Broadband Characteristics Design of Semi-Circle Type Bow-tie Antenna with Hole Slots Using FDTD Analysis

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1. Introduction

For electromagnetic compatibility, antenna measurements of fast pulse transient electromagnetic phenomena and broadband frequencies due to noises and high frequency interferences are very important. In the high bit rate mobile communications and information transport systems using millimeter waves, broadband antennas are indispensable. For subsurface radars and millimeter wave pulse radars for automobiles, broadband and short pulse antennas are essential devices. It becomes very important to develop antennas of broad frequency bands. Broadband antennas such as log-periodic dipole array antenna (300 ~ 1000 MHz frequency band) and biconical antenna (30 ~ 220 MHz frequency band) have so far been used, and horn antenna has been used to observe electromagnetic waves of frequency over 1 GHz. In this research, we are aiming at the development of broadband antennas operating from few tens of MHz to few tens of GHz frequency range. Broadband antennas such as Bow-Tie antenna have been used to transmit short pulses. Also, in recent years, fractal antennas that covers several frequency bands, such as Sierpinski antennas, have been used. In this paper, we proposed an efficient small bow-tie antenna using semi-circular disks with hole slots, and analyzed antenna characteristics of gain and radio pattern using FDTD method while changing the form and the position of a slot. From the simulations, we confirmed the fact that the proposed new antennas become broadband in a particular frequency range and have higher gain compared with Semi-Circle bow-tie antenna that we have studied.

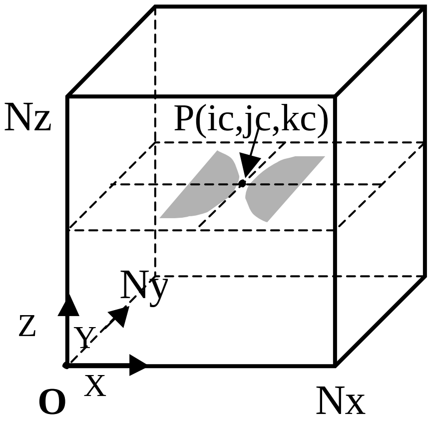


Fig.1 Analysis model of antenna

2. Analysis Method and Formulation of Electromagnetic Field

2.1 Analysis model

FDTD analysis is advantageous for antenna analysis because time domain variation of electromagnetic field beneath the antenna can be easily visualized and antenna characteristics of wideband frequency domain is obtained at a single run of the FDTD program by Fourier transform of time domain responses. The analysis model of antenna is shown in Fig. 1. The geometry of the analysis region is defined as 37.5cm × 37.5cm × 37.5cm and the antenna is located in free space. The feed point P, as shown in Fig.1, is excited by Gaussian pulse commonly used for analysis of wideband antenna characteristics in FDTD method. The location of feed point is defined as $i_f = j_f = k_f = 75$.

2.2 Formulation of FDTD method

Electromagnetic field in the analysis region is calculated by difference equations based on Maxwell's curl equations. We denote any field f of time and space evaluated at a discrete point in time and discrete point in the grid as

$$f(x, y, z) \equiv f(i\Delta x, j\Delta y, k\Delta z, n\Delta t) = f^{n}(i, j, k) \tag{1}$$

where Δx, Δy and Δz are the lattice space increments in each direction and Δt is the time increment.

For example, x-component of electric field at free space is calculated by

$$\begin{aligned} E_x^n(i+1/2, j,k) \;=\; & E_x^{n-1}(i+1/2, j,k)+\frac{\Delta t}{e_0 \Delta s}\left\{H_z^{n-1/2}(i+1/2, j+1/2, k)\right. \\ & \left.-H_y^{n-1/2}(i+1/2, j, k+1/2)+H_y^{n-1/2}(i+1/2, j, k-1/2)\right\} \end{aligned} \tag{2}$$

where, $\Delta s = \Delta x = \Delta y = \Delta z$ is 2.5mm to obtain accurate result in wideband frequency upto 10 GHz. Δt is 4ps which satisfies the Courant condition. Moreover, absorption boundary conditions used 8 layer PML.

For excitation of the antenna, delta-gap feeding model is used. The electric field Ex at the feed point P is gived by input voltage V(t),

$$E_x^n(i_f+1/2, j_f, k_f) = \frac{V(n\Delta t)}{\Delta s} \tag{3}$$

Input voltage is given by

$$V(t) = A\exp\left\{-\frac{(t-t_0)^2}{t_w{}^2}\right\} \tag{4}$$

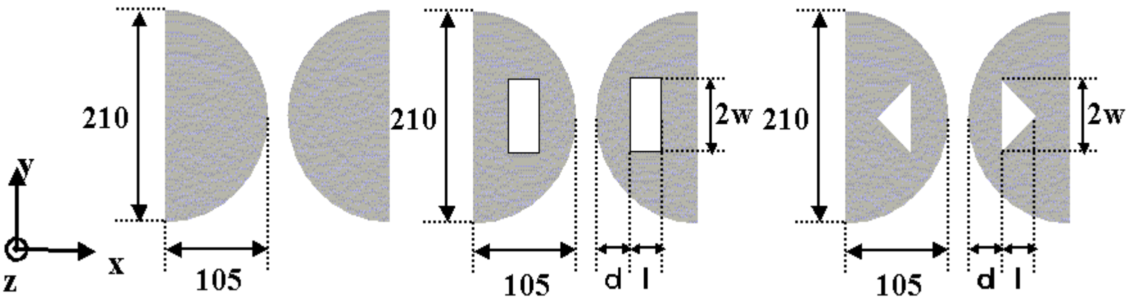
where, A is voltage amplitude, t0 = 1ns and tω = 0.3ns. The current of feeding point is calculated by

$$\begin{aligned} I((n+1/2)\Delta t) = & \left\{H_y(i_f+1/2, j_f, k_f-1/2) - H_y(i_f+1/2, j_f, k_f+1/2)\right. \\ & \left.+H_z(i_f+1/2, j_f+1/2, k_f+1/2) - H_z(i_f+1/2, j_f-1/2, k_f+1/2)\right\}\Delta s \end{aligned} \tag{5}$$

We have used Mur's second order absorbing boundary conditions.
The current density Js on the antenna surface is calculated using Js = z × H, and the current density on other areas is calculated using Jd, given by Jd $= e\,\partial \boldsymbol{E}/\partial t$. Since the magnetic field is not assigned on the antenna surface, the magnetic field on the antenna surface is extrapolated using the two magnetic fields very close to the surface.

3. Field Characteristics of Semi-Circle Type Bow-tie Antenna

The antenna used in analysis is shown in Fig. 2. Fig. 2 (a) is a Semi-Circle type Bow-tie antenna, (b) is an antenna with a straight slot, and (c) is an antenna with a right-angled isosceles triangle slot. Radius of each antenna is 105mm and gap of antenna is 2.5mm.



(a) Semi-circle type bow-tie antenna

(b) Semi-circle type bow-tie antenna with straight slots

(c) Semi-circle type bow-tie antenna with hole slots

Fig.2 Geometry of the antennas

The gain on the basis of an isotropic antenna is called absolute gain. Absolute gain of antenna Gain is calculated by

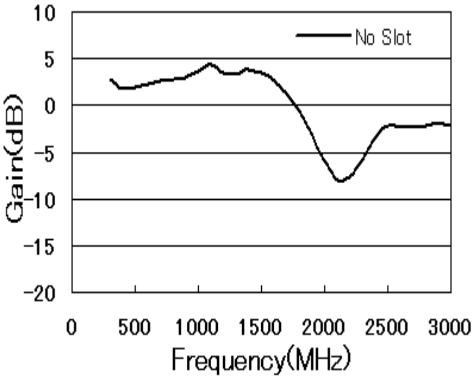
$$G_{ain} = \frac{\left|E_F(w, q, j)\right|^2 / 2h}{P_{in}(w)/4p} \tag{6}$$

where, $E_F(\omega,\theta,\phi)$ is given by

$$E_F(w,q,j) = r\sqrt{\left|E_q(w,q,j)\right|^2 + \left|E_j(w,q,j)\right|^2} \qquad (7)$$

$E\theta(\omega,\theta,\phi)$ and $E\phi(\omega,\theta,\phi)$ are calculated by carrying out Fourier transform of each far field transform. η is impedance(=120π). Moreover, Pin(ω) is the input electric power to an antenna. V(ω) and I(ω) are the Fourier transform of the input voltage of an antenna, and the current of feeding point, respectively.

The absolute gain of the Semi-Circle type Bow-tie antenna was calculated and it is shown in Fig. 3. Fig. 3 shows that the gain around 2.1GHz(λ 143mm) is low.



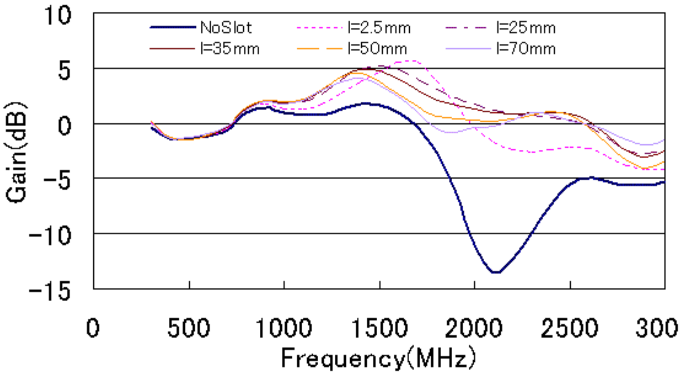
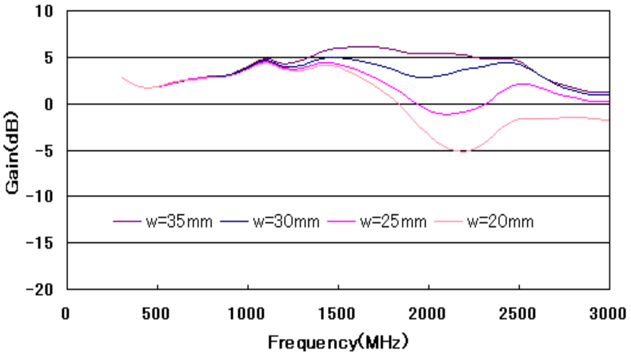


Fig.3 Absolute Gain of Antenna Model (a)　　Fig.4 Absolute Gain of Antenna Model (b)

With d=w=35mm (λ/4) and l =2.5mm~70mm in Fig. 2 (b), the absolute gain was calculated. Six characteristic graphs are shown in Fig. 4 as result. The low absolute gain is improved as seen. When standard deviation is compared, l= 35mm (λ/4) was the smallest.

Then, the antenna of Fig. 2 (c).is calculated With d=l=35mm (λ/4) from a former result. And w was varied. Four characteristic graphs are shown in Fig. 5 as result. The average of the gain of W =35mm is high and standard deviation is small. Furthermore, it have broadband characteristics as a straight slot.



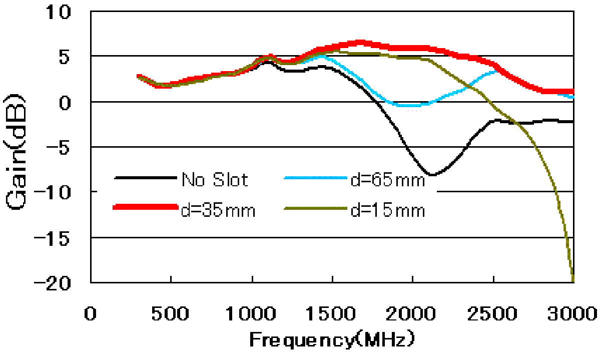


Fig.5 Absolute Gain of Antenna Model (c)
Varied w.

Fig.6 Absolute Gain of Antenna Model (c)
Varied d.

Next, the antenna of Fig. 2 (c) is calculated by the case where d is varied with l=w=35mm. Four characteristic graphs are shown in Fig. 6 as result. If a slot is far from the feed point, the gain falls by 2.0GHz. Moreover, if a slot is near the feed point, the gain falls on high frequency.

The Current distribution by d=35mm is shown in Fig. 7 with d= 35mm. Strong current is distributed also over the edge of a slot. If a slot is near, strong current distribution will adhere on the edge of a slot, and the edge of an antenna.

The radiation pattern in 2.5GHz is shown in Fig. 8. When a slot is far from the feed point, the pattern is similar to the case where there is no slot. Moreover, if a slot is too near, radiation of the front direction is weak. A beam width is small at d= 35mm, and radiation intensity to the front is stronger than other cases.

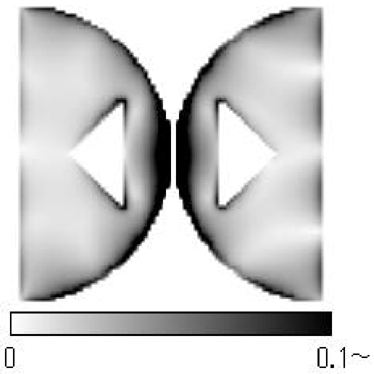


Fig.7 Current distribution by d= 35mm

4. Discussions and Conclusions

In this research, the Semi-Circle type Bow-tie antenna with a slot was proposed as an antenna for pulse radars, and influence of a slot in the characteristic using the FDTD method was analyzed. The form of a slot, and the position and the size determined the improvement of the far field characteristic for contributing greatly to the calculation result. Formation of an array of antennas and comparison with an experiment value are raised as a future subject.

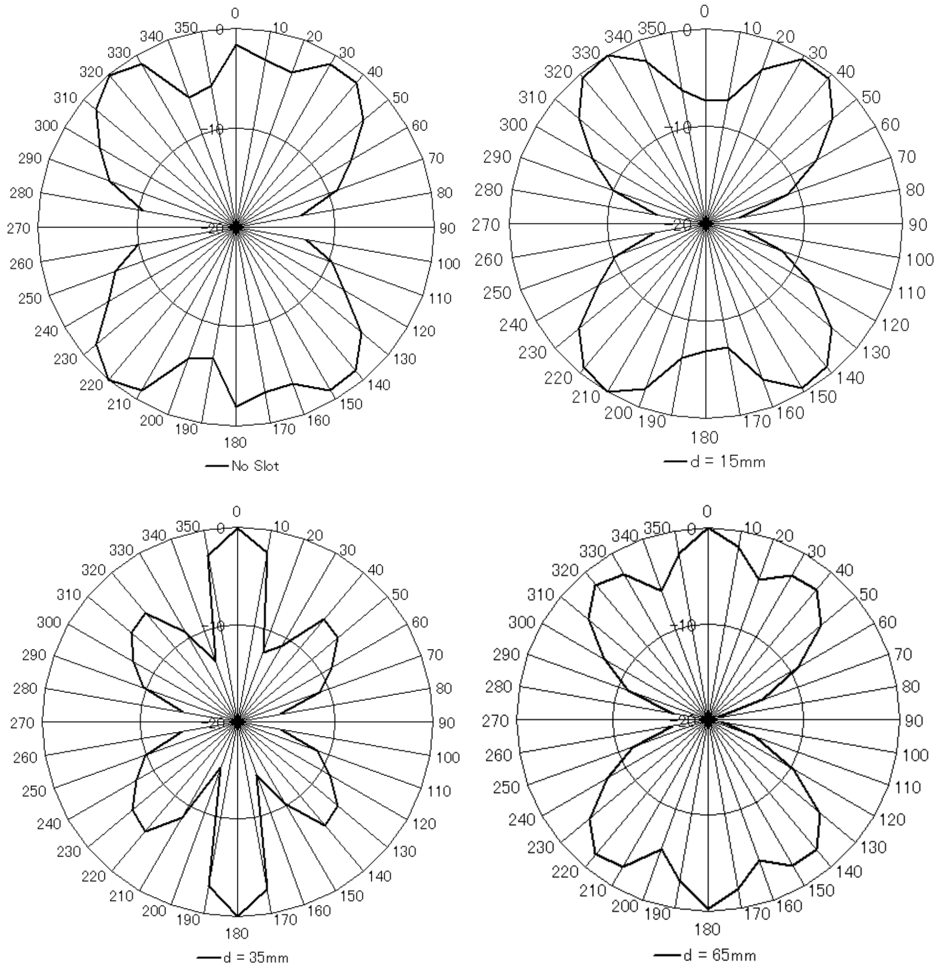


Fig.8 Radio Pattern of Antenna Model, Varied d

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