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VHF COMMUNICATION ANTENNA INTEGRATED INTO AN AIRCRAFT WINGLET

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Abstract. The article is discussing the final design of a VHF communication antenna integrated in a composite winglet of the EV-55 small transport aircraft. The antenna is designed to operate in the VHF band reserved for civil aviation, 117.975 – 137 MHz with optimal VSWR below 2.5. Compared with a standard vertically polarized monopole antenna, the radiation pattern in the horizontal plane shall not be down more than 6 dB and vary more than 6 dB [2].

1 INTRODUCTION

Designers of modern winglets are trying to introduce more functionalities into a winglet structure nowadays. This is also the case for the ACASIAS project [1], where one of the systems to be developed is a VHF antenna integrated into the winglet.

Such a design usually represents a complex and multidisciplinary task, especially due to specific technical trade-offs and bottlenecks originating from the following three distinctive engineering areas: aerodynamics, stress analysis and electromagnetics [3].

From the antenna point of view, several challenges have been faced during the design: final physical dimensions of the winglet and the VHF antenna are relatively small compared to target wavelengths (λ ≈ 2 - 2.5 m). Integration of the antenna into such a small area may easily become a challenging task focused on finding more spatially effective solutions without sacrificing necessary performance. In addition, some requirements specified for airborne VHF systems are in favour of standard monopole-like solutions installed on top or bottom of an airplane fuselage, where omnidirectional radiation pattern is preferred in horizontal plane. Such a requirement can be discriminating for the antenna situated at the tip of a wing due to obstructions caused by an airplane. In addition, winglet parts tend to attract lightning strikes more easily. Therefore, more stringent protection of the antenna and all related systems should be taken into account.

2 ANTENNA DESIGN

2.1 Winglet with integrated notch antenna

The final geometry of the winglet is depicted on Figure 1. The chosen concept is a notch antenna [4] printed on a thin, flexible PCB sandwiched in the foam filling of the winglet. The open side is tapered for broadband matching. The outer skin of the winglet is made out of Carbon Fibre Reinforced Plastic (CFRP) with an expanded copper foil at the external layer, so that a Glass Fibre Reinforced Plastic (GFRP) "window" was scarfed on the winglet skin to allow the antenna to radiate.

All simulation models discussed in the paper were prepared and analyzed in CST MWS. The protected CFRP material was modelled once as a sheet resistance (FD solver; RS= 0.05 Ω/sq at 100 MHz) and once as a multilayered thin panel (TD solver; σ ≈ 10k S/m, t = 2 mm).

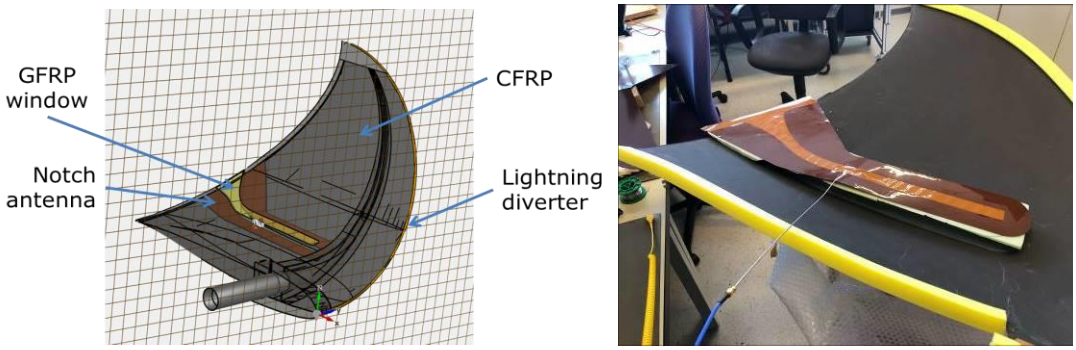

Figure 1: EV55 winglet with integrated notch antenna: structural model (left) and prototype (right)

2.2 Preliminary measurements

A half-opened model of the winglet structure (Figure 1) was used for a preliminary characterization of the integrated notch antenna's properties. During the measurement, a semi-rigid coaxial cable has been used as a feeding line and the final position of the feeding port was 240 mm from the end of the notch. The measured and simulated reflection coefficients for two different feeding points and computational methods are presented in Figure 2.

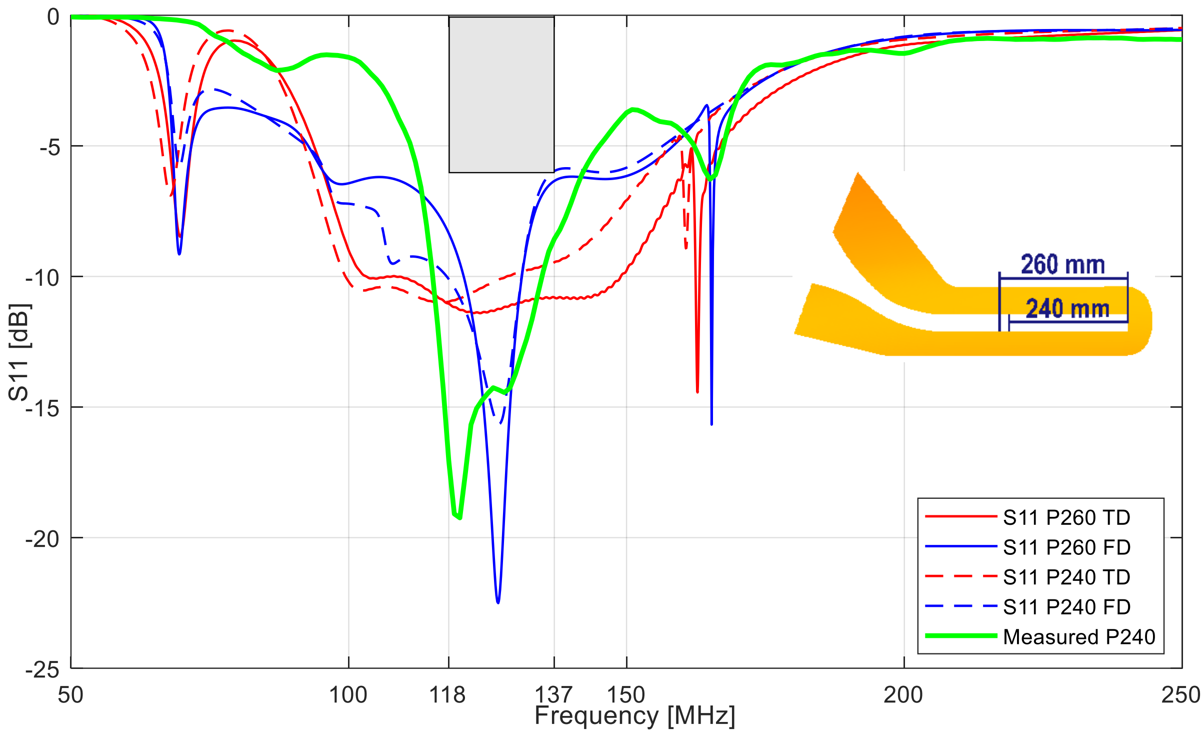

Figure 2: Comparison measured and simulated S11 results

In both cases, good results were obtained concerning the antenna matching and necessary bandwidth. The minimal requirement to VSWR ≤ 3 is satisfied in all cases. The optimal VSWR < 2.5 is fully achieved for the measured prototype and simulation models analyzed in time domain (TD). Differences in material models used in TD and FD models were ruled out as a potential source of S11 discrepancies. It seems that observed deviations in impedance behavior of the antenna are directly related with different computational methods and used types of mesh.

The antenna port position P240 seems to be less optimal than the P260. This is why all simulation models discussed in the following chapter will be related to the P260 position. The final location of the feeding port will be verified by additional measurements to be carried out on a fully enclosed winglet prototype. In any case, the impedance matching of the antenna can be further improved by matching circuits like L-C networks or via a balun.

3 ANTENNA INSTALLED ON EV-55 AIRCRAFT

3.1 Radiation efficiency of installed antenna

According to [2], the field strength of an airborne VHF antenna shall not be down more than 6 dB and vary more than 6 dB in comparison with a standard vertically polarized monopole antenna. Naturally, the radiation pattern of an installed antenna may differ with respect to a specific position on an airplane. Compared to the standard case when an antenna is installed on a fuselage (i.e. relatively uniform and large ground plane), this verification is especially important when it comes to the VHF antenna integrated inside a winglet. Therefore is useful to verify if the antenna is performing well at the place of its installation.

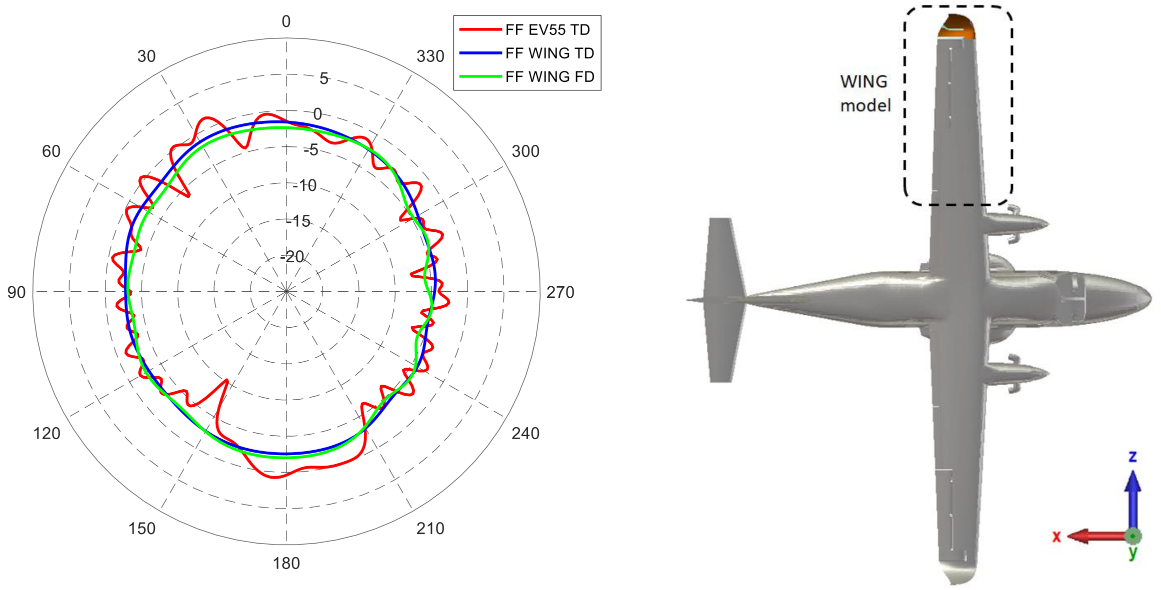

Figure 3: Antenna gain (vertical comp.) for different simulation scenarios (Phi = 0º,Theta = 0º – 360º)

Table 1: Comparison of resulting gain parameters for different simulation scenarios

Model / solver:	Maximum [dBi]	Average [dBi]	Minimum [dBi]
EV-55 / TD	1.5	-2.3	-10.0
WING / TD	-1.1	-2.7	-5.0
WING / FD	-1.8	-3.1	-5.9

Radiation efficiency of the antenna was analyzed using two different simulation models (full model of EV-55 vs. part of the airplane's wing: *EV-55* vs *WING*) and two different computational methods (TD vs. FD). The main results are depicted on Figure 3 and summarized in table Table 1.

Current results indicates that the antenna is slightly underperforming with respect to the requirements. However such a possibility has been expected considering the fact an ideal monopole antenna has benefit of 3dB due to a large conductive ground plane (2.19+ 3 dBi). The requirement for the maximum field strength deviation is usually referred to the antenna prior its final installation on an airplane. Presented results indicate that this requirement can be fulfilled without significant problems (WING models).

In addition, further analyses on full-scale EV-55 model indicated that the antennas installed on both wings are decoupled. So it is possible to use diversity strategies to improve the system performance.

3.2 Lightning strike protection

Winglets represent one of the one most probable locations where a lightning strike can hit an airplane during a flight (Zone 1A, 1B). This is why the winglet antenna has to be designed and tested to more critical electromagnetic environments than is usual for ordinary VHF antennas installed on a fuselage (Zone 1A). The main protection against possible direct attachment of a lighting strike to the antenna is provided by the winglet structure and position of the antenna. The winglet has an integrated diverter strip going along the leading edge, from the tip of the winglet to the bottom part, where it is conductively connected to the metallic structure of a wing (see Figure 1). In addition, an expanded Cu metal foil is integrated into an outer layer of the winglet external CFRP shell to provide both an additional protection to the CFRP structure and to provide better route to a lightning channel passing across the surface during a lightning strike event.

In case of possible indirect effects of lightning, it is essential to determine approximate levels of voltage and current transients induced at the port of the antenna, along the whole VHF route, and neighboring systems that may interfere with the VHF system. In this paper, only U and I transients at the port of the antenna will be discussed (transients induced in cables and other electrical systems can be obtained in a similar way).

The basic concept of a simulation model that can be used for this kind of analyses is presented on Figure 4. The model does not address possible problems due to thermal damage, dielectric breakdown, arcing and sparking events. The EM source is represented by an ideal current source positioned at the tip of the winglet (the end of the diverter strip). The applied current waveform emulates a fist return stroke (Component A). [5]

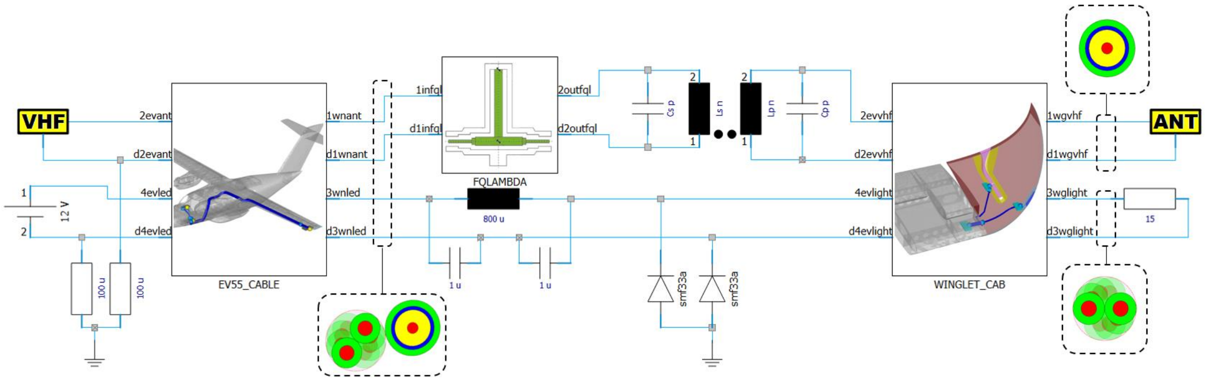

Figure 4: Basic concept of the VHF system simulation model

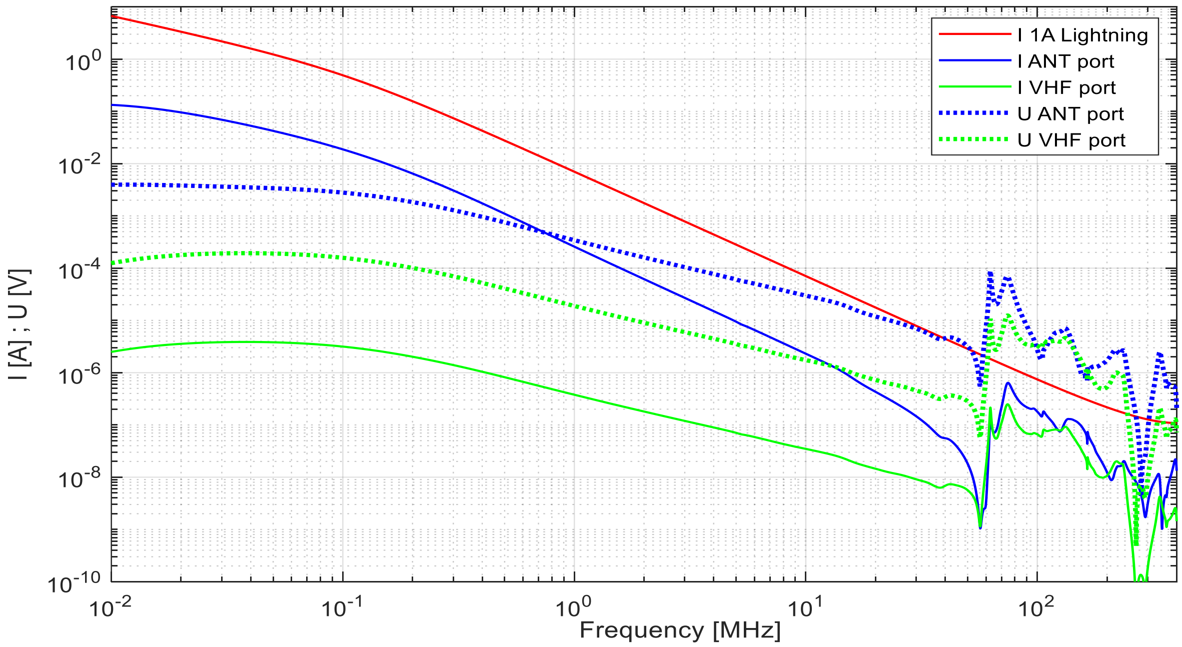

Figure 5: U and I transients at the antenna port and VHF transceiver input produced by lightning currents (current source: component A) passing through the winglet to the EV-55 wing structure

Relatively high levels of currents can be seen at the antenna port at low frequencies (see Figure 5). Character of these disturbances will naturally change at the higher frequencies, where the antenna starts to resonate, thus voltage transients will become dominant due to increasing impedance at the port. Results indicate that lightning transients at the antenna port does not represent a significant problem when considering the basic protective circuitry introduced to the VHF line. Nevertheless, the VHF antenna represents only one part of the problem and other potential sources of EM disturbances have to be analyzed to obtain full picture of the system behavior.

4 SUMMARY

Simulated and measured reflection coefficients of the notch antenna for different scenarios are showing good antenna matching and sufficient bandwidth. Radiation efficiency of the antenna installed on the EV-55 airplane is not fully meeting the general requirements. However the reason is not due to bad performance of the antenna but due to the fact that these requirements are not taking into account similar scenarios / positions for installation of a VHF antenna. The antenna has a good potential for further adjustments with respect to its bandwidth and radiation characteristics. This will give us enough space for final adjustments of the antenna during the final stage of the prototype preparation, or at higher TRLs when solving possible performance deviations due to manufacturing inaccuracies or other changes.

The last part of the paper is discussing basic protection of the winglet with integrated VHF antenna against direct and indirect effects of a lightning strike. We have presented the basic simulation model for more detailed analysis of lightning transients introduced to the VHF line via the antenna element and determined their approximate levels.

Knowledge of resulting transient levels can help us to determine whether the electronic systems are sufficiently protected at the system and sub-system levels and establish the proper lightning requirements for the whole VHF communication system at higher TRLs.

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