MUTUAL COUPLING OF ANTENNAS ON HELICOPTER TAIL BOOM

Viktor Képeši - Ján Labun - Marek Češkovič

This paper deals with mutual coupling of two VHF antennas tuned on the same constant frequency, both placed on idealized tail boom of a helicopter, with their common distance being varied. Content of this paper consist mainly of results of simulations, which were made on this subject. These results are later compared to real-life measures done on experimental model of tail boom.
K e y w o r d s: antenna coupling, helicopter tail, s-parameters, simulation, model

1 INTRODUCTION

In modern world aviation, many systems operating in radiofrequency spectrum are used. All these systems need antennas to be functional. Therefore, there are usually also many antennas placed on aircraft. Between every two antennas, there is some mutual coupling. It means that energy radiated from one antenna is received by another antenna. It's desirable in transmitter-receiver networks, but not in situations, where both antennas have to function independently from each other. In considered case, where each antenna belongs to different avionic system, mutual coupling effectively causes power losses. This problem is particularly significant on two antennas of same frequency band. It is desired to have as low mutual coupling as possible. To find out how coupling of two antennas varies with their common distance, this paper was written. It is oriented on VHF spectrum, which is widely used in aviation and it's also the most crowded spectrum. On long wide-body airplanes there's plenty of space for antenna placement. However, problem of correct antenna placement becomes more delicate on smaller structures. For this reason, helicopter tail boom was chosen as structure, on which the antennas are mounted.

2 EXPLOITED THEORIES

2.1 Friis' formula

To get the idea how coupling depends on distance between two antennas in free space [1], Friis' formula can be used

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

As can be seen from the formula, the received power is determined by transmitted power, gain of both antennas and wavelength squared. What's most important in this case is that the received power is also determined by 1/R squared. In other words, the further the antennas are apart, the weaker their mutual coupling will be. Friis' formula can be also written in decibels

$$10log_{10}P_r = 10log_{10}P_t + 10log_{10}G_t + 10log_{10}\,G_r + 20log_{10}\left(\frac{\lambda}{4\pi R}\right) \qquad (2)$$

2.2 Bull and Smithers formula

In case when antennas are placed on opposite surfaces of conductive cylinder, their mutual coupling is harder to estimate [1]. This is mainly because of diffraction on surface and created creeping wave from transmitting antenna towards receiving antenna. To simplify calculations of coupling, Bull and Smithers created following empirical formula, based on Friis' original formula

$$C = -20\ log_{10}kF^{1.75} - 20log_{10}(D + L) - 28 + SA \qquad (3)$$

where:
C is coupling
k = r/15, where "r" is radius of the cylinder in meters
F is frequency in MHz
D is the distance along the circumference of the cylinder
L is the distance along the length of the cylinder
SA is Siarkiewicz and Adams factor

2.3 S-parameters

Scattering parameters, shortly called S-parameters, are used to describe power relationship between ports. In the considered case of two antennas, port of the transmitting antenna can be presented as port 1 and port of the receiving antenna as port 2. Then power received on port 2 relative to power transmitted on port 1 is called S21 parameter. If we look back to the Friis' formula, we can see it's the P_r/P_t ratio and therefore the S21 parameter will depend on distance between those two antennas. As the S21 parameter talks about how much power is received relative to the power transmitted, it is ideal as a parameter for measuring mutual coupling of antennas.

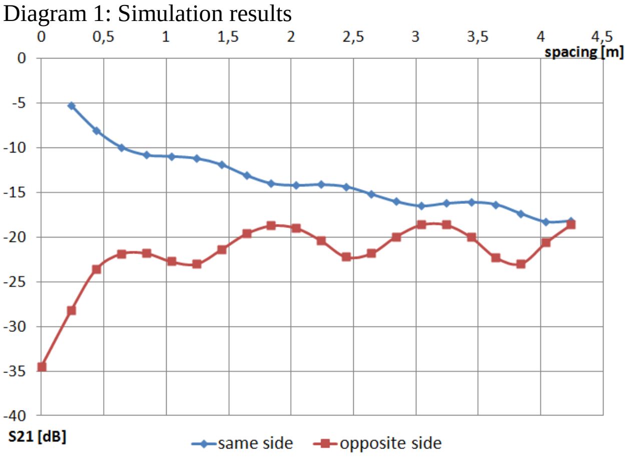
3 SIMULATIONS OF COUPLING

3.1 Specifications

All simulations were made in simulation software tool FEKO v6.1. Purpose of this paper is to find out how mutual distance of antennas mounted on helicopter tail boom affects their coupling. Hence real dimensions of tail boom were simulated, specifically dimensions of Mi-17 helicopter tail boom. To simulate this tail boom, conductive cylinder of 6,4m in length and 0,8m in diameter was modeled. To simplify simulations, narrowing of the tail section was not taken into consideration. Frequency of 125MHz (wavelength 2,4m) was chosen for simulations, as it’s approximately in the middle of aviation VHF communication frequency range. Antennas were chosen to be vertical monopoles with quarter wave length 0,6m. Active transmitting antenna was electrically connected on port 1, fixedly placed on surface of cylinder in 1m distance from its end. Receiving passive antenna was electrically connected on port 2 and placed on same side of cylinder in various spacing relative to active antenna. Spacing was chosen to correspond with already made real-life model measures, which results are presented later in this paper. After measuring S21 parameters in all spacing positions on the same side of cylinder, passive antenna was flipped on the opposite side (180 degrees to active antenna) and again, S21 parameters in all positions were measured. Results of all simulations are visualized in Diagram 1.

3.2 Results

Diagram 1: Simulation results



As can be seen from results, mutual coupling of two antennas placed on the same side of tail boom globally decreases with their common distance being increased. However, there are also some local maximums and minimums. These are evenly placed and they depend on actual wavelength. Local maximums occur every ($\lambda/2 + k*\lambda/2$), k being integer from zero to infinite. Local minimums occur every ($\lambda/4 + k*\lambda/2$), k being integer from zero to infinite. These local maximums and minimums are not very significant thou.

When antennas are placed on the opposite sides of a cylinder, shadowing takes place. Coupling is weaker when compared to measures made with both antennas on same side of the cylinder. Weakest coupling is present when antennas are placed directly against each other. This is because of the radiation pattern of used antennas. With their common distance on cylinder surface increasing, coupling becomes stronger. As can be seen from Diagram 1, after certain spacing, strength of coupling starts to oscillate around -20dB with significant local maximums and minimums, because of the creeping wave. These extremes are placed differently compared to case when both antennas were on same side, due to effect of the diameter of the cylinder. Because of this effect it is more difficult to easily determine those local max/min. But in this specific scenario, it can be said that local maximums occur roughly every ($\lambda/4 + k*\lambda/2$), and that local minimums occur approximately every ($\lambda/2 + k*\lambda/2$), k being integer from zero to infinite.

4 REAL-LIFE MODEL MEASURES

4.1 Specifications

Similar situation to the simulated one was examined [2]. A scaled down model of Mi-17 helicopter tail boom was used. Considered dimensions were 6,4m in length and 0,8m in diameter. The scaled model was four times smaller in diameter and three times in length, resulting into tube of 0,2m diameter and 2m length. This plastic tube was then coated with thin aluminum foil. Antennas were 0,156m long and 5mm thick, used on 540MHz. This corresponds to unscaled 0,624m in length and to frequency of 135MHz (wavelength 2,22m). Finished model is shown in Figure 1. Mutual coupling was measured in range from 6cm to 81cm with 5cm step. Translated to unscaled terms, from 0,24m to 3,24m with step of 0,2m. In addition to this created model, high frequency generator HM8135 and spectral analyzer HM5530 were used. Results of made measurements are visualized in Diagram 2.

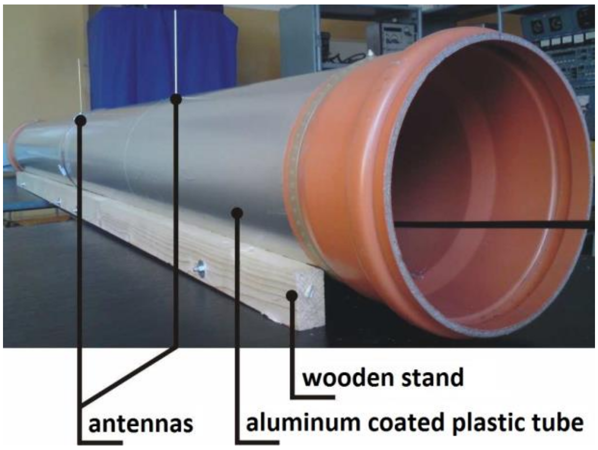
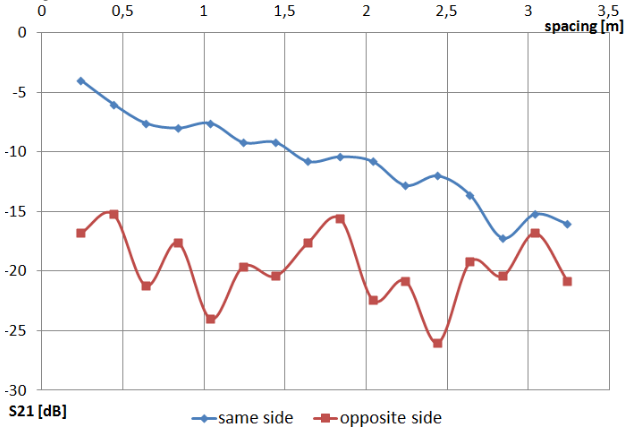


Figure 1: Model of tail boom

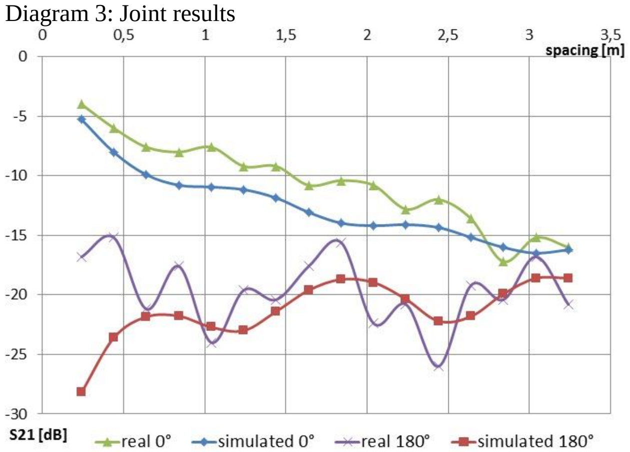
4.2 Results

Diagram 2: Real model results



Although real-life measures made on model had some differences compared to the simulation, for example used frequency or tube length, and there possibly was some noise and some interferences during measurements, the results are very similar. As can be seen from Diagram 2, coupling of antennas placed on the same side of the cylinder globally decreases with local extremes. These occur approximately as they were expected, based on results gained from simulation. Measured values of mutual coupling of antennas placed on opposite sides of the cylinder may be not as neat as the simulated ones, but they also show level of coupling oscillating around -20dB. Joint results are shown in Diagram 3.

Diagram 3: Joint results



5 CONCLUSION

From gathered information, both from simulation and from real model measurements, some conclusions can be made. To minimize coupling between two antennas, which systems are meant to work independently, few rules should be followed. When placing the second antenna on the same side of helicopter tail boom, the distance between them should be as great as possible. This is because of the descending character of coupling magnitude with mutual distance increasing. Local extremes are negligible. When the second antenna is placed on the opposite side of the tail boom than the first antenna, it is best to have it placed directly against the first antenna. If this is not possible then it has to be kept in mind that local extremes are quite significant and that coupling magnitude is oscillating around one value along almost the entire tail boom.

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AUTHORS´ ADDRESSES

Képeši Viktor, Ing.
Faculty of Aeronautics TUKE
Rampová 7, 04121 Košice, Slovakia
viktor.kepesi@tuke.sk

Labun Ján, doc., Ing., PhD.
Faculty of Aeronautics TUKE
Rampová 7, 04121 Košice, Slovakia
jan.labun@tuke.sk

Českovič Marek, Ing.
Faculty of Aeronautics TUKE
Rampová 7, 04121 Košice, Slovakia
marek.ceskovic@tuke.sk