Improvement of Multipath Propagation by Modifying DME Antenna Radiation Patterns

Yuki Hashimoto
Flight Inspector
Japan Civil Aviation Bureau
Tokoname-City, Aichi, Japan
Fax: +81 569 381350
E-mail: hashimoto-y97rg@mlit.go.jp

Nobuo Hongo
Deputy Chief Air Navigation Services Engineer
(Former Deputy Chief Flight Inspector)
Dr. Eng / Professional Engineer, Japan
Japan Civil Aviation Bureau
Hitachiota-City, Ibaraki, Japan
Fax: +81 294 72 9101
E-mail:hongoh-n977j@mlit.go.jp

ABSTRACT SUMMARY

In recent years, we have some experiences of DME UNLOCK in flight inspections associated with the renewal of VOR/DME equipment in Japan. The cause is believed to be the impact of multipath propagation resulting from the increase in terminal buildings and hangars due to airport modernization and expansion.

Regarding the impact, DME manufacturers, facility managers, flight inspections, and other related parties are working together to improve the quality of distance accuracy and radio wave characteristics.

INTRODUCTION

Currently, from the perspective of conducting efficient flight inspections, the method of omitting actual flight inspections is adopted by using a radio wave simulator using terrain data released by the Japanese government. However, it is difficult to fully reproduce the effects of complex multipath propagation by a wide variety of structures with this method, and it has often been observed that the simulation results and actual radio wave propagation are different.

This report outlines efforts to improve the effects of multipath propagation by adjusting the antenna radiation pattern (vertical plane) of DME and suppressing ground reflections as efforts to improve the effects of multipath propagation, and shares successful cases of flight observations by flight inspection aircraft effectively contributing to confirming the effects of multipath propagation in confirming radio wave propagation.

CHALLENGES IN DME INSTALLATION RELATED TO THE RADIO ENVIRONMENT IN JAPAN

The Unlock Situation of DME Receivers for Aircrafts Concerning the Chubu DME (CBE)

Regarding the cause of the DME UNLOCK events that occurred at Chubu DME (CBE) in February 2021, Maruhashi presented a paper titled "Investigation of DME Multipath Propagation" at IFIS 2022.

According to that study, the DME UNLOCK events occurred over a portion of the flight path due to multipath signals reflected by the passenger terminal building. It was only after the actual flight inspection had been conducted that the occurrence of DME UNLOCK was identified.

Because this issue had not been predicted by the prior radio propagation simulation, the case demonstrated the limitations of pre-flight simulation.

In response to this case, in Japan, the Technical Management Center (TMC), Air Traffic Services Engineering Division, Air Navigation Services Department is responsible for technical improvements based on radio propagation data obtained by flight inspection aircraft—and NEC Corporation, the DME manufacturer, jointly worked to improve and develop DME antenna radiation patterns. The chronology is as follows:

July–October 2021: Modifications were implemented to suppress ground reflections, including changes to the DME antenna radiation pattern.

FY2022 and FY2023: Based on radio propagation conditions obtained from flight inspections and experience in adjusting radiation patterns, a DME antenna was developed whose radiation pattern could be changed on site without replacing the antenna itself. The basic antenna radiation pattern was set to 4 degrees, with three selectable patterns: 2 degrees downward, 4 degrees standard, and 6 degrees upward.

Expansion of Tokyo International Airport (Haneda Airport)

Tokyo international airport (Haneda Airport) has undergone expansion work continuously for more than 30 years as an airport providing excellent access to Tokyo, the capital of Japan. The airport has experienced major changes associated with expansion, including the opening of Terminal 1 in 1993, Terminal 2 in 2004, and Terminal 3 together with the start of operation of Runway D by land reclamation in 2010. As a result of new construction and airport expansion, the reflective characteristics of radio waves have changed, and the radio environment has also continuously changed.

From April to May 2025, as part of the airport expansion project, the airport VOR/DME (Haneda VOR/DME: HME) was relocated and renewed. As a replacement for HME, a new Tokyo VOR/DME (TTE) was installed, and commissioning flight inspections were conducted.

During this inspection, DME UNLOCK occurred while inspecting the landing procedure VOR RWY34L using TTE. By applying the solution used in “Investigation of DME Multipath Propagation” (Maruhashi, 2022), the DME UNLOCK was eliminated by changing the antenna radiation pattern from 4 degrees to 6 degrees.

This was the first case in Japan in which DME UNLOCK was improved through a switchable antenna radiation pattern mechanism. This paper introduces the efforts that successfully resolved this DME UNLOCK event as one example of a successful case.

CORRELATION ANALYSIS BETWEEN DME UNLOCK AND ANTENNA RADIATION PATTERN (VERIFICATION OF IMPROVEMENT EFFECT)

Analysis of DME UNLOCK and DME Antenna Radiation Pattern from the Perspective of Distance Error

The inspection of the RJTT VOR RWY34L procedure involves flying along the 153-degree radial of TTE from 13.8 NM to 2.2 NM. When the antenna radiation pattern of DME (TTE) was set to 4 degrees, DME UNLOCK occurred at approximately 7–8 NM and 5–6 NM from the DME. Figure 1 shows an overview graph comparing the reference and error from the standpoint of distance error using the inspection data obtained at that time, and Figure 2 shows a detailed version.

In response to these results, the antenna radiation pattern was changed from 4 degrees to 6 degrees, and the DME UNLOCK was eliminated. Figure 3 shows an overview graph comparing the reference and error from the standpoint of distance error using the inspection data obtained in this configuration, and Figure 4 shows a detailed version.

In addition, data were also obtained when the antenna radiation pattern was set to 2 degrees. In that case, DME UNLOCK occurred at 14–16 NM, around 8 NM, and between 4–6 NM. Similarly, Figure 5 shows the overview graph, and Figure 6 shows the detailed version.

For the antenna radiation patterns of 4 degrees and 2 degrees, in which DME UNLOCK occurred, fluctuations in distance error that did not lead to a full DME UNLOCK can also be observed in the sections near the affected distances in Figures 2 and 6, respectively. In contrast, for the 6-degree antenna radiation pattern (Figure 4), where no DME UNLOCK occurred, the fluctuation remained small and the accuracy was stable throughout the entire section.

These results suggest that multipath has an adverse effect on distance accuracy and that suppression of multipath is important for improving distance accuracy.

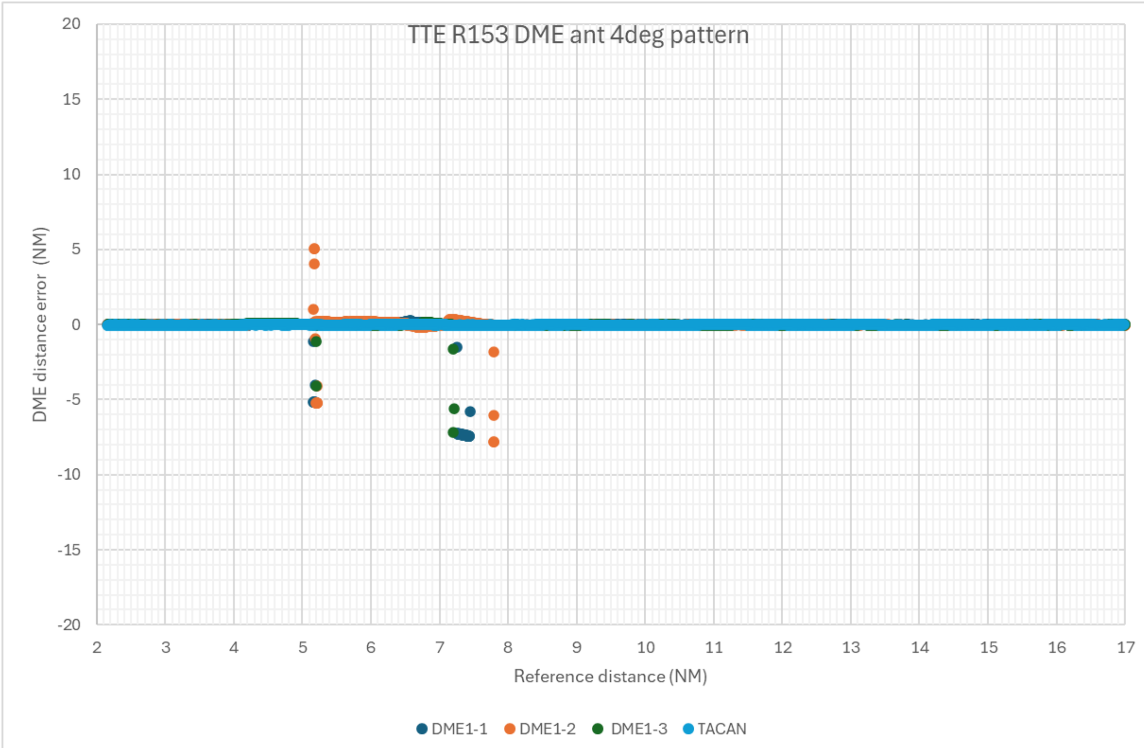

Figure 1. DME antenna radiation pattern: 4 degrees

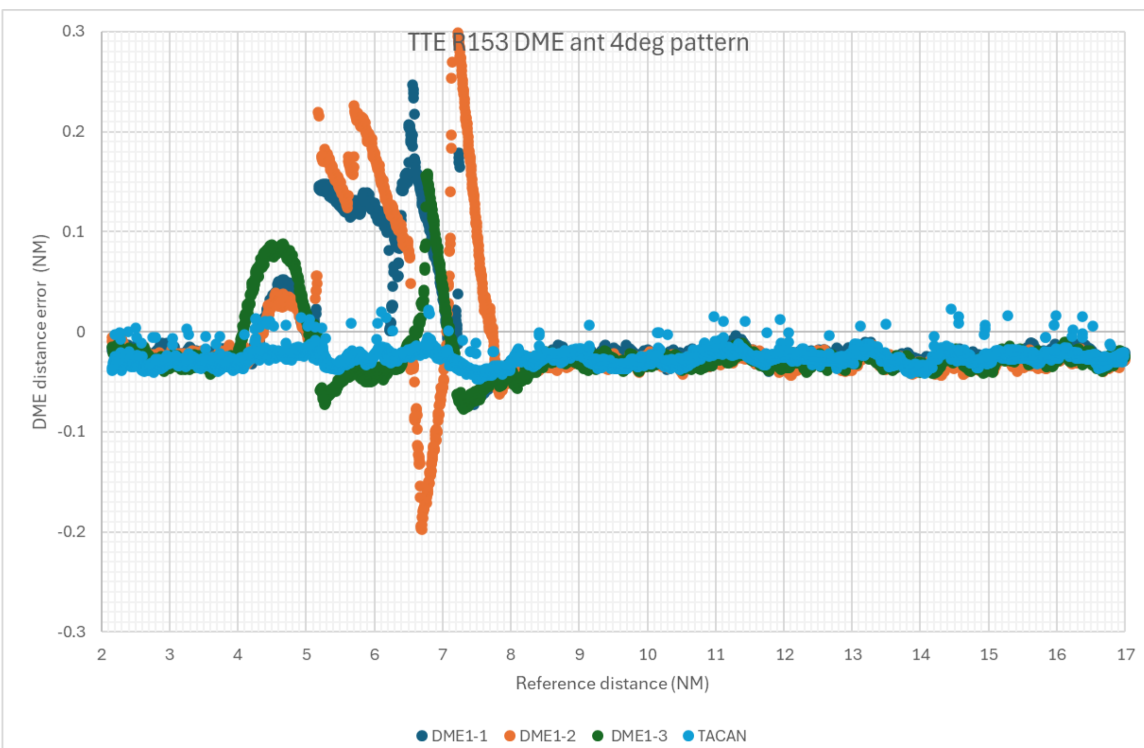

Figure 2. DME antenna radiation pattern: 4 degrees (detailed)

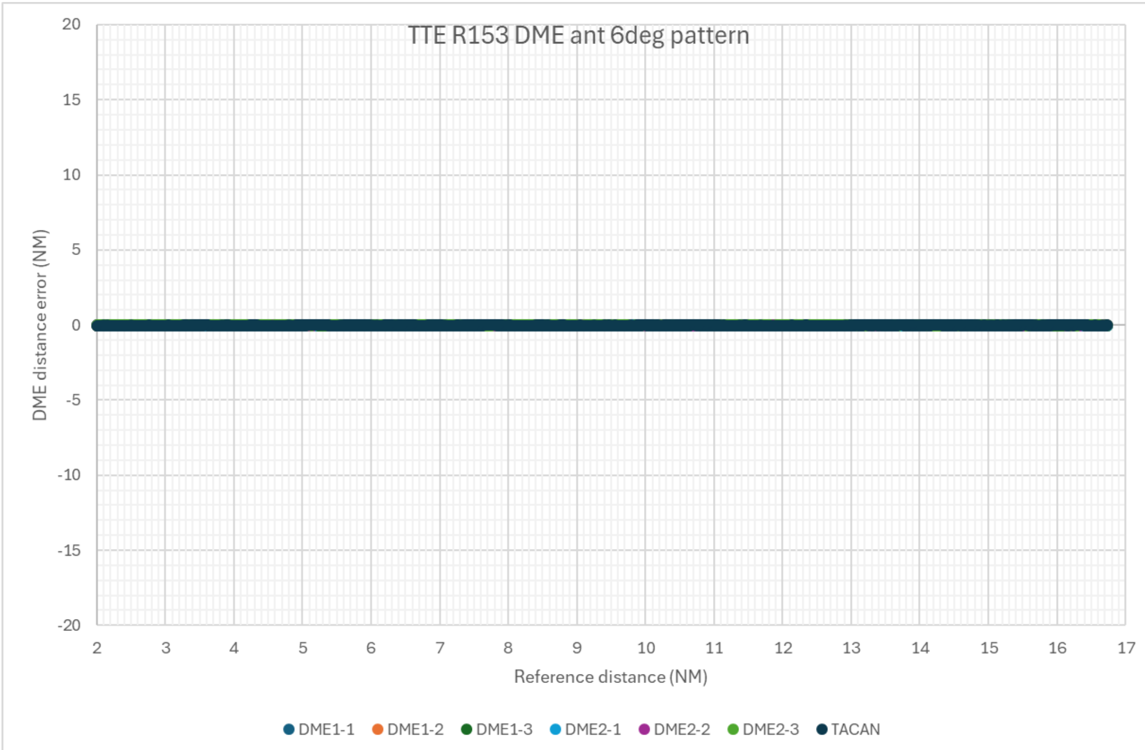

Figure 3. DME antenna radiation pattern: 6 degrees

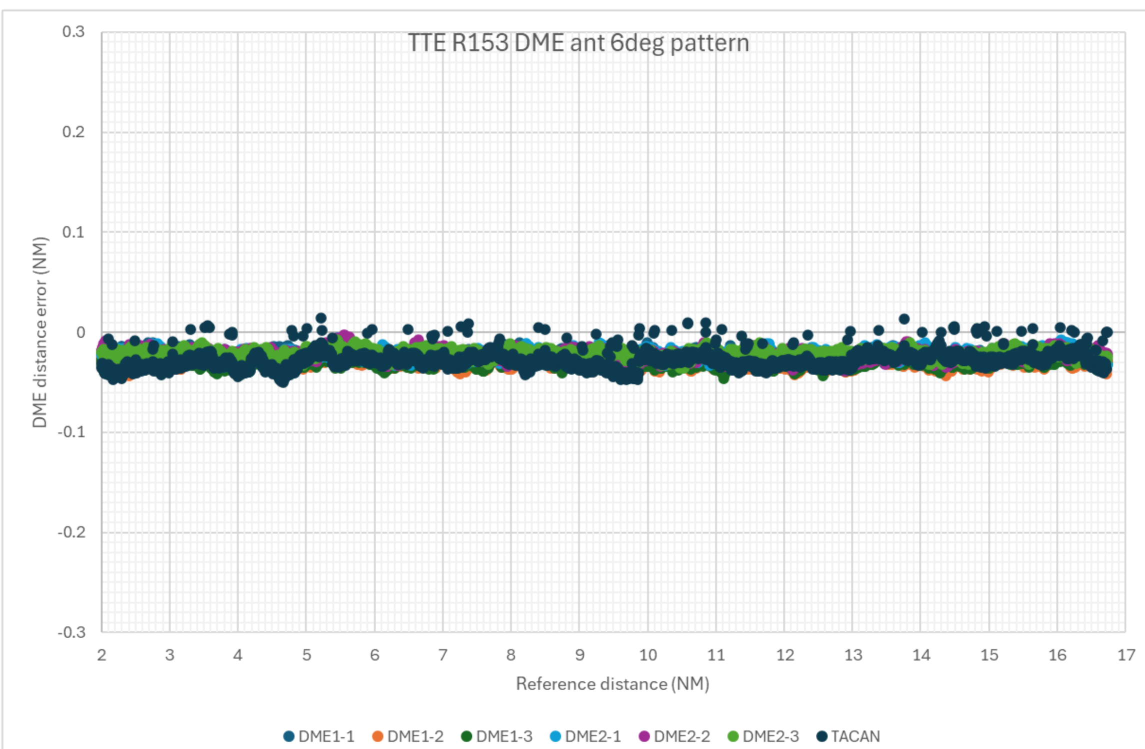

Figure 4. DME antenna radiation pattern: 6 degrees (detailed)

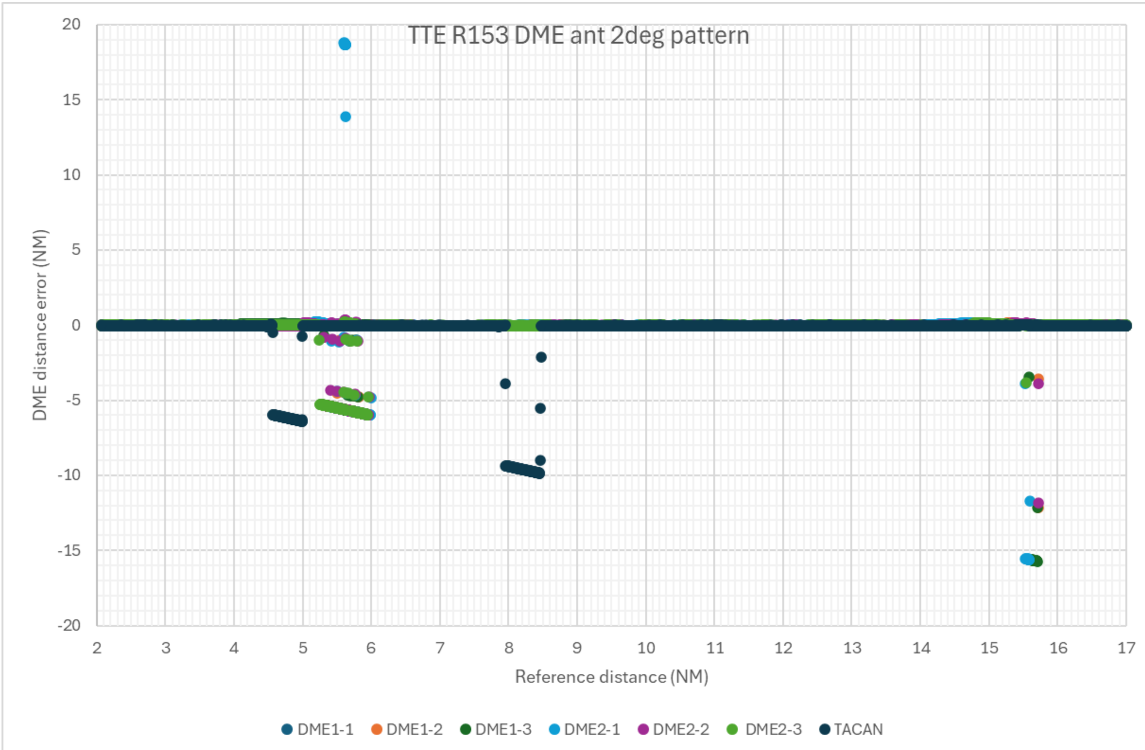

Figure 5. DME antenna radiation pattern: 2 degrees

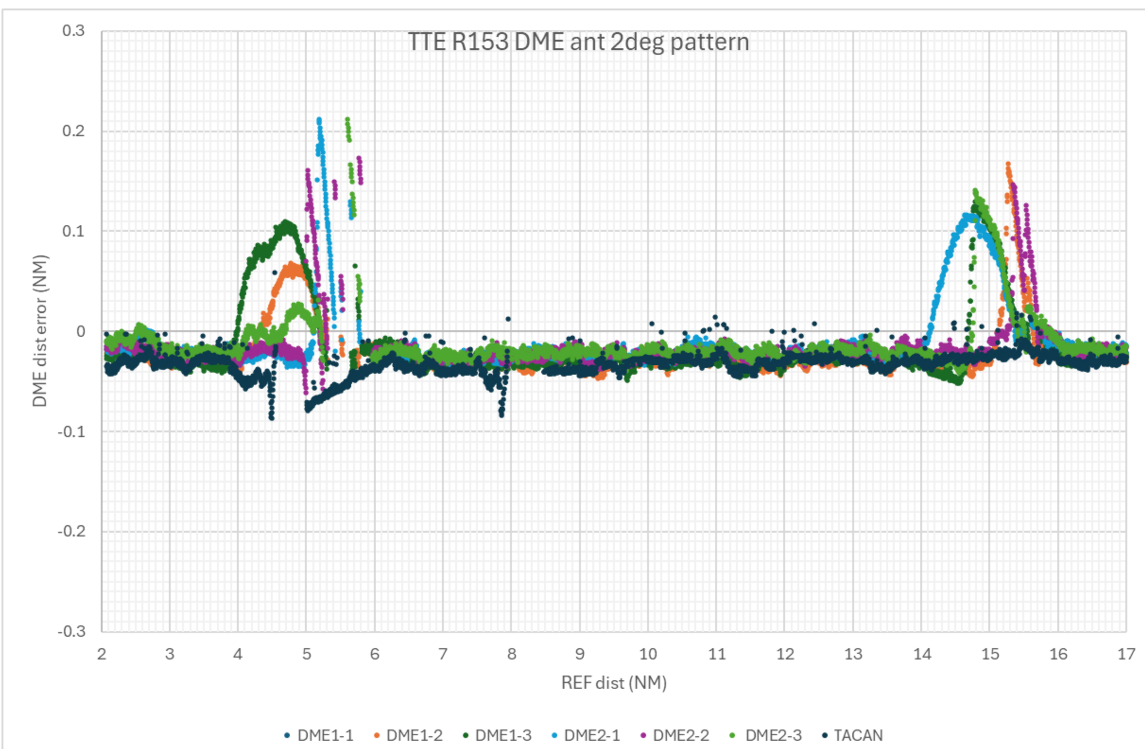

Figure 6. DME antenna radiation pattern: 2 degrees (detailed)

ANTENNA PATTERNS

Figure 7 shows the DME antenna radiation patterns when set to 2 degrees, 4 degrees, and 6 degrees.

This graph indicates that when the antenna is set to 2 degrees or 4 degrees, radio waves are emitted with relatively high signal strength even at low elevation angles of 0–2 degrees from the DME antenna.

On the other hand, when the antenna is set to 6 degrees, the signal strength at low elevation angles of 0–2 degrees become approximately 3dB to 4dB lower than in the 2-degree and 4-degree settings. It is therefore considered that the influence of multipath signals reflected from the ground and buildings on the direct wave from the DME antenna was reduced, leading to elimination of DME UNLOCK.

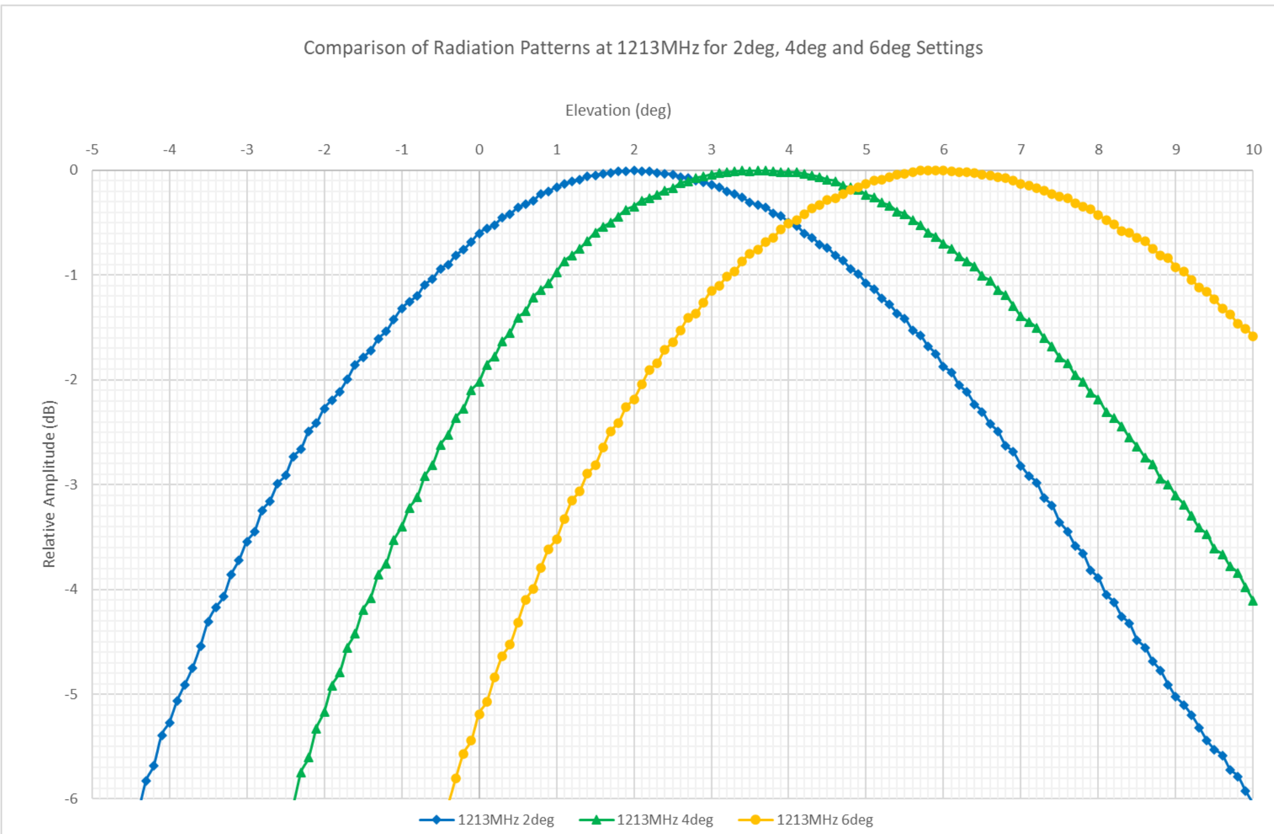

Figure 7. Comparison of antenna radiation patterns (2-degree, 4-degree, and 6-degree settings)

CAUSE ANALYSIS OF MULTIPATH (DESK STUDY)

As part of the cause analysis of the multipath effect, objects around DME (TTE) were investigated, and a desk study was conducted using a structure considered to be the likely cause.

A likely candidate was “Kaze-no-To” (風の塔: Tower of Wind), a ventilation facility for an undersea tunnel. It consists of a smaller tower with a height of 75m and a larger tower with a height of 90m and is located at a distance of 5.35NM from TTE on the 148.5-degree bearing (R148).

Focusing on the distances at which DME UNLOCK occurred on VOR RWY34L when the DME antenna radiation pattern was set to 2 degrees, DME UNLOCK was observed between 6.0NM and 4.5NM. Considering the path difference between the direct signal from TTE and the multipath signal reflected by Kaze-no-To, the path difference is estimated to range from 0.2NM to 2.3NM, corresponding to a propagation delay of 1.2µs to 14.2µs. Figure 8 shows the positional relationship between the flight path and Kaze-no-To.

Next, the arrival-time difference of the multipath wave at the time of DME UNLOCK is discussed. DME measures distance using twin pulses, with a pulse width of 3.5μs and a twin-pulse interval of 12μs for the X-channel. When the arrival-time difference is between 1 and 3.5μs or between 8.5 and 15.5μs, it is inferred that the superposition of the multipath wave distorted the pulse waveform, preventing the pulse from being recognized as a valid 3.5μs pulse and thereby causing DME UNLOCK. Also, when the arrival-time difference is between 3.5 and 8.5μs, it is inferred that the multipath wave entered between the twin pulses, disturbed the pulse waveform, and prevented the signal from being recognized as a valid twin pulse, thereby causing DME UNLOCK. Figure 9 illustrates the state of the twin pulses in this case.

In addition, the vertical positional relationship between TTE and Kaze-no-To is considered. The DME antenna is installed at an elevation of 30m above sea level, whereas the highest point of Kaze-no-To is approximately 90m. The distance between TTE and Kaze-no-To is 5.35NM (9,908m). Based on these conditions, Figure 10 shows the vertical positional relationship between the DME and Kaze-no-To. From this, it is expected that signals radiated from the DME antenna within an elevation-angle range of approximately +0.35 degrees to -0.2 degrees (depression angle) may be affected by Kaze-no-To.

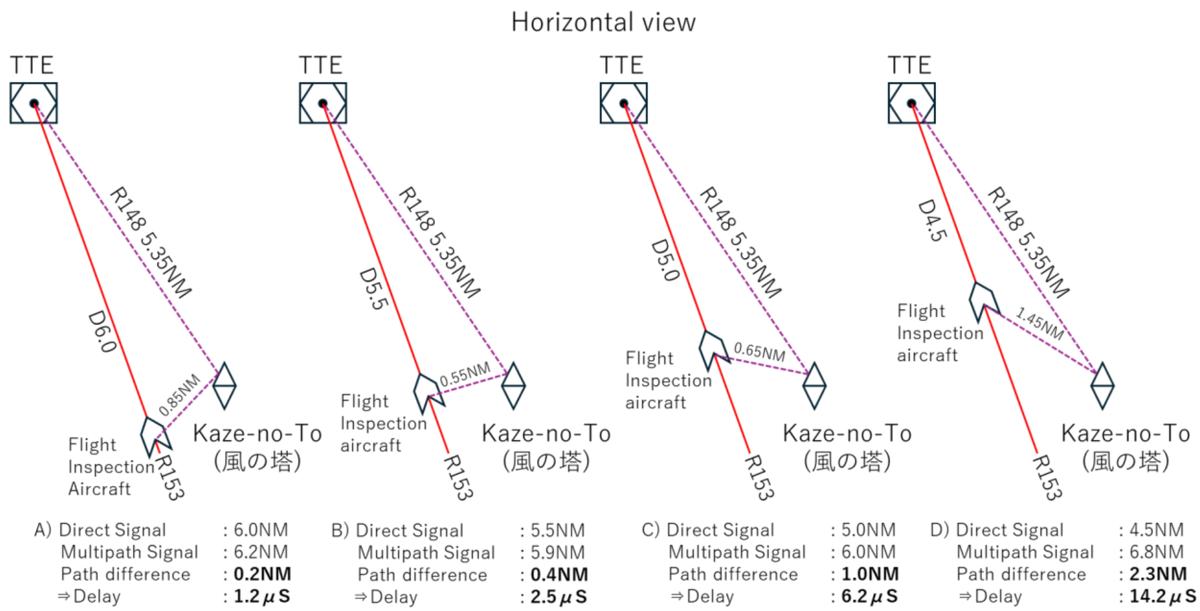

Figure 8. Horizontal positional relationship between TTE and Kaze-no-To

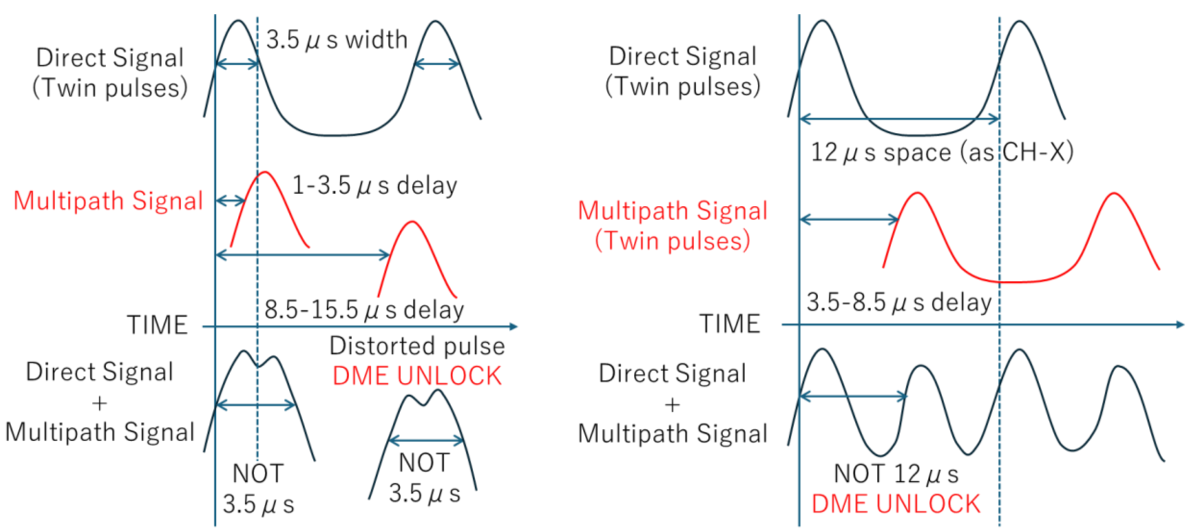

Figure 9. Effects of Multipath on DME Twin Pulses

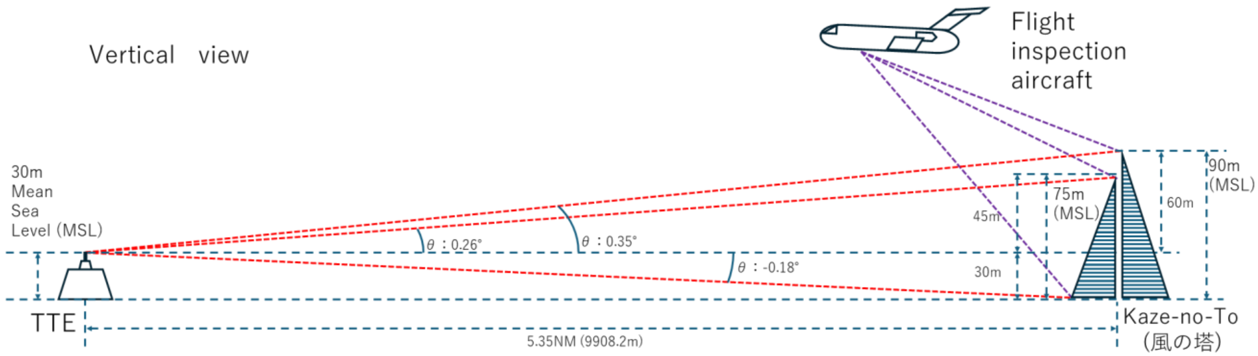

Figure 10. Vertical positional relationship between TTE and Kaze-no-To

CONCLUSION

Japan used an Automated Flight Inspection System to conduct actual flights and confirm the radio wave propagation conditions. This paper has presented a best practice that the flight inspection team, the TMC, and the manufacturer worked together to develop a DME with switchable antenna radiation patterns, and optimization of the antenna radiation pattern through flight inspection led to improvement of the DME signal environment.

When DME UNLOCK occurs during flight inspection for commissioning or equipment renewal, a mechanism that allows the antenna radiation pattern to be changed easily on site can significantly reduce the time required to study, arrange, and replace the antenna with another type, and is therefore highly effective for conducting smooth flight inspections. This was the first case that this mechanism had been used to improve DME UNLOCK situation. We plan to utilize this mechanism in future cases where DME UNLOCK occurs during flight inspection.

Although modern aircraft navigation primarily relies on GNSS, threats such as GNSS jamming and spoofing have recently become major concerns, and ICAO is also discussing countermeasures. As one solution, consideration is being given to constructing an Alternate Positioning, Navigation and Timing (APNT) network using VOR/DME.

Therefore, from the perspective of ensuring the integrity of existing radio navigation aids so that soundness air navigation services can be provided even in the event of GNSS loss, improving multipath propagation is extremely important.

FUTURE WORKS

The ability to change the radiation pattern of a DME antenna is useful; however, the design of the radiation angles themselves requires further study.

With respect to the 2-degree antenna radiation pattern, opportunities for use may be limited in environments with complex terrain or urban structures, where multipath effects caused by surrounding topography and buildings are expected. In Japan, there are plans to renew a VOR/DME installed on a mountaintop at an elevation of 700m above sea level, and the performance of the 2-degree pattern will be evaluated at that time. Based on the results of that evaluation, the switchable radiation-pattern angles will be further studied in cooperation with the manufacturer.

With regard to this initiative, we would appreciate it if members could share their knowledge on improving DME antenna performance. We would also welcome any advice on the switchable radiation-pattern mechanism introduced in Japan.

By sharing Japan's initiative, this paper invites the following discussion:

・Challenges experienced by countries/organizations where such mechanisms have already been introduced

・Case studies from countries/organizations where such mechanisms have already been introduced

・Advice regarding challenges in introducing this mechanism in Japan

ACKNOWLEDGMENTS

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REFERENCES

"Investigation of DME Multipath Propagation" (Mitsuhiro Maruhashi, IFIS 2022)

"Error Analysis of DME Using Flight Inspection Data" (Atsushi Kezuka, Shinji Saito, Takahiro Aso, Sonosuke Fukushima, Electronic Navigation Research Institute Presentation Abstracts, FY2017, 17th ENRI Research Presentation Meeting)