Numerical Estimation of Propagation Path Loss for Wireless Link Design of WAIC Systems Installed on outside Aircraft Cabin Based on Large-Scale FDTD Simulation

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Abstract:
The aim of this study is to develop an accurate and reliable method for estimating the propagation characteristics inside and outside aircraft cabins so as to advance the radio link design techniques for WAIC systems. This paper uses the FDTD method and large-scale parallel computing to conduct the world’s first study on the propagation characteristics of signals emitted by a transmit antenna above the wing tip to WAIC antennas installed inside and outside the aircraft cabin (Airbus 320-200). EMF distributions created by a 4.4 GHz wireless transmitter inside the cabin are analyzed and propagation characteristics are determined from the analysis results.

Keywords: Wireless Avionics Intra-Communication (WAIC), aircraft, propagation characteristics, large-scale FDTD analysis

Classification: Antennas and propagation

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1 Introduction

A recent proposal uses wireless systems to replace wire harnesses with a view to improving safety functions such as emergency lighting and barometric pressure sensing while reducing aircraft cabin operation cost. AVSI (Aerospace Vehicle Systems Institute) has been considering the use of the wireless communication standard WAIC (Wireless Avionics Intra-Communication) to this end and has proposed the use of the frequency band from 4.2 GHz to 4.4 GHz [1]. To realize high speed and reliable wireless communication, designing practical wireless links makes it essential to determine the propagation characteristics inside and outside the aircraft cabin. Unfortunately, the labor costs incurred in performing
comprehensive measurements in actual environment are excessive.

Given the above, the authors used a supercomputer to conduct large-scale simulations based on the FDTD method [2, 3], and reported the attenuation characteristics of the electromagnetic fields and polarization dependency of the WAIC system [4, 5] in a common aircraft cabin.

At least one WAIC transmitter is expected to be installed at the wing tip. Electromagnetic waves radiated from the wing tip are combined with waves reflected from the wing and enter the aircraft through multiple windows. Inside the cabin, these electromagnetic waves are reflected multiple times by the surrounding metal. Therefore, the electric field distribution becomes extremely complex. For this reason, highly accurate evaluations of electric field intensity (received electric power) at the reception device are critical in designing WAIC wireless links.

This paper considers WAIC receiver sites inside and outside the aircraft cabin, and quantitatively evaluates the propagation loss characteristics obtained from numerical analyses based on the theoretical value published by ITU [6, 7]. The results clarify the effectiveness of the large scale supercomputer-based numerical analysis technique.

2Numerical analysis model of narrow body aircraft cabin and FDTD analysis parameters

Figure 1 outlines the numerical model, which follows the structure and dimensions of the Airbus 320-200, a narrow body aircraft. We assumed that the aircraft is on the dry ground and empty. The simulation parameters are the same as those given in [8]. The analysis space is discretized using 5 mm cubic voxels. The green solid line in Figure 1 is a magnetic wall. Symmetry allows us to analyze split regions. The green dotted line is the absorption boundary: a ten layer CPML. structure. The excitation source emitted a sinusoidal wave at 4.4 GHz. Repetition count for FDTD analysis was set at 6000 periods to ensure convergence. The transmit antenna (λ/2 Dipole antenna with vertical polarization) had an input power of 100 mW. This antenna, which models an icing sensor, is installed + 0.5 m inboard of the wing tip.

![Aircraft cabin model](image-url)
3 Simulation results

We evaluated the propagation characteristics in the WAIC frequency band. Two evaluation points were set: 15 m from the transmit antenna (external) and 18 m (internal). Centered on each evaluation point, the electric field intensity was determined in a square region of about 1 wavelength (70 mm × 70 mm).

Figure 2(a), 2(b) summarizes the theoretical values (external) and propagation path loss (internal, external) as averaged over a certain section and derived from numerical analyses. The vertical axis shows the propagation loss, the horizontal axis shows the distance from the transmit antenna to each evaluation point. The bottom and top horizontal axes plot the distance between the transmit antenna and the internal and external evaluation points, respectively.

The propagation pass loss of inside and outside the aircraft cabin is larger than the case of FSPL. Outside the aircraft cabin, propagation losses due to structures specific to aircraft such as wings and engines are conceivable. Inside the aircraft cabin, the electromagnetic field strength is strongly attenuated by multiple reflections, and it is understood that the internal path has greater propagation loss than the external path. The maximum difference is about 15.5 dB in Figure 2(a).

Propagation path loss obtained from the numerical analyses contains waves reflected from the wing, which are not considered in the theoretical values. The electromagnetic field distribution becomes complicated because the reflected waves are synthesized into direct waves.

In order to evaluate the propagation pass loss inside the aircraft cabin, we compared it with the indoor propagation loss in a typical office environment. The difference in propagation loss is about 10 dB at maximum. We can confirm that the loss due to multiple reflections on the surrounding metal wall in aircraft is large. Moreover, in order to evaluate propagation pass loss outside the aircraft cabin, we compared it with outdoor propagation loss in an urban area. The difference in propagation loss is about 30 dB at maximum. We can confirm that losses due to the movement of many people and cars are large.
As shown in Figure 2(a), the propagation loss decreases as the distance from the ordinary antenna decreases. However, Figure 2(b) shows the opposite. Figure 3 shows a two-dimensional field distribution yielded by numerical analysis. Black dotted lines indicate aircraft structures outside the evaluation plane. As shown in the height pattern of Figure 3, the wave reflected from the wing interferes with the direct wave, which makes the electromagnetic field distribution complicated.

**Fig. 2.** Propagation path loss at evaluation point of inside and outside of aircraft cabin.

**Fig. 3.** Two-dimensional field distribution (xy plane) when the transmit antenna is installed at the wing tip.
4 Conclusions

In this report, the authors considered two evaluation points, one inside and one outside the aircraft cabin, as candidate WAIC receiver sites and quantitatively compared theoretical values with the propagation path loss obtained from numerical analyses given a wing tip transmitter site.

The propagation path loss yielded by the numerical analyses contains the influence of the waves reflected from the wing, a characteristic not considered in the theoretical assessments; we showed that the influence of the reflected wave on the direct wave is large, which makes the electromagnetic field distribution very complicated.

We also confirmed the effectiveness of using numerical analyses and the importance of considering the dispersion of electric field strength in designing wireless link schemes.

We have compared the numerical analysis and actual measured results for other aircraft, and confirmed that the obtained results agree roughly [9]. From these results, we believe that the results of this study can be considered valid to some extent. We are also planning to compare numerical analysis with actual measurement results.

In addition, we have already confirmed that the existence of passengers influences the propagation characteristics in aircraft cabin [10]. Therefore, we would like to consider the effects of passengers and multipath fading.