Aircraft Antenna Placement Investigation Utilizing Measured Sources in Simulation Model

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***Abstract*—An antenna placement investigation for a hypersonic aircraft model is presented. A method is proposed to process measured antenna data as equivalent sources in a simulation model. This method is beneficial especially due to the often limited availability of exact design data of commercial antennas due to IP reasons. Therefore, realistic and reliable simulation models of such antennas are difficult to implement. With the proposed approach, expensive back-engineering becomes redundant and is replaced by basic measurements. A comparison with a full-simulation model verifies this approach.**

I. Introduction

Antenna siting or antenna placement investigations on large host platforms like airplanes, ships, cars, or satellites have become more important over recent years. The growing number of communication standards as well as the increasing variety of antennas used require such investigations to ensure a correct functioning and unimpeded interoperability of all communications, radar, or navigation systems on the respective platform. Various simulation approaches have been employed to address this problem [1]–[4].

Challenges arise when commercial antennas are to be used in antenna placement investigations, however, the exact design parameters (electrically and mechanically) are deliberately kept secret due to IP reasons by the manufacturer. Based on a simple datasheet it ist difficult to design a reliable and trustworthy equivalent simulation model. In this case, it is a valid option to employ measured antenna data as radiation sources in a simulation model. This method has proven to be necessary and besides easier and more accurate than reverse engineering antenna design data. Consequently, time and money consuming back-engineering to obtain the crucial antenna information to put into the simulation model is needless and is replaced by simple measurements. The authors of [4]–[7] make use of this approach and utilize measured antenna data as equivalent radiation sources in numerical simulation models.

In this work, an antenna placement investigation is performed to analyze the influence of the host platform on the overall radiation characteristic of an antenna and to obtain an optimal mounting position on the example of a hypersonic glider in the context of the HEXAFLY-INT project. The HEXAFLY-INT is an international research project under the lead of ESA-ESTEC with the goal of designing, fabricating, and free flight testing an unpowered hypersonic glider with several breakthrough technologies on board. This hypersonic glider, the experimental flight test vehicle (EFTV), is depicted in Fig. 1. The test platform with a length of about 4 meters can achieve a speed of up to Mach 8 during its cruise within the atmosphere. Results from this project shall proof the feasibility of high-speed civil long-distance transportation [8], [9].

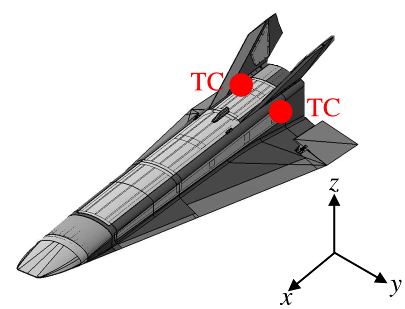

Fig. 1. Hypersonic flight vehicle EFTV with indicated mounting positions for two TC antennas on the rear end of the fuselage.

A ground station is using a telecommand (TC) communication system to remotely control the EFTV glider's flight path. For this purpose, two TC antennas are placed on the EFTV vehicle as indicated in Fig. 1. This work is motivated by the objective, to investigate and analyze the structural impact of the hypersonic aircraft on the radiation characteristic of two TC antennas being mounted on it. Since the unimpeded and reliable TC communication link is vital for a successful flight test. A more thorough investigation, detailed explanations, and additional results of this antenna in-situ performance analysis for the HEXAFLY-INT project can be found in [10].

The TC antenna used here is an airborne instrumentation antenna by TECOM Industries with a center frequency of 450 MHz. It is specially designed for such extreme environmental conditions of hypersonic flights, e.g. on atmospheric rockets or tactical missiles. This model is of inverted-f type, linearly polarized, and it was chosen by the project partners to be used on the EFTV for the TC communication link. Due to

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the lack of information concerning this TC antenna in terms of material parameters or detailed design information, a reliable and trustworthy simulation model of this antenna is difficult to implement.

In this study, the influence of the host platform on the radiation characteristic is investigated. In an initial step, an isolated TC antenna is measured on a large ground plane in the measurement chamber. Subsequently, these radiation characteristics are transformed into a near-field radiation source through a spherical wave expansion (SWE) [11], [12]. Afterward, these equivalent sources are employed in a simulation model and placed on the respective host platform. First, they are placed on a cylinder structure with approximate dimensions of the EFTV and finally on the EFTV itself.

Section II covers the measurement setup and results of the stand-alone TC antenna, whereas Section III deals with its installed performance on the cylinder and the EFTV. Finally, in Section IV the results are summarized and the employed method evaluated.

II. Antenna Measurements in CATR

This section covers the measurement setup and results of the stand-alone TC antenna. The German Aerospace Center (DLR) in Wessling, Germany, operates a dual-reflector compact antenna test range (CATR) measurement facility for antenna and radar cross-section (RCS) measurements. A picture of this CATR is seen in Fig. 2. The CATR is located inside

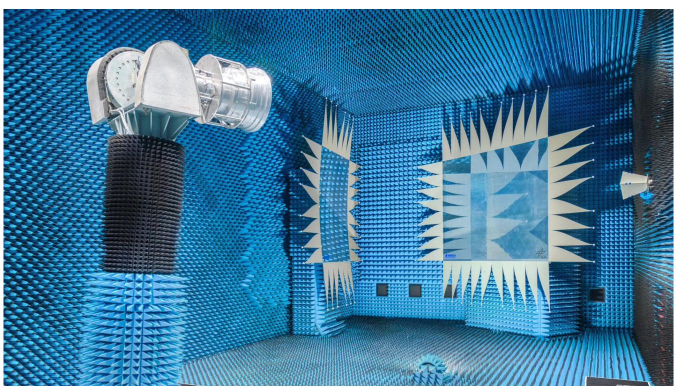

Fig. 2. Compact antenna test range (CATR) measurement facility of the German Aerospace Center (DLR) in Weßling, Germany.

a shielded, anechoic chamber with a length of 24 meters, a width of 11.7 meters, and a height of 9.7 meters. The quiet zone (QZ) has a maximum diameter of 3.4 meters in which amplitude variations of up to ±0.5 dB, phase ripples of up to ±5 degrees, and a cross-pol level of typically −40 dB are expected. Detailed descriptions, measurement quality, and working principle of this CATR are found in [13] and [14].

The TC antenna mounted on a large conducting host platform (ground plane) to support correct functioning and attached to the positioner of the CATR is depicted in Fig. 3. The edges of the 1.4-m-square ground plane are equipped with pyramidal foam absorbers to minimize diffraction effects. The antenna has its center frequency at 450 MHz. Measurements in a spherical setup bypassing the dual-reflector system were performed from 300 MHz to 600 MHz. Measured quantities cover among others the realized gain, dielectric and conductivity losses, and the port matching of the antenna. The measurement results from the CATR are shown in Fig. 4. There, the gain distribution of the horizontal (H) and vertical (V) polarized field components are plotted in the two main cuts. To get a more comprehensive view on the radiation characteristic, a 3D radiation pattern is shown in Fig. 5. The hemispherical coverage of this single TC antenna is apparent.

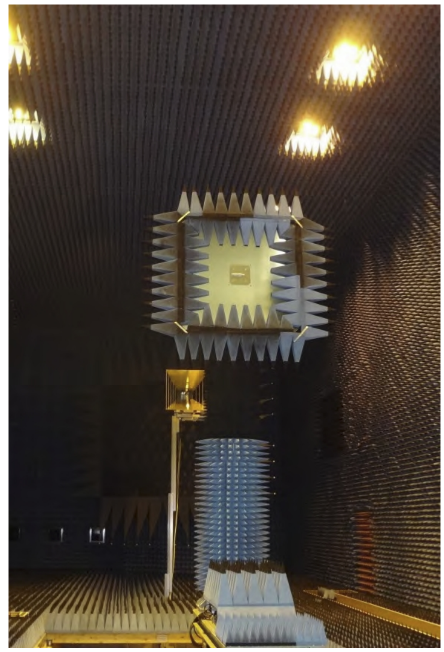

Fig. 3. TC antenna mounted on a large ground plane and attached to the positioner of the CATR.

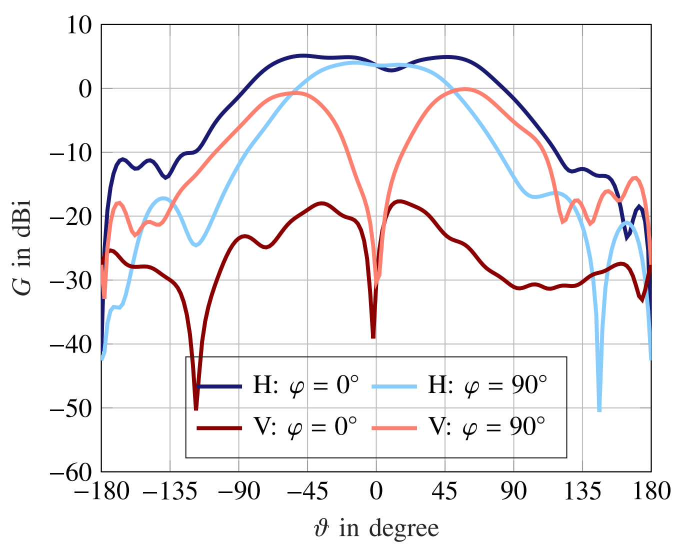

Fig. 4. Measured gain distribution of horizontal (H) and vertical polarized (V) components in principal cuts $\varphi = 0°$, $\varphi = 90°$.

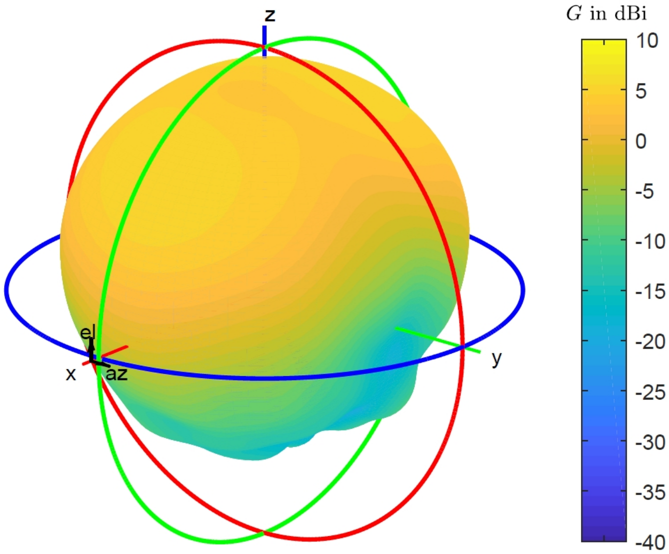

Fig. 5. Measured gain distribution of TC antenna mounted on a large ground plane in CATR.

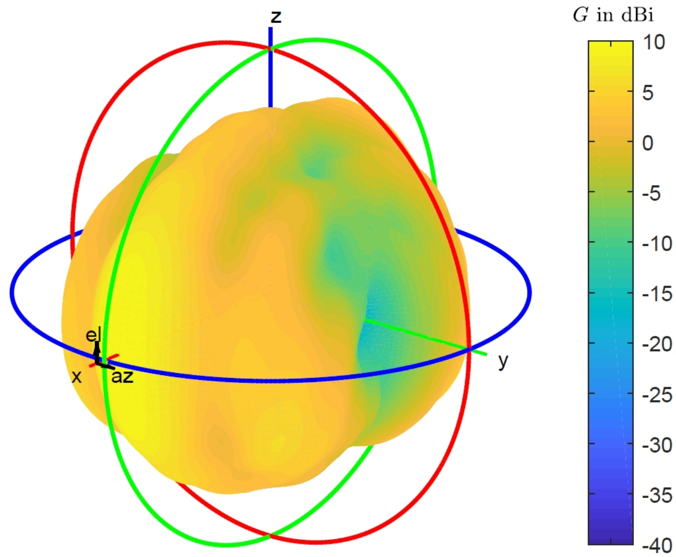

Fig. 7. 3D radiation pattern gain distribution of two TC antennas mounted on cylinder body of Fig. 6.

III. Antenna Placement Results

In the next step, the structural impact of the host platform on the overall radiation characteristic is investigated. The antenna design framework (ADF) by IDS which uses a MoM solver together with MLFMA is used here for simulation. In this manner, first, the equivalent sources from the TC antennas are placed on a cylindrical body with similar dimensions as the EFTV as pre investigations for comparison. This cylindrical body with the resulting surface current distribution is depicted in Fig. 6. The electrical size of the cylinder and the EFTV, in terms of wavelength, exhibits a length of about 6λ at the considered frequency of 450 MHz. The currents reveal their largest values at the mounting positions. To get a comprehensive view of the radiation characteristic of these two TC antennas on the cylinder structure, Fig. 7 shows the 3D radiation pattern of the gain distribution.

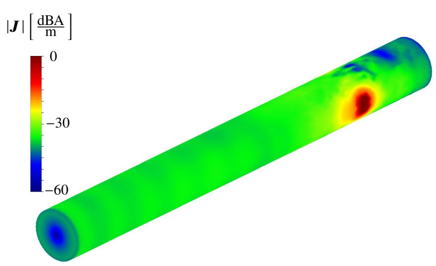

Fig. 6. Normalized surface currents $|\boldsymbol{J}|$ on cylinder caused by two TC antennas placed on the rear side of the cylinder.

Now, the two TC antennas are simulated when being placed on the rear end of the EFTV glider, as indicated in Fig. 1 with the two red dots. The surface currents evoked by the equivalent sources in the simulation model of these two antennas are depicted in Fig. 8. There, not only the mounting positions reveal high levels of surface current densities and so contribute to the overall radiation characteristic, but also the wings edges and the top side of the fuselage show significant currents.
The overall radiation characteristic of this configuration can be seen in the 3D radiation pattern of the gain distribution in Fig. 9. The influence of the EFTV glider structure with its wings and vertical stabilizers on the gain behavior is evident when comparing this plot to the results of the cylinder in Fig. 7. To support and verify the proposed method of working

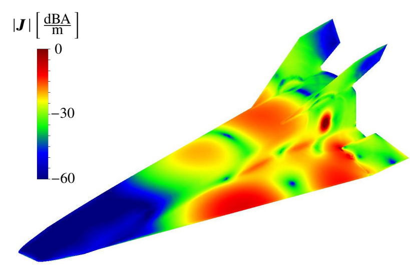

Fig. 8. Normalized surface currents $|\boldsymbol{J}|$ on EFTV caused by two TC antennas placed on the rear side of the EFTV.

with measured antenna data in a simulation model employing an SWE, a second, full-simulation model is created. With the help of ANSYS HFSS which uses a FEM solver, the whole EFTV structure together with the two TC antennas placed on it is simulated. The unknown antenna design data was back-engineered to match the results acquired by measurements and the data provided by the manufacturer. A comparison of the simulated gain distribution of both methods for the two TC antennas mounted on the EFTV is shown in Fig. 10. The trend of both curve pairs in this plot reveals a good agreement, which proofs the effectiveness of the proposed method. This method is closer to reality than a pure simulation since it works on actual measured data.

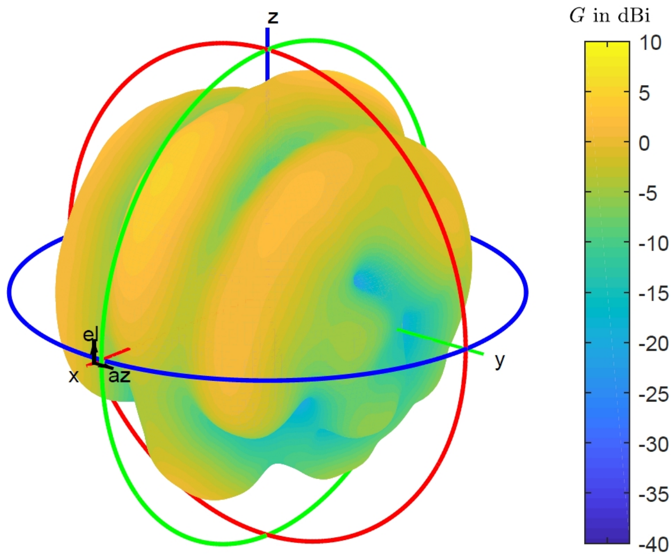

Fig. 9. 3D radiation pattern gain distribution of two TC antennas mounted on EFTV structure of Fig. 8.

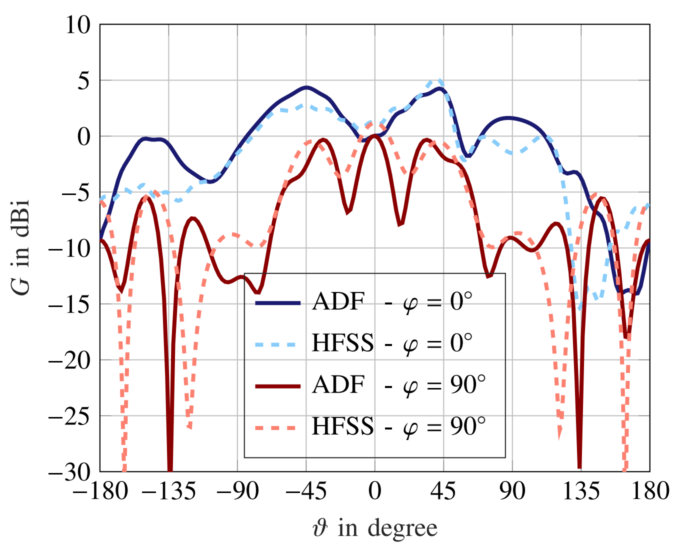

Fig. 10. Simulated gain distribution with ADF (MoM) and HFSS (FEM) of two TC antennas mounted on EFTV model in principal cuts.

IV. Conclusion

An antenna placement investigation that utilizes measured antenna data in a simulation model on the example of a cylinder body and a hypersonic glider has been presented. The structural influence of the host platform on the overall radiation characteristic has been drawn out. The obtained results demonstrate the wide variety of application cases in the field of antenna siting problems especially when the exact design data of the employed antennas are unknown. Using measured data in a simulation model can replace time-consuming back-engineering.

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