Electromagnetic Interference Evaluations of Aircraft Radio Altimeter Due to Sub-6 Band 5G Mobile Communications System at Japanese Conditions

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Abstract

Aircraft radio altimeters (RAs) are essential avionic devices for measuring aircraft altitude. Aircraft RAs operate between 4.2–4.4 GHz. However, Sub-6 5G mobile systems have been introduced in adjacent radio altimeter bands. In Japan, the radio altimeter frequency band and guard band for 5G mobile systems are both 100 MHz, which is narrower than those in other countries. Thus, under Japan's narrow guard band conditions, the risk of interference is higher than in other countries such as the United States and France.

In this study, the electromagnetic interference (EMI) issues of aircraft RAs due to Sub-6 band 5G mobile communications systems under Japanese conditions are discussed. First, EMI susceptibility evaluations of aircraft RAs under Japanese Sub-6 band 5G mobile systems are discussed. Twelve RAs for large fixed-wing aircraft and eight RAs for small- and medium-fixed-wing aircraft and helicopters are measured. The study subsequently discusses the development of the EMI occurrence condition analysis method, based on the measured EMI susceptibility characteristics of RAs, the characteristics of Sub-6 band 5G mobile base stations, and a three-dimensional airport model.

Introduction

Aircraft radio altimeters (RAs) are essential avionic devices for measuring aircraft altitude. Altitude readings are crucial because they serve as both a visual confirmation for pilots and an input for various aircraft control systems [1]. RAs operate within a frequency range of 4.2–4.4 GHz. However, the global frequency assignment for the Sub-6 5G mobile communication system occurs in bands adjacent to the RA frequency, resulting in interference. Hence, it is necessary to understand and ensure the coexistence of these frequencies to maintain the safety and reliability of RAs.

In Japan, the frequency bands of 3.7–4.1 and 4.5–4.6 GHz are currently assigned to 5G mobile systems, but detailed interference tolerance in these frequency bands has not been extensively studied. Furthermore, the guard band on both sides of the RA band is 100 MHz, which is narrower than those in the United States and most other countries [1]–[6]. In this study, we investigated electromagnetic interference (EMI) in aircraft RAs due to Sub-6 band 5G mobile communication systems in Japan.

First, the EMI characteristics of the RAs are measured using a narrow guard band. Next, the interference tolerance masks (ITMs) are calculated using the measured interference thresholds. The obtained ITMs are then compared to those reported for wider guard bands. Finally, the current progress and updates of the RA-interference analysis methodology for 5G mobile communication systems are discussed using the obtained results.

Comparison of Sub-6 Band 5G Mobile Systems in Various Countries

Figure 1 shows the frequency allocations of Sub-6 band 5G mobile systems in Japan, the United States, and France. In Japan, the 5G mobile communication system operates at frequencies of 3.6–4.1 GHz and 4.5–4.6 GHz with a 100 MHz guard band. However, in the United States and France, frequency bands of 3.7–3.98 GHz and 3.49–3.8 GHz are allocated to commercial services, and the guard bands are 200 and 400 MHz, respectively. Table 1 lists the base station specifications for these three countries. Among them, the United States has the highest maximum antenna power under regulations (62 dBm/MHz (82 dBm/100 MHz)), followed by Japan (60.8 dBm/MHz (80.8 dBm/100 MHz)), and France (58 dBm/MHz (77.5 dBm/90 MHz)). In addition, unnecessary emission strength is below −39 dBm/MHz in Japan (−46 dBm/MHz or less for base stations with equivalent isotropic radiated power (EIRP) less than 25 dBm/MHz) and −12.9 dBm/MHz in France and the United States.

Table 2 lists the differences in the interference thresholds for RAs used in studies on spectrum sharing in Japan and those reported by the Radio Technical Commission for Aeronautics (RTCA) [1]. In Japan, the interference thresholds for RAs are determined using ITU-R M.2059 [7], which describes typical technical specifications for RAs. The thresholds reported by RTCA are lower than those reported by ITU-R M.2059, especially for out-band interference, where it is 20 dB lower than that of ITU-R M.2059. However, the interference thresholds reported by RTCA are more comprehensive because the EMI tests are conducted using nine RAs and the interference thresholds are measured at different altitudes.

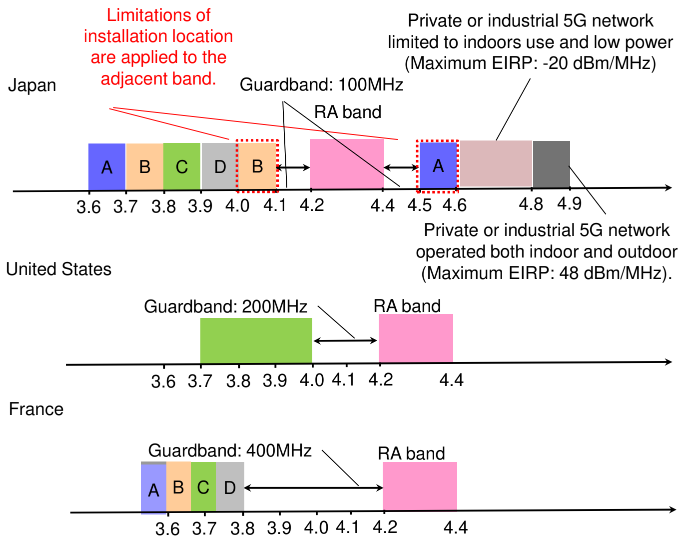


Figure 1. Frequency allocation for Sub-6 band 5G mobile systems in Japan, the United States, and France.

Table 1. Comparison of base station specifications in Japan, the United States, and France

Country/Specifications	Japan	United States	France
Frequency (GHz)	3.6–4.1, 4.5–4.6	3.7–3.98	3.49–3.8
Transmitting power (EIRP)(dBm/MHz)	60.8	62	58
Out-band emission (dBm/MHz)	−39 or less	−12.9 or less	−12.9 or less
Down tilt	Not required	Not required	Required

Table 2. Differences between the interference thresholds adopted in Japan and those reported by the RTCA [1]

Parameters/Specifications	ITU-R M.2059	RTCA Report
In-band interference threshold value (dBm/MHz)	−117	−119
Out-band interference threshold value (dBm)	−53	−74

Evaluation of EMI Characteristics under Japanese Frequency Conditions

As mentioned in the previous section, the interference threshold obtained using ITU-R M.2059 is not suitable for studying spectrum sharing because it is not comprehensive. In addition, Japanese Sub-6 band 5G mobile systems are operated within a narrow guard band compared with those of the United States, as discussed in the RTCA report. To accurately measure the EMI of aircraft RAs in Japan, it is necessary to obtain the EMI characteristics of the RAs under Japanese frequency conditions. However, the EMI characteristics of the RAs are proprietary information of manufacturers and must be obtained through experiments.

Thus, in collaboration with the Association of Air Transport Engineering and Research (ATEC), All Nippon Airways (ANA), Japan Airlines (JAL), and NAKANIHON AIR, we conducted extensive EMI measurements over three months [6]. In addition, we collected RAs from multiple aircraft operators. The numbers of RAs used for the test are as follows:

Category 1 RA (RAs for large fixed wings): 12 units

Category 2 RA (RAs for medium and small fixed wings): 8 units

Category 3 RA (RAs for helicopters): 8 units

Category 1 RAs include those based on the frequency-modulated continuous-wave (FMCW) ranging method, whereas Categories 2 and 3 include those based on both the FMCW and pulse ranging methods. Figure 2 shows the RA interference susceptibility test setup, and Figure 3 shows the block diagram. The setup is based on the RTCA DO-155 test setup [8], which includes fixed or step attenuators, an optical delay line (RFOptic ODL), a 3 dB hybrid, and a dual-channel vector signal generator (Anritsu MG3710E).

The transmitted signal from the RA passes through the attenuator and the delay line. Concurrently, this transmitted RA signal merges with the interference signal within the 3-dB hybrid. This combined signal is then directed back to the RA receiving port. The altitude output from the altimeter, which could be either the ARINC429 label 164/165 signal or the analog voltage, is continuously monitored and recorded. The interference criteria are the same as those described in the RTCA 5G interference assessment report [1] and AVSI AFE 76s2 reports Volumes I [2] and II [3].

1. Mean error: Interference power at which the mean altitude error exceeds 0.5%.
2. Cumulative distribution function (CDF) error: Fewer than 98% of all data points in the RF power-on interval fall within 2%.
3. No computed data (NCD): Altitude output labeled with NCD.

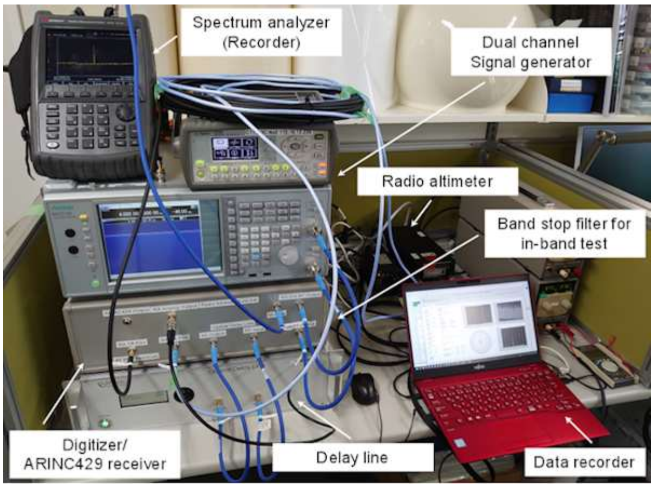


Figure 2. Radio altimeter interference susceptibility test setup.

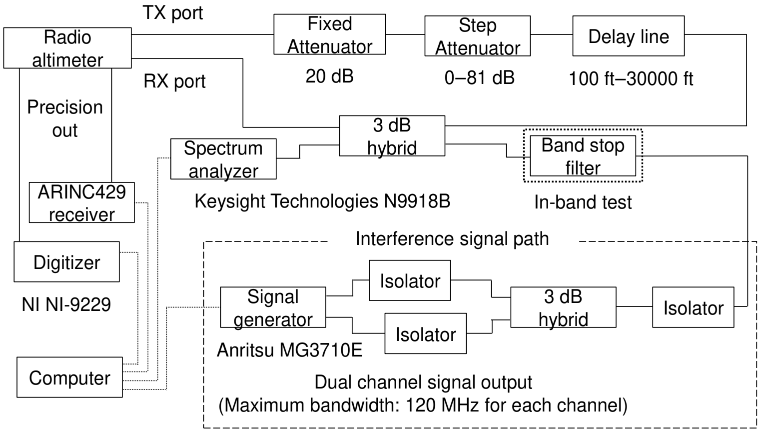


Figure 3. Block diagram of the RA interference susceptibility test setup.

The loop losses re obtained from RTCA DO-155 (Appendix B) (antenna beam width: 60°; antenna gain: 12). However, the altitude outputs of some RAs are unstable with nominal loop loss values, particularly in high-altitude regions. Thus, loop losses are reduced until a stable altitude output is obtained. The measurement altitudes are 200, 1,000, 2,000, 5,000, and 7,000 ft. Figure 4 shows the frequency conditions for the measurements. These include the in-band and out-band (guard bands of 100 MHz on the upper and lower adjacent bands, 200 MHz on the lower adjacent band, and 300 MHz on the lower adjacent band), assuming a Japanese Sub-6 5G frequency allocation. A 5G NR test signal (NR-FR1-TM1.1) is used as the interference signal for out-band interference measurements, and additive white Gaussian noise is used for in-band interference measurements.

Figure 5 shows an example of the out-band measurement results at 1,000 ft. An intermittent interference signal with 20 s on and 10 s off is inputted to the receiver port of the RA during the test. The interference signal power is increased by 1 dB to investigate the interference threshold, CDF error threshold, and NCD at −23, −23, and −12 dBm, respectively. The lowest value is employed as the interference threshold for the ITM calculations.

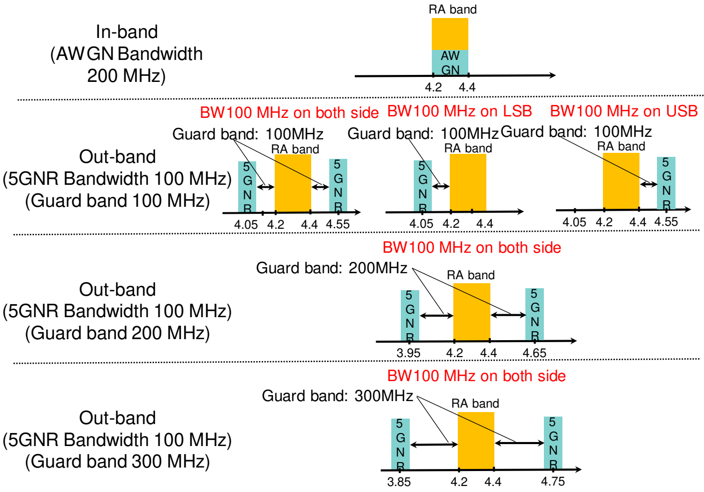


Figure 4. Interference signal frequency conditions for the in-band and out-band test conditions.

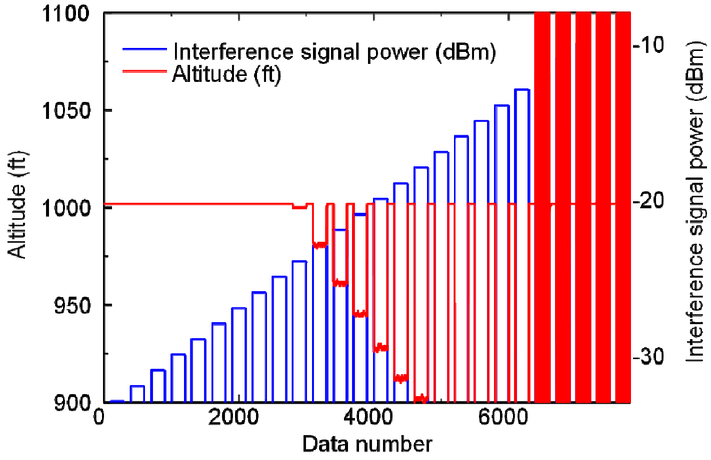
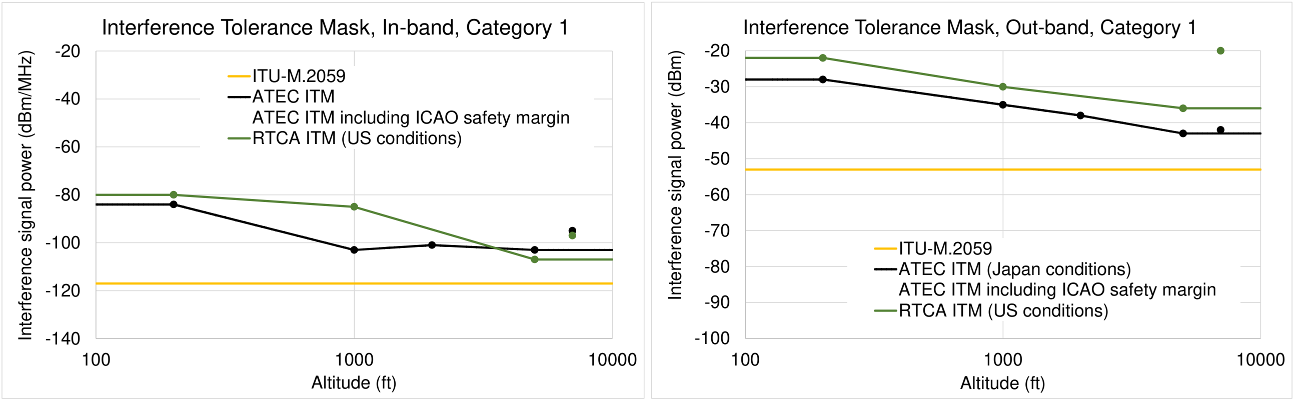


Figure 5. Example of measurement results for the out-band test. (Mean error threshold: –23 dBm, CDF error threshold: –23 dBm, NCD: –12 dBm)

Evaluation of ITMs under Japanese Frequency Conditions

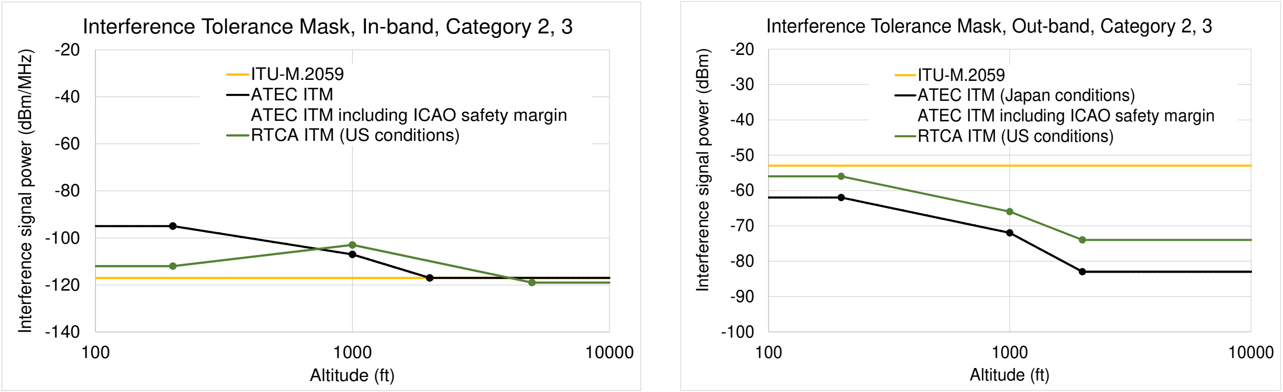
The ITMs are calculated from the results of all measurements to investigate the spectrum-sharing conditions. The conditions for the occurrence of interference are evaluated by comparing them with the interference signal power from Sub-6 band 5G mobile communication systems. The additional 6-dB interference margin for avionics systems is the ITM determined by the International Civil Aviation Organization (ICAO).

Figure 6 shows the (a) in-band and (b) out-band ITMs for Category 1 RAs calculated from all measurement results. The ITM obtained herein is referred to as the ATEC ITM, and that obtained from the RTCA report is referred to as the RTCA ITM. For the out-band ITM, the ATEC and RTCA ITM are based on the least-guard bands at 100 and 220 MHz, respectively. As shown in Figure 6 (a), the in-band ATEC ITM exhibits the same trend as the RTCA ITM. However, for the out-band ITMs, the ATEC ITM is lower than the RTCA ITM with a maximum difference of 7 dB (Figure 6 (b)). This is attributed to the narrower guard band used under our measurement conditions.



(a) In-band ITM **(b) Out-band ITM**

Figure 6. Comparison of the ITMs obtained herein (ATEC ITM) and those in the RTCA report (RTCA ITM) for Category 1 RAs.



(a) In-band ITM **(b) Out-band ITM**

Figure 7. Comparison of the ITMs obtained herein (ATEC ITM) and those in the RTCA report (RTCA ITM) for Categories 2 and 3 RAs.

Figure 7 shows (a) the in-band and (b) the out-band ITMs of Categories 2 and 3 RAs calculated from all measurement results. Similar to Category 1, the in-band ATEC ITM exhibited the same trend as the RTCA ITM, and the out-band ATEC ITM is always lower than the RTCA ITM due to the narrower guard band in Japan. The maximum difference between the out-band ATEC and RTCA ITMs is 9 dB. These results indicate that the Sub-6 5G frequency allocation in Japan requires extra consideration for ITMs, especially in the out-bands, due to the narrow guard band.

Tables 3 and 4 compare the ATEC and RTCA ITMs of Category 1 RAs and Categories 2 and 3 RAs, respectively. Although the regulatory maximum transmitting power of base stations in Japan is 1.2 dB lower than that in the United States, the ITM value decreases by 7 dB due to the narrow guard band. This indicates that the Japanese frequency condition is more susceptible to interference than the United States frequency condition. Therefore, Japan has a higher interference risk because of its narrower guard bands, even with slightly lower station power.

By comparing the ATEC ITM with the minimum interference threshold of ITU-R M.2059, we found that for Category 1 RAs, the ATEC ITM is higher than the ITU-R M.2059 value. However, for Categories 2 and 3 RAs, the ATEC ITM values are also higher than the ITU-R M.2059 values. Because the difference between the ATEC ITM and ITU-R M.2059 is approximately 30 dB, the interference conditions of the RAs must be revised. In addition, spectrum-sharing conditions should be reviewed and reconsidered.

Table 3. Comparison of out-band ITMs for Category 1 RAs.

Type/Altitude (ft)	ITU-R M.2059 (dBm)	RTCA ITM (dBm)	ATEC ITM (dBm)
200	−53	−22	−28
1,000	−53	−30	−35
2,000	−53	-	−38
5,000	−53	−36	−43
7,000	−53	−36	−43

Table 4. Comparison of out-band ITMs for Categories 2 and 3 RAs

Type/Altitude (ft)	ITU-R M.2059 (dBm)	RTCA ITM (dBm)	ATEC ITM (dBm)
200	−53	−56	−62
1,000	−53	−66	−72
2,000	−53	−74	−83
5,000	−53	−74	−83

Table 5. The out-band ITM excess in spectrum sharing obtained using the RTCA reports interference evaluation model for base stations.

Country/ITM excess (dB)	Japan	RTCA report (United States)
Category 1	15	14
Category 2	56	48
Category 3	53	45

Furthermore, considering spectrum sharing for Category 1 RAs, where the ITU-R M.2059 interference threshold is lower than the ATEC ITM, interference is not evaluated under the maximum interference condition in Japan. Therefore, it is necessary to reevaluate the spectrum-sharing conditions following international technical standards. Table 5 lists the excess out-band ITM when the Japanese base station conditions and ATEC ITM are considered in the base station evaluation model reported by the RTCA. Excesses are observed in all categories, and Japan had higher values than the United States, even in Category 1 RAs, indicating a high risk of interference in Japan.

Development of Analysis Methodology for Aircraft RA Interference due to Sub-6 5G Mobile Communication Systems

The RA-interference analysis methodology for 5G mobile communication systems is investigated. This section introduces the current progress and updates of the research. Using the measured EMI characteristics of RAs under Japanese frequency conditions and a detailed airport model, the interference conditions are estimated in a three-dimensional space (Figures 8 and 9). We calculated the worst interference scenario for installing 5G base station antennas at hypothetical locations using an actual airport model. The analysis models and conditions are as follows:

Airport model

- Hiroshima Airport
- Three-dimensional model based on the Geospatial Information Authority of Japan.

5G base station

- A macrocell base station (EIRP:60.8 dBm/MHz）
- Maximum radiation pattern of the ITU-R M.2101 model [9].
- The antenna is placed on an obstacle clearance surface (OCS).

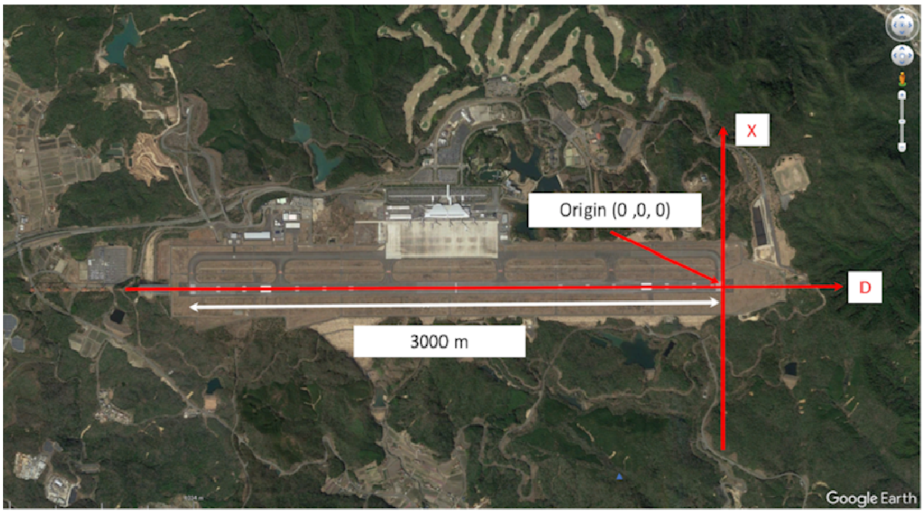


Figure 8. A satellite image of Hiroshima Airport used for the interference analysis.

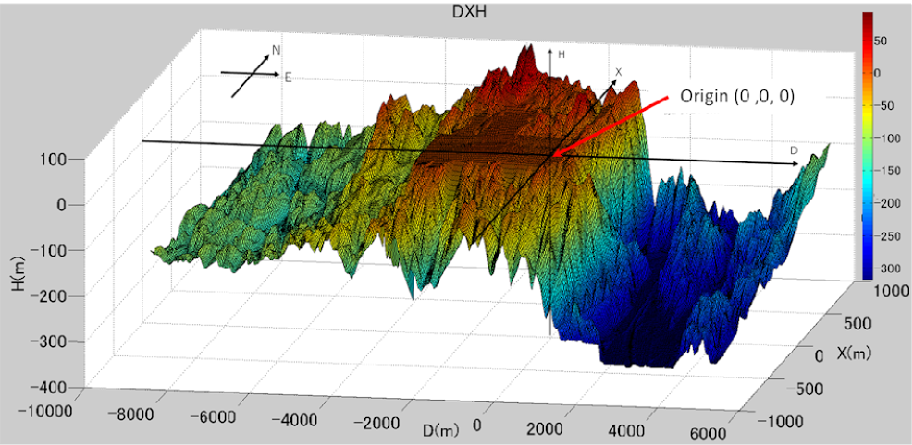
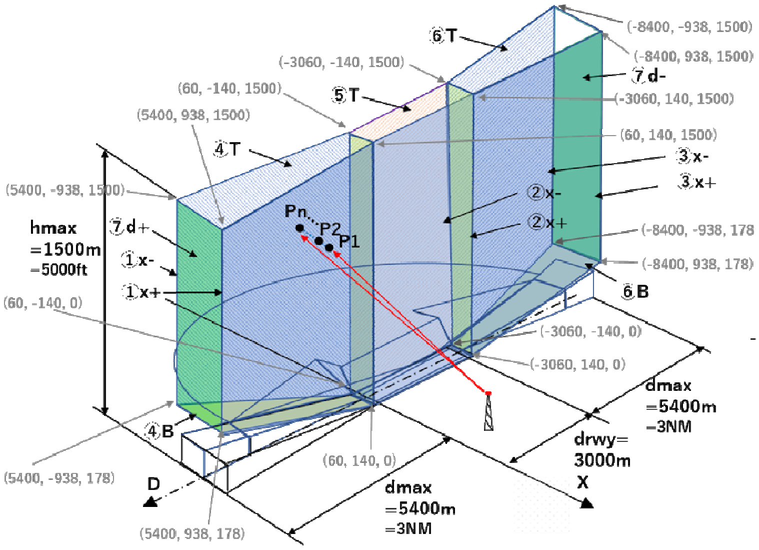


Figure 9. Three-dimensional Hiroshima Airport model.

Aircraft RA

- The ITM for the analysis is calculated based on the measured EMI characteristics of 12 RAs in a large fixed-wing aircraft.
- Twelve radio altimeters are not modified for the interference susceptibility.
- ITM at 4.05 GHz, representing the 100-MHz guard band, is used for the analysis.
- A 6-dB ICAO safety margin and RA antenna-radiation pattern (not considering the pitch/roll of the aircraft) are used.

The analysis space and location of the base station antenna are shown in Figure 10. The interference margin is analyzed within a three-dimensional space. Figure 11 shows typical analysis results for the X plane (X=140 m). Consequently, the low altitude and proximity to the base station affected the RAs. Depending on the topographical conditions of the airport, it is confirmed that there are areas where the interference margin varied owing to differences in distance and altitude from the base station. This section discusses the development of the analytical methodology. Detailed results will be presented in future studies.



Location of the base station antenna: (D, X, H) = (0,227,35)

Figure 10. The analysis space and the location of the base station antenna.

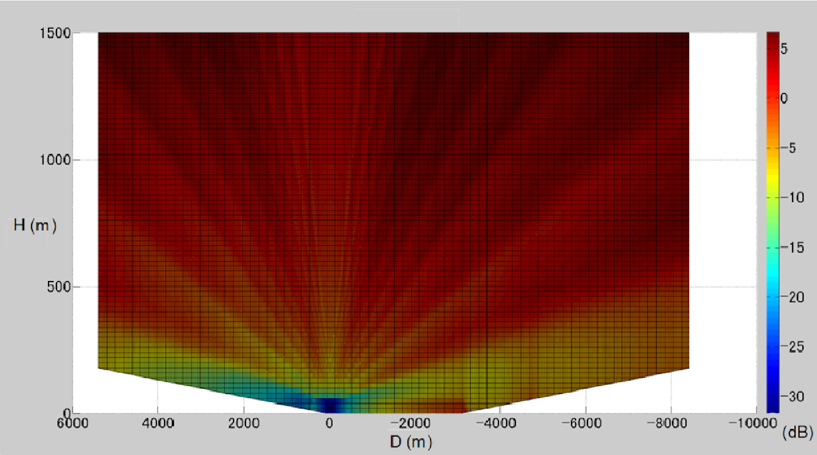


Figure 11. An example of the analyzed interference margin on the X-plane (X=140 m).

Conclusions

In this study, we investigated the EMI between aircraft RAs and Sub-6 band 5G mobile systems under Japanese frequency conditions. In Japan, there are minimal or no restriction areas for Sub-6 5G base stations around airports or heliports, despite the guard band being narrower than in other countries. This situation arises from insufficient coverage of the EMI characteristics of aircraft RAs and a lack of awareness of aircraft safety in previous studies on Japanese spectrum sharing.

EMI tests confirmed that the risk of interference is not low simply because Japan's base station power is low; overall, the risk of interference is higher than in other countries due to Japan’s narrow guard band conditions. In future studies, frequency-sharing conditions should be considered to prevent RA interference.

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References

[1] Radio Technical Commission for Aeronautics (RTCA), “RTCA SC-239: Assessment of C-Band Mobile Telecommunications Interference Impact on Low Range Radar Altimeter Operations,” RTCA Paper No. 274-20/PMC-2073, Oct. 2020.

[2] Aerospace Vehicle Systems Institute, AFE 76s2 Report Derivation of Radar Altimeter Interference Tolerance Masks Volume I: Introduction, Test Procedures, and Fundamental Test Results, Doc ID 76s2-REP-03, Dec 2021.

[3] Aerospace Vehicle Systems Institute, AFE 76s2 Report Derivation of Radar Altimeter Interference Tolerance Masks Volume II: Spurious Test Results, Doc ID 76s2-REP-04, Dec 2021.

[4] Ministry of Internal Affairs and Communications, “New Generation Mobile Communication Systems Committee Report (in Japanese),” Jul. 2018.

[5] Radio Technical Commission for Aeronautics (RTCA), “Guidance Document on Radar Altimeter RF Interference Rejection and Tolerance,” DO-399, to be published.

[6] S. Futatsumori, “Radio Altimeter Interference Susceptibility Test Results Under Japanese Sub-6 5G Mobile Communications System Frequency Conditions,” ICAO Frequency Spectrum Management Panel, WG/15, Aug. 2022.

[7] International Telecommunication Union, “Operational and Technical Characteristics and Protection Criteria of Radio Altimeters Utilizing the Band 4 200-4 400 MHz,” Report M.2059-0, Feb. 2014.

[8] Radio Technical Commission for Aeronautics (RTCA), "Minimum Performance Standard for Airborne Low-Range Radar Altimeters," DO-155, Nov. 1974.

[9] International Telecommunication Union, "Modelling and Simulation of IMT Networks and Systems for Use in Sharing and Compatibility Studies," Report M.2101-0, Feb. 2017.