UAV-based Antenna and Field Measurements

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***Abstract*—This paper overviews the emerging antenna and EM field measurement strategies based on the modern Unmanned Aerial Vehicle (UAV) technology. UAVs are currently being exploited as source/probe antenna positioners in various applications from HF to microwaves. Several contributions from all-over the world will be discussed in terms of measurement approach, RF setup and positioning strategies. A measurement example at 350 MHz highlights the importance of position and orientation accuracy in the post-processing chain.**

I. MOTIVATION AND STATE-OF-THE-ART

The antenna pattern characterization becomes a very challenging task both at low operating frequencies (from HF to UHF) and when large radiating structures are involved i.e. either large antennas or antennas installed on large platforms.

In the low-frequency range, the quality of the anechoic chamber absorbers becomes unacceptable for accurate measurements even if either large chambers or near-field facilities are available. Outdoor test ranges can be suitable for relatively small antennas and arrays, however, the AUT mounting configuration will be generally quite different from the operative installation conditions.

In the case of receiving antenna systems with enough sensitivity, the in-situ antenna pattern measurement can be performed exploiting astronomical sources [1] or satellites. Otherwise, in-situ antenna measurement can be performed by means of RF test sources or receivers mounted on balloons or helicopters [2], [3]. These solutions allow for very large test distances satisfying the far-field conditions. Nowadays, the emerging technology of Unmanned Aerial Vehicles (UAVs or drones) is being exploited to perform the same measurement operations at a lower cost and with higher flexibility.

The concept of a UAV-mounted far-field flying test source has been already exploited by many researchers [4]-[11]. Single antenna elements (dipole, biconical, log-periodic) have been measured in [4], [7], [8]. Digitally-beam-formed arrays for radio astronomy operating at VHF have been considered in [5], [10] in terms of both embedded element and array patterns. Small dishes (5-6 m) have been characterized in [6] and [11] at VHF and UHF, respectively. An HF radar oceanographic antenna has been instead measured in [9].

Fig. 1. Micro Unmanned Aerial Vehicle (UAV) equipped with RF synthetizer, dipole and differntial GNSS receiver.

The most common flying test source configuration is based on a multi-rotor platform (see Fig. 1) equipped with a RF transmitter and an antenna, which should be properly selected/designed and mounted according to the required measurement conditions and scan strategy. A small airplane platform has been instead adopted in [8]. The high flexibility of UAVs relies on their autonomous GPS-controlled navigation, which is exploited to perform completely automated measurements. Generally-speaking, a scan strategy defined with both geographic coordinates and heading angles (yaw orientation angle from geographic North) is uploaded to the UAV before take-off. The flight duration is in the order of 10-15 minutes for battery-powered multi-rotors. Fixed-wing

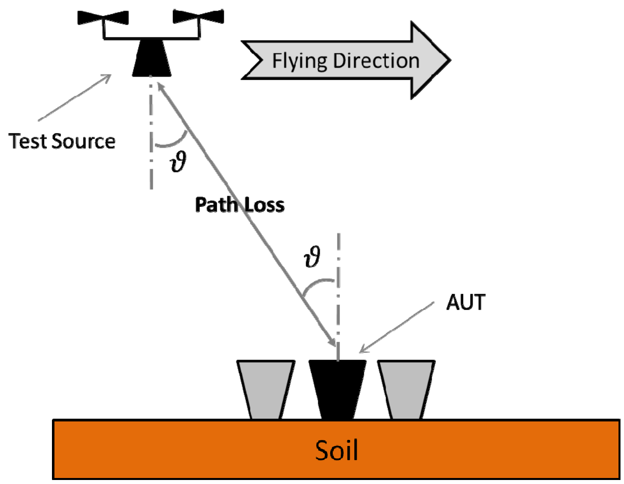

Fig. 2. Scan strategy example for UAV-based flying test source.

architectures and fuel-powered UAVs can instead fly longer. After landing, both position and orientation data, recorded from the onboard GPS and Inertial Measurement Unit (IMU), respectively, are available for post-processing.

The accuracy of the raw GPS position data is in the order of few meters, whereas the orientation accuracy is generally within 2°. These uncertainty levels can be acceptable for many applications. However, in order to improve the measurement quality, a motorized total station (topographic optical instrument) tracking a retroreflector installed on the bottom of the UAV has been adopted in [4]. This solution provides an accuracy of a few millimeters on the UAV position, however, it is not very practical in terms of set-up time. Moreover, the target can be lost when the sunlight is very bright. A Post-Processing Kinematic (PPK) Global Navigation Satellite System (GNSS) has been instead exploited in [5] and [11] in order to obtain a more robust positioning solution with an accuracy of a few centimeters. It is composed of a master station on the ground and an additional dual-frequency receiver (OEM module) on the UAV.

As far as the onboard RF generator is concerned, a single-frequency continuous-wave PLL-based synthesizer is adopted in [4]-[9]. Comb and noise generators are instead used in [10] and [11], respectively: these two solutions allows for a more efficient simultaneous multi-frequency measurement. The receiving equipment which is connected to the AUT port ranges from spectrum analyzers in zero span mode [4],[6], [8] to the more complex radar [9] and radio-astronomical digital receivers [5], [7], [10], [11].

Broadcast tower characterization [12], [13], propagation measurements [14] and field mapping [15] have been instead performed by means of calibrated receiving equipment mounted on UAVs. In general, the spurious radiation of the UAV electronics should be shielded in order not to affect the measurement. On the other hand, in high power applications, the UAV electronics should be able to operate in presence of strong EM interferences.

Even more challenging applications have been envisaged in [16]-[18]. A revolutionary UAV-based near-field test facility was proposed to characterize the radiation pattern of satellite ground stations and antennas installed on large structures like aircrafts. The UAV RF payload will feature a wireless link to the ground with frequency translation in order to recover the phase of the measured signal. Advanced near-field to far-field transformations which can deal with irregular near-field scans are necessary since the accuracy of the UAV trajectories (few meters) is generally defined by the onboard navigation unit, which uses the GPS signal as input. The position and orientation of the UAV-mounted source/probe will be however measured with three or more laser trackers. The accuracy of these systems is typically below 0.1mm at a measurement distance of 30m, allowing for a measurement frequency range up to 50 GHz.

II. Result Example

An example of far-field UAV-based pattern measurement is discussed in this section. The AUT is the dual-polarized Vivaldi element of the Sardinia Array Demonstrator (SAD) [19], designed as an Italian contribution to the development of the international Square Kilometer Array (SKA) low-frequency radio telescope [20].

According to its operative conditions, the ground-based AUT is oriented toward the zenith. Its width and height are both equal to about 1.5 m. The flying test source in Fig. 1 performed a linear flight at a constant height of about 70 m from the AUT. The flight direction was selected in order to scan the E-plane of the AUT. The test source *E*-field orientation was set parallel to the flight direction in order to excite the co-polar component. It should be pointed out that the UAV navigation control system does not allow to set an arbitrary orientation of the UAV nadir direction with respect to ground. The perpendicular direction is automatically maintained within about 10° during the overall flight. The discussed measurement configuration can be sketched as in Fig. 2. It is apparent that both the test source pattern and the path loss are not constant during a linear scan [4]. These contributions should hence be removed from the power pattern measured at the AUT port using the technique reported in [21].

The post-processed E-plane co-polar antenna pattern at 350 MHz is shown in Fig. 3 with the dashed green line. It has been obtained using both the PPK-GNSS position data and the IMU orientation data [22]. Such a measured pattern agrees within 1 dB with the simulated data reported with the black solid line. This remarkable result has been obtained because both measurement and simulations have been performed in the same operative conditions i.e. radiating element placed over the soil ground. The same measurement would not have been possible with other consolidated systems without perturbing the soil effect.

Fig. 3 also shows an extracted measured pattern which does not take into account the real orientation of the UAV (cyan-dash-dotted line) i.e. the UAV nadir direction is considered as perpendicular to the ground. In this flight, the nadir direction of the UAV measured by onboard IMU was actually about from 5 to 10° tilted away from the ground perpendicular. It can be

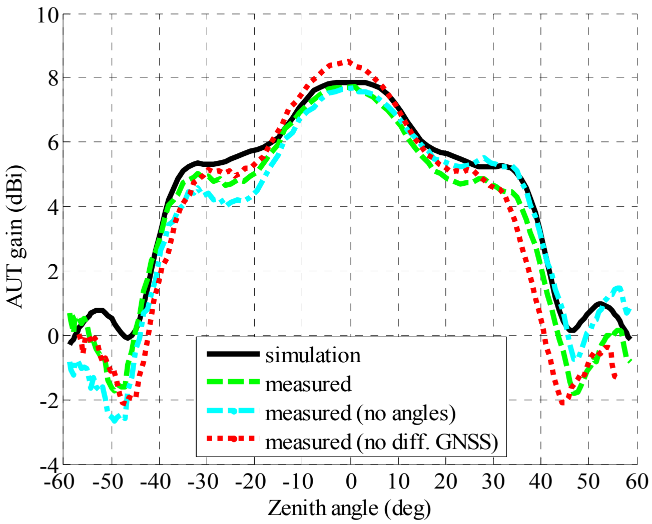

Fig. 3. Example of E-plane co-polar antenna patterrn at 350 MHz. Measurement extraxcted from: PPK-GNSS and onboard IMU data (green dashed line), PPK-GNSS data only (cyan dash-dotted line), onboard GPS and IMU data (red dotted line); simulation (solid black line).

observed that a significant pattern asymmetry appears if such an orientation information is neglected. As reported in [23], the heading information instead mainly affects the cross-polar data.

The red dotted-curve in Fig. 3 has been obtained using the onboard GPS position (metrical accuracy) instead of the PPK-GNSS solution one (centimetrical accuracy). The increased discrepancy confirms the necessity of using UAV positioning system that are more accurate than the GPS stand-alone positioning.

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