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Hybrid Electromagnetic Analysis Methods Suitable for Airport Surfaces in the VHF Band

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The Ground-Based Augmentation System (GBAS) is a navigation system to support precision approaches and landings using GNSS, which is being implemented worldwide. A VHF Data Broadcast (VDB) antenna of GBAS is installed on the ground and broadcasts augmentation information to an aircraft. The VDB coverage should be constructed, including throughout runway surfaces to support the auto-landing. The VDB antenna installation positioning should desirably be determined by electromagnetic simulations, because experimental means are so time-consuming. However, precise full-wave analyses of airport surfaces, including buildings, require considerable computational memory and time. Accordingly, the authors have suggested various hybrid methods using the ray-tracing, Aperture Field Integral Method (AFIM) and full-wave analyses to calculate the electromagnetic fields on the airport surfaces, including buildings and land shapes. This paper shows three hybrid methods suggested by authors.

Key Words: GBAS, VDB, Coverage, Hybrid Method, Ray-tracing, AFIM, Full-wave

1. Introduction

The Ground-Based Augmentation System (GBAS) is a navigation system to support precision approaches and landings using GNSS, which is being implemented worldwide. VHF Data Broadcast (VDB) of GBAS improves its integrity performance by broadcasting augmentation information, which is generated by four reference stations installed near runways. VDB antennas with mount poles are also installed on the ground. VDB coverage should be constructed at the altitude exceeding 12ft, including throughout runway surfaces to support auto-landing.

VDB antenna installation positioning should desirably be determined by electromagnetic simulations because experimental means are so time-consuming. Ideally, one VDB antenna should construct coverage of all runways at an airport with multiple runways. The antennas should be installed as low as possible to reduce the power attenuation due to the ground fading. There are land-shape variations between the VDB antenna and aircraft at some airports.

Full-wave analytical methods like FEM (Finite Element Method), FDTD (Finite Difference Time Domain) and MOM (Method of Moment) can calculate complex electromagnetic behavior among complex constructions. However, these full-wave analysis of airport surfaces, including buildings and runways, requires considerable computational memory and time, given the VDB frequency from 108 to 118Hz and its wavelength is about 3m. The runway length becomes 1000 wavelength. The number of meshes on one side of the full-wave analysis space becomes 10,000 in the case that the mesh size of 0.1 wavelength is used.

Accordingly, the authors have suggested various hybrid methods using ray-tracing, Aperture Fields Integral Method (AFIM) and partial full-wave analyses to calculate the airport surface, including buildings and land shapes. The ray-tracing method can calculate wide-area propagations, including reflections on the building surfaces and refractions at the building edges because ray tracing approximates geometrical optics at the expense of accuracy. The ray-tracing accuracy declines on the analytical model, which is narrow in comparison to wavelengths. These full-wave analyses, which can't take the entire airport surface into account, are partially available. This paper shows three hybrid methods suggested by authors based on the characteristics of airport configurations.

2. Hybrid Method 1: Full-wave and Ray-tracing

Firstly, the hybrid method of the partial full-wave analysis and ray-tracing is shown in this section. This method is applicable to cases where a VDB antenna is installed near terminal buildings. The authors focused on the fact that the terminal, control tower, hangars and other buildings are located in a narrow area. Most airports have this characteristic. The authors also focused on that there are no buildings in apron and landing areas and only slight land shape variations exist in these areas.

The hybrid method is outlined in Fig. 1. The full-wave analysis is not adopted for the whole of the analytical area, but a partial area where buildings exist. The slight land shape variations in the apron and landing areas contribute attenuation to the propagation of VDB signals. The attenuation level is calculated by a method requiring small memory and short computation time, like raytracing. The attenuation is multiplied to the radiated power from building areas, which are calculated by full-wave analysis. The VDB antenna of the aircraft on the runway receives the combined power of the direct and ground reflected

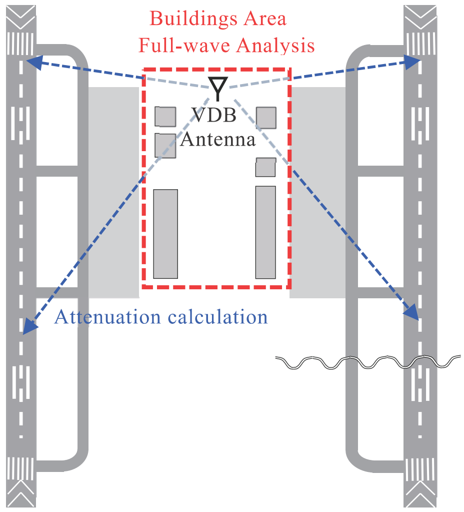

Figure1 Hybrid of Full-wave and Raytracing and Aperture Field Integration Method

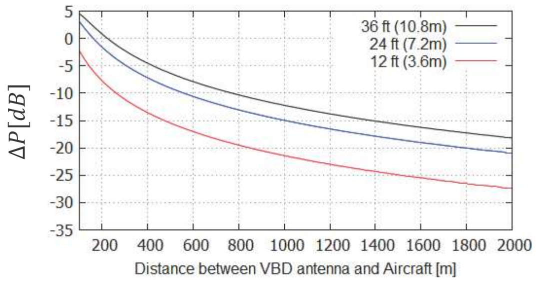

Figure2 Attenuation due to ground reflection

waves. Here, phases of the ground reflected wave are inverted by the reflection on the ground because VDB utilizes horizontal polarization. Therefore, these two waves have anti-phase because their path lengths are almost the same. The combined power of them becomes small.

Fig. 2 shows the attenuation ΔP calculated by the ray-tracing method where the ground is completely flat. The height of VDB transmission antenna is 6m and that of the receiving antenna are from 12 to 36 feet. Fig. 2 shows how the combined power declines for a lower receiving antenna position. The final received power generated by this hybrid method is calculated using the radiated field by the full-wave method P_d and attenuation ΔP as shown in Equation (1).

$$P_{sum}[dBm] = P_d[dBm] + \Delta P[dB] \qquad (1)$$

The validity of this hybrid method is discussed by using the scaled-down airport model constructed in an anechoic chamber in Ref. [4]. The frequency in the measurement was changed according to the scale ratio. The results of the received powers calculated by this hybrid method agree with the measurement.

3. Hybrid Method 2: Ray-tracing and AFIM

Secondly, a hybrid method of ray-tracing and the Aperture Field Integration Method is shown in this section. This method applies to cases where buildings exist between the VDB antenna and aircraft on runways. The authors have developed the method focusing on the fact that passenger terminals, cargo terminals, control towers and other buildings are arranged in a straight line.

The ray-tracing method can calculate wide-area propagation, including reflections on the building surfaces and refractions at the building edges because ray-tracing approximates geometrical optics at the expense of accuracy. While the ray-tracing method can reduce computation memory and time, accuracy declines when the spaces between buildings are narrow. Electromagnetic waves radiated from narrow spaces cannot be approximated as geometrical rays, because the waveform cannot be maintained as plane-wave.

The outline of the second method is shown in Fig. 3. The received power of the aircraft antenna on the runway is basically calculated by the ray-tracing method. The radiated field from the narrow building space is calculated by the Aperture Field Integration Method shown in Equation (2) instead of ray tracing. The final received power of this hybrid method is calculated by the sum of the field of AFIM and other rays such as that through the external edge of buildings.

$$E = -jk\frac{e^{-jkr}}{2\pi r}\int_{-\frac{d}{2}}^{\frac{d}{2}}\int_{-\frac{h}{2}}^{\frac{h}{2}} E_0 e^{jky\sin\theta}\mathrm{d}x\mathrm{d}y \qquad (2)$$

In Equation (2), E is the source of the re-radiated field, d is the distance between buildings, h is the building height, r is the propagation distance from the re-radiated point and the received position above the runway and the θ is the angle between the directions of the building front and the received position. Ref. [5] shows the validity of this hybrid method. The source of the radiated field was calculated by three-dimensional full-wave FEM analysis (ANSYS HFSS). Although efforts to derive re-

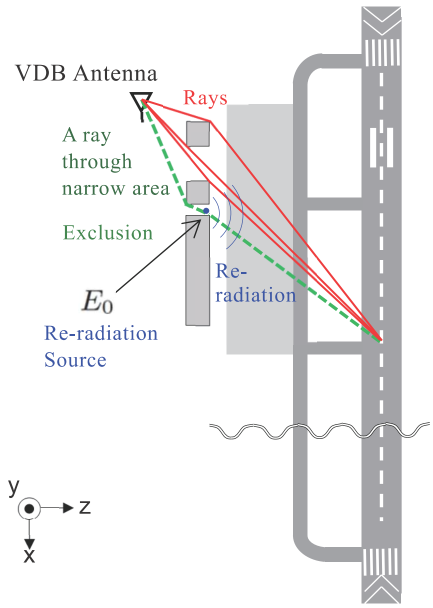

Figure 3 Hybrid of Raytracing and Aperture Field Integration Method

radiated fields using the ray-tracing method will constitute future work, the validity of this hybrid method was shown by a comparison from the measurement using the scaled-down airport model.

4. Hybrid Method 3: 2D FDTD and Ray-tracing

Finally, the hybrid method of ray-tracing and two-dimensional FDTD is shown in this section. This method applies to cases where significant land-shape variations exist between VDB antenna and aircraft on the runway as shown in Fig. 4(a). Airports constructed by embankments on slopes of hills and mountains provide this situation.

The effect of the large land shape variation is calculated by the two-dimensional FDTD method as shown in Fig. 4 (b). Two-dimensional analysis requires little computational memory and time, despite the fact FDTD is full-wave analysis. The electromagnetic fields through buildings can be calculated by the ray-tracing method as shown in Fig. 4(c). Here, the ground reflections are included in two-dimensional FDTD calculations and not taken into account in the ray-tracing. The second method described in previous section is considered applicable where a narrow space exists between buildings. The basis of this method is the fact that the effect of the ground is common to all rays in the ray-tracing simulation shown in Fig. 4(c). The two-dimensional FDTD calculates the attenuation due to land shape variation as with Equation (1). A two-dimensional FDTD is considered effective in the event of wide-spread land shape variation as shown in Fig. 4(b) because the land shape variation is in the Fresnel zone.

The validity of this hybrid method was discussed in Ref. [6] by comparison from the measurement using a scaled-down airport model.

5. Conclusion

Three hybrid methods which are applicable to calculate the airport surface propagation suitable for GBAS VDB were shown in this paper. The ray-tracing, partial full-wave analysis AFIM and 2D-FDTD are utilized in the hybrid method base on the airport characteristics. Calculation of electromagnetic propagation, including the runway, buildings and other structures, can be conducted, even without a large computer. The authors hope these hybrid methods will contribute to GBAS deployment.

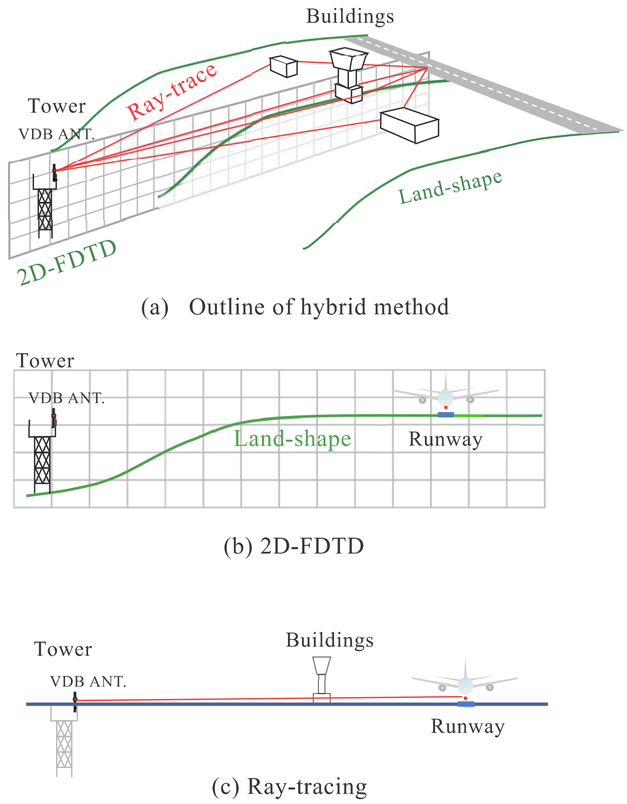

Figure 4 Hybrid of 2D-FDTD and Raytracing

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