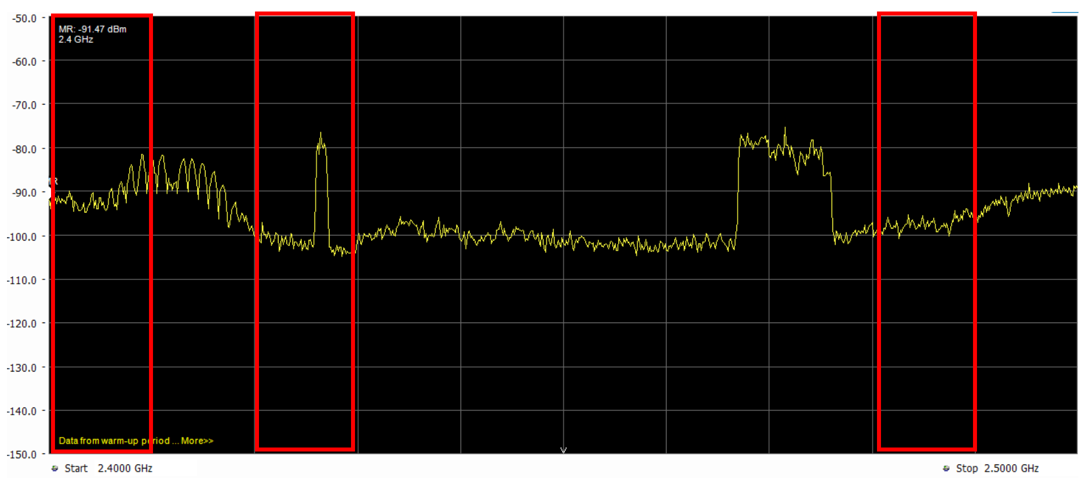

Figure 62. RF noise floor for a 'medium' noise environment.

The 'high' noise measurement, shown in Figure 63, averaged around -100 dBm, reaching -70 dBm at its highest.

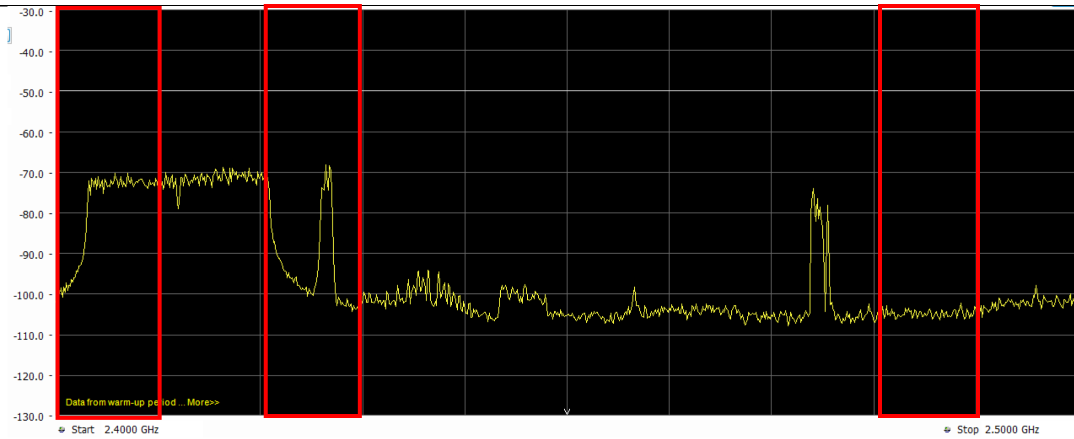

Figure 63. RF noise floor for a 'high' noise environment.

Data was collected at three different distances for each test window with varying amounts of obstacles between the receiver and RID transmitter. For example, the test point at a horizontal distance of 100m was within line of sight to the receiver while the 300m point had multiple buildings between the receiver and transmitter and no line of sight from the receiver's location even at a height of 300ft. However, as shown in Figure 64, the 300m test point consistently received a higher number of packets from the RID device when compared to the lower distance of 100m.

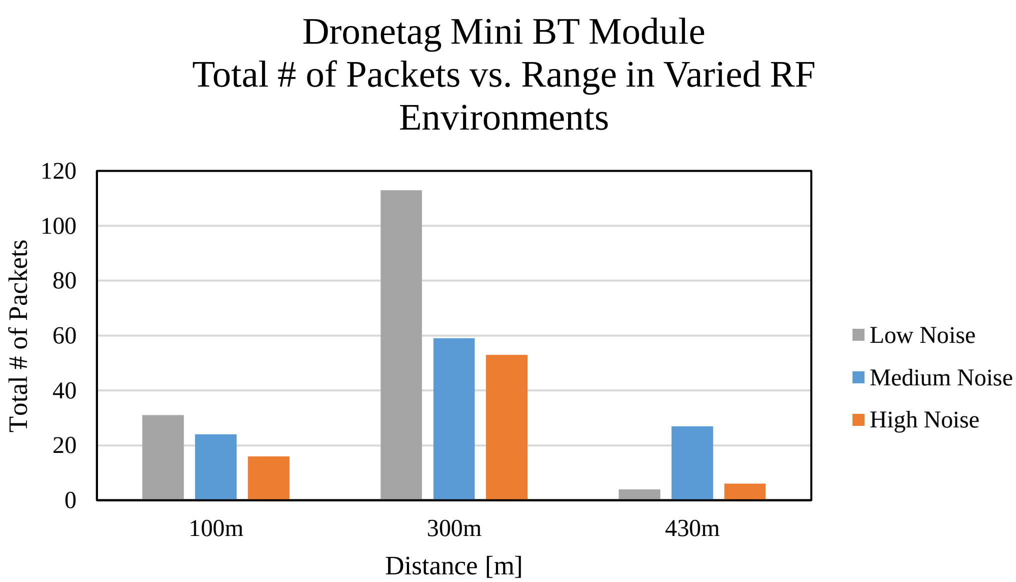

Figure 64. Total number of packets received by Dronetag module in varied RF environments.

The 'low' noise environment exhibited the highest received rates for the 100m and 300m test points but decreased to virtually zero at 430m.

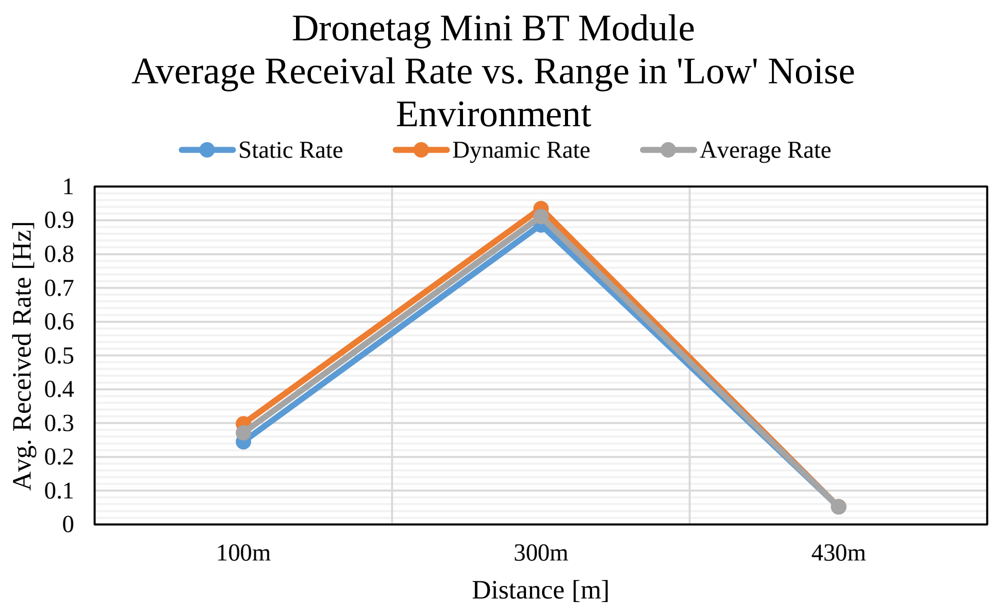

Figure 65. Average receival rate of Dronetag module vs. range in a ‘low’ noise environment.

As the RF environment worsened, the received rate started to decrease. The 300m test point still exhibited the highest rate, shown in Figure 66.

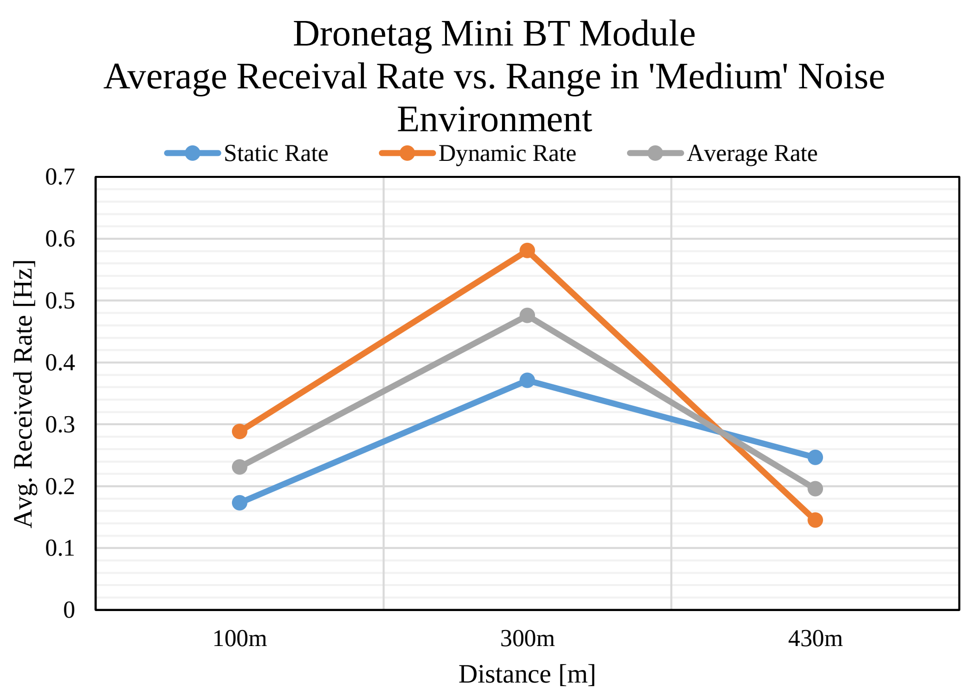

Figure 66. Average receival rate of Dronetag module vs. range in a ‘medium’ noise environment.

The poorest RF noise environment coincided with the lowest received rates, only reaching 0.4 Hz at its highest. The static rate also increased at the 430m test point to 0.35 Hz while the dynamic rate dropped to 0.06 Hz.

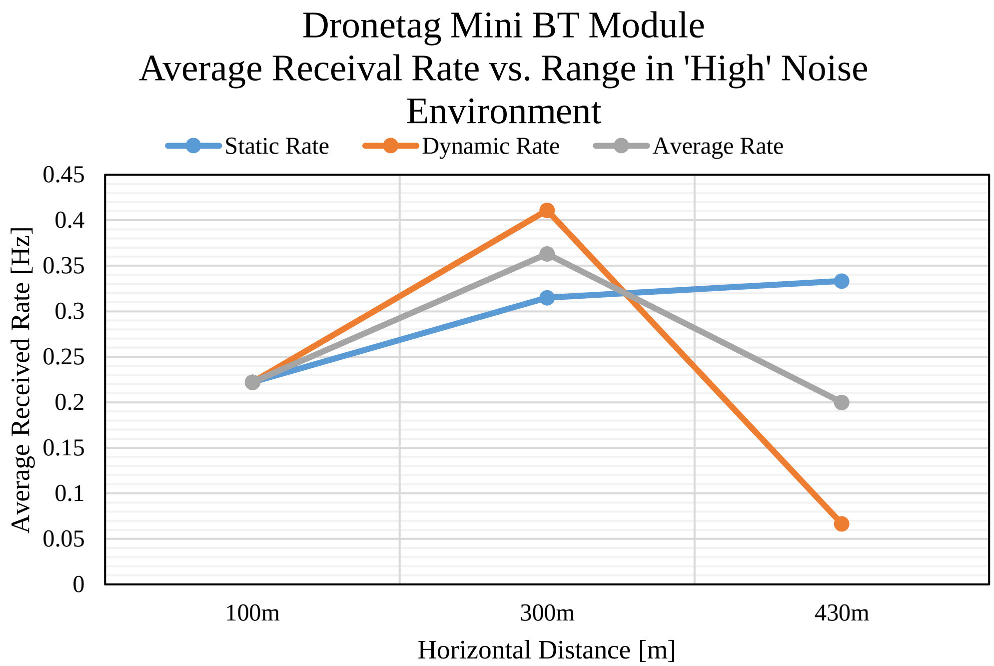

Figure 67. Average receival rate of Dronetag module vs. range in a ‘high’ noise environment.

Figure 68 compares the average rates and displays that these values were not significantly different from each other. An outlier for this test can be seen at the 300m test point in the ‘low’ noise environment.

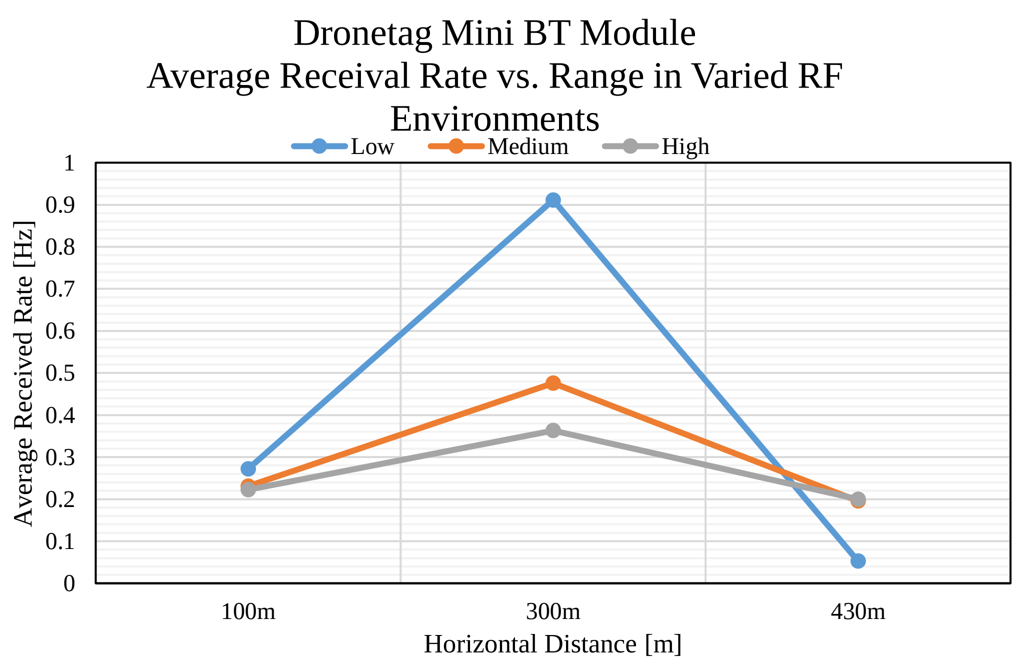

Figure 68. Average receival rate of Dronetag module vs. range in varied RF environments.

Overall, these results were similar to those observed in the range testing of the Dronetag with the internal and external antenna, with slightly decreased performance at 430m.

5 LESSONS LEARNED

The test methods and device performance in the A40 research project provided a variety of lessons learned for RID performance research. One significant lesson is that of the test environment. As seen in multiple tests conducted in the A40 research effort, the testing environment may have impacted the RID systems, whether that was due to RF interference, physical interference from surrounding obstructions, or other factors. To further understand the impacts and implications of test environments on RID systems, the A40 research performers suggest testing in a variety of environments to better understand the interaction between these systems and their environments, and whether there are significant performance trends based on the test area. Though the test environments in this research effort did vary, the locations were still considered rural. Testing in a more urban environment would provide increased understanding of RID performance in relation to environment. Another consideration for the testing of RID systems includes the amount of data collected. Though a significant amount of data was acquired throughout the entirety of the project, adding test points in smaller vertical and horizontal increments, repeating test procedures multiple times, and acquiring data from additional test methods would further clarify the trends, or lack thereof, in performance of RID systems. A higher volume of repeated data could, for example, provide more clarity as to why the RID systems saw a different in performance at the 500m and 700m horizontal test points. The number of devices tested in RID research is also a significant lesson learned, as each device had different specifications based on different performance standards, and different RID protocol types performed differently than their counterparts. Assessing a higher number of Bluetooth RID devices as well as different Wi-Fi systems would provide more context to how each system performs in comparison to other devices running the same protocol. This would also provide more insight as to how Bluetooth and Wi-Fi systems perform in comparison to each other. The basis of the testing for the devices in the A40 research effort was set by the minimum broadcast and power levels detailed in the ASTM RID standard, indicating that operation above the minimum standard could result in improved device performance. Additional testing at higher broadcast and power levels is recommended to determine if RID system performance improves.

6 CONCLUSIONS AND NEXT STEPS

Testing at the minimum allowed by the ASTM standard shows worst case results, however, the RID systems worked well enough to be useful in some real-world scenarios. The received rates within 700m were consistently high enough to be relied upon and in certain instances even distances above 1000m had well enough performance to be considered passable. The testing in this research effort has shown that remote ID has potential to be part of technologies moving forward, but many implementations of it will have to occur with configurations much higher than the minimum.

Though this project focused on obtaining an idea of the baseline performance of different RID systems, there are many considerations for future RID research on RID systems themselves, as well as their integration into more complex systems. A future ASSURE project aims to assess the use of RID devices as a part of detect-and-avoid systems. Further testing of the different communication protocols as well as altering broadcast rates and power levels above the minimum would allow for a better understanding of how the RID devices perform in different scenarios. For example, the encounter testing could be further improved by raising the broadcast rate and/or power level to find the minimum that would be needed to receive the RID messages while in the aircraft. Additionally, the introduction of antennas on the receiver side could result in increased ranges for the RID devices. The use of external antennas for receivers could also provide interesting results that could improve the findings in the ground and air encounters.

7 APPENDIX

A40 – Validation of ASTM Remote Identification Standards

Preliminary Range Testing

Flight Test Report

MISSISSIPPI STATE UNIVERSITY

RASPET FLIGHT RESEARCH LABORATORY

01 April 2021

Table of Contents

Revision number	Edition date	Reason for change	Pages/Sections Affected
REV-A40-001	04/01/2021	Initial Draft	All
REV-A40-002	07/20/2021	Final Draft	All

1 INTRODUCTION

The objective of the overall A40 - Validation of ASTM Remote Identification Standards project is to operationally validate that the American Society for Testing and Materials International (ASTM) Remote Identification (Remote ID, or RID) Broadcast standards satisfy stakeholder needs. As defined by the FAA's final ruling on RID, "remote Identification is the capability of an unmanned aircraft in flight to provide certain identification, location, and performance information that people on the ground and other airspace users can receive." This research will provide data artifacts that are needed to enable the FAA's acceptance of ASTM Remote ID and ASTM Detect and Avoid standards.

This report has been written to capture the results and lessons learned from the preliminary flight test campaign where two representative RID-Broadcast devices were range tested across multiple broadcast rates and power levels.

The following systems were tested:

Dronetag Mini – The Dronetag Mini is a Bluetooth 4.0- and 5.0-enabled RID-Broadcast module which can be attached to a UAS. The unit tested in the test event was capable of broadcasting at user-definable rates and power levels.

Vendor 1 Aircraft – The Vendor 1 Aircraft (actual manufacturer to be unnamed) is a UAS with integrated Wi-Fi-enabled RID-Broadcast capabilities.

Testing was conducted in an open field/rural environment with range testing up to 3 km from the RID Receiver. The RID Receiver used in this testing was a Samsung Galaxy S20 FE 5G. The open-source RID application, OpenDroneID, was used to capture RID messages transmitted by the RID-Broadcast devices and log these messages for analysis.

2 TEST OBJECTIVE(S)

2.1 Primary Objective(s)

The primary objective of this preliminary flight testing was to test the range capabilities of two representative RID-Broadcast transmission devices at varying broadcast rates and power levels.

2.2 Secondary Objective(s)

N/A.

3 TEST EQUIPMENT

3.1 Test Aircraft

3.1.1 Autel EVO II

This Autel EVO II was used for preliminary testing of a small UAS equipped with Bluetooth 4.0 and 5.0 enabled RID Broadcast technology. The aircraft was outfitted with a Bluetooth RID device built by Dronetag – the Dronetag Mini.

Figure 69. Autel EVO II.

3.1.2 Vendor 1 Aircraft

This aircraft was used for preliminary testing of a small UAS equipped with Wi-Fi-enabled RID Broadcast technology. Specialized firmware was installed to activate Wi-Fi NAN RID Broadcasting. These firmware installations enabled various RID broadcast rates to be transmitted at fixed power levels.

3.1.3 Hardware Additions/Modifications

3.1.3.1 **Autel EVO II Hardware Additions/Modifications**

The Autel EVO II was outfitted with Dronetag Mini weighing <0.05 ± 0.05 kg (<0.1 ± 0.1 lb). Per the reported specifications of the Autel EVO II, the base takeoff weight of the EVO II is 1150 g (1.150 kg) and the max takeoff weight is 1999 g (1.999 kg). The EVO II outfitted with the Dronetag Mini weighed 1.160 kg. This weight was below that of the maximum takeoff weight as stated in the specification. No changes in performance or flight characteristics were observed due to the installation of the Dronetag Mini.

The device was attached to the EVO II via hook-and-loop fasteners. The device contained an internal GPS antenna that was oriented to face upwards to ensure the best GPS signal reception.

3.1.3.2 **Vendor 1 Aircraft Hardware Additions/Modifications**

There were no hardware additions or modifications to this aircraft.

3.1.4 Software Additions/Modifications

3.1.4.1 **Autel EVO II Software Additions/Modifications**

There were no software additions or modifications to this aircraft.

3.1.4.2 Vendor 1 Aircraft Software Additions/Modifications

The Vendor 1 aircraft was equipped with specialized firmware installations to enable Wi-Fi RID Broadcasting at various transmission rates. Each individual firmware installation pertained to a specific transmission rate. The firmware packages were developed by Vendor 1 and did not affect the flight control system.

Four firmware packages were used in the flight test. These firmware packages enabled the following Wi-Fi-enabled broadcast rates at the specified power level and frequency band:

Rate: ~1 Hz; Power Level: 28 dBm; Frequency Band 2.4 GHz

Rate: ~3 Hz; Power Level: 28 dBm; Frequency Band 2.4 GHz

Rate: ~5 Hz; Power Level: 28 dBm; Frequency Band 2.4 GHz

Rate: ~1 Hz; Power Level: 28 dBm; Frequency Band 5.8 GHz

3.2 Ground Control Station (GCS)

3.2.1 Autel EVO II GCS

The Autel EVO II utilizes a handheld controller with a 3.26" OLED viewing screen and can also be equipped with a smartphone for additional capability.

Figure 70. Autel EVO II controller.

3.2.2 Vendor 1 Aircraft GCS

The Vendor 1 aircraft utilizes a handheld remote controller that connects to a smartphone.

3.2.3 Hardware Additions/Modifications

There were no hardware additions or modifications made to the controller for either aircraft.

3.2.4 Software Additions/Modifications

There were no software additions or modifications made to the controller for either aircraft.

3.3 Test Specific Equipment

- Dronetag Mini Bluetooth Enabled RID Broadcast Device (x1)
- Samsung Galaxy S20 FE 5G (x1)
- Apple iPad Mini (5th Generation) (x1)
- RF Explorer 6G COMBO+ (x1)
- Tektronix RSA306B (x1)
- Laptop with Tektronix RSA306B Software Package (x1)
- Tripod with phone/tablet mount (x1)
- BadElf GPS (x1)
- MSWIN Handheld Radio (x2)
- Mobile Internet Hotspot (x1)
- Personal Cellular Phones (x3)
- Laptop/SSD for Log File Collection (x1)
- Launch Pad (x1)
- Canopy (x1)
- Folding table (x1)
- Folding chairs (x5)
- Generator (x1)
- Extension cord (x1)
- Power strip (x1)
- Stopwatch (x1)
- Weather Station (x1)
- Weather Station Battery (x1)
- Weather Station Laptop (x1)

4 INSTRUMENTATION

4.1 Samsung Galaxy S20 FE 5G

- P/N: SM-G781U1/DS
- S/N: RFCN90MZPEM
- Data Collection Specific Software Description: Specialized software application (OpenDroneID) for capturing data (Wi-Fi, Bluetooth 4, and Bluetooth 5).

Figure 71. Samsung Galaxy S20 FE 5G

4.2 RF Explorer 6G COMBO+

- P/N: N/A
- S/N: B3EJKML7E8JKE8K7
- Software Description: ver 03.16 02-Jul-20

Figure 72. RF Explorer 6G COMBO+

4.3 Tektronix RSA306B / B035933

- P/N: N/A
- S/N: N/A
- Software: SignalVu-PC
- Antenna: RM-WB1-DN (SUB-6, 5G CELLULAR) SUB-6 SURFACE MOUNT ANTENNA, 600-6000 MHZ

Figure 73. Tektronix RSA306B

5 DATA COLLECTION

The following descriptors were recorded for each test aircraft, TX device, and RX device test/combination:

- Platform
- TX Frequency
- TX Power
- Platform General Description and Configuration
- Make and Model of the TX chip
- Power Amplifier (PA) [Present or Not]
- Type of PA [Present or Not]
- Antenna Type
- RX Sensitivity [if not a phone/tablet]
- RX Device Make, Model, Firmware, and Operating System (OS) Version
- Placement Description/GPS Coordinate/Multi-Resolution Land Characteristics (MRLC) classification

RF noise floor measurements in the appropriate band(s) (2.4GHz and/or 5.8GHz) were recorded (data files) via spectrum analyzers prior to takeoff. RF Noise floor measurements were taken in three stages:

1) aircraft power off, RID-Broadcast transmitter power off (ambient measurement)
   - AC OFF/RID OFF
2) aircraft power on, RID-Broadcast transmitter power off (if possible)
   - AC ON/RID OFF
3) aircraft power on, RID-Broadcast transmitter power on
   - AC ON/RID ON

Note: *Required noise measurements:*

Bluetooth Low Energy (BLE)-based RID-Broadcast Systems

1) 2400 MHz – 2500 MHz

2) Channel 37 (Center = 2402 MHz, 2 MHz wide span typical [2401-2403])

3) Channel 38 (Center = 2426 MHz)

4) Channel 39 (Center = 2480 MHz)

2.4 GHz Wi-Fi-based RID-Broadcast Systems

1) 2400 MHz – 2500 MHz

2) Channel 6 (Center = 2437MHz, 20 MHz wide span [2427-2447])

5.8 GHz Wi-Fi-based RID-Broadcast Systems

1) 5400 MHz – 5500 MHz

2) Channel 149 (Center = 5745, 20 MHz wide span [5735-5755])

RF measurements were taken during test points to monitor the RF environment in near real time. This was accomplished via peak hold measurements and taking a screenshot of the RF analysis software Graphical User Interface (GUI) at the conclusion of a 60 second test point. The RF environment was monitored throughout testing. Changes in the RF environment were noted (test notes) and new RF noise floor measurements (data file) were taken if changes necessitated.

The primary noise floor measurement device was the Tektronix RSA306B; however, a RF Explorer 6G COMBO+ was also used for comparative data.

RID receiver log files were captured and recorded for each test point. These log files were captured and recorded via an open-source RID Receiver application – OpenDroneID (https://github.com/opendroneid). The application has been developed specifically for Android operating systems. The Android-based device used in this testing is capable of receiving Wi-Fi, Bluetooth 4.0, and Bluetooth 5.0-enabled RID Broadcast messages.

Table 20. GO/NO GO Parameters.

Parameter	Unit	Parameter Source	Go / No Go
Noise Floor Measurement	[dBm]	RSA306B	No Go
RID Receiver Log File	[-]	Receiver(s)	No Go

6 OPERATIONAL AREA/TEST SITE

The testing was performed at Mississippi State University's R. R. Foil Plant Science Research Center, colloquially known as "North Farm." This location was chosen due to its lack of obstructions, ensuring clear line of sight from RID-Broadcast device to RID-Receiving device. The site also allowed for the possibility of flying over people to be mitigated.

Figure 74. North Farm location.

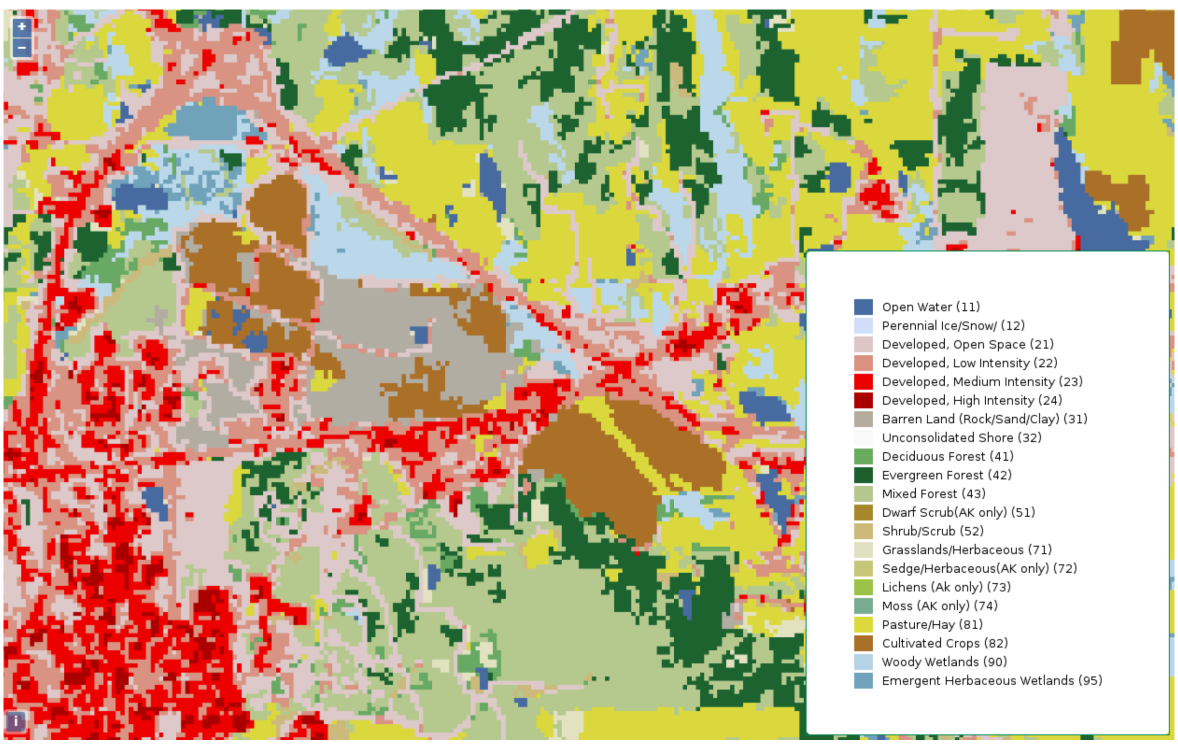

Figure 75. Multi-Resolution Land Characteristics (MRLC) classification of North Farm Area.

Figure 76. Test point locations.

7 TEST METHODOLOGY

7.1 Setup

7.1.1 RID Receivers Setup

The RID Receiver (Samsung Galaxy S20 FE 5G) was mounted vertically (90° ± 5°), at a height of 140 cm ± 10 cm, with its back facing towards the Test Aircraft/RID-Broadcast device.

> **Note:** *An Apple iPad Mini (5th generation) was intended to be used to capture Bluetooth-based RID-Broadcast messages; however, during testing, it was found that the Apple iPad Mini was unable to log messages being transmitted from Dronetag Mini. It was determined that this was due to an incompatibility between the iOS-version of the OpenDroneID application and the Dronetag Mini. The application developer was contacted, and the likely source of the issue has been identified. Range testing was continued without use of the Apple iPad Mini. Following testing, the developers of the iOS-version of the OpenDroneID application provided an updated version that is expected to correct the incompatibility issue – testing of this updated iOS-based application has not been conducted at the time of writing this report.*

A weather station was placed near the receiver location to monitor and record wind conditions during testing to ensure they stayed under safe operational limits. The following table displays the coordinates of each piece of hardware on each of the 3 days of testing.

Table 21. Location of testing instruments.

	Day 1	Day 2	Day 3
Samsung S20 FE 5G	33° 28’ 45.83” N 88° 47’ 20.24” W	33° 28’ 45.73” N 88° 47’ 20.25” W	33° 28’ 45.66” N 88° 47’ 20.24” W
Tektronix RSA306B Antenna	33° 28’ 45.65” N 88° 47’ 20.23” W	33° 28’ 45.71” N 88° 47’ 20.31” W	33° 28’ 45.76” N 88° 47’ 20.31” W
Vaisala WXT530 Weather Transmitter	33° 28’ 45.58” N 88° 47’ 20.43” W	33° 28’ 45.43” N 88° 47’ 20.50” W	33° 28’ 45.53” N 88° 47’ 20.41” W

Figure 77. RID Receiver and Test Location.

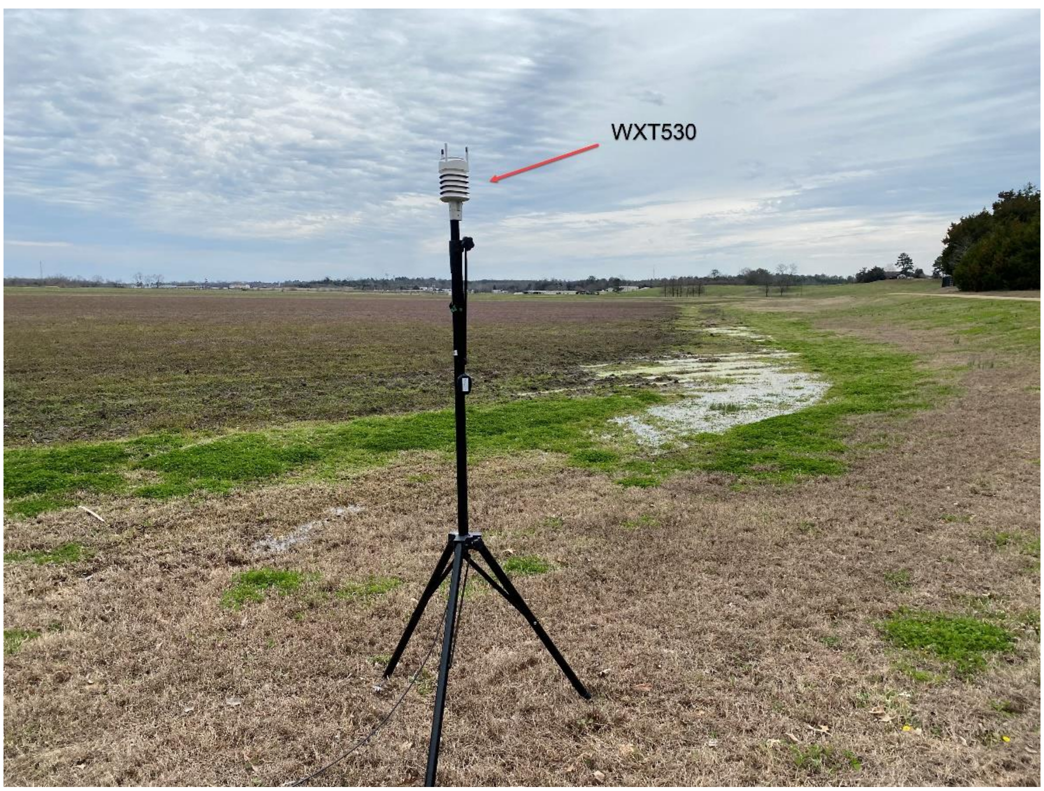

Figure 78. Weather Station Test Location.

7.1.2 Autel EVO II & Dronetag Mini (Bluetooth 4.0- & 5.0-enabled RID Broadcast) Setup

The Dronetag RID-Broadcast module was installed to the Autel EVO II via hook-and-loop fasteners and oriented facing the front of the aircraft. per manufacturers specifications as can be seen in Figure 11.

Figure 79. Autel EVO II Equipped with Dronetag Mini.

The Test Conductor set the broadcast rate and power level to the specified values prior to testing. The Test Director then verified that the appropriate settings were input.

Four Bluetooth 4.0- and 5.0- enabled RID broadcast configurations were tested:

1) Rate: ~1 Hz (Basic Data – 911 ms; Dynamic Data – 1167 ms); Power Level: 5 dBm
2) Rate: ~3 Hz (Basic Data – 333 ms; Dynamic Data – 433 ms); Power Level: 5 dBm
3) Rate: ~6 Hz (Basic Data – 167 ms; Dynamic Data – 267 ms); Power Level: 5 dBm
4) Rate: ~1 Hz (Basic Data – 911 ms; Dynamic Data – 1167 ms); Power Level: 8 dBm

7.1.3 Vendor 1 Aircraft (Wi-Fi-enabled RID-Broadcast) Setup

The Test Conductor installed the required firmware version for the desired broadcast rate, transmission power level, and frequency band prior to testing. The Test Director verified that the correct firmware was installed after each installation.

Four Wi-Fi-enabled RID-Broadcast configurations were tested:

1) Rate: ~1 Hz; Power Level: 28 dBm; Frequency Band 2.4 GHz
2) Rate: ~3 Hz; Power Level: 28 dBm; Frequency Band 2.4 GHz
3) Rate: ~5 Hz; Power Level: 28 dBm; Frequency Band 2.4 GHz
4) Rate: ~1 Hz; Power Level: 28 dBm; Frequency Band 5.8 GHz

7.2 Vertical Range Testing

Four vertical range test points were conducted per tested configuration. Each vertical test point consisted of the aircraft hovering for 60 seconds over the receivers (within 20 m horizontally) at predetermined altitudes: 100’, 200’, 300’, and 400’ AGL. The aircraft was approximately oriented facing heading 115° (facing away from the RID Receiver) for all test points and configurations. This orientation was found to provide the best results when compared to other orientations.

7.3 Horizontal Range Testing

Six test points were planned for each tested configuration, however, not all test points were conducted for each configuration due to range limitations of tested configurations. Each horizontal test point consisted of the aircraft hovering for 60 seconds at 300’ AGL and at predetermined horizontal distances from the receiver: 500, 1000, 1500, 2000, 2500, and 3000 m.

Figure 80. Vertical and Horizontal Test Point Diagram.

8 DATA ANALYSIS & RESULTS

8.1 Radiofrequency Noise Floor Data

8.1.1 Tektronix LNA Gain

The Tektronix RSA306B includes a low-noise amplifier (LNA) which allows for optimal noise floor levels through the amplification of the input signal. Additional noise occurs as a result of the LNA process. Thus, the LNA gain amount was calculated to be 22 dBm, and the average noise floor measurement values were adjusted accordingly to represent the true noise floor.

Note: *The RF Explorer 6G COMBO+ also includes an LNA. The LNA gain has not been calculated for the RF Explorer 6G COMBO+ at this time as this data was taken for comparison purposes.*

8.1.2 Bluetooth Noise Floor 1

Bluetooth Noise Floor 1 measurements were captured on Day 1 of testing prior to launch of the first Dronetag Mini configuration (Rate: ~1 Hz; Power Level: 5 dBm).

Frequency Band / Channel	Test Configuration	Tektronix RSA306B Avg Noise Floor, [dBm]	RF Explorer 6G COMBO+ Avg Noise Floor, [dBm]	Tektronix RSA306B Adjusted Avg Noise Floor, [dBm]
2400–2500 MHz	AC OFF/RID OFF	-85.6	-85.3	-107.6
	AC ON/RID OFF	-85.5	-85	-107.5
	AC ON/RID ON	-85.2	-85.1	-107.2
Channel 37 (2402±1 MHz)	AC OFF/RID OFF	-91.8	-102	-113.8
	AC ON/RID OFF	-91.7	-102	-113.7
	AC ON/RID ON	-91.8	-102	-113.8
Channel 38 (2426±1 MHz)	AC OFF/RID OFF	-91.5	-101.9	-113.5
	AC ON/RID OFF	-91.1	-101.9	-113.1
	AC ON/RID ON	-90.1	-101.8	-112.1
Channel 39 (2480±1 MHz)	AC OFF/RID OFF	-90.8	-101.5	-112.8
	AC ON/RID OFF	-91	-101.5	-113
	AC ON/RID ON	-90.8	-101.5	-112.8

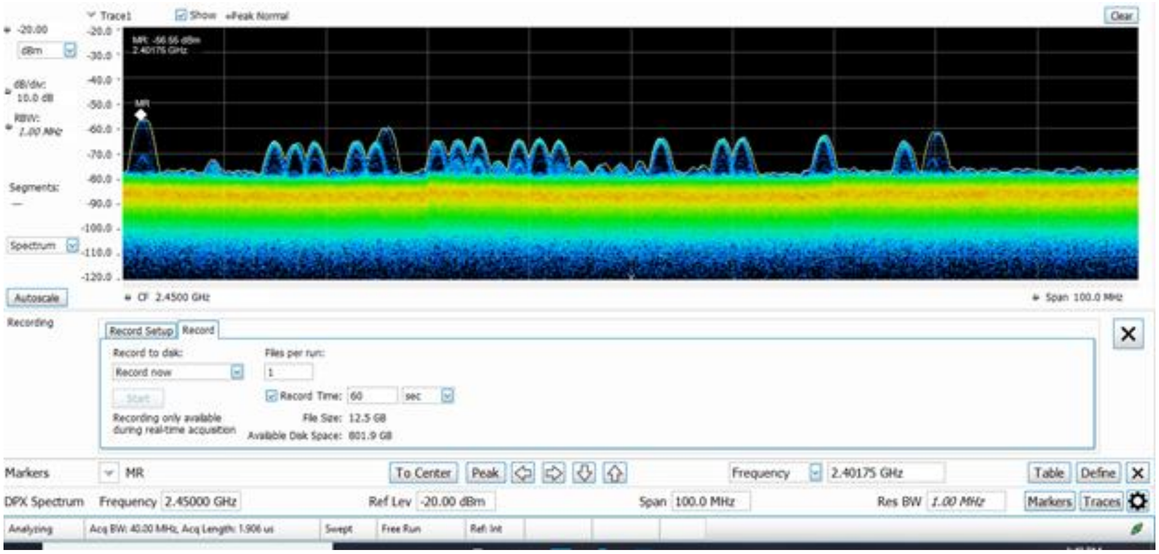

Figure 81. Bluetooth Noise Floor 1 – Tektronix: 2400 – 2500 MHz (AC OFF / RID OFF).

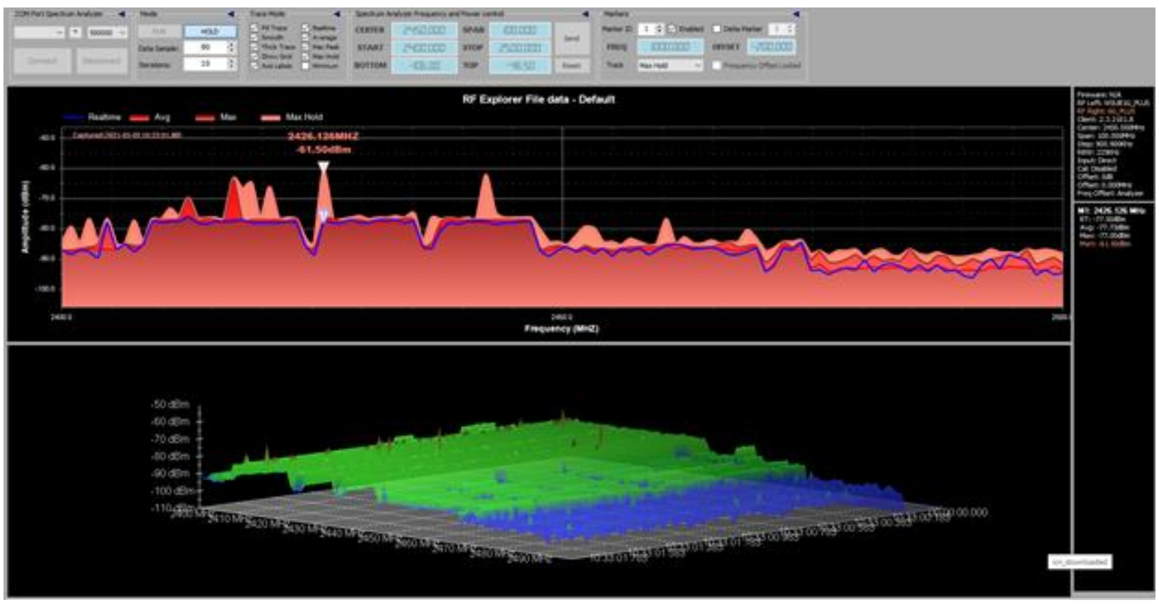

Figure 82. Bluetooth Noise Floor 1 – RF Explorer: 2400 – 2500 MHz (AC OFF / RID OFF).

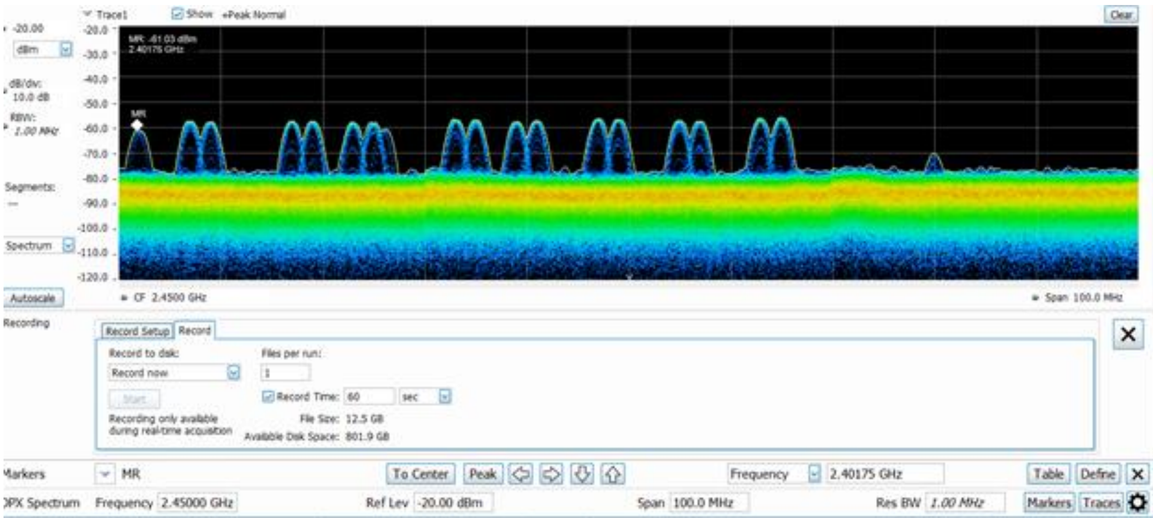

Figure 83. Bluetooth Noise Floor 1 – Tektronix: 2400 – 2500 MHz (AC ON / RID OFF).

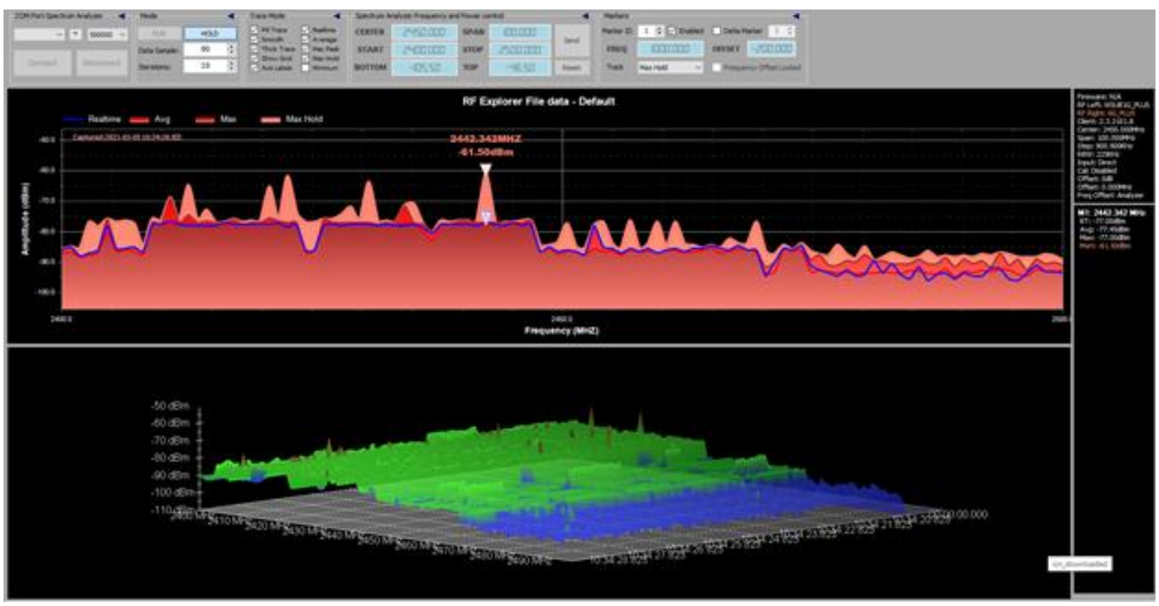

Figure 84. Bluetooth Noise Floor 1 – RF Explorer: 2400 – 2500 MHz (AC ON / RID OFF).

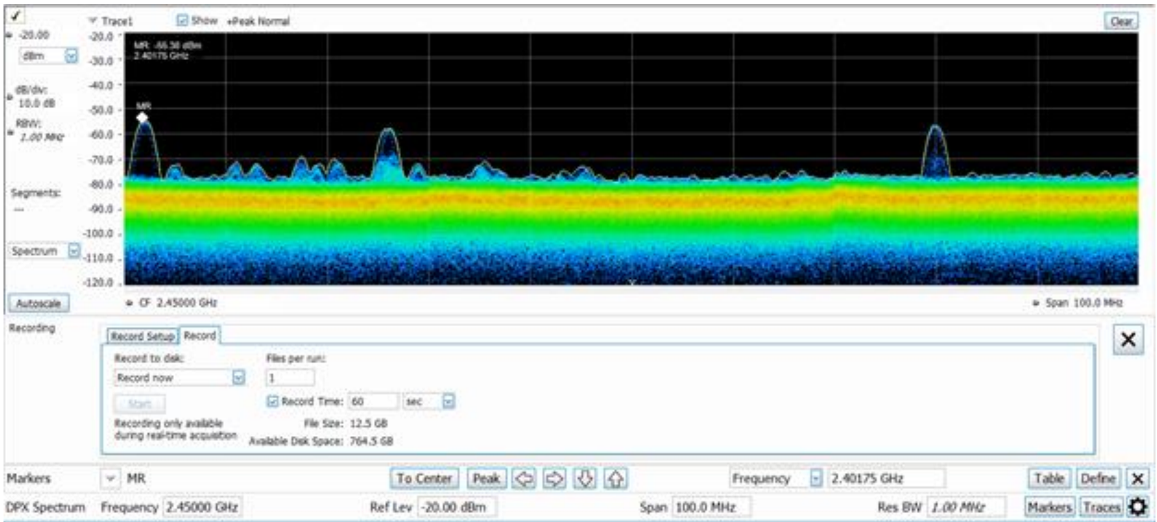

Figure 85. Bluetooth Noise Floor 1 – Tektronix: 2400 – 2500 MHz (AC ON / RID ON).

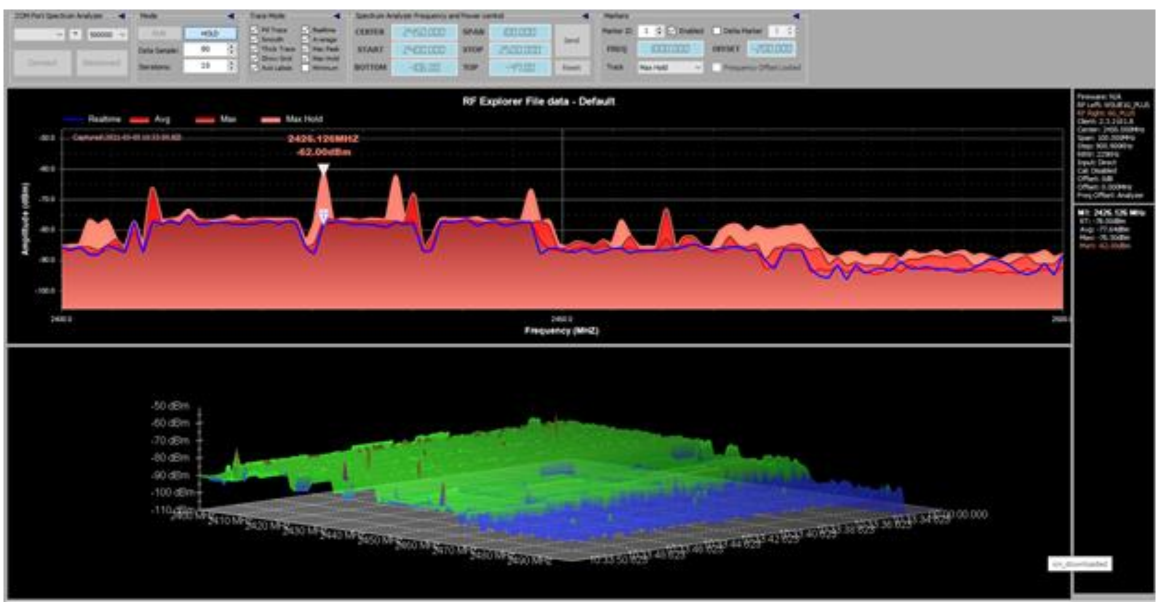

Figure 86. Bluetooth Noise Floor 1 – RF Explorer: 2400 – 2500 MHz (AC ON / RID ON).

8.1.3 *Bluetooth Noise Floor 2*

Bluetooth Noise Floor 2 measurements were captured on Day 1 of testing prior to launch of the third Dronetag Mini configuration (Rate: ~6 Hz; Power Level: 5 dBm). These noise floor measurements were captured as the range testing of the third Dronetag Mini configuration was executed several hours after the initial noise floor (Bluetooth Noise Floor 2) measurements were captured. These measurements were captured in order to capture any delta in RF noise floor due to differences in RF traffic in the early evening hours.

Frequency Band / Channel	Test Configuration	Tektronix RSA306B Avg Noise Floor, [dBm]	RF Explorer 6G COMBO+ Avg Noise Floor, [dBm]	Tektronix RSA306B Adjusted Avg Noise Floor, [dBm]
2400–2500 MHz	AC OFF/RID OFF	-83	-84.9	-105
	AC ON/RID OFF	-81.5	-84.8	-103.5
	AC ON/RID ON	-81.3	-84.9	-103.3
Channel 37 (2402±1 MHz)	AC OFF/RID OFF	-86	-102	-108
	AC ON/RID OFF	-86.3	-102	-108.3
	AC ON/RID ON	-86.3	-102	-108.3
Channel 38 (2426±1 MHz)	AC OFF/RID OFF	-87	-101.9	-109
	AC ON/RID OFF	-86.8	-102	-108.8
	AC ON/RID ON	-86.8	-101.8	-108.8
Channel 39 (2480±1 MHz)	AC OFF/RID OFF	-86.3	-101.5	-108.3
	AC ON/RID OFF	-86.2	-101.5	-108.2
	AC ON/RID ON	-86	-101.4	-108

8.1.4 Bluetooth Noise Floor 3

Bluetooth Noise Floor 3 measurements were captured on Day 2 of testing prior to launch of the fourth Dronetag Mini configuration (Rate: ~1 Hz; Power Level: 8 dBm) for horizontal range testing (vertical range testing was conducted prior to the conclusion of Day 1 testing).

Frequency Band / Channel	Test Configuration	Tektronix RSA306B Avg Noise Floor, [dBm]	RF Explorer 6G COMBO+ Avg Noise Floor, [dBm]	Tektronix RSA306B Adjusted Avg Noise Floor, [dBm]
2400–2500 MHz	AC OFF/RID OFF	-87.2	-84.7	-109.2
	AC ON/RID OFF	-86.3	-85.1	-108.3
	AC ON/RID ON	-84	-85.1	-106
Channel 37 (2402±1 MHz)	AC OFF/RID OFF	-92.6	-102	-114.6
	AC ON/RID OFF	-92.2	-102	-114.2
	AC ON/RID ON	-91.6	-102	-113.6
Channel 38 (2426±1 MHz)	AC OFF/RID OFF	-92.6	-102	-114.6
	AC ON/RID OFF	-91.7	-101.9	-113.7
	AC ON/RID ON	-92	-101.5	-114
Channel 39 (2480±1 MHz)	AC OFF/RID OFF	-91.7	-101.5	-113.7
	AC ON/RID OFF	-91.4	-101.5	-113.4
	AC ON/RID ON	-90.5	-102	-112.5

8.1.5 Wi-Fi Noise Floor 1

Wi-Fi Noise Floor 1 measurements were captured on Day 2 of testing prior to launch of the first Vendor 1 Aircraft configuration (Rate: ~1 Hz; Power Level: 28 dBm; Frequency Band: 2.4 GHz).

Frequency Band / Channel	Test Configuration	Tektronix RSA306B Avg Noise Floor, [dBm]	RF Explorer 6G COMBO+ Avg Noise Floor, [dBm]	Tektronix RSA206B Adjusted Avg Noise Floor, [dBm]

2400–2500 MHz	AC OFF/RID OFF	-86.1	-85	-108.1
	AC ON/RID ON	-86	-85.2	-108
Channel 6 (2437±10 MHz)	AC OFF/RID OFF	-91.6	-78.6	-113.6
	AC ON/RID ON	-91.7	-78.8	-113.7

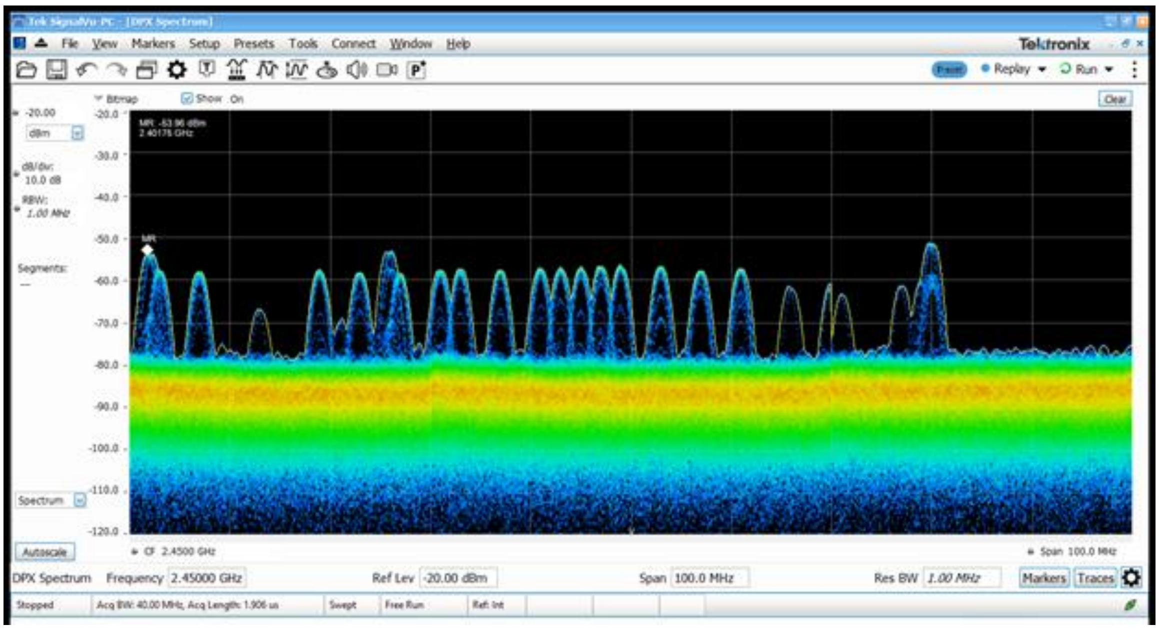

Figure 87. Wi-Fi Noise Floor 1 – Tektronix: 2400 – 2500 MHz (AC OFF / RID OFF).

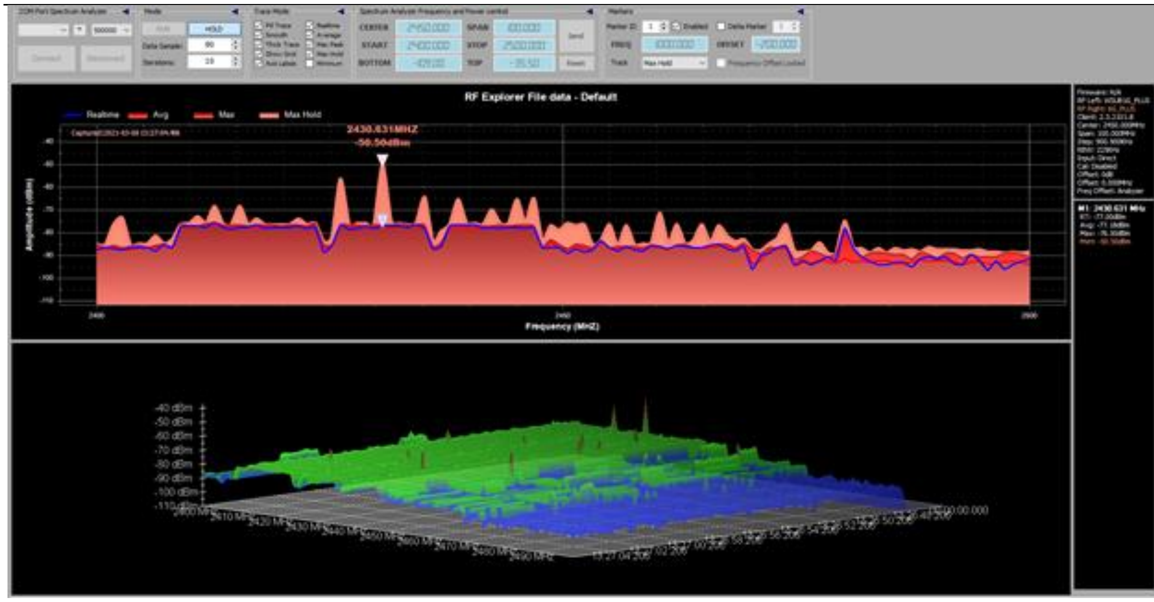

Figure 88. Wi-Fi Noise Floor 1 – RF Explorer: 2400 – 2500 MHz (AC OFF / RID OFF).

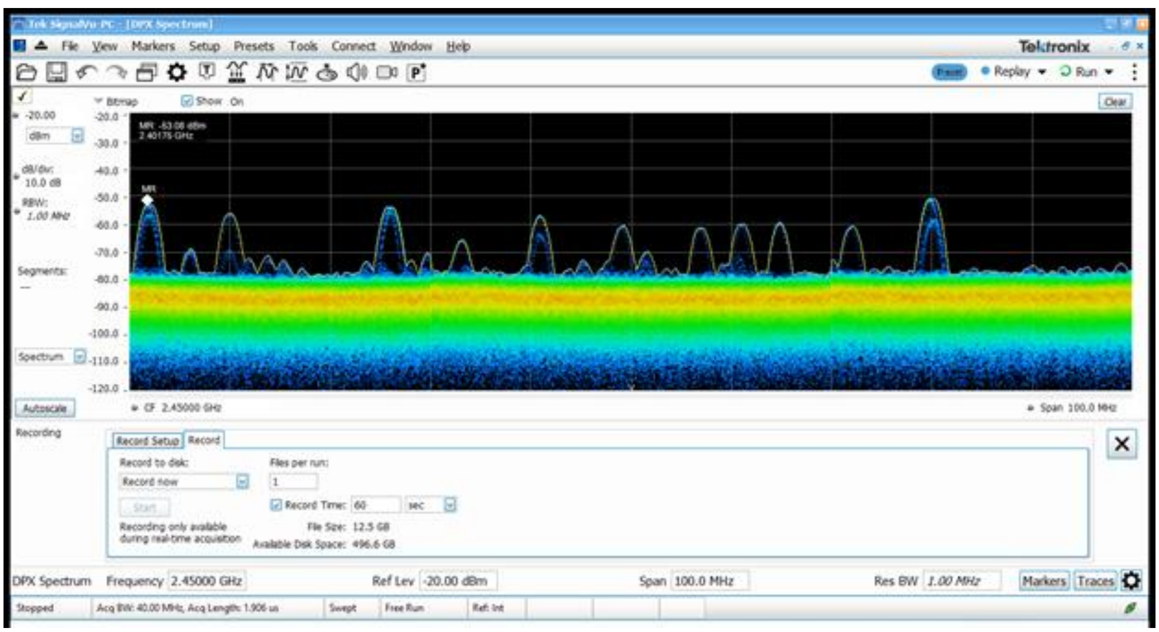

Figure 89. Wi-Fi Noise Floor 1 – Tektronix: 2400 – 2500 MHz (AC ON / RID ON).

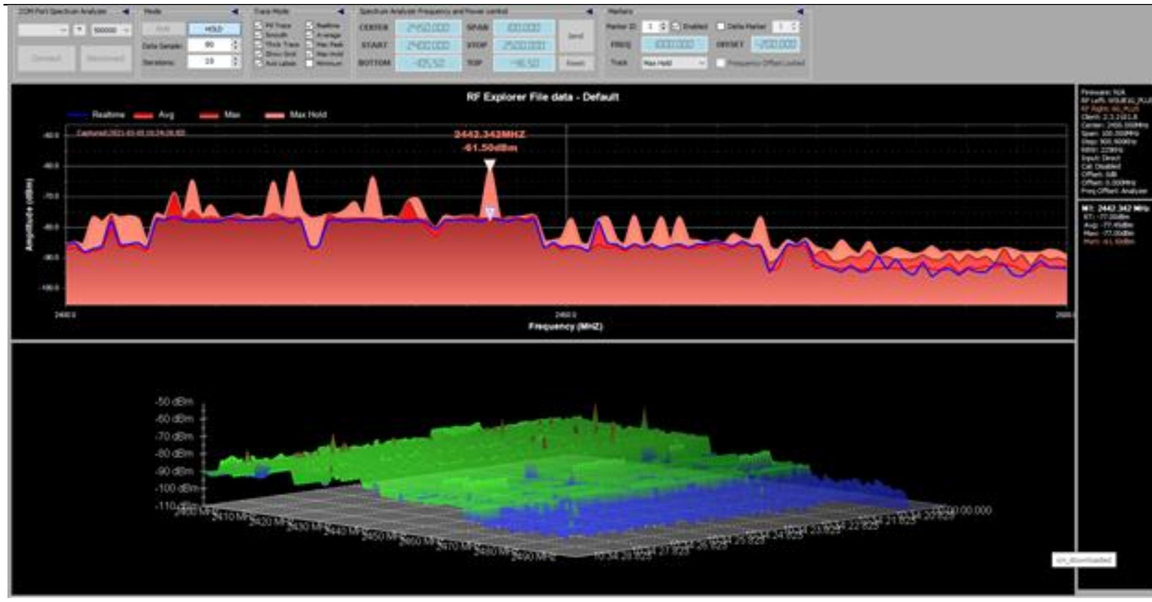

Figure 90. Wi-Fi Noise Floor 1 – RF Explorer: 2400 – 2500 MHz (AC ON / RID ON).

8.1.6 Wi-Fi Noise Floor 2

Wi-Fi Noise Floor 2 measurements were captured on Day 3 of testing prior to launch of the third Vendor 1 Aircraft configuration (Rate: ~5 Hz; Power Level: 28 dBm; Frequency Band: 2.4 GHz) for continued horizontal range testing (initial horizontal range testing was conducted prior to the conclusion of Day 2 testing).

Frequency Band / Channel	Test Configuration	Tektronix RSA306B Avg Noise Floor, [dBm]	RF Explorer 6G COMBO+ Avg Noise Floor, [dBm]	Tektronix RSA306B Adjusted Avg Noise Floor, [dBm]
2400–2500 MHz	AC OFF/RID OFF	-77	-85.1	-99
	AC ON/RID ON	-79	-85.1	-101
Channel 6 (2437±10 MHz)	AC OFF/RID OFF	-81.9	-78.7	-103.9
	AC ON/RID ON	-81.9	-78.9	-103.9

8.1.7 Wi-Fi Noise Floor 3

Wi-Fi Noise Floor 3 measurements were captured on Day 3 of testing prior to launch of the fourth Vendor 1 Aircraft configuration (Rate: ~1 Hz; Power Level: 28 dBm; Frequency Band: 5.8 GHz).

Frequency Band / Channel	Test Configuration	Tektronix RSA306B Avg Noise Floor, [dBm]	RF Explorer 6G COMBO+ Avg Noise Floor, [dBm]	Tektronix RSA306B Adjusted Avg Noise Floor, [dBm]
5400–5500 MHz	AC OFF/RID OFF	-78.5	-86.7	-100.5
	AC ON/RID ON	-80.6	-86.6	-102.6
Channel 149 (5745±10 MHz)	AC OFF/RID OFF	-81.6	-91.9	-103.6
	AC ON/RID ON	-92.1	-91.9	-114.1

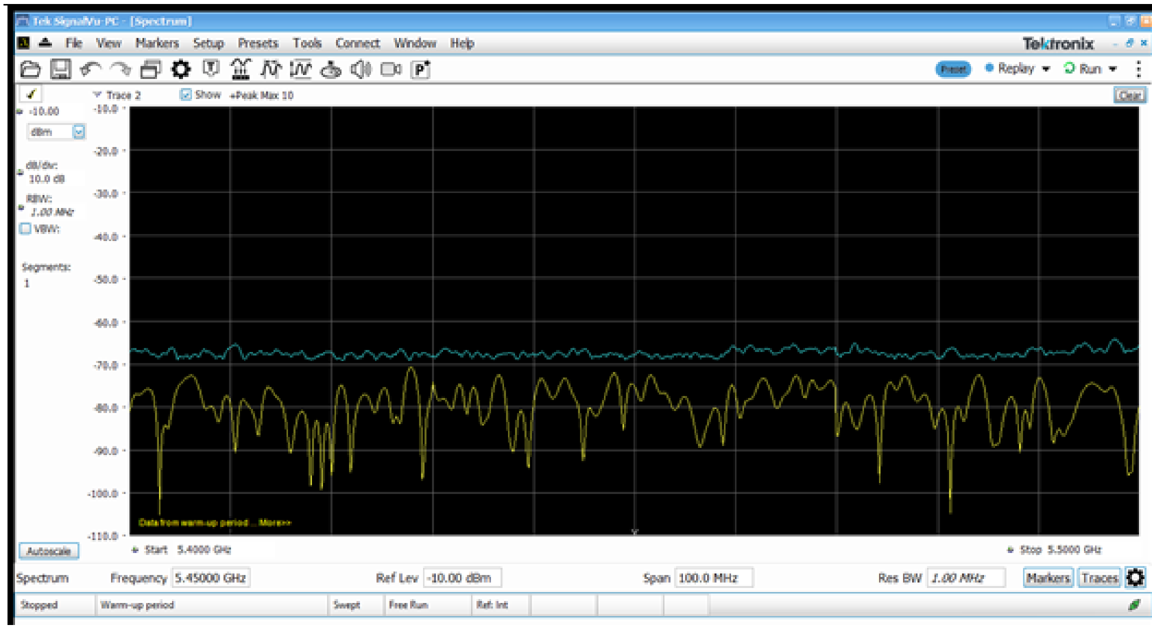

Figure 91. Wi-Fi Noise Floor 1 – Tektronix: 2400 – 2500 MHz (AC OFF / RID OFF).

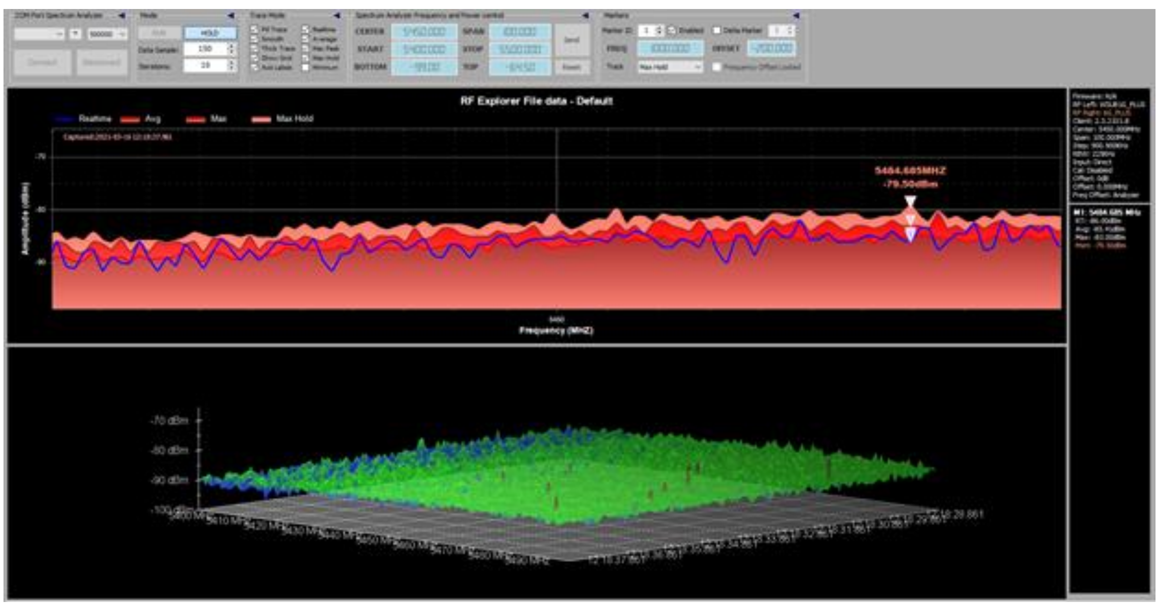

Figure 92. Wi-Fi Noise Floor 1 – RF Explorer: 2400 – 2500 MHz (AC OFF / RID OFF).

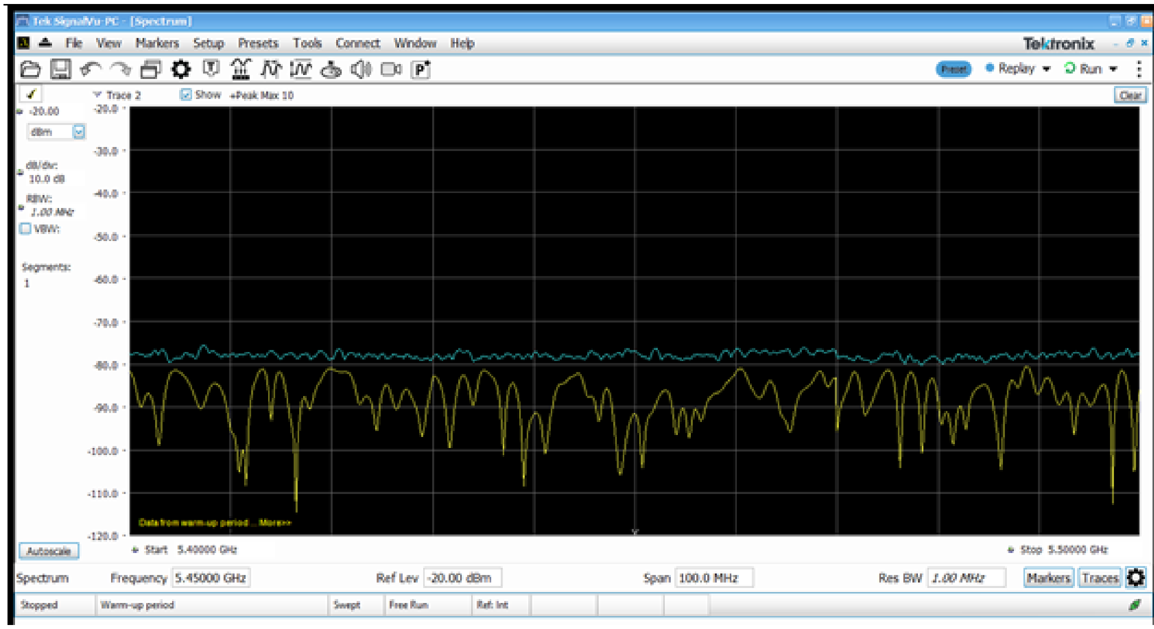

Figure 93. Wi-Fi Noise Floor 3 – Tektronix: 2400 – 2500 MHz (AC ON / RID ON).

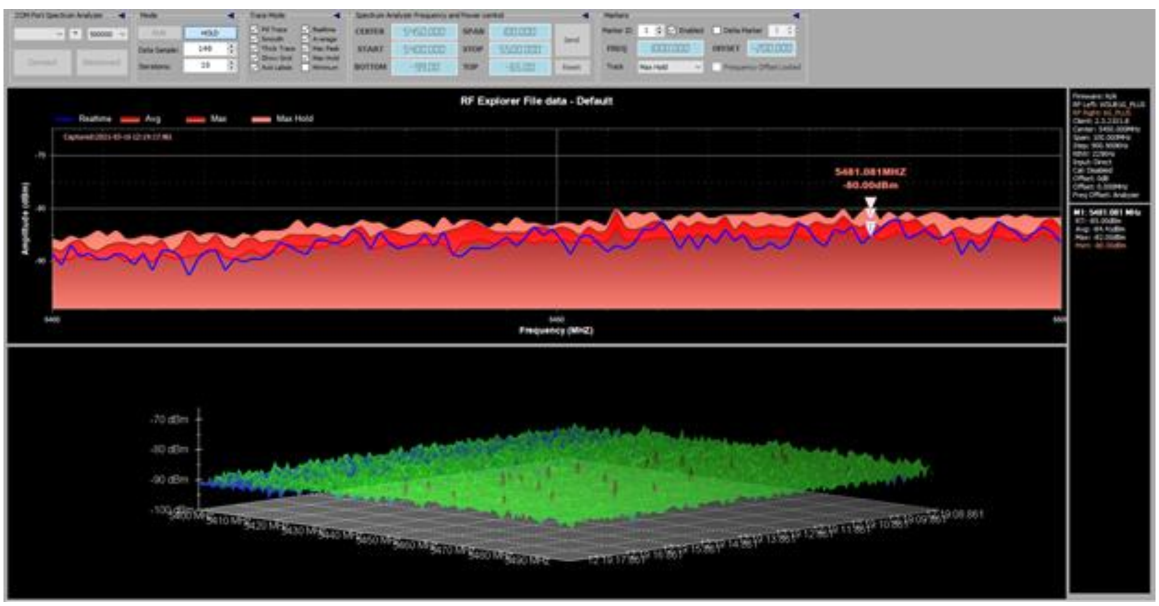

Figure 94. Wi-Fi Noise Floor 3 – RF Explorer: 2400 – 2500 MHz (AC ON / RID ON).

8.2 Dronetag Mini (Bluetooth 4.0 and 5.0-enabled RID) Data

8.2.1 Dronetag Mini (Bluetooth 4.0 and 5.0-enabled RID) Vertical Range Test Results

The following figures depict the "received" rate of packets that the RID Receiver (Samsung Galaxy S20 FE 5G) captured during the vertical range test points for the Dronetag Mini. The "received" rate was calculated via the timestamp associated with each RID-Broadcast packet which in actuality represents the time at which the message was generated and sent. The data in these plots is broken down into three categories: 1) BT4 and BT5, 2) BT4 Only, and 3) BT5 Only. The Dronetag Mini was configured to broadcast RID messages via both BT4 and BT5 packets. Therefore, the collected log files were separated into these three categories to characterize the combined "received" rate and the individual BT4 and BT5 "received" rates.

8.2.1.1 Avg Rate vs Altitude for Bluetooth Configurations

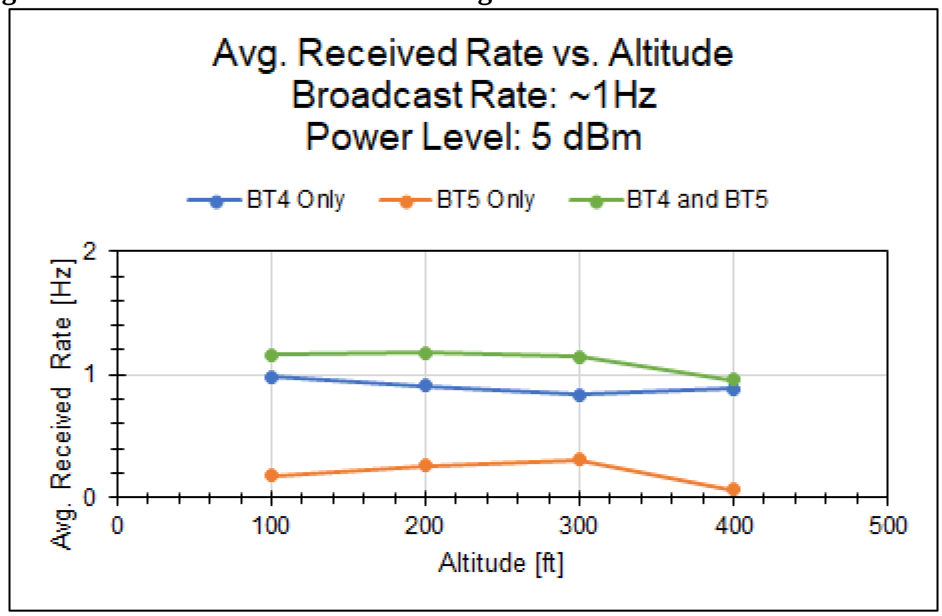

Figure 95. Avg Rate vs Altitude, Bluetooth 4.0 and 5.0 at 1 Hz, 5 dBm

1 Hz 5 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
100	1.16	100	0.98	100	0.18
200	1.175	200	0.9125	200	0.2625
300	1.1444	300	0.8333	300	0.3111
400	0.9556	400	0.8889	400	0.0667

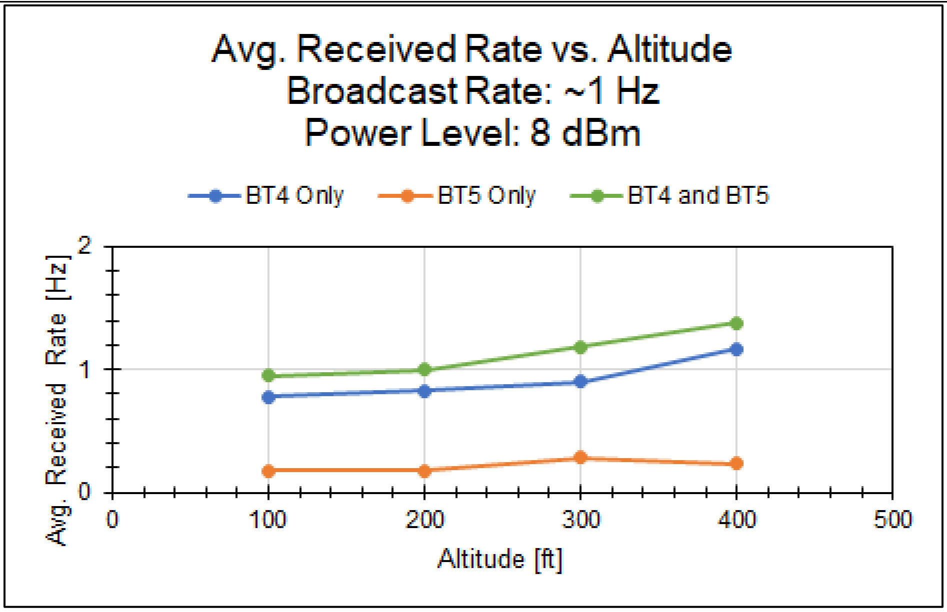

Figure 96. Avg Rate vs Altitude, Bluetooth, 4.0 and 5.0 at 1 Hz, 8 dBm

1 Hz 8 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
100	0.95	100	0.775	100	0.175
200	1	200	0.825	200	0.175
300	1.1857	300	0.9	300	0.2857
400	1.3833	400	1.1667	400	0.2333

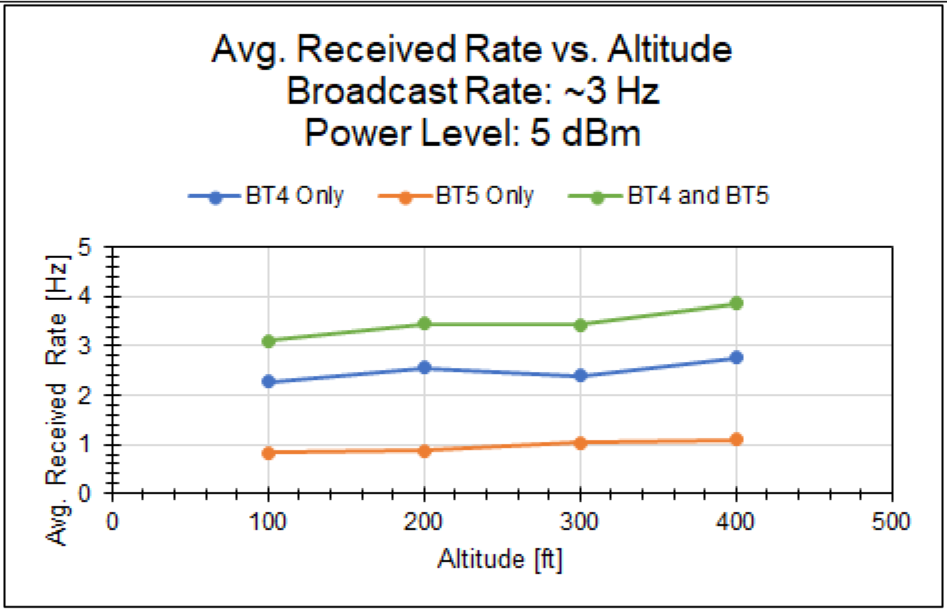

Figure 97. Avg Rate vs Altitude, Bluetooth, 4.0 and 5.0 at 3 Hz, 5 dBm

3 Hz 5 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
100	3.1111	100	11.913	100	2.499
200	3.45	200	12.763	200	2.105
300	3.4375	300	12.700	300	2.408
400	3.8667	400	12.137	400	1.910

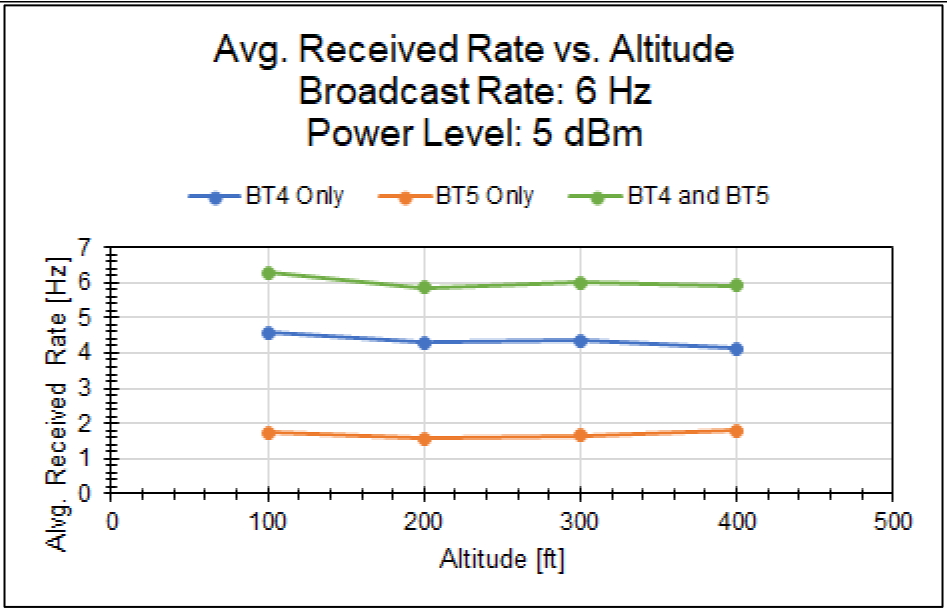

Figure 98. Avg Rate vs Altitude, Bluetooth, 4.0 and 5.0 at 6 Hz, 5 dBm

6 Hz 5 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
100	6.3	100	29.4	100	4.150
200	5.85	200	29.34	200	4.344
300	6	300	29.24	300	3.524
400	5.9143	400	27.37	400	4.459

8.2.1.2 Combined Bluetooth 4.0 and 5.0 Performance Comparison

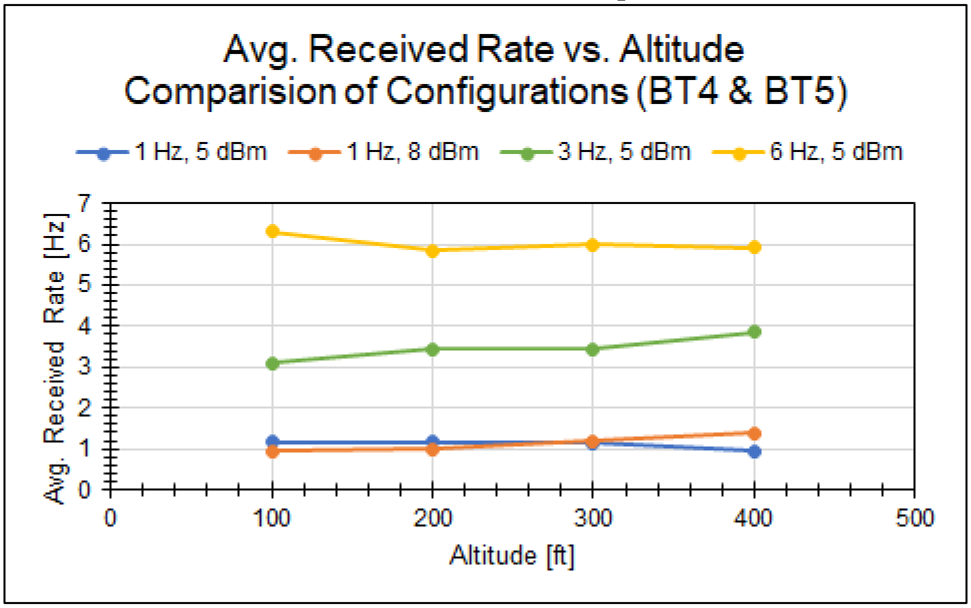

Figure 99. Combined Bluetooth 4.0 and 5.0 Performance Comparison

1 Hz 5 dBm		1 Hz 8 dBm		3 Hz 5 dBm		6 Hz 5 dBm	
BT4 & BT5 (Full Packets Only)		BT4 & BT5 (Full Packets Only)		BT4 & BT5 (Full Packets Only)		BT4 & BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
100	1.16	100	0.95	100	3.1111	100	6.3
200	1.175	200	1	200	3.45	200	5.85
300	1.1444	300	1.1857	300	3.4375	300	6
400	0.9556	400	1.3833	400	3.8667	400	5.9143

8.2.2 Dronetag Mini (Bluetooth 4.0 and 5.0-enabled RID) Horizontal Range Test Results

The following graphics depict the "received" rate of packets that the RID Receiver (Samsung Galaxy S20 FE 5G) captured during the horizontal range test points for the Dronetag Mini. The 300 ft vertical test point results (0 m) have also been included in these plots.

8.2.2.1 Avg Rate vs Horizontal Distance for Bluetooth Configurations

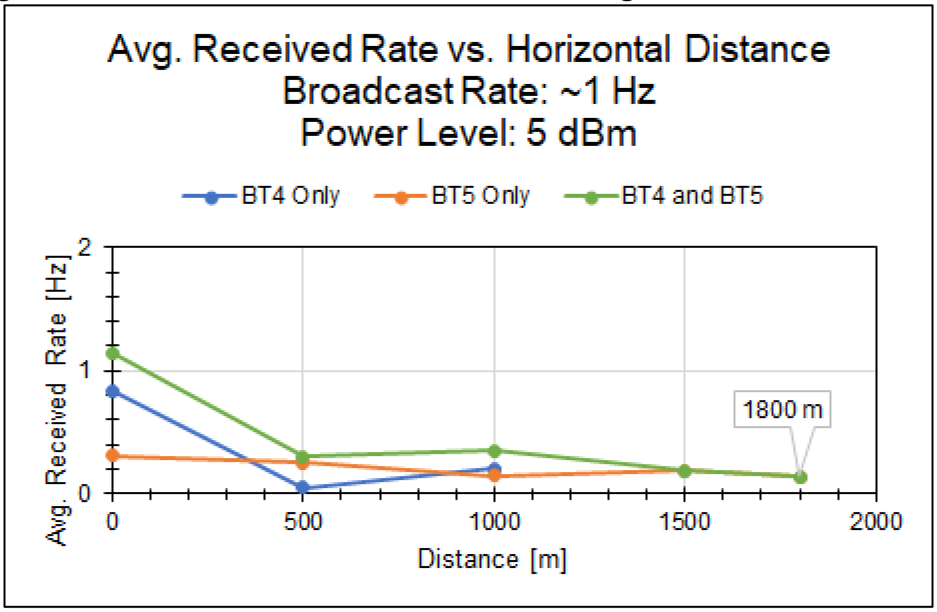

Figure 100. Avg Rate vs Horizontal Distance, Bluetooth 4.0 and 5.0 at 1 Hz, 5 dBm

1 Hz 5 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
0	1.16	0	0.83	0	0.31
500	0.3	500	0.05	500	0.25
1000	0.35	1000	0.2	1000	0.15
1500	0.1857	1500	0	1500	0.19
1800	0.14	1800	0	1800	0.14
1900	0	1900	0	1900	0

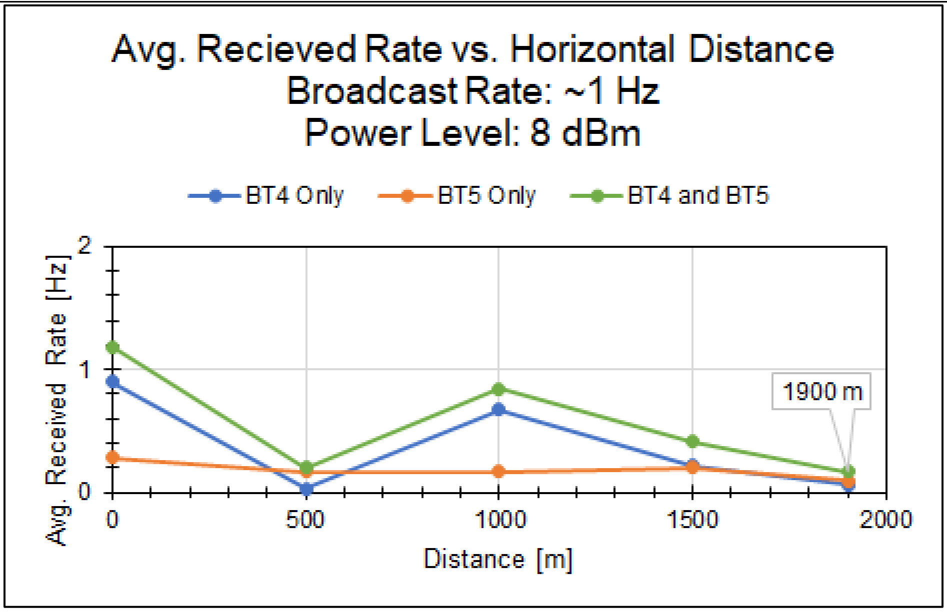

Figure 101. Avg Rate vs Horizontal Distance, Bluetooth 4.0 and 5.0 at 1 Hz, 8 dBm

1 Hz 8 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
0	0.95	0	0.9	0	0.2857
500	0.2	500	0.0286	500	0.1714
1000	0.8429	1000	0.6714	1000	0.1714
1500	0.4167	1500	0.2167	1500	0.2
1900	0.1667	1900	0.0667	1900	0.1

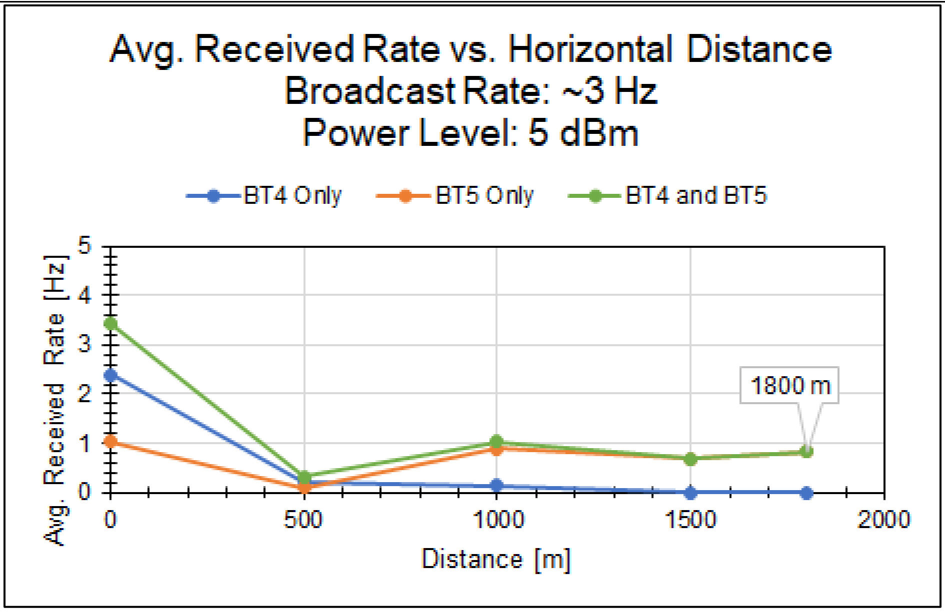

Figure 102. Avg Rate vs Horizontal Distance, Bluetooth 4.0 and 5.0 at ~3 Hz, 5 dBm

3 Hz 5 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
0	3.1111	0	2.4	0	1.0375
500	0.3143	500	0.2143	500	0.1
1000	1.0286	1000	0.1286	1000	0.9
1500	0.6833	1500	0	1500	0.6833
1800	0.8286	1800	0	1800	0.8286

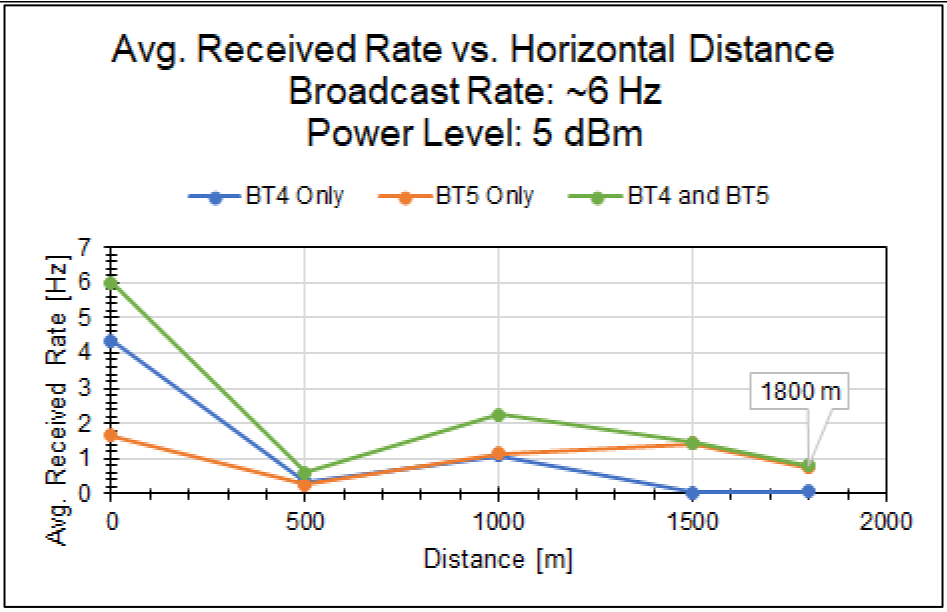

Figure 103. Avg Rate vs Horizontal Distance, Bluetooth 4.0 and 5.0 at 6 Hz, 5 dBm

6 Hz 5 dBm					
BT4 & BT5 (Full Packets Only)		BT4 (Full Packets Only)		BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
0	6.3	0	4.3429	0	1.657
500	0.59	500	0.33	500	0.26
1000	2.2375	1000	1.0875	1000	1.15
1500	1.4625	1500	0.0375	1500	1.425
1800	0.7857	1800	0.0571	1800	0.7286

8.2.2.2 Combined Bluetooth 4.0 and 5.0 Performance Comparison

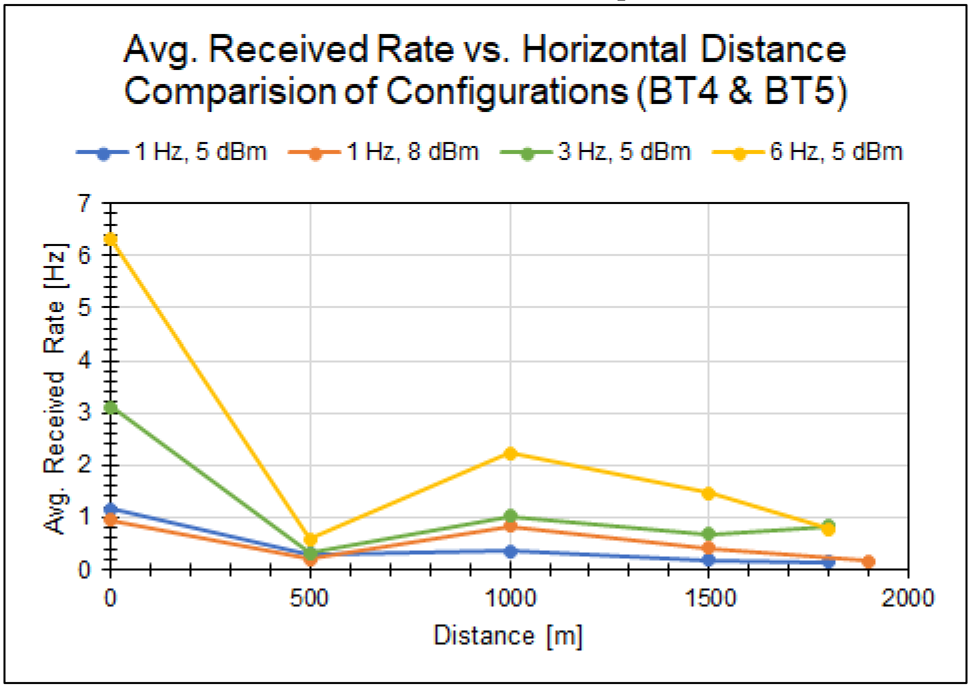

Figure 104. Combined Bluetooth 4.0 and 5.0 Performance Comparison

1 Hz 5 dBm		1 Hz 8 dBm		3 Hz 5 dBm		6 Hz 5 dBm	
BT4 & BT5 (Full Packets Only)		BT4 & BT5 (Full Packets Only)		BT4 & BT5 (Full Packets Only)		BT4 & BT5 (Full Packets Only)	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
0	1.1444	0	1.1857	0	3.4375	0	6
500	0.3	500	0.2	500	0.3143	500	0.59
1000	0.35	1000	0.8429	1000	1.0286	1000	2.2375
1500	0.1875	1500	0.4167	1500	0.6833	1500	1.4625
1800	0.14	1900	0.1667	1800	0.8286	1800	0.7857

8.3 Vendor 1 Aircraft (Wi-Fi-enabled RID) Data

8.3.1 Vendor 1 Aircraft Vertical Range Test Results

The following graphics depict the "received" rate of packets that the RID Receiver (Samsung Galaxy S20 FE 5G) captured during the vertical range test points for the Vendor 1 Aircraft. The Vendor 1 Aircraft was configured with different firmware installations to enable various broadcast rates and RID transmission over 2.4 GHz or 5.8 GHz bands.

8.3.1.1 Avg Rate vs Altitude for Wi-Fi Configurations

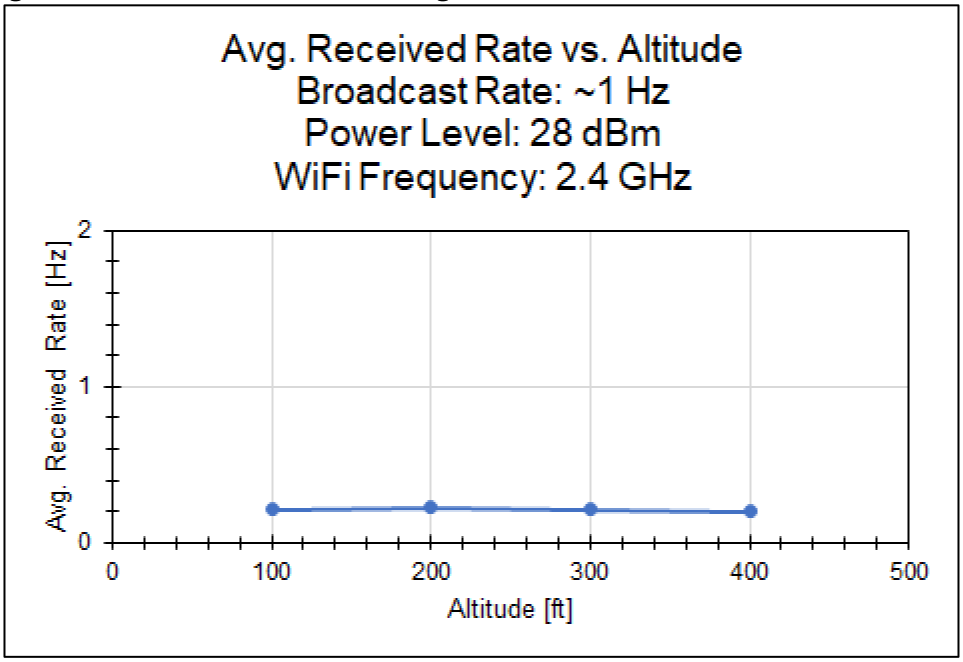

Figure 105. Avg Rate vs Altitude, 2.4 GHz Wi-Fi at ~1 Hz, 28 dBm

Firmware 4	
1 Hz, 2.4 GHz	
Altitude (ft)	Avg Rate
100	0.2125
200	0.2232
300	0.2143
400	0.2

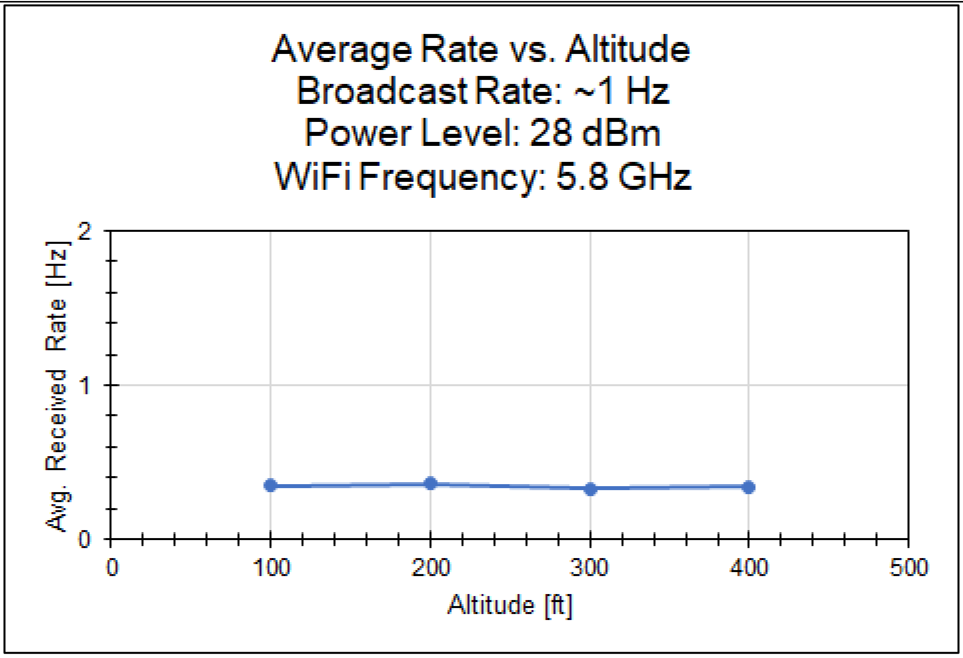

Figure 106. Avg Rate vs Altitude, 5.8 GHz Wi-Fi at ~1 Hz, 28 dBm

Firmware 7	
1 Hz, 5.8 GHz	
Altitude (ft)	Avg Rate
100	0.3504
200	0.3595
300	0.3295
400	0.344

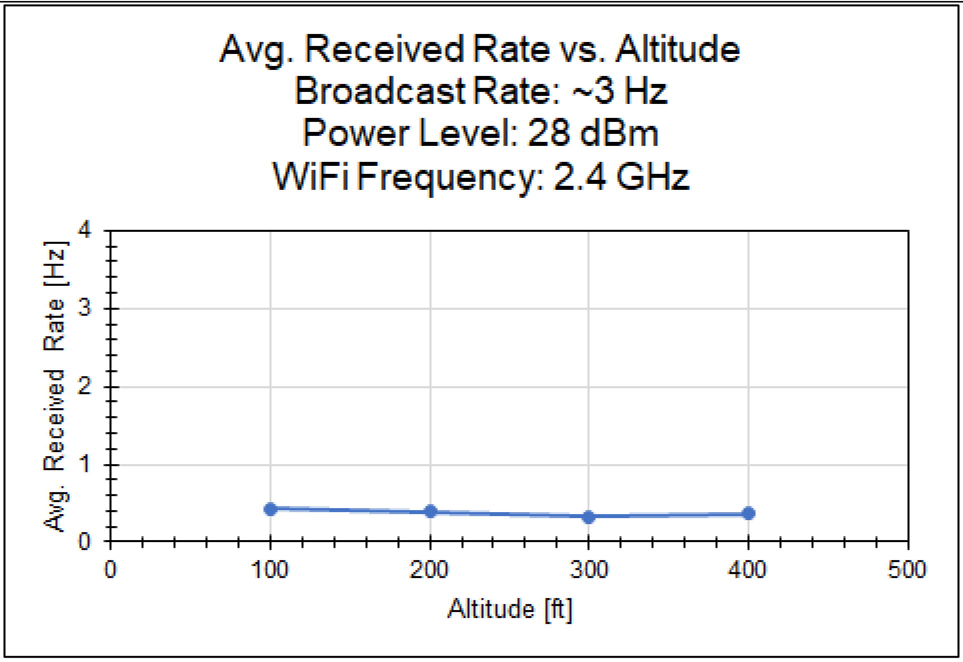

Figure 107. Avg Rate vs Altitude, 2.4 GHz Wi-Fi at ~3 Hz, 28 dBm

Firmware 3	
3 Hz, 2.4 GHz	
Altitude (ft)	Avg Rate
100	0.4333
200	0.3857
300	0.3286
400	0.3714

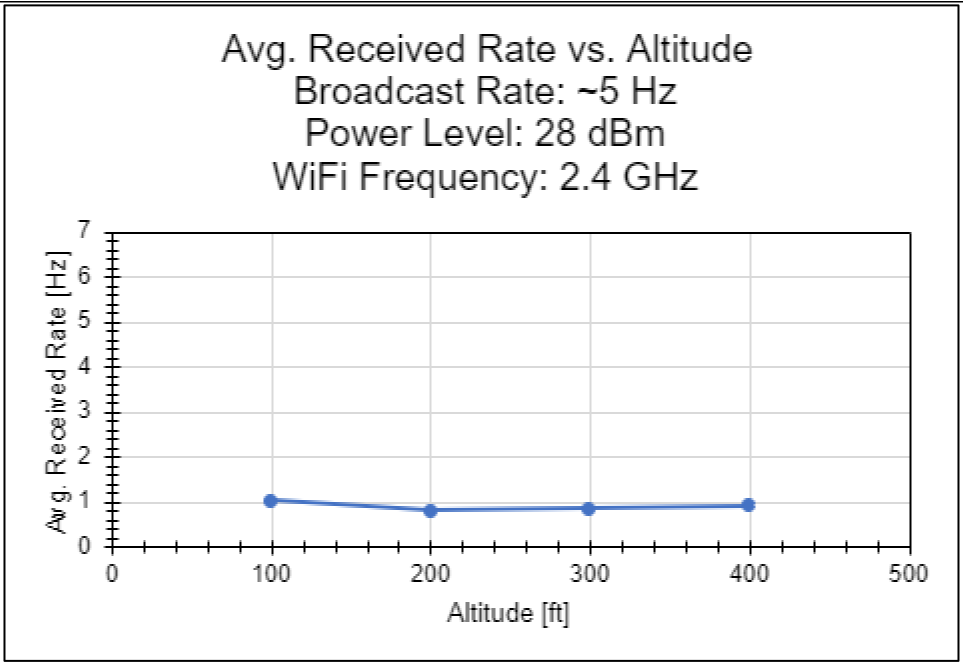

Figure 108. Avg Rate vs Altitude, 2.4 GHz Wi-Fi at ~5 Hz, 28 dBm

Firmware 1	
5 Hz, 2.4 GHz	
Altitude (ft)	Avg Rate
100	1.0126
200	0.7865
300	0.8398
400	0.9111

8.3.1.2 All Wi-Fi Firmware Performance Comparison

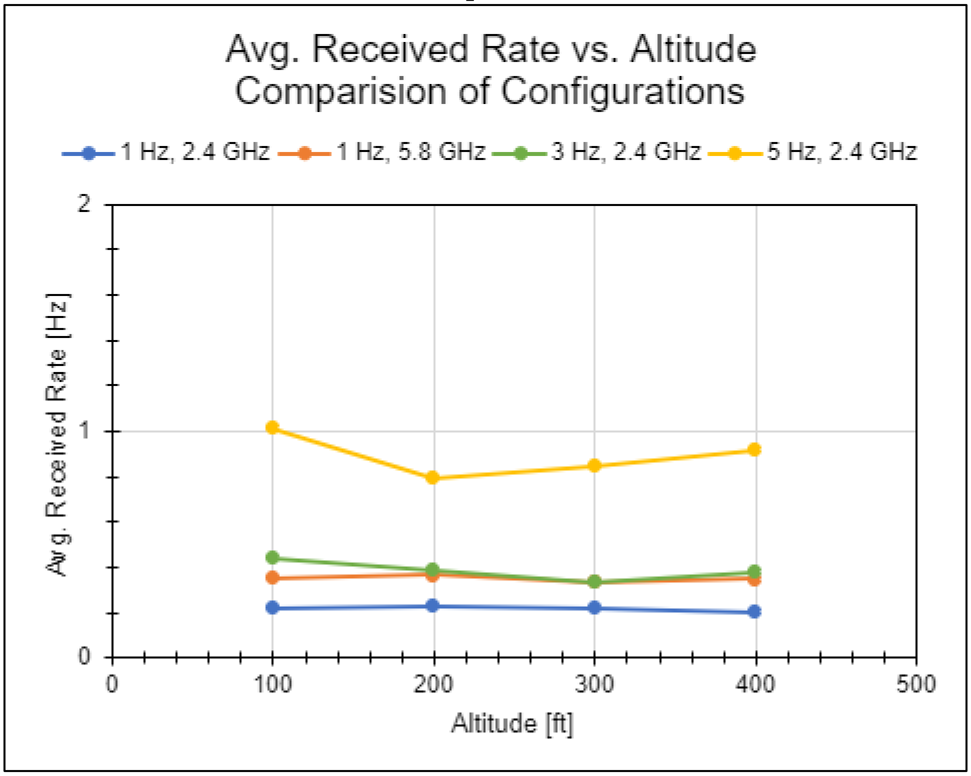

Figure 109. All Wi-Fi Firmware Performance Comparison

Firmware 4		Firmware 7		Firmware 3		Firmware 1	
1 Hz, 2.4 GHz		1 Hz, 5.8 GHz		3 Hz, 2.4 GHz		5 Hz, 2.4 GHz	
Altitude (ft)	Avg Rate	Altitude (ft)	Avg Rate	Altitude (ft)	Avg Rate	Altitude (ft)	Avg Rate
100	0.2125	100	0.3504	100	0.4333	100	1.0126
200	0.2232	200	0.3595	200	0.3857	200	0.7865
300	0.2143	300	0.3295	300	0.3286	300	0.8398
400	0.2	400	0.344	400	0.3714	400	0.9111

8.3.2 Vendor 1 Aircraft Horizontal Range Test Results

The following graphics depict the "received" rate of packets that the RID Receiver (Samsung Galaxy S20 FE 5G) captured during the horizontal range test points for the Vendor 1 Aircraft. The 300 ft vertical test point results (0 m) have also been included in these plots.

8.3.2.1 Avg Rate vs Horizontal Distance for Wi-Fi Configurations

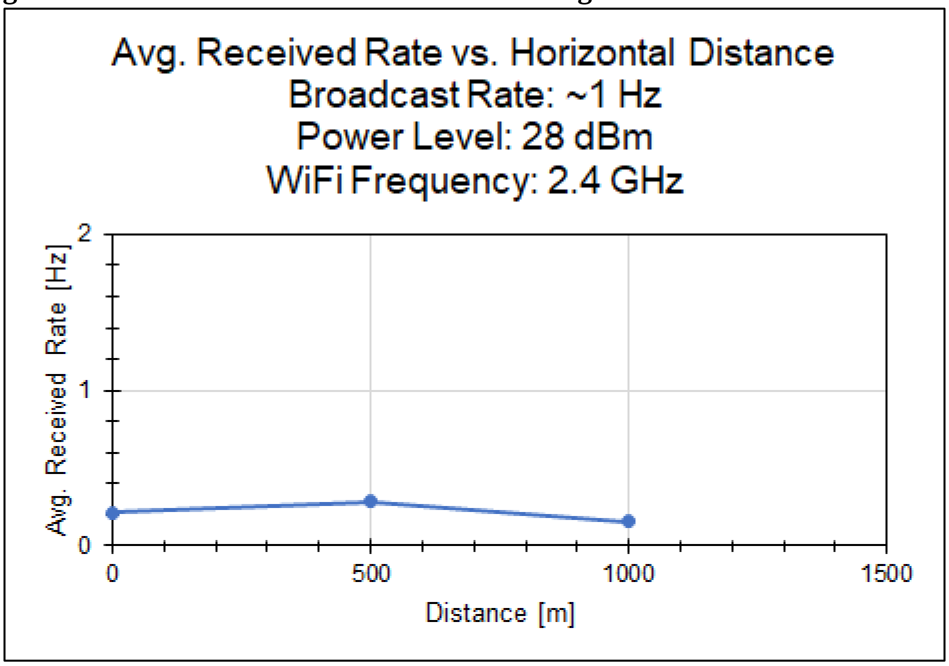

Figure 110. Avg Rate vs Horizontal Distance, 2.4 GHz Wi-Fi at ~1 Hz, 28 dBm

Firmware 4	
1 Hz, 2.4 GHz	
Distance	Avg Rate
0	0.2143
500	0.2857
1000	0.1571

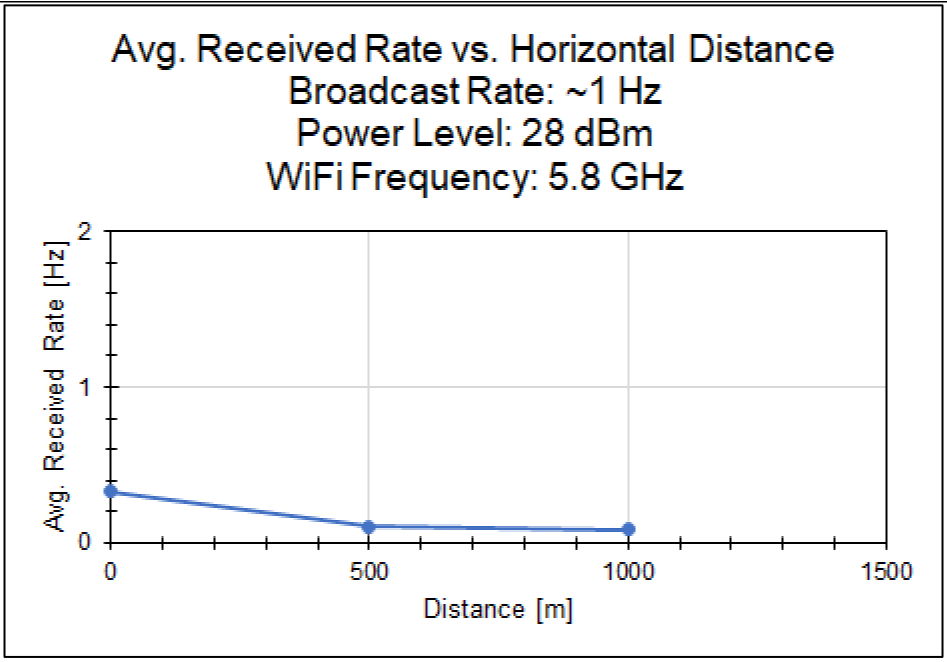

Figure 111. Avg Rate vs Horizontal Distance, 5.8 GHz Wi-Fi at ~1 Hz, 28 dBm

Firmware 7	
1 Hz, 5.8 GHz	
Distance	Avg Rate
0	0.3295
500	0.105
1000	0.0852

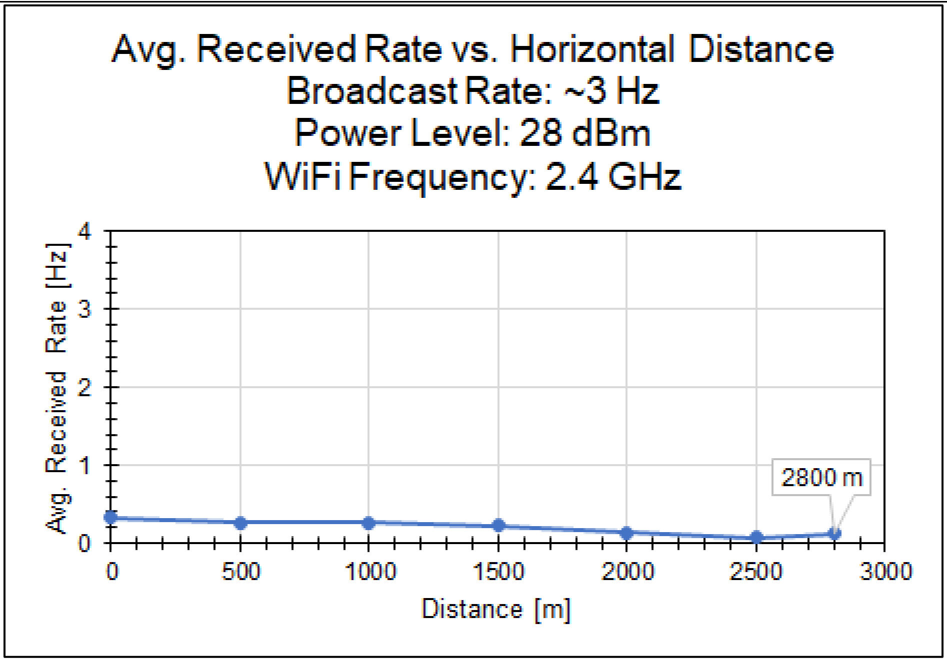

Figure 112. Avg Rate vs Horizontal Distance, 2.4 GHz Wi-Fi at ~3 Hz, 28 dBm

Firmware 3	
3 Hz, 2.4 GHz	
Distance	Avg Rate
0	0.3286
500	0.2667
1000	0.2667
1500	0.22
2000	0.1333
2500	0.0717
2800	0.1245

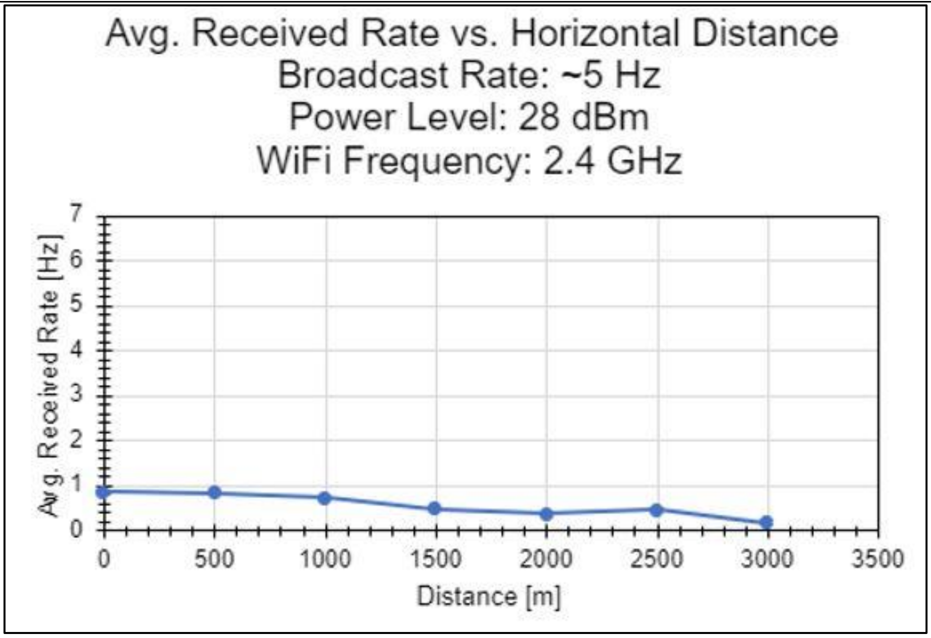

Figure 113. Avg Rate vs Horizontal Distance, 2.4 GHz Wi-Fi at ~5 Hz, 28 dBm

Firmware 1	
5 Hz, 2.4 GHz	
Distance	Avg Rate
0	0.8398
500	0.8353
1000	0.7237
1500	0.4808
2000	0.3519
2500	0.4484
3000	0.1696

8.3.2.2 All Wi-Fi Firmware Performance Comparison

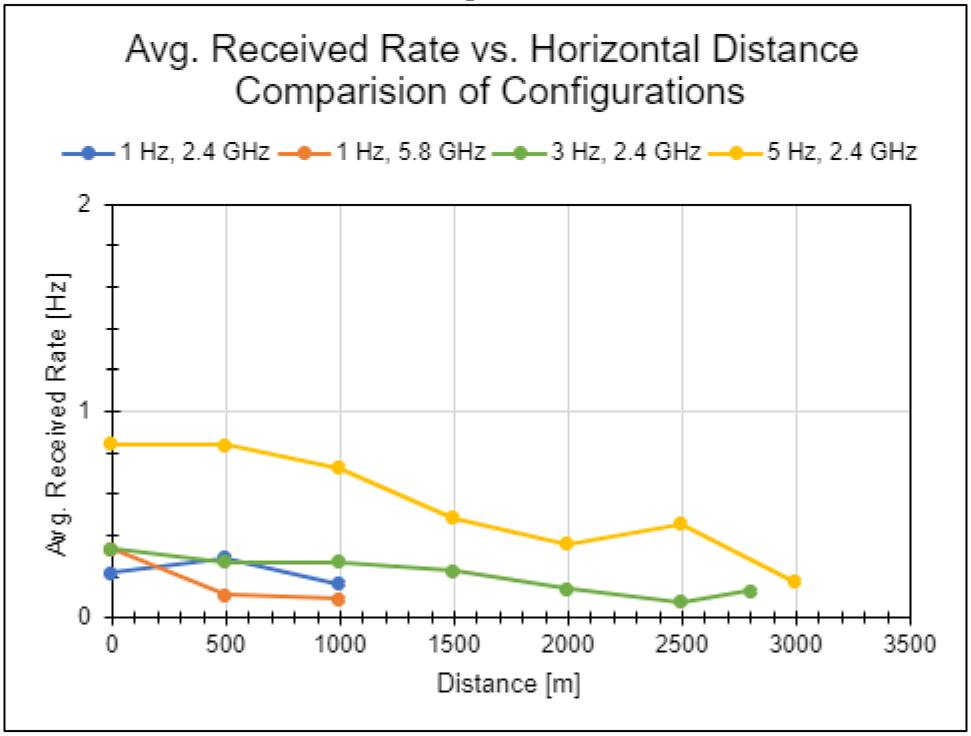

Figure 114. Wi-Fi Horizontal Performance Comparison – All Configurations

Firmware 4		**Firmware 7**		**Firmware 3**		**Firmware 1**	
1 Hz, 2.4 GHz		1 Hz, 5.8 GHz		3 Hz, 2.4 GHz		5 Hz, 2.4 GHz	
Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate	Distance	Avg Rate
0	0.2143	0	0.3295	0	0.3286	0	0.8398
500	0.2857	500	0.105	500	0.2667	500	0.8353
1000	0.1571	1000	0.0852	1000	0.2667	1000	0.7237
				1500	0.22	1500	0.4808
				2000	0.1333	2000	0.3519
				2500	0.0717	2500	0.4484
				2800	0.1245	3000	0.1696

8.4 Bluetooth 4.0/5.0 Validation Testing

During analysis of the Dronetag Mini Bluetooth-enabled RID data, it was found that at a horizontal distance of 500 meters there was a noticeable decline in the average received rate. The rate would then either stay the same or increase at the next test point of 1000 meters. It was hypothesized that the reason for this decline in the rate may have been from the presence of high voltage power lines between the Dronetag Mini and the S20 receiver. A next round of validation testing was conducted to test this hypothesis by recreating the test and then moving 500 meters past the power lines so that they would no longer be a factor in the testing. A broadcast rate of 6 Hz and transmission power of 5 dBm were used. The results generated from this validation test are shown below.

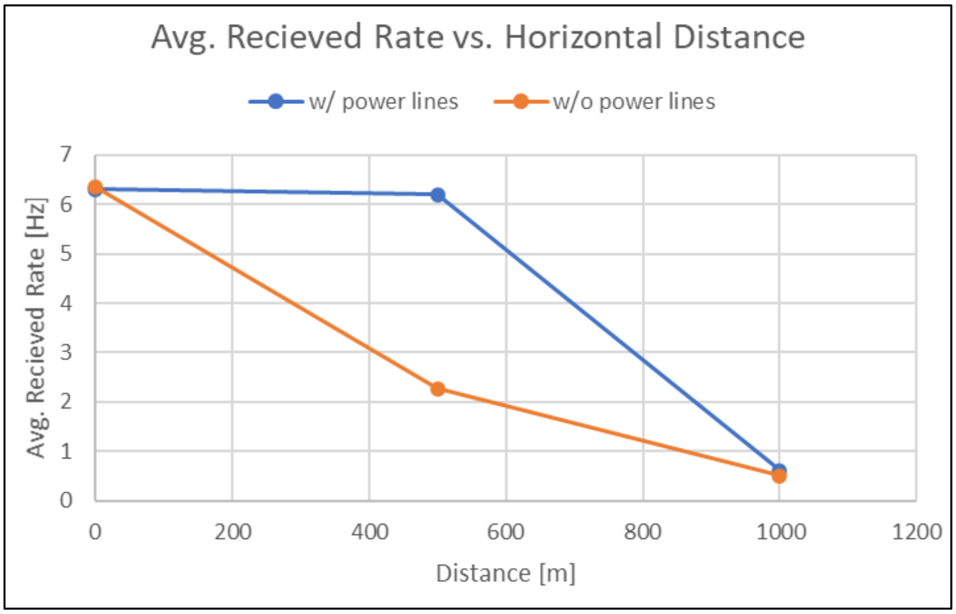

Figure 115. Results of validation testing for Bluetooth 4.0/5.0 performance at 500 meters

The average received rate did not decline with the power lines between the receiver and Dronetag Mini and instead maintained a steady average value of 6 Hz, the full broadcast rate used for the test. When the receiver was moved past the power lines, the average received rate declined sharply at 500 meters, replicating what was seen in the preliminary test even though the power lines were now outside the transmission path. At the time of this report, the team is still investigating the possible cause of this loss in received rate.

9 CONCLUSIONS

9.1 Vertical Test Points

Altitude did not seem to play a significant role in deterioration of the received rate for both Bluetooth and Wi-Fi. However, the Wi-Fi received rate was found to be consistently lower that its transmission rate even at the lowest altitude vertical test point (100 feet) above the receiver – for example: ~5 Hz transmission produced ~1 Hz received rate. The received rate was relatively consistent and did not change as the altitude increased for each firmware. During the vertical tests, Bluetooth 4.0 received at a higher average rate for all broadcast rates and power levels. A change in power level did not correlate to a change in received rate for the Bluetooth test points either.

9.2 Horizontal Test Points

Horizontal test data showed noticeable differences in performance between Bluetooth and Wi-Fi. At 500 m from the receiver, there was a significant decrease in the average received rate for Bluetooth 4.0. The rate decreased to virtually 0 Hz for Bluetooth 4.0 at all broadcast rates while Bluetooth 5.0 only saw a decrease at broadcast rates of 3 Hz and 6 Hz. It is currently unknown what caused this decrease, and further testing will have to be done as discussed previously. The furthest distance recorded for Bluetooth was at 1900 m with a broadcast rate of 1 Hz and a power level of 8 dBm. At this power level Bluetooth 5.0 performed worse than Bluetooth 4.0 at a distance of 1000 m. Bluetooth 4.0 had the same or worse performance for all other horizontal ranges. The only exception being the points right above the receiver as noted in Section 9.1. Overall, Bluetooth 4.0 had a severe decrease in the received rate for the test points past 1000 m. Notably, for 3 Hz and 6 Hz the average rate was near 0 Hz for while Bluetooth 5.0 performed much better. The received rate for all Bluetooth test points was always less than the broadcast rate and many times was less than half of what was being broadcasted at any range.

Horizontal Wi-Fi testing did not show a noticeable difference in the range for 2.4 GHz and 5.8 GHz frequencies. The broadcast rate played a larger role, where increasing the rate to 3 Hz and 5 Hz greatly increased the distance from 1000 m to 2800 m for the 3 Hz broadcast rate and 3000 m for the 5 Hz broadcast rate. The average received rate for all four transmission rates and only approached 1 Hz with a 5 Hz broadcast rate. A direct comparison between the highest broadcast rates for the Wi-Fi and Bluetooth systems shows that the Wi-Fi system had greater range, and the Bluetooth system had a higher received rate. Notably, for 1 Hz broadcast rates the Bluetooth system had a higher range while the average received rate is similar between the two.

10 LESSONS LEARNED

Although it is currently unknown whether the presence of the power lines between the receiver and transmitter caused issues with the receiving rate, further testing will aim to remove this variable. The team will ensure that the receiver and transmitter have adequate separation from any obstacles that could potentially hinder the data transmission. This includes things such as tents, vehicles, and power lines.

During testing, it was noted that one of the main inhibiting factors was the controller battery for the sUAS. The controller battery, while long-lasting, takes a significant amount of time to charge and prohibits testing once it is dead. The use of a second controller would allow the team to continue testing after the first one has died. The team also plans to obtain more batteries and rotate them regularly so that there is always a surplus of charged batteries. The combination of these two things would significantly reduce the chance of testing being inhibited by a lack of batteries for the sUAS.

Future testing may use a different method as well due to the amount of time it took to complete this test. Although the test method allowed the team to accurately determine the range of the receiver, it did not accurately reflect a real world sUAS flight due to the drone being stationary. ASTM has provided testing methods for RID devices depending on the environment the test is being conducted in. Two of these methods can be employed in future tests. The first method was used in this flight test where the drone is positioned at incremental distances from the receiver, and data is recorded for 60 seconds. The second method that the team may employ in future testing is to have the drone start above the receiver and continuously fly away at a constant speed until the datalink is lost or no packets are received. This method is more representative of real-world behavior and will also reduce the amount of time spent testing. In the case of urban or dense-urban testing locations, the receiver will be moved incremental distances while the drone is stationary.