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Impact of the Rotor Blade Rotation of a UAV on an Installed Field Probing Antenna

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Abstract

In recent years, in-situ antenna measurements employing unmanned aerial vehicles (UAVs) gained increasing interest. Related to this development, questions arise on the performance and accuracy of UAV-based measurements where the correction of the probing antenna influence, possibly dependent on moving parts of the UAV, is a critical point in particular in near-field measurements. This contribution deals with the field modulation caused by the rotating rotor blades, which has to be taken into account for precise measurements. A characterization of the arising modulation through measurement results is presented.

1 Introduction

Antenna near-field (NF) measurements in combination with a subsequent near-field to far-field transformation (NFFFT) are a powerful technique for the characterization of an antenna under test (AUT) [1]. While NF measurements are traditionally performed in anechoic chambers, in-situ measurements, especially employing unmanned aerial vehicles (UAVs), gained more interest in the recent years. With their mobility and flexibility, UAV-based antenna measurements open up new opportunities such as the measurement of large antennas or antennas installed in their operational environment [2, 3]. It is well known that the correction of the probe antenna's influence on the measured field data is crucial for exact results from NF antenna measurements [4]. Within UAV-based measurements, the UAV itself must be considered as being part of the probe antenna. This implies that the probe itself is not static and has rotating parts which may influence the pattern of the isolated probe antenna, not only in NF measurements, but also in FF measurements. One way to decrease the mutual coupling between the probe and the UAV rotors is by spatial separation. Such a separation, however, is not always possible due to the UAV size and the mass distribution of the overall setup. In general, it is best for the flight dynamics of a UAV if its center of gravity coincides with the geometrical center between the motors [5].

Every UAV has a radar "fingerprint" that is almost unique due to its number of rotors, their rotation speed and the copter shape. There are several publications on the influence of the rotors on the radar signature of a UAV [6, 7]. Most works deal with the analysis of the radar micro-Doppler effect to identify UAVs and distinguish them from other flying objects or birds [8]. However, there are not many papers that investigate the UAV rotors' influence on electromagnetic radiation in a general way. Therefore, we investigate the impact of the rotor blade rotation on the characteristics of an installed probe antenna and illustrate the corresponding field modulation. It is obvious that the exact influence and differences in the arising modulation effect depend on the type and radiation characteristics of the used probe antenna. However, the general occurrence and characterization of the rotor-caused modulation and the conclusions derived from the measurements give valuable insights towards an improved characterization and understanding of UAV-based probing systems.

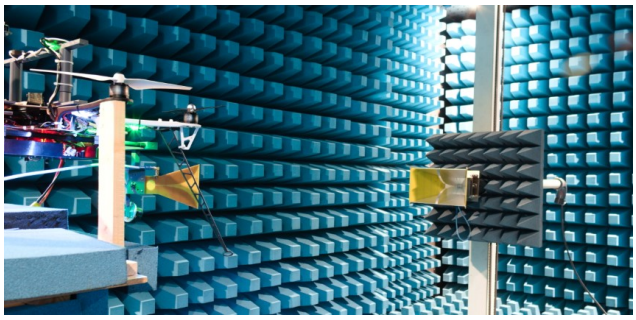
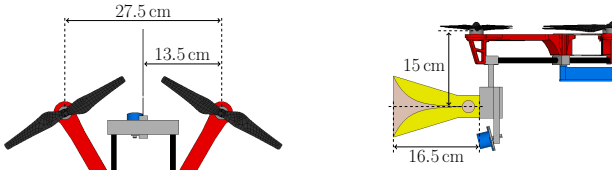


Figure 1. The measurements were performed in an anechoic chamber. The UAV, including the Vivaldi probe antenna, was mounted on a wooden holder. The horn antenna on the opposite was used in combination with a signal analyzer to measure the field.

2 Measurement Setup

Measurements were performed in an anechoic chamber, where a multicopter with six rotors was mounted on a wooden holder, including a PCB-fabricated Vivaldi antenna that is used as field probe in UAV-based NF measurements. The Vivaldi antenna was fed from a signal generator with an unmodulated, time-harmonic signal of 2.45 GHz. A horn antenna was mounted as field probe at a distance of 1.1 m



(a) (b)

Figure 2. The Vivaldi probe antenna is mounted at the front of the copter. The top (a) and side view (b) show how the antenna is mounted below the rotors.

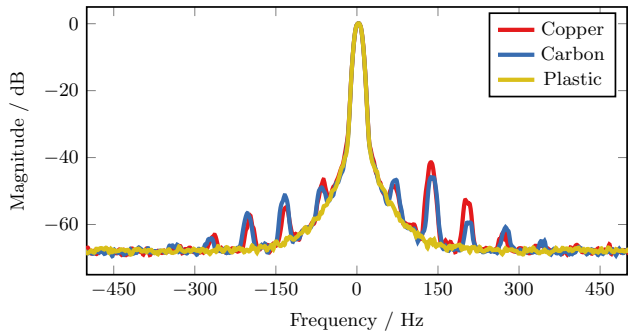
from the Vivaldi antenna. It was connected to a signal analyzer of type R&S FSIQ [9]. The setup is shown in Fig. 1, where both antennas are depicted in vertical polarization. The Vivaldi antenna was rotated by 90° for some measurements to achieve horizontal polarization. For these measurements, also the horn antenna was rotated such that the polarizations of both antennas were always aligned.

The Vivaldi antenna itself is fixed at the front of the copter but with some parts below the rotors. The position is a trade-off between flight performance and spatial separation of the antenna from the copter. Fig. 2 shows a schematic of the copter including dimensions.

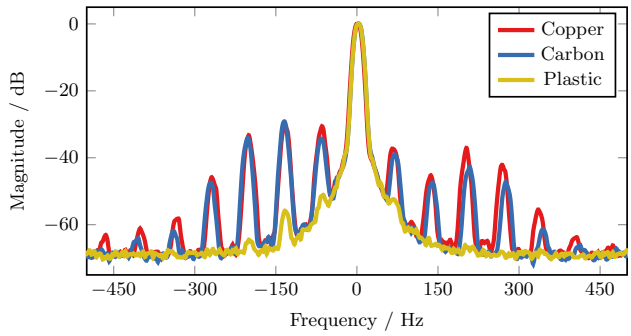
3 Rotor-induced Field Modulation

The impact of the rotating rotor blades was measured at 2.45 GHz while the results have been double-checked with measurements at other frequencies. The copter has six rotors but only the two at the front were spinning during the measurements, which was due to power management and mechanical stability of the holder. However, measurements with the two front rotors and also all six rotors have been compared and revealed that the influence of the rear rotors is negligible for the presented measurements. The two active rotors spinned at a constant rate of 34 $^1/_s$, while the frequency spectrum was measured with the signal analyzer.

For the characterization of the influence of the rotor material, dieletric glass-fiber-based rotors and carbon-fiber rotors were used as both rotor materials are common. Since the exact conductivity of the carbon-fiber material is not known, some of the dielectric rotors were coated with copper tape to include a "worst case" scenario of conducting rotors. Figure 3 (a) and (b) show the measured frequency spectra for the different rotor types for vertical and horizontal polarization of the Vivaldi antenna, respectively. Every spectrum is an average of 15 subsequent measurements. The frequency axis is shown relative to the center frequency of 2.45 GHz and the average noise level of the measurement setup was about −130 dBm. The spectrum without spinning motors/rotors contains only the peak of the carrier frequency while there are additional frequency peaks arising when the rotors are spinning. These additional frequency peaks characterize the modulation that is caused by



(a)



(b)

Figure 3. The comparison of the frequency spectra for the different rotor types reveal the impact of different rotor materials. While rotors made of copper (red) and carbon-fiber (blue) have a modulation effect, the impact of the plastic rotors (yellow) is negligible. Also the polarization of the antenna, whether being vertical (a) or horizontal (b), is of importance. The plots show the offset frequencies around the center frequency of 2.45 GHz. The shown spectra are averages of 15 consecutive measurements.

the rotating rotors. In both plots, the single frequency peaks appear at 68 Hz and multiples thereof with a maximum deviation of about ±5 Hz which may be due to the measurement resolution bandwidth of 10 Hz. 68 Hz is exactly twice the rotation speed of the spinning rotors. The reason for the double frequency to appear in the spectrum is that each rotor comprises two blades. The modulation itself is a combination of amplitude and phase modulation where the latter partially causes the harmonics.

In fact, the measurements reveal that the copper-coated rotors have the highest impact on the field modulation of all investigated rotor materials, where the effect of the carbon-fiber rotors is almost similar. In contrast, the impact of the dielectric rotors is negligible. The difference, however, between the vertical and the horizontal polarization of the Vivaldi antenna is significant. For the vertical polarization, the highest modulation frequency peaks are about −40 dB lower than the carrier frequency peak while they are only −30 dB lower for the horizontal polarization. It can also clearly be seen from Fig. 3(b) that higher harmonics are more present for the horizontal polarization of the antenna. It was expected that the influence of the rotors is lower for

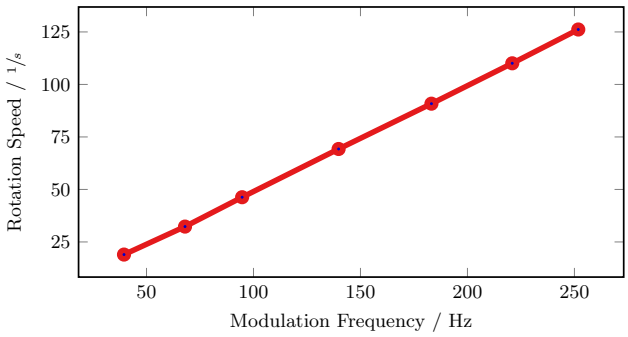


Figure 4. The modulation frequencies caused by the rotors fit almost perfectly with the rotation speeds and the theoretical frequencies that can be calculated from it.

the vertical case since the antenna's polarization is perpendicular to the rotation plane of the rotors. Multiple measurements and measurements at different carrier frequencies have shown that the modulation effect is consistent and repeatable.

Further, the relation between the observed modulation frequencies and the rotation speed was investigated. For this, the rotor speed was gradually increased between the measurements, while it was constant during a single measurement. The rotation speed of the rotors was measured with a handheld revolution counter. The data show clearly that the modulation scales with the rotation speed, i.e., the modulation frequencies match the rotation speed and multiples thereof as it is the case in Fig. 3. The relationship between the rotation speed and the frequency peak closest to the carrier is depicted in Fig. 4. With the knowledge of this relationship, it becomes possible to compensate for the rotor-induced modulation in UAV-based antenna measurements. For this, the rotation speed of the motors of the UAV must be known which can be either read out directly from the motors or be calculated from the motor control signals.

4 Conclusion

The modulation caused by rotating rotor blades of a UAV on the measurement signal of a probe antenna was investigated. It was shown that conducting rotor materials, such as copper and carbon-fiber, have a larger impact on the measured signal in comparison to dielectric materials, such as glass-fiber rotors, whose impact is negligible. However, it also becomes clear that even though for conducting rotors the modulation effect is present in the frequency spectrum, it is not dominant. It can, therefore, be concluded that the rotor-caused modulation in UAV-based measurements certainly has an impact on the accuracy of the measurements themselves, but also that a compensation is only necessary if the overall error level is below the induced modulation sidebands. Within this consideration the polarization of the antenna with respect to the rotation plane of the rotors must be taken into account.

Acknowledgements

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