Mutual Coupling between Monopoles on F-4 Aircraft at Transition Frequencies: A Comparison between MoM and MoM/UTD Hybrid Method at UHF Band

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Abstract — In this paper, the analysis of mutual coupling between monopole antennas mounted on the aircraft at UHF band is presented. The Method of Moments (MoM) and hybridized MoM with Uniform Geometrical Theory of Diffraction (UTD) method (MoM/UTD) are used to calculate the coupling in 225 MHz-400 MHz frequency range. Numerical results with MoM and MoM/UTD are performed and the reliability of these methods is discussed based on the measurement results.

Keywords — Antenna Coupling, MoM, MoM/UTD

I. INTRODUCTION

Aircrafts have many communication and navigation systems for different purposes. The radiated electromagnetic interference (EMI) between the antennas of these systems is a potential serious problem and always has to be considered. The power output of the transmitter systems, sensitivity of the receiver systems and the coupling between the antennas mainly determine the EMI safety range [1,2]. So one has to compute or measure the coupling between two antennas to decide whether a potential EMI risk exists. The analytical calculation of the coupling between surface mounted antennas on aircraft or similar complex structures is difficult and time consuming, so predictions by either numerical or asymptotic methods are preferred [3].

The electrical size of the structure to be analyzed increases at high frequencies because of the shorter wavelength. Practically, these methods can be used up to UHF band. High frequency asymptotic methods, like UTD, should be utilized for electrically large structures. However, this method also has some limitations like others. For low frequencies $kL > 1$ limitation should be considered [4]. Here k is the wavenumber and L stands for the distance parameters as defined in [4]. Generally, this method becomes practical beginning from UHF. At high frequencies, the accuracy of the model becomes a limitation [5]. So, UHF band can be considered as a transition frequency range from low frequency methods to high frequency methods. A comparison between MoM and MoM/UTD method at transition frequencies is presented.

II. ANALYSIS

The analysis has been performed in the 225 MHz – 400 MHz frequency range between COM2/V-UHF radio communication antennas located on the top and the bottom of the fuselage and on the tail (Fig. 1). The antennas are quarter wavelength monopoles. The simulations are realized by two different methods: MoM and MoM/UTD Hybrid Method.

Two scenarios have been investigated in this work: The mutual coupling between A1-A2 and A2-A3. The location of the antennas on the aircraft can be seen in Fig. 1.

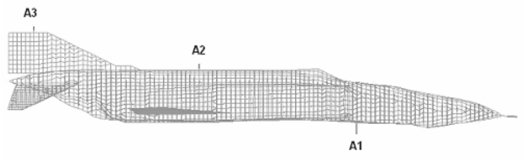

Figure 1. MoM Model and Antenna Locations.

Segment and grid sizes of around 1/10 wavelength or less. The problem solution time is proportional to the cube of the number of segments while the computer-memory requirement is proportional to the square of the number of segments. Here, 12 cross sectional data of the model are defined, and subsequently models are generated for 175 MHz. The segment length is chosen to be equal to $\lambda/10$ at the frequency of interest. The total number of segments for the aircraft adds up to 10910.

High modeling frequency, so lower wavelength and segment length, increases the segment number of the model. For such a huge amount of segments, MoM analysis requires modeling the structure surfaces using wire segments rather than using patch model of surfaces.

Since the size of the aircraft becomes significant in terms of wavelength at UHF and above, the low frequency methods like MoM are not useful due to long computation time and high memory requirement at these frequencies. So, an asymptotic method, the UTD is normally used. This technique based on ray tracing, considers the propagation of Electromagnetic (EM) waves as tubes of rays [6]. At each point in the space, the total EM field is calculated by superposing the incident field, reflected fields, diffracted fields and all other higher order interactions (double reflection, diffraction-reflection, reflection-diffraction etc.).

In the MoM/UTD Hybrid Method, the MoM interaction Matrix is modified according to the interaction between wire segments via UTD objects: flat plates and cylinders. The MoM/UTD hybrid model of the aircraft consists of 18 plates, 9 cylinders and wire-segmented monopoles.

The technique used to hybridize the MoM and UTD was presented by Thiele and Newhouse [7-8]. Basically, the original MoM matrix elements are increased with the additional fields due to interaction mechanisms up to third order.

In short, the *mn*'th element of the new impedance matrix is

$$Z'_{mn} = Z_{mn} + Z^{g}_{mn}. \quad (1)$$

Here Z_{mn} is due to direct field from source to observation point and Z^{g}_{mn} is due to other interactions (reflection, diffraction…).

The Linville method, a technique used in RF amplifier design, is used to compute the maximum coupling between the two antennas. Then mismatch losses are considered to reduce to maximum coupling due to input and output load mismatches. The maximum coupling according to Linville method is [9]:

$$C_{\max} = \frac{1-\sqrt{1-L^2}}{L} \quad (2)$$

where

$$L = \frac{|Y_{12}Y_{21}|}{2\,\mathrm{Re}[Y_{11}]\cdot \mathrm{Re}[Y_{22}] - \mathrm{Re}[Y_{12}Y_{21}]}. \quad (3)$$

As can be seen in the equation above, to calculate the maximum coupling given in eq.(2), firstly the two-port admittance parameters for the coupled antennas should be determined by exciting each antenna with the other short-circuited, then the self and mutual admittance from the currents computed by NEC should be computed [9].

In case of maximum coupling load admittance on antenna 2 must be matched[10]:

$$Y_L = \left[\frac{1-\rho}{1+\rho}+1\right]\mathrm{Re}[Y_{22}] - Y_{22} \quad (4)$$

where

$$\rho = \frac{C_{\max}(Y_{12}Y_{21})^*}{|Y_{12}Y_{21}|} \quad (5)$$

and the corresponding input admittance of antenna 1 is:

$$Y_{IN} = Y_{11} - \frac{Y_{21}Y_{12}}{Y_L + Y_{22}}. \quad (6)$$

The mismatch losses are calculated according to:

$$\begin{aligned} MLin &= 10\cdot\log\left(1-|\Gamma_{in}|^2\right) \\ MLout &= 10\cdot\log\left(1-|\Gamma_{out}|^2\right) \end{aligned} \quad (7)$$

where

$$\begin{aligned} \Gamma_{in} &= \frac{Z_{in}-Z_o}{Z_{in}+Z_o} \\ \Gamma_{out} &= \frac{Z_L^*-Z_o}{Z_L^*+Z_o}. \end{aligned} \quad (8)$$

III. MEASUREMENT AND RESULTS

Antenna coupling measurements have been performed in an 8.4m x 4.8m x 3.3m Semi-Anechoic Chamber (SAC). A 1:10 scaled model of the F-4 aircraft was used. The measurement setup picture can be found in Fig. 2 and depicted in Fig. 3.

Figure 2. Coupling Measurements in SAC.

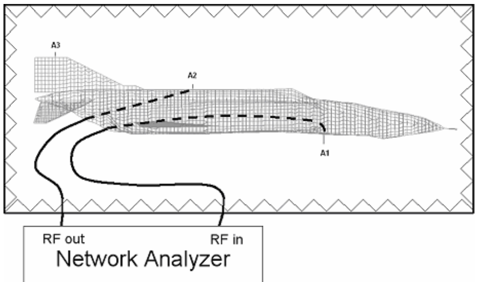

Figure 3. Detailed Measurement Setup Drawing in SAC.

The inner dimensions of the room are approximately 7.2 m long, 3.6 m wide, and 2.7 m high from the tip of the absorbers.

The frequency range to be considered for the analysis is 225 MHz-400 MHz. The aircraft model has 1:10 scaling, so the measurement was performed in 2.25

GHz-4 GHz frequency range. S_{21}, S_{11}, S_{22} parameters were measured via the network analyzer, then mismatch losses and optimum coupling were calculated according to these scattering parameters:

$$ML_1 = 10 \cdot \log\left(1 - |S_{11}|^2\right) \tag{9}$$

$$ML_2 = 10 \cdot \log\left(1 - |S_{22}|^2\right) \tag{10}$$

$$C = 10 \cdot \log\left(|S_{21}|^2\right) - ML_1 - ML_2 \,. \tag{11}$$

The MoM coupling and MoM/UTD Hybrid method coupling between three antennas on aircraft were computed, then measured in SAC and plotted (See Fig. 4. and Fig. 5).

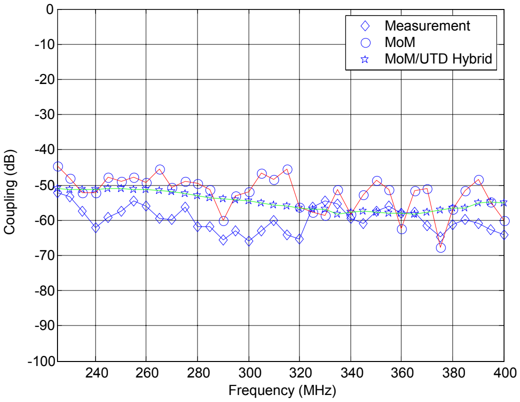

Figure 4. Coupling Between A1 and A2.

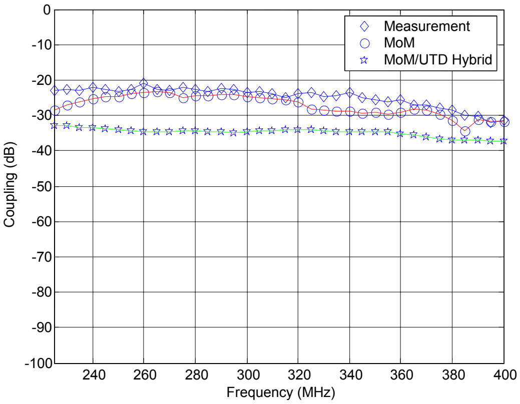

Figure 5. Coupling Between A2 and A3.

IV. CONCLUSION

In this work an efficient approach to the numerical analysis of mutual coupling between the UHF communication antennas of F-4 aircraft has been presented. The results show that coupling gathered from both methods approximated to measurement results nearly by ±10 dB. MoM results are closer to the measurement results with respect to MoM/UTD results.

The accuracy of the simulation results depends on how precisely the model represents the aircraft. For the measurements, the precision of the scaled model used in the measurements influences the measurement accuracy. In the case of MoM/UTD, the number of objects used and the number of maximum interactions allowed by the software affects the simulation results. In the case of MoM, wire grid size is important for the accuracy of the results. Detailed information can be found in [11] and [12].

The authors emphasize that one will better use MoM model even at the transition frequencies. A quick analysis for simplified MoM/UTD model of the complex structure can be carried out for introductory information and at higher frequencies it will be mandatory to use this model.

ACKNOWLEDGEMENT

The authors would like to thank to M. Emre Aydemir for the aircraft model, Ersan Baran for his kind help in carrying out the measurements and Nazlı Candan for her constructive suggestions on manuscript.

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