Using Small Unmanned Aerial Systems (sUAS) and Helium Aerostats to Perform Far-Field Radiation Pattern Measurements of High-Frequency Antennas

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***Abstract*— A new methodology is described for performing near-free space far-field radiation pattern measurements of high frequency (HF) antennas utilizing small Unmanned Aerial Systems (sUAS) and helium-filled aerostat balloons for the radar antennas onboard NASA's planned Europa Clipper mission to Jupiter's moon Europa. Adapted from land-based measurements, this test methodology involves hoisting the antenna to be tested above the earth to minimize ground interactions while flying a sUAS with onboard measurement package to map the far field radiation pattern. Initial results producing radiation pattern maps are promising with work remaining to fully adapt fixed VHF measurements to the dynamic HF antenna test setup.**

I. Introduction

It is notoriously difficult to measure three dimensional far-field radiation patterns and free space impedance of high frequency (HF) antennas due to their often physically large size and electrically large wavelengths of operation. Because of these characteristics, typical antenna measurement techniques, such as anechoic chamber pattern mapping and isolation room measurements, are precluded from use in most cases with HF antennas. Computer simulations using electromagnetic modeling software and non-free-space measurements (i.e. over a metallic ground plane with well-known characteristics) are often performed in lieu of physical measurement environment, such as an anechoic chamber or isolation room, that approaches free space operation characteristics.

The Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) instrument is a dual-band sounding radar operating at 60 MHz and 9 MHz. REASON was selected by NASA to be part of the baseline science payload onboard NASA's planned Europa Clipper mission, which would map ice coverage of the surface of Europa, one of Jupiter's moons[1]. For each band of operation, dipole arrays are used for both the transmit and receive antennas. In order to fill this gap of capabilties for measuring free space performance of HF antennas, the Jet Propulsion Laboratory has explored new techniques for antenna measurements. By making use of helium-filled aerostats and autonomous, unmanned aircraft with calibrated radio frequency (RF) measurement equipment, near free space measurements of HF antennas at an outdoor test range can be performed. With the advent and evolution of amateur sUAS aircraft, it is now possible to assemble a cost-effective autonomous aircraft with RF sensors to perform accurate, airborne measurements. Two different dipole antennas are considered for testing using this methodology for REASON: a half-wavelength 60 MHz dipole and half-wavelength 9 MHz dipole, with the main technique development focused on the 9 MHz antenna as the 60 MHz dipole can be measured using traditional techniques. For preliminary test technique development, two electrically similar but non-flight half-wave dipoles are substituted to validate test techniques prior to involving critical hardware. The 60 MHz antenna is a fixed element, half-wavelength dipole 2.1m in length. The 9 MHz antenna is a flexible wire, half-wavelength dipole 16 m in length.

II. sUAS Configuration

The sUAS used for this measurement technique is a DJI S1000 octocopter, a commercial off the shelf platform that has onboard navigation and autopilot-capable avionics. The S1000 is equipped with a custom measurement payload that consists of a Windows PC, USB spectrum analyzer, and a calibrated, wideband HF/VHF biconical measurement antenna.

The sUAS as shown in Fig. 1 contains the added GPS receivers for tracking position as well as generating stable reference signals for the RF equipment, a barometer for altitude measurements and gyroscope.

Figure 1. Picture of sUAS configured with measurement payload with mounted biconical dipole

III. VHF Antenna Measurements

While the primary purpose of developing this airborne measurement system is to enable characterization of HF antennas, it is important to first understand the system performance using a fixed antenna on the ground. It is nearly impossible to get near-free space ground-based measurements of the 9 MHz dipole without interaction from the earth and other objects around due to the separation distance required. The 60 MHz dipole can be measured using both traditional measurement techniques which provide a known baseline measurement to verify operation of the sUAS system before measuring the 9 MHz dipole using the helium aerostat.

A. VHF Antenna Test Configuration

To characterize the 60 MHz dipole, the antenna was placed on a fixed tower 15 m (3λ) above the ground and isolated from the metal tower below by a 3 m section of non-metallic PVC pipe. The antenna is mounted in a vertically polarized orientation to position the null of the antenna towards the ground.

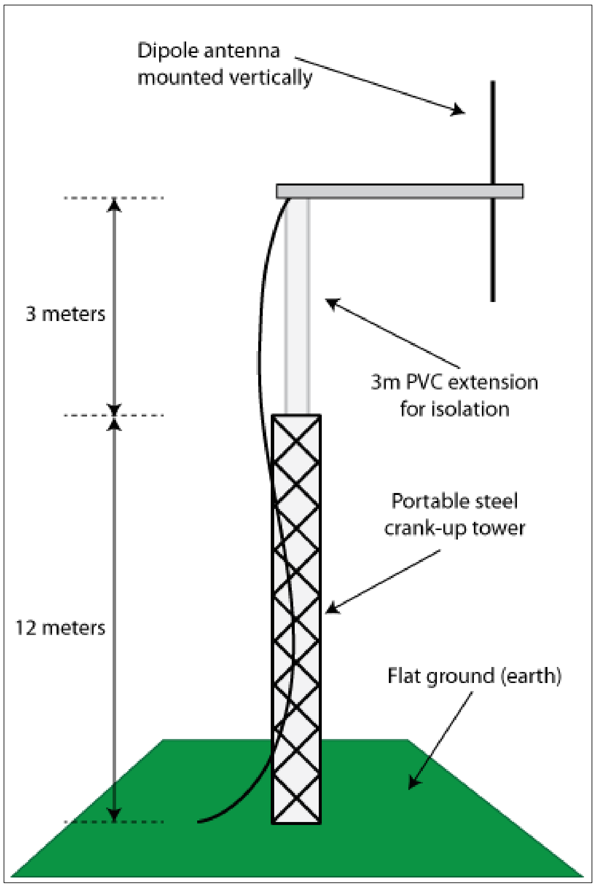

Figure 2. Mounting configuration for VHF dipole antenna

To determine how the height affects the radio frequency (RF) antenna performance, EZNEC antenna software was used to model the radiation pattern and impedance of the antenna at increasing heights above the ground.[3] An elevation of 15 meters is the height where ground effects were no longer seen in the impedance value converting the value expected in free space. The antenna was connected to a signal generator on the ground producing an unmodulated tone at 60 MHz with a 0 dBm output power. The Friis transmission equation (1) from [3] is used to estimate the maximum received power at the sUAS spectrum analyzer using 0 dBm transmit power. Max power received occurs when both the antenna under test and measurement antenna are aligned at anticipated maximum gain. A base-10 logarithm is applied and the equation rearranged in (2) to allow values to be added and subtracted as decibel (dB) ratios instead of absolute wattage values.

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi R}\right)^2 G_r G_t \qquad (1)$$

$$P_r = P_t + G_r + G_t + 20\log\left(\frac{\lambda}{4\pi R}\right) \qquad (2)$$

Using (2) with values P=0 dBm, λ=5 m, R=15 m, G_r=0 dBi, and G_t=2 dBi for a standard dipole, the resulting received power at the sUAS spectrum analyzer is -29.5 dBm. This value is below the maximum input to the analyzer, ensuring a measurement that is not saturating the receiver. With the noise floor around -90 dBm, this provides about 60 dB of signal-to-noise ratio (SNR) and dynamic range for measurements.

B. Collecting Data Using the sUAS

The GPS coordinates of the center of the antenna under test are captured and a flight plan developed for the sUAS that is executed by the onboard autopilot. The pattern measurement flight plan consists of a half-sphere of points spaced 15° in both elevation and azimuth centered about the antenna under test location. The sUAS is programmed to fly to each elevation cut level and complete a full 360° circle at that elevation before proceeding to the next level. Each elevation cut plane has 24 points spaced 15° apart where the sUAS at each to log received power and GPS position to create a three-dimensional signal strength map with 145 total measurement points per half sphere as illustrated by figures 3 and 4. The sUAS maintains position of the measurement antenna towards the antenna under test during flight. The measurement antenna onboard the sUAS was positioned vertically to measure co-polarized performance.

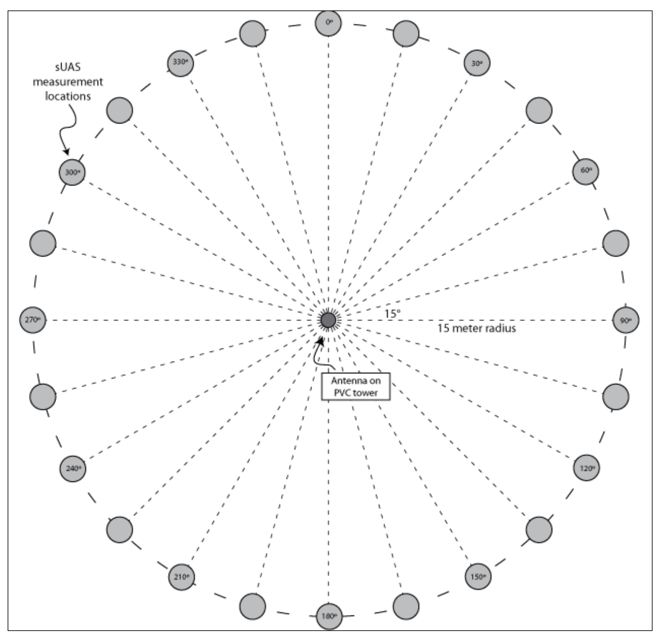

Figure 3. An azimuth cut at 0° elevation of sUAS flight path with 15° point spacing around fixed VHF antenna

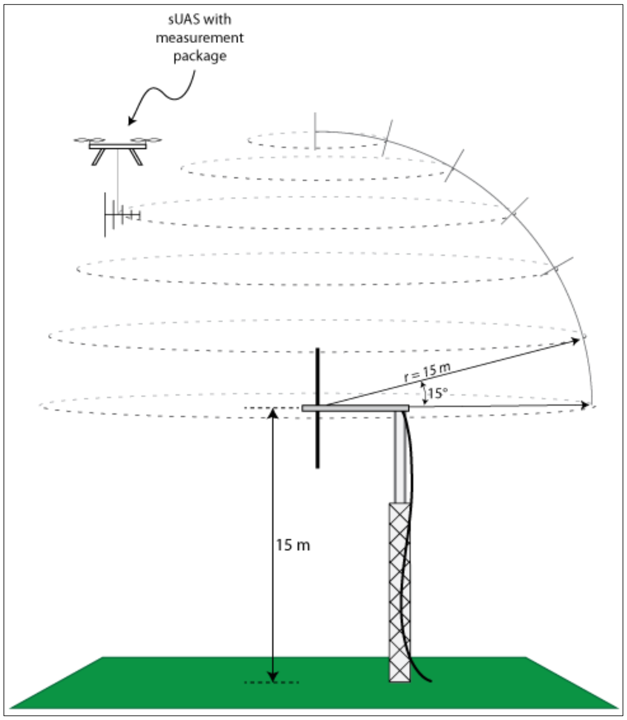

Figure 4. Three dimensional depiction of hemispherical sUAS flight path around fixed VHF antenna

Once a half-sphere flight plan is completed with measurements taken, the antenna tower is lowered and the antenna is rotated 180° to capture the pattern of the other half. This is done because the sUAS cannot fly under the antenna due to the presence of the supporing structure, but can fly over the structure uninhibited.

C. VHF Mapping Results

Received signal strengths were compiled along with positions logged during flight and plotted in MATLAB. The resulting graphs indicate that the 60 MHz dipole measurements are consistent with expected results, with the measured maximum received signal around -32 dBm.

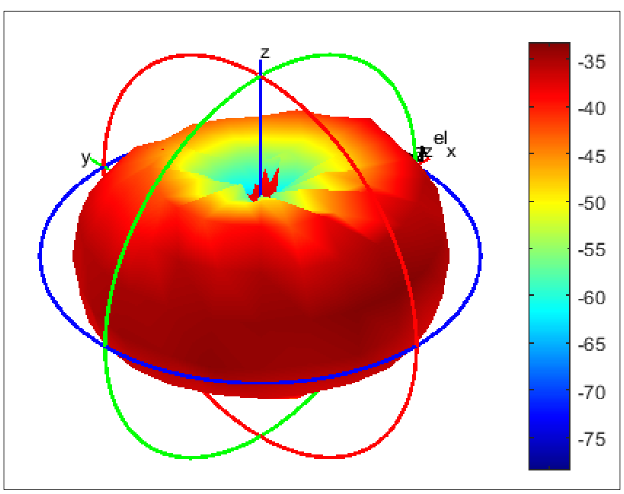

Figure 5. Vertical polarization (co-polarization) signal strength mapping of 60 MHz dipole using sUAS

IV. HF Antenna Measurements

Characterization the far-field radiation pattern of the HF antenna is generally the same process used for the VHF antenna. Due to the wavelength (λ) at 9 MHz (33m), it is not until approximately 100 m (3λ) in elevation above a soil ground that effects on the RF antenna performance are minimized to approach free space behavior. It is possible to perform near-field pattern mapping near the ground at these frequencies with a calibrated ground plane.[4] However, the effects from the ground plane must still be de-embedded and the ground plane presence makes a near free space impedance measurement difficult. The planned testing of the 9 MHz antenna will make use of the sUAS measurement platform to collect radiation pattern data and a helium aerostat platform to hoist it above the earth to minimize ground interaction for near free-space measurements.

A. Aerostat Platform

The aerostat selected, as seen in Fig. 6, for hoisting the 9 MHz antenna assembly is approximately 8 m in diameter and 3 m in height. It uses 93 m_3 of helium to provide approximately 65 kg of payload lift. The airfoil is 152 µm (6 mils) urethane with 300 meters of non-conductive Spectra kevlar tether cord. All components of the aerostat, minus attachment points for tethers, are non-conductive to limit interaction with the antenna.

Figure 6. Helium aerostat being launched at the test range without antenna or measurement equipment attached

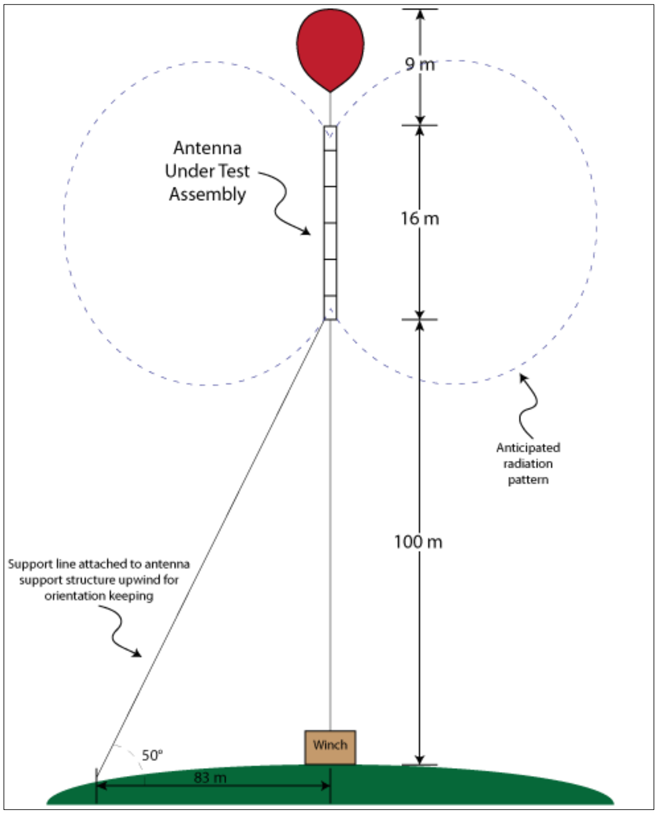

Figure 7. Antenna assembly configuration with aerostat

The 9 MHz antenna is suspended vertically under the aerostat to orient the null of the antenna pattern towards the earth and towards the aerostat above. It is kept in position by a support structure that hangs independently of the aerostat tether line, keeping the antenna hanging vertically if the aerostat is flying downwind of the tether point at the ground.

The dipole was modeled in EZNEC [2] over a soil plane where it was determined that a minimum altitude of approximately 100 m was necessary to diminish ground effects on the antenna impedance. It is important to keep the top of the aerostat under 150 m (500 ft) altitude as this is the maximum altitude that a tethered or moored balloon can be flown without special authorization from the Federal Aviation Administration.[3]

B. HF Antenna Airborne Measurement Equipment

A standalone transmitter and vector network analyzer (VNA) are housed onboard the antenna support structure in a custom hard-sided transport case. The equipment case is battery powered and houses a wireless access point (WAP) for remote control via a Wi-Fi link back to the ground. The transport case is mounted at the center of the antenna near the feedpoint to minimize the coaxial cable run to the signal source feeding the antenna. This setup was chosen to prevent having to run control cables back down to the ground which may interact and couple with the antenna under test, altering the test results. The equipment enables calibrated S_{11} measurements and provides a stable 9 MHz transmitter source for far-field radiation pattern mapping.

Figure 8. Transport case housing a vector network analyzer, wireless access point, micro PC, signal generator, and battery.

The measurement equipment houses a micro Windows 10 PC that interfaces with a GPS receiver and three-axis inertial measurement unit (IMU) containing a gyroscope, accelerometer, and magnetometer. These parameters are logged continuously during flight for post-processing to track and correct any movement which may affect signal measurements i.e. swaying that may produce polarization mismatches.

The embedded signal generator is connected to a small amplifier, producing +13 dBm of output power at 9 MHz to the antenna under test. Using (1) and (2) as part of the same process for the VHF antenna, this additional power requirement was determined because of the reduced sensitivity of the receiving antenna at HF frequencies. Using the parameters from the HF antenna test flight plan for (1) and (2), a maximum received signal strength of -31 dBm is expected, also providing approximately 60 dB of SNR for measurements at 9 MHz.

C. HF Antenna Test Flight Plan

The flight plan for the aerostat setup is a cylindrical mapping of points, unlike the spherical mapping performed with the VHF antenna. The sUAS cannot fly directly under the aerostat because of tether lines and cannot fly over the aerostat due to maximum height restrictions by the government on sUAS flights [5].

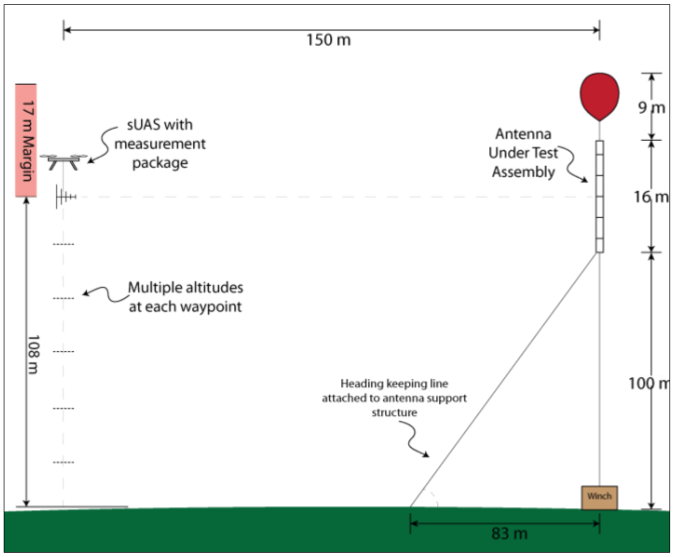

Figure 9. Configuration of aerostat with sUAS parameters

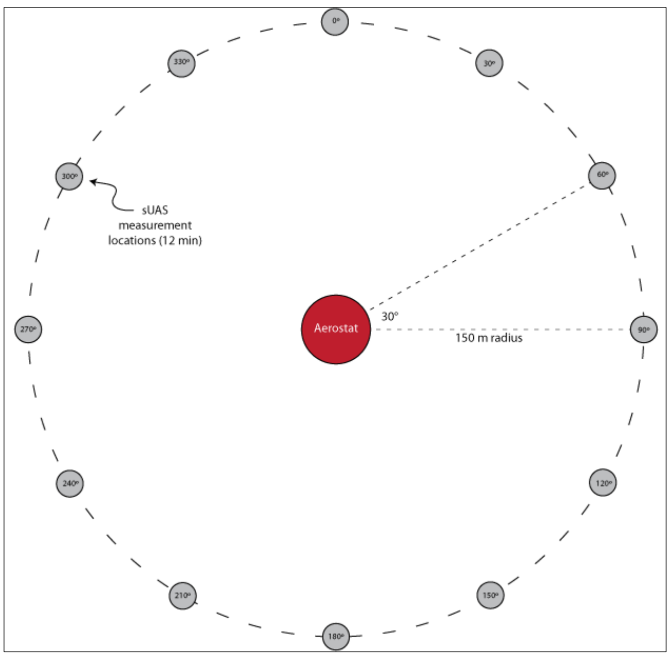

Figure 10. Azimuth flight pattern for sUAS HF testing

Measurements are being taken approximately 10 times further away than the beginning of the far field. The beginning of the far field has been determined using (1) where antenna length D is 16 m, and wavelength of operation λ is 33.3 m. This gives a far field distance *R* of 15.37 m. However, condition (2) and (3) must also be met.

$$R = \frac{2D^2}{\lambda} \quad (1)$$

$$R >> D \quad (2)$$

$$R >> \lambda \quad (3)$$

With the measurement distance of 150 m for *R*, conditions (2) and (3) are satisfied with *R* being approximately 10 times larger than *D* and 5 times larger than λ at 33.3 m. Because the main interest of the radiation pattern mapping of the HF antenna is focused on determining the gain and rolloff characteristics of the central null of the pattern, elevation cuts are measured in 30° increments around the antenna. The sUAS is taking measurements at the same elevation of the center of the antenna and then in 5 m increments down to ground level in a vertical column. This measurement is repeated around antenna assembly, keeping it at the center of the circle formed.

D. Sources of Error & Minimization

Although every effort is made to monitor weather patterns and perform testing when the most ideal conditions are available, it is inevitable that during testing local winds vary, leading to movement in the aerostat platform and drift for the sUAS. During flight, all position data such as roll, pitch, yaw, latitude, longitude, and altitude are being constantly logged for further analysis in post processing. It is anticipated that during post processing, position data from both the aerostat and sUAS can be used to account for polarization mismatch losses i.e. the measurement antenna and antenna under test are angled with respect to one another due to winds. It is also anticipated that corrections to antenna measurement data can be made using position data from both the aerostat and sUAS for unexpected variations in relative position during a measurement i.e. recording a measurement point off target due to a wind gust.

V. Conclusions

The sUAS antenna far-field measurement system has shown to be a viable option for ground based low frequency antennas and will be a viable option for performing airborne far-field pattern measurements of an HF antenna. If error sources are managed and accounted for during the measurement process, accuracy will be maintained and results admissible.

Acknowledgement

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