Influence of Passengers on the Mutual Coupling of Devices in a Simplified Fuselage

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Abstract

In this paper, the influence of human passengers on the mutual coupling of devices in a rectangular simplified scale model fuselage is examined. The coupling is compared to that of an empty fuselage. Both measured and FDTD-simulated results are presented and compared.

1. Introduction

An important EMI issue for commercial aircraft is the possible interference generated by on-board personal electronic devices (PEDs), such as cell phones, laptops, etc. In Georgakopoulos, et al, the mutual coupling between a simulated PED, located in the cabin area of a simplified scale model aircraft fuselage, and an antenna mounted on the exterior of the fuselage was predicted using the FDTD method and compared with measurements [1], [2]. The previous work was performed for a completely empty fuselage. An airline fuselage is, however, filled with passengers and various structures: metallic frames, foam seat cushions, wires, various insulating and decorative materials, etc.

A detailed model would include all of these geometrical features and material properties, but the complexity and computational resources for such an undertaking renders it impractical. Surprisingly, it has been reported that the seat cushions and even their metal frames have a negligible impact on the coupling of such antennas [3]. Passengers, on the other hand, have a high probability of modifying the EMI environment due to their dispersive and lossy nature. In this paper, the *S*-parameters of a simulated PED located within a scaled fuselage-like enclosure and an antenna mounted on the exterior of this enclosure are both measured and computed using FDTD[4], [5]. The *S*-parameters are determined when the enclosure is filled with "simplified passengers," and they are compared with those of an empty enclosure.

2. Measurements

The "simplified fuselage" is an aluminum box having a rectangular cross section that would enclose the fuselage of a 1:20 scaled Boeing 757 [1]. The structure of the human body is extremely complex and consists of a variety of dispersive and lossy materials [5]-[7]. Modeling the details of the human body, on the scale of an airliner, is prohibitive. A model using salt water and porcine tissue has been reported in [8]. However, considering the scale of a human compared to the fuselage, the passengers in this paper are modeled using circular-cross-section plastic tubes (90 mm long, 15.9 mm diameter) containing 0.9% salt water. As illustrated in Fig. 1, there are 6 passengers on every row, and 15 rows (90 passengers in total) inside the fuselage. The distance between adjacent rows is 75 mm. To keep the passengers in their designated locations and upright, an expanded polystyrene support system was constructed. The complete set of 90 passengers and their support system is shown in Fig. 2. The permittivity and loss tangent of the saline solution was measured using Hewlett-Packard's open-ended coaxial Dielectric Probe [9]. The measured permittivity and conductivity of the 0.9% salt water at $20^{o}C$ are plotted in Figs. 3 and 4, respectively.

The experimental setup is essentially identical to that for the PED measurements previously reported [1], [2]. The measured *S*-parameters of the fuselage with and without passengers are shown in Figs. 5-7. Because the system is reciprocal ($S_{12} = S_{21}$), only S_{12} is plotted. From Figs. 5-7, it is evident that the presence of the passengers has a negligible impact on S_{11} (the two curves are indistinguishable), which is the reflection coefficient of the exterior antenna. However, the passengers did have a significant effect on S_{22} and S_{12}. As shown, S_{22} (the interior antenna) and S_{12} without passengers exhibit much more oscillatory behavior due to the large number of resonances present inside the fuselage. However, S_{22} and S_{12} with the passengers exhibit much smoother distributions since many resonant components have been significantly dampened by the "human bodies" which are highly dielectric and lossy. Due to

this phenomenon, the presence of the passengers can slightly reduce possible aircraft system upsets by PED emissions as compared to an empty fuselage.

3. Simulations

To compare measurements with predictions, the mutual coupling between the internal PED antenna and the antenna mounted on the exterior of the fuselage was simulated using an FDTD algorithm [4], [5]. The *S*-parameters were computed following the procedure described in [10]. Due to the large permittivity of the salt water, a very small cell size of $\Delta x = \Delta y = \Delta z = 2.5$ mm ($\lambda/40$ at 3 GHz in free space or about $\lambda/5$ at 3 GHz in the salt water) was used. To allow the excitation pulse to decay to a low level, the simulation was executed for 60,000 time steps. From the numerical experiments, it has been found that the coupling is not very sensitive to variations in the passenger permittivity and conductivity. An additional simulation was performed with all windows sealed with metallic walls, except for Window C (the one at the same cross section as the external antenna). The resultant S_{12} agrees very well with that of the all-window-open case. This suggests that the direct path through Window C accounts for the majority of coupling, which explains the insensitivity of S_{12} to the constitutive parameters of the passengers. Based upon this observation, it can be justified that, for this particular configuration, a complete dispersive modeling of the salt water is not necessary. Hence, the average permittivity and conductivity values (70.35 and 8.05 S/m) are used for the rest of the simulations.

The measured and simulated *S*-parameters with the passengers are plotted in Figs. 8-10. As shown, S_{11}, which is essentially just the reflection coefficient of the external monopole, has a null at 2500 MHz. The null of FDTD simulated result is shifted to a lower frequency by about 100 MHz. However, S_{22}, which is the reflection coefficient of the internal antenna, exhibits a similar trend as that of S_{11} but with more oscillations due to the fuselage's highly resonant characteristics. Of the *S*-parameters, S_{12} is the most important since it represents the energy generated by the external PED which could interfere with the aircraft's communication system. A very good agreement, between predictions and measurements, is observed between 1,500 MHz and 5,500 MHz. The discrepancy near the lower frequencies is probably due to the extremely low coupling level. However, the differences at the high end of the frequency band can be attributed to the large dispersion error caused by the coarse discretization. Moreover, it is important to note that the maximum coupling, which is higher than -40 dB, occurs between 2.0-3.5 GHz. This level of coupling is sufficiently high to draw the attention of the communication system designers.

4. Conclusions

In this paper, the effects of passengers on the mutual coupling between an internally-simulated PED and an externally-mounted antenna were investigated. By comparing the *S*-parameters for the empty scale model fuselage with those when the scale model was filled with 90 liquid-filled tubes (which were used to simulate human passengers), it was found that the presence of passengers significantly dampens the reverberations that occur within the fuselage. This dampening effect reduces the maximum coupling by approximately 15 dB. The reduced threat, with passengers present, potentially represents a relaxation in the EMI shielding requirements.

5. References

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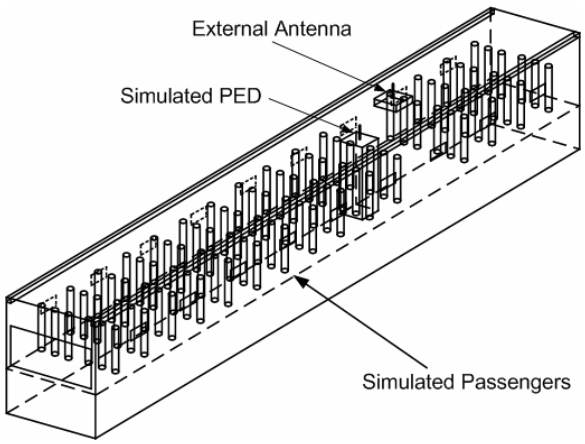

Fig. 1. Geometry of the Simplified Fuselage filled with 90 passengers.

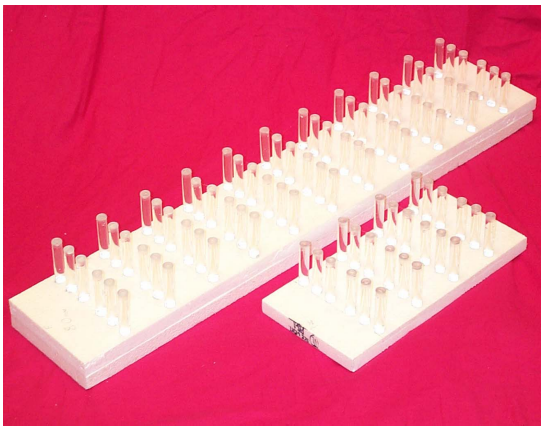

Fig. 2. A photograph of the 90 passengers in their support structures.

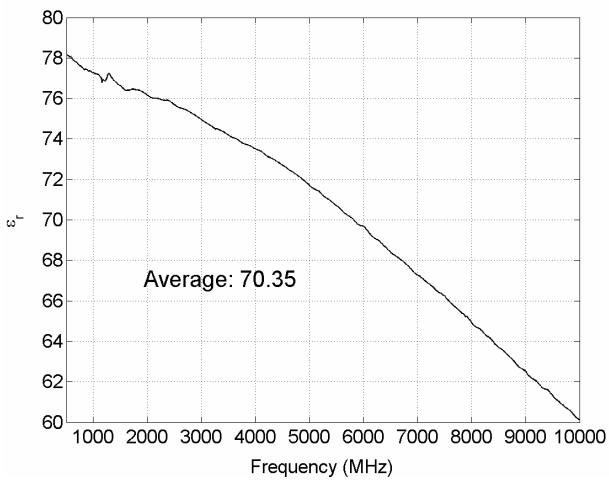

Fig. 3. Measured permittivity of the 0.9% salt water at 20 °*C*.

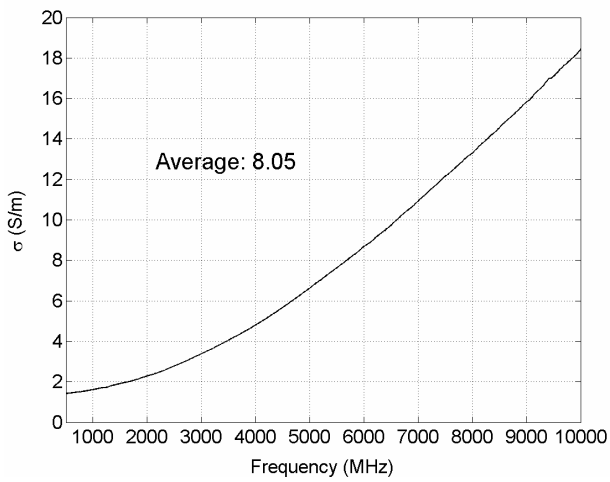

Fig. 4. Measured conductivity of the 0.9% salt water at 20 °*C*.

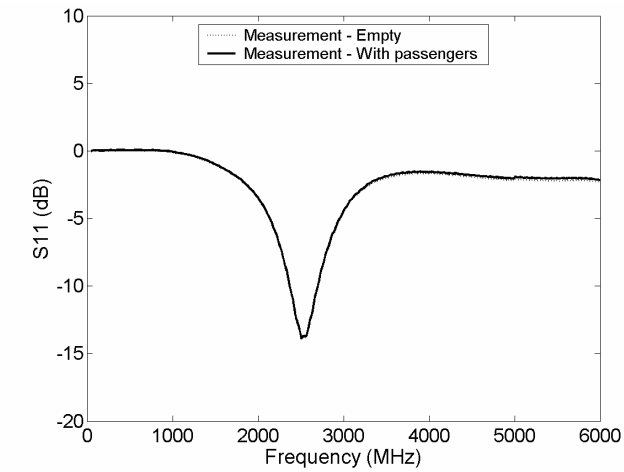

Fig. 5. Measured S_{11} (the exterior antenna) of the simplified fuselage with and without passengers.

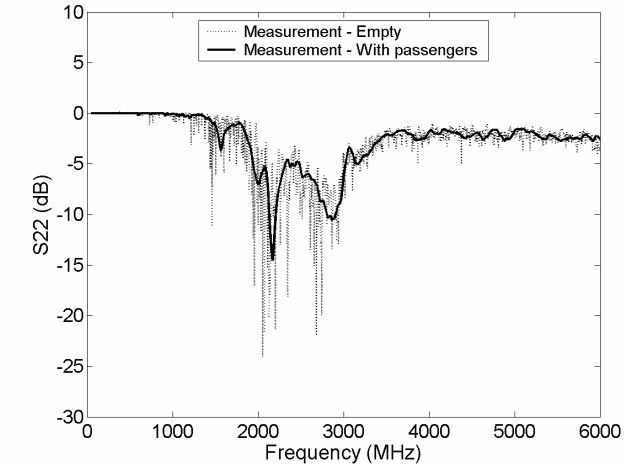

Fig. 6. Measured S_{22} (the interior antenna) of the simplified fuselage with and without passengers.

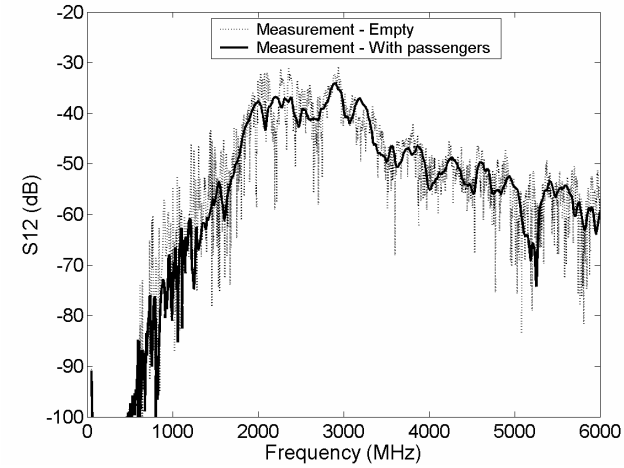

Fig. 7. Measured S_{12} of the simplified fuselage with and without passengers.

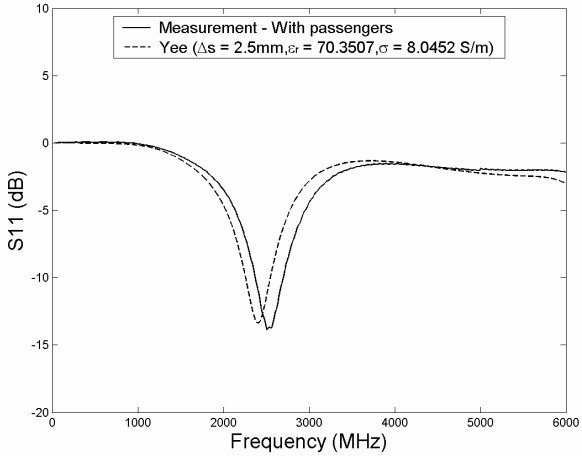

Fig. 8. Measured and simulated S_{11} of the simplified fuselage filled with passengers.

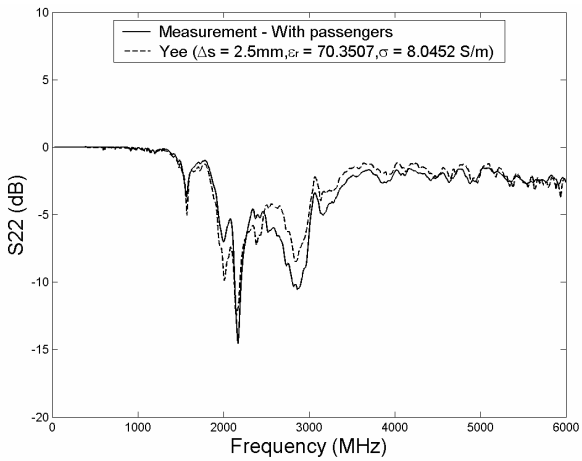

Fig. 9. Measured and simulated S_{22} of the simplified fuselage filled with passengers.

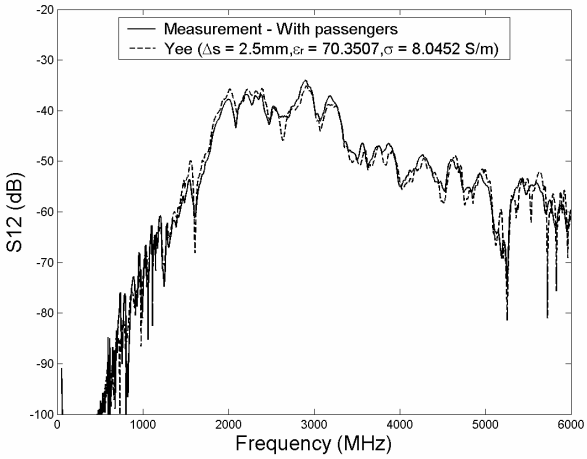

Fig. 10. Measured and simulated S_{12} of the simplified fuselage filled with passengers.