BROADBAND CHARACTERISTICS DESIGN OF SEMI-CIRCLE TYPE
BOW-TIE ANTENNA WITH HOLE SLOTS USING FDTD ANALYSIS

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Abstract: For electromagnetic compatibility, antenna measurements of fast pulse transient electromagnetic phenomena and broadband characteristics due to noises and high frequency interference are very important. We analyzed the characteristics of a semicircle type bow-tie antenna with various slots using the FDTD method. It was shown, from the simulation results, that the shape and the position of slot influenced greatly the broadband characteristics of the antenna. We confirmed that a semicircle type bow-tie antenna with a triangle slot was effective as broadband antenna.

Key words: Broadband Antenna, FDTD method, Semicircle type bow-tie antenna.

1. Introduction

Now, a variety of antennas are put in practical use with remarkable development of communication devices and technology. In recent years, the interest about a broadband antenna is increasing in all fields, such as a radar, mobile communications, and EMC, and research is done briskly[1]–[3]. Moreover, EMC (Electromagnetic Compatibility) has been an important subject regarding miniaturization and high-frequency usage of an electric device or a communication system. Also for the pulse noise or high frequency measurement in EMC, broadband and efficient small antennas are needed.

Furthermore, as one of the frameworks of ITS (Intelligent Transport Systems), there is an automatic operation system, which research is done actively now. It is important for the safe run of vehicles, detection of obstacles, such as distance with forward vehicles and guardrails, and research of the radar for automobile collision prevention is done briskly[4][5]. Because this, development of the antenna for millimeter wave pulse radars with broadband characteristic is desired.

In order to transmit and receive a pulse with narrow width by the pulse radar, more broadband antennas are needed. In the ground penetrating radar, the triangle bow tie antenna is well used as an broadband antenna[6][7]. Moreover, in recent years, it is reported that fractal antennas, such as Sierpinski antenna, have the multiband characteristic[8]. In order to improve the resonance characteristic, we changed the form of a bow tie antenna and set up a slot[9][10].

In this paper, the characteristic of a semicircle type bow tie antenna with hole slot is analyzed using the FDTD method for the purpose of the optimal design of a broadband antenna. In order to find out the optimal arrangement of a slot, we analyzed the influence that it has on the antenna characteristic, when the case where setting of a slot is changed, and a new slot are added. From the result, the absolute gain characteristic of an antenna was able to be increased by devising the arrangement of the slot.

2. Antenna analysis with FDTD method

2.1 Analysis Model

Analysis model is shown in Fig. 1. The size of

![Fig. 1. Analysis model](image)

analysis space is 377.5x377.5x377.5mm. The antenna composed of the perfect conductor space was arranged as free space. P(\(i_x, j_x, k_x\)) is a feeding point of the antenna.
2.2 FDTD method

An electromagnetic field inside the analysis space is calculated from the differential equation based on Maxwell's equation. FDTD method differentiates at the space and the time. Therefore, arbitrary field \( \phi \) is described as follows.

\[
\phi(x, y, z, t) = \phi(i \Delta x, j \Delta y, k \Delta z, n \Delta t) = \phi^n(i, j, k)
\]

\( i, j, \) and \( k \) are the Cartesian coordinates of the position, and \( n \) means the number of time steps. And, \( \Delta x, \Delta y, \Delta z \) are the size of the division of the lattice, and \( \Delta t \) is a time increment. For example, electric field \( E_x \) in the free space is computed with the following formula.

\[
E_x^n(i+1/2, j, k) = E_x^{n-1}(i+1/2, j, k) + \frac{N}{\varepsilon_0 \Delta t} \left( H_y^{n+1/2}(i+1/2, j+1/2, k) - H_y^{n-1/2}(i+1/2, j-1/2, k) - H_y^{n+1/2}(i+1/2, j, k+1/2) + H_y^{n+1/2}(i+1/2, j, k-1/2) \right)
\]

where, \( \Delta s = \Delta x = \Delta y = \Delta z \) is 2.5mm to obtain accurate results in wideband frequency up to 10 GHz. \( \Delta t \) is 4ps which satisfies the Courant condition.

For excitation of the antenna, delta-gap feeding model is used. The electric field \( E_x \) at the feed point \( P \) is given by the input voltage \( \Delta V^n(i_f+1/2, j_f, k_f) \).

\[
E_x^n(i_f+1/2, j_f, k_f) = \frac{\Delta V^n(i_f+1/2, j_f, k_f)}{d}
\]

d was a distance between the antennas, and it was set at \( d=2.5 \text{mm} \) here. And, the current in the feeding point is computed as follows.

\[
I^{\text{on}}(i_f, j_f, k_f) = \left[ H_y^{\text{on}}(i_f+1/2, j_f, k_f+1/2) - H_z^{\text{on}}(i_f+1/2, j_f, k_f-1/2) + H_y^{\text{on}}(i_f+1/2, j_f+1/2, k_f+1/2) - H_y^{\text{on}}(i_f+1/2, j_f-1/2, k_f+1/2) \right] \Delta s
\]

In this case, the position of the feeding point was \( i_f=j_f=k_f=75 \). Moreover, absorption boundary conditions used 8 layer PML and it is applied in the boundary of \( x=0, N_x \Delta s, y=0, N_y \Delta s, z=0 \) and \( N_z \Delta s \). Here \( N_x=N_y=N_z=150 \).

3. Results

A semi-circle type bow-tie antenna is a curve-shaped to be smooth and to be stable in resonance characteristics.

Analyzed antennas are shown in the figure 2. Antenna radius was set at 105mm to simulate a characteristics around 1GHz. Sierpinski antenna was made with the simplest structure.

Absolute gain of four antennas is shown in the figure 3. The fall of gain can be improved when a Sierpinski antenna is compared with a bow-tie antenna. And, some gain falls are improved even if a semi-circle type bow-tie (SCBT) antenna is compared with a bow-tie antenna. Therefore, better gain improvement can be thought to be attained by arranging a slot to the SCBT antenna. Delta is optimized for each parameter \( l, w \) and \( d \). \( l=w=d=35 \text{mm} \) is optimum value, and this copes with 1/4 of the resonance wavelengths \( \lambda_f \) of SCBT. Gain of Delta is flatter and stable than other antennas. By the above, Delta slot is effective for the gain improvement.

![fig. 2. Antenna model 1](image)

![fig. 3. Comparison of Absolute Gain 1](image)
Antenna model with increased slot

Mas model added two slots of the same size. Delta2 added a smaller slot than the slot of Delta near the feed point. Sierpinski imitated the slot form of the Sierpinski antenna of mod-3. Parameters are d=i=w=d_i=i=35 mm=1.02 \lambda, l_2=w_2=1/2 w=1/2 l and \ d_2=d_1-l_2.

The comparison of absolute gain of these antennas is shown in the figure 5. One more resonance part is solved with Delta2. Resonance part increase with Mas and Sierpinski more than Delta. Arranging the slots of the same size doesn't improve the gain by comparison with Delta2.

And, the comparison when the size of smaller slot in Delta2 is changed is shown in the figure 6. \lambda_2 is 1/4 wavelength of 3.7GHz which gain of falls in Delta2, and 0.52 \lambda_2=1.16 \lambda_2. 1.01 \lambda_2 includes the biggest of gain and the most flat gain. Adopted frequency was 1.6GHz, whose absolute gain was the best with Delta. Frequency adopted with Delta and NoSlot was 2.1GHz, in which the difference came out. Strong distribution occurs on the edge of the antenna and edge of the slot around the feeding point.

Comparison of Voltage Standing Wave Ratio

Next, the current distribution at the antenna was simulated. That result is shown in the figure 8.

The radiation pattern of three antennas is shown in the figure 9. Adopted frequency was 2.5GHz in which the difference was remarkable. Directional characteristics are improved by arranging a slot. Because there is no big difference with absolute gain, there is no big difference in the radiation pattern as well with Delta and Delta2.

4. Conclusion

In this paper, the antenna characteristics of semi-circle type bow-tie antenna with hole slot was simulated by using the FDTD method. Furthermore, we analyzed the influence of changing arrangement
and number of slot on antenna characteristics. We simulated it regarding the absolute gain increase, VSWR, current distribution and radiation pattern. A bow-tie antenna was made a semi-circle, and arranging a slot, we got a broadband characteristics and improved gain drastically. We succeeded in adjusting the resonance part by adding a miniature slot too. In this results, Semi-circle type bow-tie antenna could get a remarkable broadband character when it was compared with a usual bow-tie antenna. We could confirm that the arrangement of the slot improved the absolute gain characteristics of the antenna.

Formation of an array of antennas and Comparison with experimental value are raised as a future subject.

References
