Method for Predicting the Lightning Strip Protection Area Using the FDTD Method

Masato Kawabata[#1], Taisuke Tokunaga[*2], Masafumi Miyoshi[*3], Yasuo Takahashi[*4]

[#]*Fukuoka Industrial Technology Center*
3-6-1 Norimatsu, Yahatanishi-ku, Kitakyushu City, Fukuoka Pref. 807-0831, Japan
[1]kawabata@fitc.pref.fukuoka.jp

[*]*Kawasaki Heavy Industries, Ltd.*
1 Kawasaki-cho, Kakamigahara City, Gifu Pref. 504-8710, Japan
{[2]tokunaga_taisuke, [3]miyoshi_masafumi, [4]takahashi_yasuo}@khi.co.jp

***Abstract*—A radome is a weatherproof enclosure that protects an antenna from various weather hazards such as rain and hailstorm. In general, radomes are constructed using a dielectric material to minimize the attenuation of electromagnetic signals. In addition, lightning diverter strips can be placed on the radome for protecting the antenna from a lightning stroke. In this study, we propose a new method to predict the protection area of lightning strips using the finite-difference time-domain (FDTD) method and to develop an optimum design for the arrangement of the lightning strips. A comparison between a flat plate and a curved plate with one lightning strip and that between one lightning strip and two lightning strips placed on the curved plate are demonstrated using the FDTD method. The lightning protection area of the curved plate with one lightning strip is slightly smaller than that of the flat plate. The lightning protection area of the curved plate with two lightning strips is slightly greater than that of two overlapping protection areas of one strip.**

Key words: Lightning protection, Lightning diverter strip, Radome, FDTD method

I. Introduction

A radome is a weatherproof enclosure that protects an antenna from various weather hazards such as rain and hailstorm. In general, radomes are constructed using a dielectric material to minimize the attenuation of electromagnetic signals. Furthermore, lightning strips (e.g., segmented diverter strip) can be placed on the radome for protecting the antenna from a lightning stroke (e.g. aircraft etc.). In general, a high voltage and current tests are conducted to determine the appropriate arrangement of the lightning strips. The testing configuration of lightning protection of the radomes is designed according to specifications [1]. In order to develop a lightning protection design, the lightning strips are placed on the radome from the experimental lightning protection area of a flat plate that has the same wall structure and the same lightning strip as the radome. However, the lightning strip arrangement by this method may be excessive, because the safety takes priority. The lightning strips are expected to have a minimum arrangement, because they are likely to disturb the electromagnetic signal emitted from and received by the antenna. Some lightning protection designs have been investigated experimentally and analytically. The lightning protection of a nose cone radome with lightning strips of varying heights has been experimentally analyzed under low and high ambient humidity conditions [2]. A simple model has been proposed to determine the minimum height of the lightning strips required to avoid a radome puncture [3]. However, these models cannot be applied to an arbitrary radome.

In this study, we propose a new method to predict the protection area of lightning strips using the finite-difference time-domain (FDTD) method and to develop an optimum design for the arrangement of the lightning strips. We have focused on the electric power between the strike point and the ground electrode just before an electrical discharge. The thresholds for the lightning protection area and the resistance of the lightning strip are determined from the experimental result of the flat plate that has same wall structure and the same lightning strip as the radome. The lightning protection area on a curved plate with two strips is estimated by using the FDTD model based on the abovementioned thresholds and resistance, without experimental investigation.

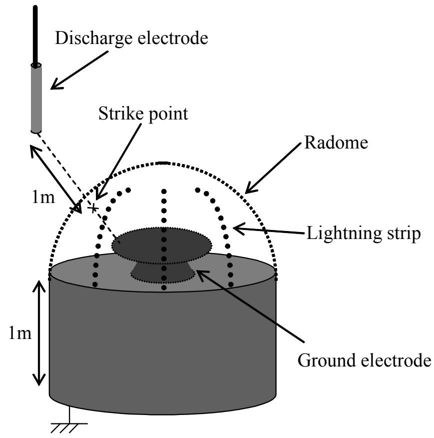


Fig. 1 Testing setup

II. Prediction Method

A. Testing Configuration

The testing setup described by [1] is shown in Fig.1. A ground electrode is placed inside the radome. A discharge electrode is placed at a distance of 1 m from the strike point.

The surge pulse is energized to the discharge electrode, and the radome puncture is confirmed. Then, the strike point is changed by moving the discharge electrode. This process is repeated until it is ensured that the radome is not punctured.

Flat plates with one lightning strip are evaluated by this testing method, and the experimental lightning protection areas are obtained.

B. FDTD Model of Flat Plate with One Lightning Strip

The lightning path of an electrical discharge depends on various factors such as atmospheric condition [2]. It is not possible to uniquely estimate the lightning path by the FDTD analysis. Therefore, we have focused on the electric power between the strike point and the ground electrode, which is probably related to the radome puncture.

The FDTD model for developing a flat plate with one lightning strip is shown in Fig.2. The discharge and ground electrodes, the frame, the ground line, and the analysis boundary are perfect electric conductors (PECs). The analysis boundary is defined as the return path between the discharge and ground electrodes. The driving point of the surge pulse is at the center of the discharge electrode, and the pulse amplitude is 1 MV. Though the flat plate is composed of four layers of a dielectric material (Paint, FRP, Foam core, and FRP), the flat plate used for the FDTD calculation is modeled as air. Because the flat plate is mostly composed of a foam core layer whose permittivity is almost 1, the calculation time and the required memory size can be reduced. Though the lightning strip mounted on a high resistance thin tape is composed of adjacent conductive disk patches with a very small gap between them, it is approximated to a simple resistance wire. It is assumed that the discharge phenomenon on the lightning strip is the same as the simple discharge on a resistance wire.

The cell size is given by $\Delta x = \Delta y = 90$ mm and $\Delta z = 50$ mm. The electrode length and location are given by $L_1 = L_2 = L_3 = 1000$ mm and $L_4 = 800$ or 900 mm.

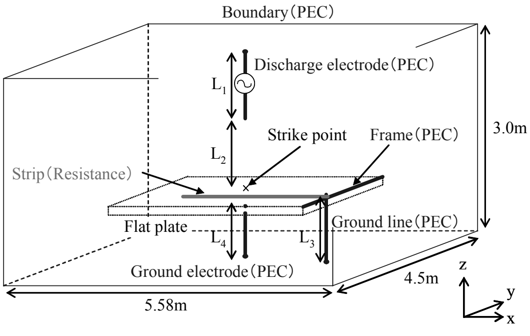


Fig. 2 FDTD model for developing a flat plate

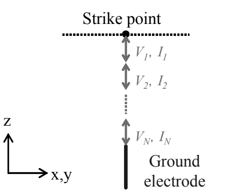


Fig. 3 Evaluation components

The evaluation components are shown in Fig.3. The evaluation electric power P is defined by the following equation:

$$P(t) = \sum_{n=1}^{N} V_n(t) I_n(t) \quad (1)$$

$$P = \left| P(t) \right|_{\max} \quad (2)$$

where $V_n(t)$ and $I_n(t)$ denote the voltages and displacement currents at each cell and N denotes the number of cells between the strike point and the ground electrode.

The maximum value of the instantaneous powers is used as an evaluation value, and this value is compared to the experimental lightning protection area. The strike points used in the calculation and the experimental lightning protection area are shown in Fig.4. The discharge and ground electrodes are placed above and below the strike point, respectively. The position of both the electrodes changes with the strike point. Since the resistance of the lightning strip during electrical discharge is not known, the electric powers are calculated by varying the resistance of the lightning strip from 0 to 10 kΩ/Δx. Both the inclination and the value of the contour line change with the resistance. The threshold for the lighting protection area and the resistance of the lightning strip are determined by comparing with the experimental results.

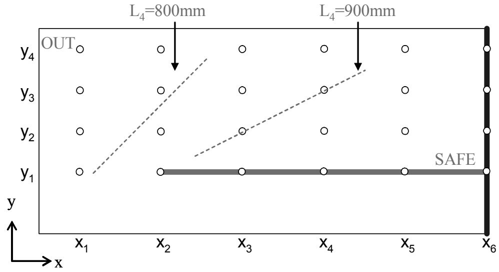
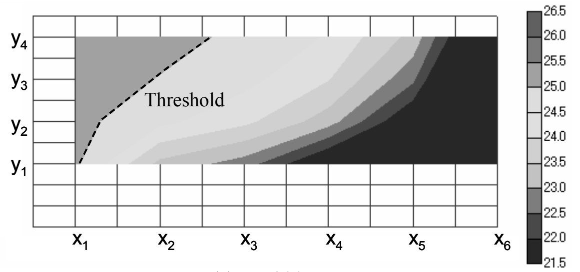
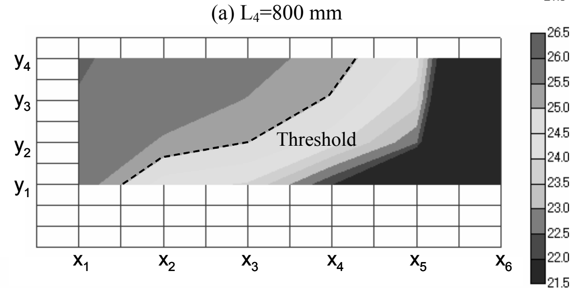


Fig. 4 Strike points for calculation (white circles) and experimental lightning protection areas (red dot lines)



(a) L_4=800 mm



(b) L_4=900 mm

Fig. 5 Electric powers calculated by FDTD (in dB)

Electric powers calculated for resistances equal to 6 kΩ/Δx, are shown in Fig.5. The contour line of 25 dB agrees well with the experimental result, even if the length of the ground electrode varies. This contour line can be estimated to be the threshold for the lightning protection area.

It is thought that the resistance of the lightning strip and the threshold for the lightning protection area are uniquely determined by comparing the calculated and the experimental results, even if a different flat plate is used.

C. Consideration of Stair-step FDTD Model for Lightning Strip

The development of stair-step model of a curved lightning strip is investigated, in order to apply the proposed method to a curved lightning strip. The stair-step model is shown in Fig.6. The stair-step approximation has a significant effect on the lightning strip model whose resistance varies with an increase in the length of the lightning strip by $\sqrt{2}$ times its original length. Electric powers are calculated for resistances equal to 6 kΩ/Δx and 4.243 kΩ/Δx. The value of 4.243 ($\cong 6/\sqrt{2}$) is corrected by the strip length extension. The length of the ground electrode L_4 is 900 mm.

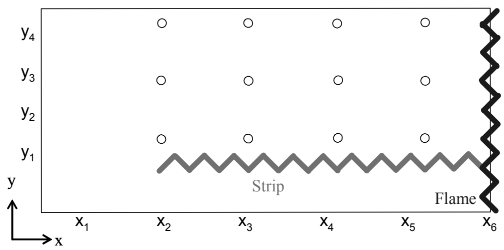
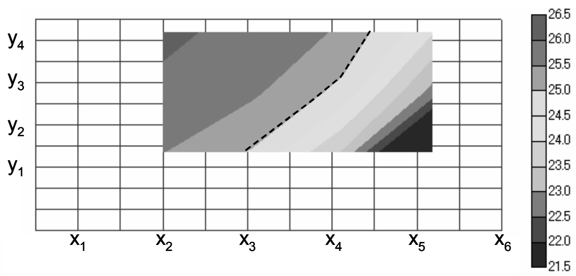
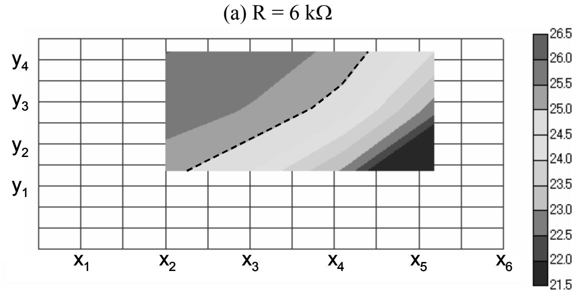


Fig. 6 Stair-step model and strike points (white circles)



(a) R = 6 kΩ



(b) R = 4.243 kΩ

Fig. 7 Electric powers calculated by FDTD (in dB)

The calculated electric powers are shown in Fig.7. Comparing with the threshold of Fig.5 (b), that in the resistance of 4.243 kΩ/Δx is corresponding better than that in the resistance of 6 kΩ/Δx. Comparing Figs.5 (b) and 7 (b), the deviation in the threshold line of 25 dB is less than the cell size. Therefore, the main objective of using the stair-step model for developing a curved lightning strip is to rectify the resistance of the lightning strip according to the extension of the length of the strip.

III. Evaluation of Lightning Protection Area

It is thought that the threshold for the lightning protection area and the resistance of the lightning strip determined in Section II are unique values related to both the wall structure and the lightning strip. Though the actual radome has a curved surface and two or more strips, the lightning protection area of the radome under various equipment conditions can be predicted without experimental investigation if the radome has the same wall structure and the same lightning strip.

The lightning protection areas of the curved plate are estimated as a preliminary examination in order to apply the proposed method to develop radomes. The FDTD model used for developing the curved plate with one lightning strip, which has a surface area of 1980 mm × 1440 mm and a curvature of 1000 mm, is shown in Fig.8. The calculated electric power is shown in Fig.9 (b). The result of the flat plate that has the same surface size is also shown in Fig.9 (a). As shown in Figs.9 (a) and (b), the lightning protection area of the curved plate with one lightning strip is slightly smaller than that of the flat plate. The electric powers are calculated when the two parallel lightning strips are placed 360 mm or 540 mm apart on the curved plate. The results are shown in Figs.9 (c) and (d). As observed from Figs.9 (b), (c), and (d), the lightning protection area of the curved plate with two lightning strips is slightly greater than that of two overlapping protection areas of one strip, and the protection area tends to extend with a decrease in the spacing between two strips.

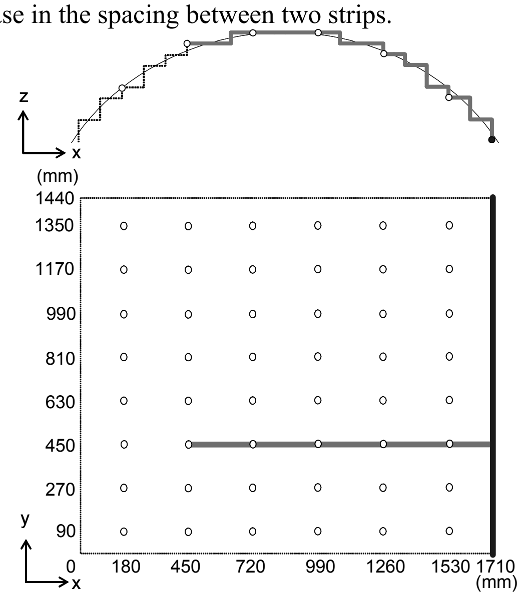
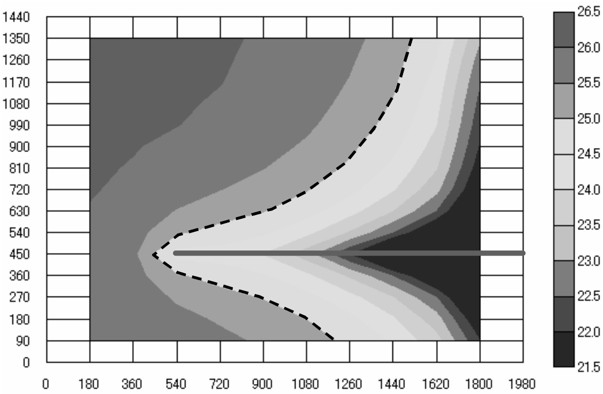
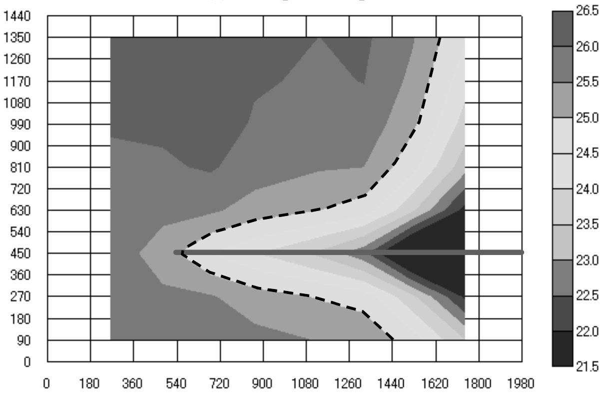


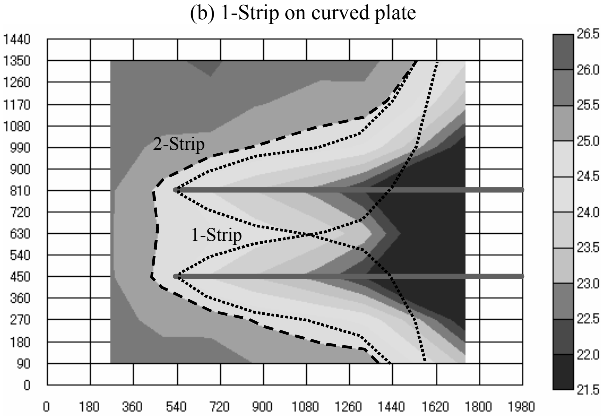
Fig. 8 FDTD model for developing a curved plate and strike points (white circles)



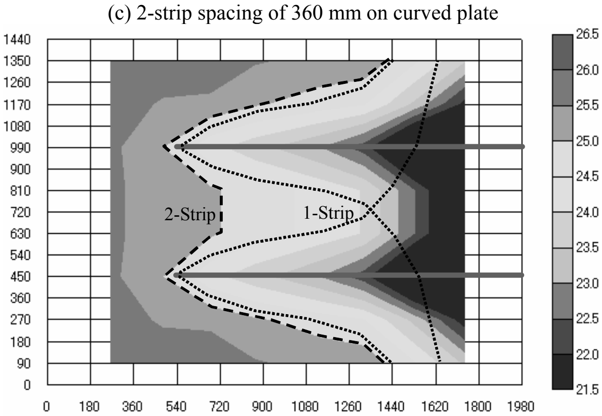
(a) 1-Strip on flat plate



(b) 1-Strip on curved plate



(c) 2-strip spacing of 360 mm on curved plate



(d) 2-strip spacing of 540 mm on curved plate

Fig. 9 Electric powers calculated by FDTD (in dB)

From these results, it is found that the lightning protection area also depends on the arrangement of the lightning strip and the surface contour. In future, the lightning protection area of an actual radome will be calculated and the validity of the proposed method will be verified by comparing the results obtained using this method with the experimental results.

IV. Conclusion

The objective of this study was to develop an optimum design for arranging the lightning strips by evaluating the electric power between the strike point and the ground electrode, and a new method for predicting the protection area of the lightning strip using the FDTD method was proposed.

The resistance of the lightning strip and the threshold for the lightning protection area are determined by comparing the calculated electric powers with the experimental lightning protection area of the flat plate. The main objective of using the stair-step model for developing a curved lightning strip is to rectify the resistance of the lightning strip according to the extension of the length of the strip.

The lightning protection area of the curved plate is estimated as a preliminary examination, in order to apply the proposed method to develop radomes. The lightning protection area of the curved plate with one lightning strip is slightly smaller than that of the flat plate. The lightning protection area of the curved plate with two lightning strips is slightly greater than that of two overlapping protection areas of one strip. In future, we intend to estimate the lightning protection area of an actual radome and verify the validity of the proposed method by comparing the results obtained using this method with the experimental results.

References

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[3] A. Delannoy, A. Bondiou-Clergerie, P. Lalande, P. Blanchet, P. Laroche, G.L. Bacchiega, and I. Gallimberti, “New investigations of the mechanisms of lightning stroke to radomes, Part II: Modeling of the protection efficiency,” Proc. of 2005 Int. Conf. on Lightning and Static Electricity, 2001-01-2884, Seattle, USA, Sept. 2001.