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Proposed Technical Conditions for Interference Protection of a Radio Altimeter

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ABSTRACT

Recently, concerns about adjacent-band interference between radio altimeters and 5G mobile communication services have been raised. The interference effects between the two services were analyzed, and various technical methods were proposed to prevent interference. In this study, we analyze the interference effects between aircraft radio altimeters and 5G mobile communication services using the Minimum Coupling Loss (MCL) and Monte Carlo (MC) methods. We also propose technical conditions for preventing interference caused by the receiver characteristics of the aircraft radio altimeter.

Key Words : Radio altimeter, 5G mobile communication, interference analysis, MCL, MC

Ⅰ. Introduction

A radio altimeter is installed on the fuselage of an airplane or helicopter to measure altitude, which is the distance between the aircraft and ground surface. The measurement is performed by emitting radio waves directly below the ground surface and receiving the reflected radio waves during operation[1].

The Radio Technical Commission for Aeronautics (RTCA) recently submitted a report addressing the issue of interference between aeronautical radio altimeters and 5th generation (5G) mobile communication services in adjacent frequency bands. This report highlights the occurrence of such interference, which arises owing to the utilization of these frequency bands by both systems[2]. Owing to concerns surrounding interference within the aviation industry, the commercialization of C-band mobile communication wireless services in the United States was postponed. Moreover, plans are underway to implement alternative interference mitigation methods to replace aeronautical radio altimeters[3].

The Ministry of Internal Affairs and Communications (MIC) in Japan conducted an interference analysis between radio altimeters and 5G mobile communication services in adjacent bands. They developed technical conditions to ensure spectral compatibility between radio altimeters and 5G mobile communications based on the obtained results. These technical conditions propose a guard band of 100 MHz between 5G mobile communications and radio altimeters, considering the characteristics of the filter implementation. In addition, the installation of high-power transmission 5G base stations within 200 m of the approach path of the aircraft is prohibited to prevent interference[4].

South Korean mobile communication operators initiated the provision of commercial 5G services in 2019, utilizing the 3.42 – 3.7 GHz frequency band. In November 2019, Korea's Ministry of Science and ICT developed a 5G+ spectrum plan, which encompassed a provision for 300 MHz in the 3.7 – 4.0 GHz

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frequency band[5]. To facilitate the future utilization of the 3.7–4.0 GHz band for 5G services, conducting sharing studies with heterogeneous wireless services within the same frequency range is crucial. In addition, interference analysis is necessary to evaluate the compatibility with heterogeneous wireless services in adjacent bands[6].

This paper discusses the technical conditions for ensuring frequency compatibility between radio altimeters operating within the 4.2–4.4 GHz frequency band and 5G mobile communication services utilizing the 3.7–4.0 GHz frequency band. A model for aircraft entry was developed considering the landing approach of an aircraft equipped with a radio altimeter. By employing the Minimum Coupling Loss (MCL) and Monte Carlo (MC) methods, technical conditions have been proposed to prevent interference between 5G mobile communication and radio altimeters.

The remainder of this paper is organized as follows: Section II outlines the interference analysis methods employed between the aircraft radio altimeter and 5G mobile services. Section III provides details of the simulation parameters used for the aircraft radio altimeter and 5G system, along with various results. Finally, Section IV concludes the paper with a summary of the results.

Ⅱ. Interference-analysis method

2.1 Basic scenario

The compatibility analysis between the 5G mobile system and aircraft radio altimeter involved four interference scenarios: interference from the 5G base station transmission to the aircraft radio altimeter, interference from the 5G user equipment to the aircraft radio altimeter, interference from the aircraft radio altimeter to the 5G base station, and interference from the aircraft radio altimeter to the 5G user equipment. In this study, we particularly focus on the interference scenario caused by 5G base stations that affect aircraft radio altimeters.

Two subcategories are present within this interference scenario: in-band interference caused by unwanted radiation levels emitted by 5G base stations and out-of-band interference resulting from the receiver filter characteristics of the radio altimeter. The RTCA report expressed concerns regarding the occurrence of out-of-band interference, primarily owing to the receiver filter characteristics of the radio altimeter. Therefore, this study only considered the out-of-band interference arising from the receiver filter characteristics of the radio altimeter.

Fig. 1 depicts a model designed to account for the approach of the aircraft during landing and establish a restricted zone. The model considers an aircraft equipped with radio altimeters commencing its descent at an altitude of 1000 ft and concluding at the landing point (touchdown point) with a final approach altitude of 200 ft. The aircraft runway was assumed to be a straight line of a specified length, and the landing point was positioned 200 m beyond the runway threshold.

The International Civil Aviation Organization (ICAO) recommends a glide angle of 3° for these approaches. However, certain airports may opt to reduce them to 2°. Hence, for this model, a glide -path angle of 2.5° was assumed, accommodating variations in glide angles at different airports.

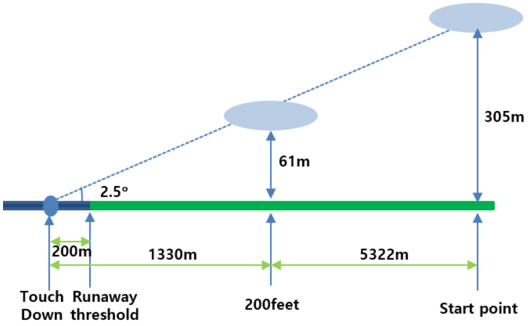

Fig. 1. Aircraft approach modeling.

2.2 Evaluation of interference effects by the MCL method

The MCL method was employed to calculate the necessary isolation between an interferer and victim system to guarantee an interference-free operation. This method offers simple implementation and does not require computer-based computation. However, a key limitation of the MCL method is its reliance on worst-case analyses that yield spectrally inefficient outcomes when applied to scenarios with statistical characteristics[7].

The separation distance required to avoid the out-of-band interference caused by the receiver characteristics of the radio altimeter can be computed using the following equation, derived from the MCL method:

$$Distance_{sep} = 10^{(\frac{EIRP_{BS}-F_{RA}+G_{RA}-BL_{RA}+M-32.44}{20})/f}, \quad (1)$$

where $EIRP_{BS}$ denotes the effective isotropic radiation power (dBm) of the 5G base station in the direction of the entry runway of the aircraft, F_{RA} represents the receiver filter characteristics of the radio altimeter, and G_{RA} represents the receiver antenna gain (dBi) of the radio altimeter. M represents the safety margin (dB), and f corresponds to the frequency (MHz). The term BL_{RA} (in dBm) refers to the overload threshold level of the radio altimeter. This refers to the signal level of the interference at which an overload occurs in a radio altimeter receiver. Generally, a receiver front-end overload occurs when an interfering signal provides sufficient power to saturate the front end of a radio altimeter receiver, resulting in nonlinear behavior and inherent effects such as harmonic distortion or intermodulation.

2.3 Evaluation of interference effects by MC method

The MC simulation is a statistical technique that incorporates numerous independent instances of time and location in space. Each simulation trial involves the construction of a scenario using various random variables. These variables determine factors such as the positions of the interferers relative to the victim, strength of the victim's desired signal, and specific channels employed by the victim and interferer.

The probability of the occurrence of a specific event can be accurately evaluated by considering a sufficient number of simulation trials. This approach provides a high level of accuracy in assessing the likelihood of various outcomes[7].

Fig. 2. illustrates the scenario for conducting MC-based interference analysis at the starting point and 200 ft altitude in aircraft approach modeling, as shown in Fig. 1. During aircraft flight, a radio altimeter considers the total interference signal strength from all base stations within a specific circular area beneath the aircraft. The projection of the radio altimeter onto the ground was positioned at the center of the circular area. The calculation included the overall interference caused by the antenna beamforming of the 5G base station serving each user on the radio altimeter[6].

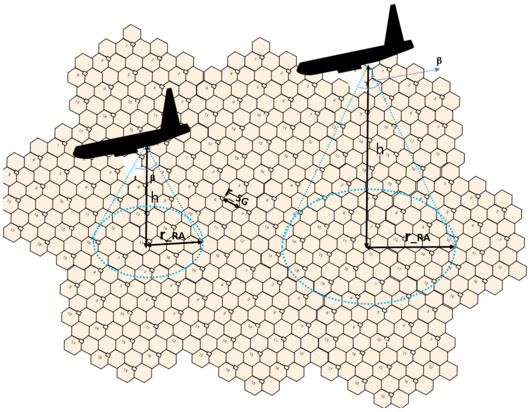

Fig. 2. Interference analysis scenario to apply the Monte Carlo (MC) method.

The analysis procedure depicted in Fig. 3 illustrates the assessment of the interference effect of 5G base stations on aircraft radio altimeters using the MC method. First, the parameters for both the 5G system and aircraft radio altimeter were established. These

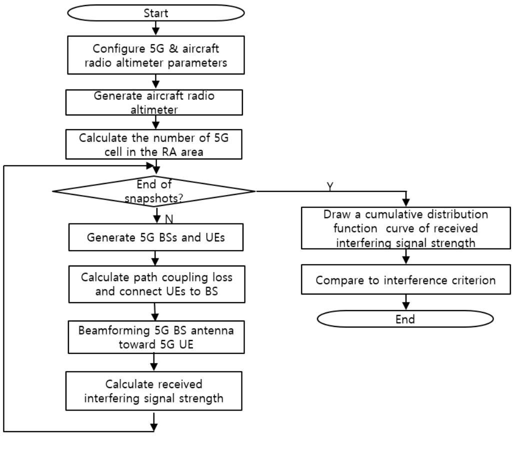

Fig. 3. Analysis procedure based on MC method.

parameters include the transmitter carrier frequency, transmission power, spectrum emission mask, receiving filtering mask, maximum antenna gain, antenna height, antenna pattern (including azimuth and elevation angles), propagation loss models for each path, interference protection ratio, and other relevant factors.

After setting the parameters, the aircraft radio altimeter was used. Subsequently, the provided formula was used to calculate the number of 5G base stations falling within the coverage of the radio altimeter.

$$N\__{5G} = (r\__{RA}/r\__{5G})\hat{}2, \tag{2}$$

where $r\__{5G}$ refers to the cell radius of the 5G system, and $r\__{RA}$ represents the cell radius of the aircraft radio altimeter, which can be calculated as

$$r\__{5G} = \tan(\beta/2)\cdot h, \tag{3}$$

where h represents the current height of the aircraft and β denotes the elevation beamwidth of the radio altimeter antenna.

In the next step, 5G base stations were generated, and user equipment was randomly generated for each snapshot within the 5G base station cell radius based on the input parameters. Path loss calculations were performed for each base station and user equipment path. Each user equipment established a connection with the base station that provided the minimum path loss, determined if the base station was linkable, and established a connection accordingly.

Next, the 5G base station antenna was aligned or beamformed in the direction of the user equipment antenna. Subsequently, the received interference signal strength at the radio altimeter for each snapshot was calculated using the following equation:

$$\mathrm{I} = \sum_{\mathrm{i}=1}^{\mathrm{N_{5G}}} P_i - ACIR(\Delta f) + G_{i\_5G}\left(\theta_{5G_{BS},RA}, \varphi_{5G_{BS},RA}\right) - \mathrm{PL}_{\mathrm{I},5\mathrm{G_{RA}}}\left(\mathrm{d_{5G,RA}}\right) + \mathrm{G_{i_{RA}}}\left(\theta_{RA,5G_{BS}}, \varphi_{RA,5G_{BS}}\right), \tag{4}$$

$$ACIR(\Delta f) = 1/(1/10\log_{10} ACLR + 1/10\log_{10} ACS), \tag{5}$$

where P_i represents the transmitted signal power level in front of the antenna of the i^{th} 5G base station. $ACIR(\Delta f)$ denotes the ratio of the adjacent channel interference received by the radar altimeter, as given by equation (5). *ACLR* refers to the adjacent channel leakage ratio in decibels, whereas *ACS* represents the adjacent channel selectivity in decibels. In addition, G_{i_5G} represents the antenna gain of the i^{th} 5G base station in the direction of the aircraft radio altimeter. $PL_{i\_5G,RA}$ represents the path loss value for the propagation path between the 5G base station and aircraft radio altimeter. Furthermore, G_{i_RA} signifies the antenna gain of the aircraft radio altimeter towards the i^{th} 5G base station.

The antenna gain of the 5G base station was determined using the beamforming antenna pattern described in [8]. The antenna array of the 5G base station is denoted as $N_H \times N_V$ and the beamforming gain is calculated as follows:

$$A_{array} = 10 \cdot \log_{10}\left(\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{n,m} \cdot v_{n,m}\right|^2\right) \tag{6}$$

where $v_{n,m}$ represents the superposition vector, and $w_{n,m}$ denote the beamforming weight factors. Detailed formulas for $v_{n,m}$ and $w_{n,m}$ can be found in [8].

A radio altimeter is typically installed at the center of an aircraft, with its antenna pointing vertically toward the ground. The maximum beam direction of the antenna was aligned with the downward vertical direction of the aircraft. The gain of the radar altimeter in the direction towards the i^{th} 5G base station is calculated as follows:

$$G_{i_{RA}}\left(\theta_{RA,5BS}, \varphi_{RA,5BS}\right) = G_{rel}(\theta, \varphi) + G_{RA\_max} \tag{7}$$

where $G_{rel}(\theta, \varphi)$ represents the relative gain at a given azimuth and elevation, while G_{RA_max} denotes the maximum antenna gain of the radio altimeter.

Following a simulation run for a specified number of snapshots, the calculated receiving interference signal strength was used to generate a cumulative distribution function (CDF) curve. Subsequently, the CDF curve of the received interference signal was compared with the interference protection criteria outlined for aircraft radio altimeters [1] to determine the interference probability.

Ⅲ. Simulation parameters and results

3.1 Simulation parameters

Tables I and II list the technical characteristic parameters of the 5G system and the aircraft radio altimeter that are essential for conducting interference analysis calculations or simulations.

The parameters of the 5G system were assumed based on the 3GPP standards[9] and domestic technical standards. For example, the 5G base station was assumed to have a total radiated power (TRP) limit of 35 dBm/MHz and a channel bandwidth of 100 MHz, as shown in Table 1. The 5G cell deployment environment was considered suburban, with a cell radius of 0.6 km and a base station tilt angle of 6°[10].

Radio altimeters installed in aircraft have various system parameters. In [1], diverse parameters of commonly used analog and digital altimeters were introduced. We assumed a D2 type Frequency Modulated Continuous wave (FMCW) for this analysis. The D2-type altimeter was equipped with a receiving antenna gain of 9 dBi, and its antenna pattern was determined based on [11]. In terms of interference criteria for the radio altimeter, we assumed an interference-to-noise ratio (I/N) of -6 dB, which is a widely accepted interference criterion. In addition, the allowable interference signal level was -111 dBm/MHz, ensuring the protection of the selected D2-type radio altimeter. The free-space loss model was used to estimate the path loss between the 5G base station and aircraft radio altimeter[12].

Table 1. Radio altimeter parameters.

Parameter	Value
Carrier frequency (MHz)	4300
Transmitting power(dBm)	20
3 dB emission bandwidth (MHz)	177
Noise figure (dB)	9
-3 dB Intermediate frequency bandwidth (MHz)	1.95
Antenna gain (dBi)	10
RF selectivity	24
Protection criteria (dB), I/N	-6
Acceptable interference signal level (dBm/MHz)	-111

Table 2. 5G system parameters.

Parameter	Value	
	BS	UE
Carrier frequency (MHz)	3950	
Channel bandwidth (MHz)	100	
Cell radius(km)	0.6	
Tx power (dBm/MHz)	35	-
Number of antenna elements	8×8	2×2
Element gain (dBi)	5	
Antenna height(m)	25	1.5
Antenna ohmic loss(dB)	3	
Tilt degree of base station (°)	6	

3.2 Simulations results

Fig. 4 shows the separation distance calculated by varying the overload threshold level of the radio altimeter. The interference analysis parameters listed in Tables 1 and 2 were used in Equation (1). When the overload threshold level of the radio altimeter was set to -43 dBm/100 MHz, a separation distance of 1.97 km was necessary to prevent interference from the 5G base station transmission signals from affecting the receiver characteristics of the radio altimeter. However, if the overload threshold level is -30 dBm/100 MHz, a separation distance of 0.44 km was required. These results demonstrate that the separation distance needed for radio altimeter protection varies depending on the overload threshold level.

Fig. 5 illustrates the CDF of the received

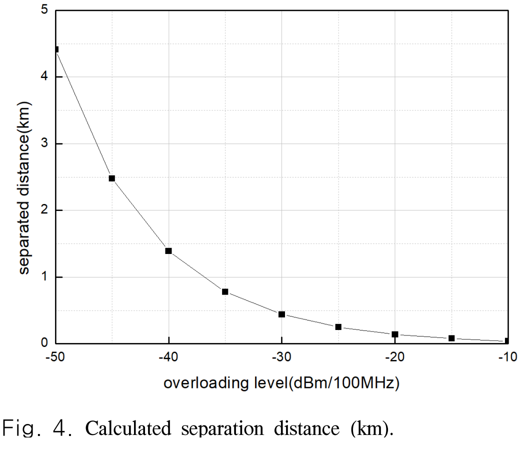

Fig. 4. Calculated separation distance (km).

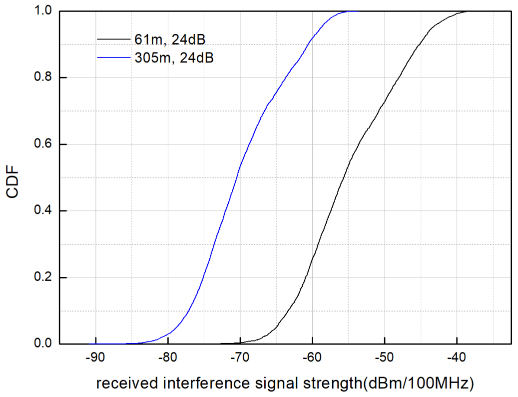

Fig. 5. Received interference signal strength at the RA.

interference signal strength from the 5G base stations as a function of the altitude of the aircraft radio altimeter. A vertical antenna pattern was applied to the radio altimeter, and the location and number of 5G base stations were kept constant to calculate the strength of the interference signal received by the radio altimeter. As the altitude of the radio altimeter increased, the strength of the received interference signal decreased.

Fig. 6 presents the CDF results for the received interference signal strength from the 5G base stations with variations in the receiver filter characteristics of the radio altimeter. The radio altimeter operated at an altitude of 61 m. To avoid overloading the radio altimeter, it can tolerate signal levels of up to -40 dBm/100 MHz without improving the receiver filter performance.

Applying a typical interference criterion of I/N = -6 dB, the allowable interference level for the radio altimeter was -91 dBm/100 MHz (-111 dBm/MHz). Comparing the simulation results with this interference criterion, it is evident that the receiver characteristics of the radio altimeter need to be strengthened by >45 dB compared to the initial 24 dB.

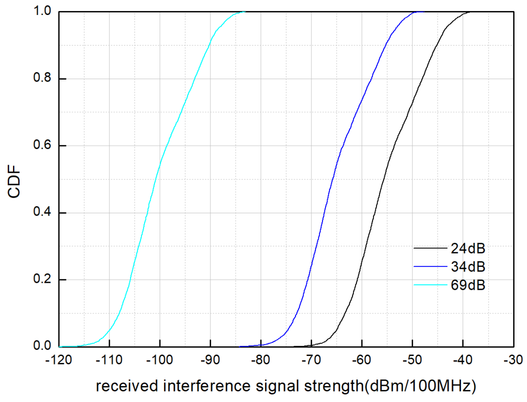

Fig. 6. Proposed receiver filter performance of RA.

Ⅳ. Summary

In summary, this study analyzed the interference effects between 5G mobile communication services and radio altimeters operating in adjacent bands. We established an aircraft entry model that reflects the actual approach of an aircraft and proposed an interference analysis procedure based on the MCL and MC methods.

Calculations and simulations were performed using the proposed methods to determine the technical conditions necessary to prevent the interference caused by the receiver characteristics of the radio altimeter. We provided appropriate separation distances based on the overload protection level of the altimeter to avoid interference from 5G base station transmission signals. In addition, the simulation results provide insight into the altimeter receiver filter characteristics required to prevent interference.

These findings contribute to establishing the technical conditions for spectrum compatibility between aircraft altimeters and 5G systems.

References

[1] “*Operational and technical characteristics and protection criteria of radio altimeters utilizing the band 4200-4400MHz,*” Rec. ITU-R M.2059, Feb. 2014. (https://doi.org/10.1176/appi.ajp.158.5.721)

[2] http://www.rcta.org/wp-content/uploads/2020/10.

[3] https://www.faa.gov/newsroom/faa-statements-5g.

[4] https://www.soumu.go.jp/menu_news/kaiken/01koho01_02001101.html

[5] https://mma.prnewswire.com/media/1136543/5G_Mid_Band_Spectrum_Global_Update.pdf?p=pdf.

[6] H.K. Son, "Proposed Separation Distance for Interference Protection of Radio Altimeter", *in Proc. KICS Joint Conference on Communications and Information (JCCI 2023), pp.519-520, Yeosu, Korea, June, 2023*

[7] "*A comparison of the minimum coupling loss method, enhanced minimum coupling loss method and the Monte-Carlo simulation*," ERC Rep. 101, 1999. (https://doi.org/10.1016/j.brs.2015.09.048)

[8] "*Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies*," Rec. ITU-R M.2101-0, Feb. 2017. (https://doi.org/10.1109/MCSE.2009.158)

[9] 3GPP TR38.104 V15.8.0, "*Technical Specification Group Radio Access Network; NR; Base Station (BS) radio transmission and reception*," Release 15, 2019. (https://doi.org/10.14509/29884)

[10] "*Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses*," Rep. ITU-R M.2292-0, Dec. 2013. (https://doi.org/10.1080/03091900110078412)

[11] "*Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses*," Rec. ITU-R M.1851-1, Jan. 2018. (https://doi.org/10.1177/154193120004400503)

[12] "*Calculation of free-space attenuation*," Rec. ITU-R P.525-3, Sep. 2016. (https://doi.org/10.1016/S0140-6736(00)03157-7)

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