Cavity-backed Resistance-loaded Monopole Antenna for Impulse Radar - Part 2 -

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Abstract

The cavity-backed resistance-loaded planar monopole antenna for the impulse radar is analyzed by using the electromagnetic simulator "Fidelity" based on the FDTD method. The input impedance and radiation characteristics show the broadband operation for 1.0 GHz to 4.5 GHz. Next, the actual gain of the active transmitting antenna consisting of amplifier circuit and monople antenna is formulated. The scattering parameters of amplifier circuit of the transmitting antenna are examined by using the circuit simulator "S-nap", and the actual gain of this antenna consisting of the amplifier circuit and the monopole antenna is calculated.

Introduction

An antenna must operate effectively over a wide range of frequencies and have the reduced ringing within the antenna structure in many applications such as the impulse radar, which transmit and receive impulse signal. For the ground penetrating radar antenna, a T-bar fed slot antenna has suitable characteristics such as the wide-band operation of input impedance and the low multiple reflection without absorber [1], [2]. However, the dimension of this antenna is almost a half-wavelength at the lowest operating frequency, therefore it is not small. The cavity-backed monopole antenna is relatively small in size and used for the impulse radar [3].

In this paper, the cavity-backed resistance-loaded monopole antenna is analyzed and its broadband operations of input impedance and radiation characteristics are examined for the frequencies from 0.5 GHz to 4.5 GHz. In the numerical analysis, the electromagnetic simulator "Fidelity" based on the finite-difference time-domain (FDTD) method is used [4]-[6]. Next, the scattering parameters of amplifier circuit of the transmitting antenna are examined by using the circuit simulator "S-nap" [7], and the actual gain of this antenna is calculated.

Structure of resistance-loaded monopole antenna

Figure 1 shows the structure of cavity-backed resistance-loaded planar monopole antenna. The monopole antenna is located within a rectangular cavity of Cx = 48 mm by Cy = 44 mm by Cz = 44 mm in dimensions. The conducting plate of 30 cm by 30 cm in size is attached at the aperture of cavity. In order to improve the impedance characteristics in the wide frequency range, the planar monopole antenna is adopted. The length of monopole antenna L is 36 mm. The resistance R is loaded between the top of monopole and the wall of cavity for reducing ringing within antenna structure. In the numerical analysis of FDTD method, space steps are from 1 mm to 4 mm (non-uniform mesh). The calculation region is 140 mm by 130 mm by 136 mm in dimensions. The perfectly matched layer of six-layer and fourth-order is used as the absorbing boundary condition. The resistor is replaced to a conducting material with conductivity σ such as [8],

$$\sigma = \frac{\Delta z}{R\Delta x\Delta y}, \quad (1)$$

where, Δx, Δy and Δz are the space steps in the x, y, and z-direction, respectively.

Formulation of actual gain

Figure 2 shows the equivalent circuit of the transmitting antenna including the amplifier circuit. The scattering matrix represents the amplifier circuit. V_i^+ and V_i^- are the incident and reflected voltages at the i-th port (i=1, 2). The input impedance of amplifier circuit terminated by antenna element is expressed by Z_{in}^a. The voltage V_1 at the input port of amplifier circuit is given by

$$V_1 = \frac{Z_{in}^a V_{in}}{Z_g + Z_{in}^a}. \quad (2)$$

Γ_s is the reflection coefficient seen from the input port of amplifier circuit toward the generator, and Γ_L is that seen from the output port toward the antenna. Γ_S, Γ_L are expressed as follows.

$$\Gamma_S = \frac{Z_g - Z_0}{Z_g + Z_0} = \frac{V_1^+}{V_1^-} \quad (3)$$

$$\Gamma_L = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = \frac{V_2^+}{V_2^-} \quad (4)$$

The reflected voltages are expressed in terms of the scattering parameters:

$$V_1^- = S_{11}V_1^+ + S_{12}V_2^+ \quad (5)$$

$$V_2^- = S_{21}V_1^+ + S_{22}V_2^+ \quad (6)$$

Γ_{in} is the reflection coefficient seen from the generator toward the amplifier circuit terminated with the antenna. On the other hand, Γ_{out} is the reflection coefficient seen from the antenna toward the amplifier when the input port is terminated by Z_g. Substituting eq. (4) into eqs. (5) and (6),

$$V_1^- = S_{11}V_1^+ + S_{12}\Gamma_L V_2^- \quad (7)$$

$$V_2^- = S_{21}V_1^+ + S_{22}\Gamma_L V_2^- \quad (8)$$

are obtained. Therefore, from eqs. (7) and (8), Γ_{in} is summarized as follows,

$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \quad (9)$$

From eqs. (2) and (9), the voltage V_1 at the input port of amplifier is obtained as

$$V_1 = V_1^+ + V_1^- = V_1^+\left(1 + \Gamma_{in}\right) = \frac{Z_{in}^a V_{in}}{Z_g + Z_{in}^a} \quad (10)$$

Z_g and Z_{in}^a are expressed using Γ_S and Γ_{in}, respectively. Therefore,

$$V_1^+ = \frac{V_{in}}{1 + \Gamma_{in}} \frac{Z_{in}^a}{Z_g + Z_{in}^a} = \frac{V_{in}}{2} \frac{1 - \Gamma_S}{1 - \Gamma_S\Gamma_{in}} \quad (11)$$

is obtained. The average power delivered to the antenna is expressed as follows.

$$P_L = \frac{\left|V_2^-\right|^2}{2Z_0}\left(1 - \left|\Gamma_L\right|^2\right) \quad (12)$$

From eq. (8), V_2^- is expressed in terms of V_1^+.

$$V_2^- = \frac{S_{21}V_1^+}{1 - S_{22}\Gamma_L} \quad (13)$$

Then, the average power delivered to the antenna is expressed as

$$P_L = \frac{\left|V_{in}\right|^2}{8Z_0} \frac{\left|S_{21}\right|^2\left(1 - \left|\Gamma_L\right|^2\right)\left|1 - \Gamma_S\right|^2}{\left|1 - S_{22}\Gamma_L\right|^2\left|1 - \Gamma_S\Gamma_{in}\right|^2}. \quad (14)$$

Since Z_g is equal to the characteristic impedance Z_0, Γ_S becomes zero. Then P_L is reduced as

$$P_L = \frac{\left|V_{in}\right|^2}{8Z_0} \frac{\left|S_{21}\right|^2\left(1 - \left|\Gamma_L\right|^2\right)}{\left|1 - S_{22}\Gamma_L\right|^2} \quad (15)$$

The gain of amplifier circuit G_a is defined as the ratio between the power delivered to the antenna and the input power to the amplifier circuit. Therefore, G_a is summarized as follows.

$$G_a = \frac{\left|S_{21}\right|^2\left(1 - \left|\Gamma_L\right|^2\right)}{4\left|1 - S_{22}\Gamma_L\right|^2} \quad (16)$$

Let G_d be the directivity of antenna element, the actual gain of active antenna is expressed as

$$G = G_a G_d \quad (17)$$

Numerical and experimental results

Figure 3 show the calculated and measured input impedance characteristics of antenna with the monopole width W = 24 mm. The loaded resistance is 100 Ω or 220 Ω. The calculated input impedances agree well with the measured results. Figure 4 show the calculated input impedance for the monopole width W = 36 mm. The loaded resistance is 68 Ω, 82 Ω or 100 Ω. Figure 5 show the calculated input impedance characteristics for the loaded resistance R = 100 Ω. The width of monopole antenna is from 12 mm to 36 mm. Figure 6 shows the directivity characteristics for W = 24 mm and W = 36 mm. The directivity of this antenna is from 4 dBi to 8.5 dBi for the frequencies from 0.5 GHz to 4.5 GHz. Figure 7 and 8 show the electric field radiation patterns in the xz- and yz-plane, respectively. When W= 36 mm and R = 68 Ω, the input impedance and radiation characteristics show the broadband operation for 1.0 GHz to 4.5 GHz.

Figure 9 shows the amplifier circuit of transmitting antenna. Figure 10 shows the calculated scattering parameters of amplifier circuit. Figure 11 shows the calculated actual gain of transmitting antenna. Due to the mismatching of impedance between the amplifier circuit and the monopole antenna, the actual gain deteriorates.

Conclusion

The cavity-backed resistance-loaded planar monopole antenna has been analyzed and its broadband operation of the input impedance and radiation characteristics has been shown for the frequencies from 1.0 GHz to 4.5 GHz. The actual gain of the transmitting antenna consisting of the amplifier circuit and planar monopole antenna has been calculated. The amplifier circuit will have to be optimized in order to improve the actual gain characteristics of transmitting antenna for impulse radar.

References

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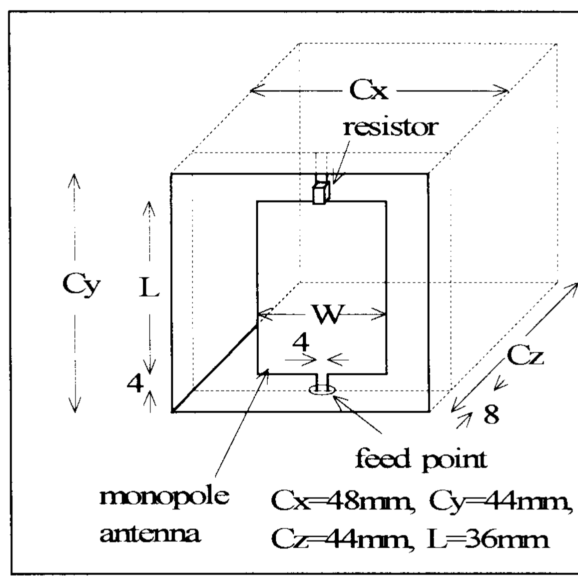


Fig.1 Cavity-backed resistance-loaded monopole antenna. L=36mm

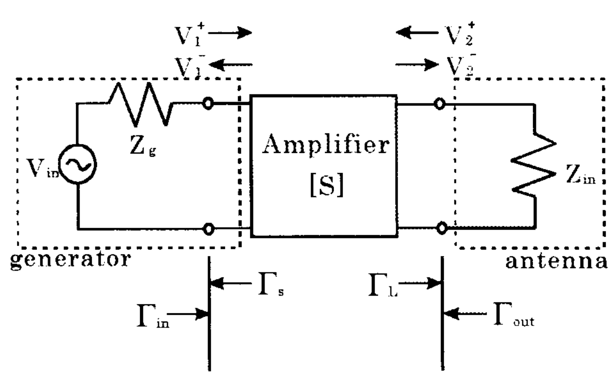


Fig. 2 Equivalent circuit of active transmitting anenna.

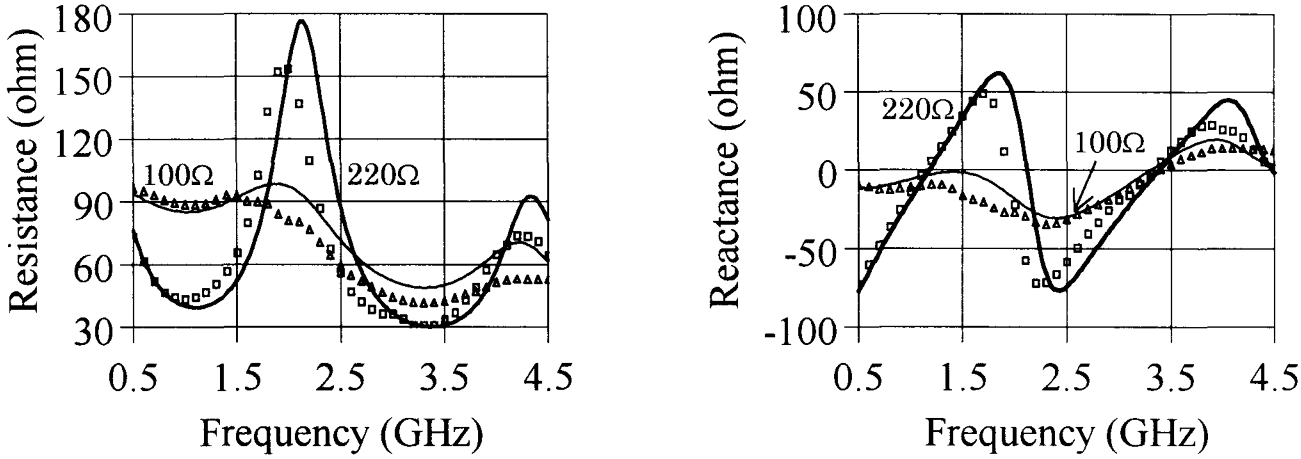


Fig. 3 Input impedance characteristics. W=24mm

calculated

measured

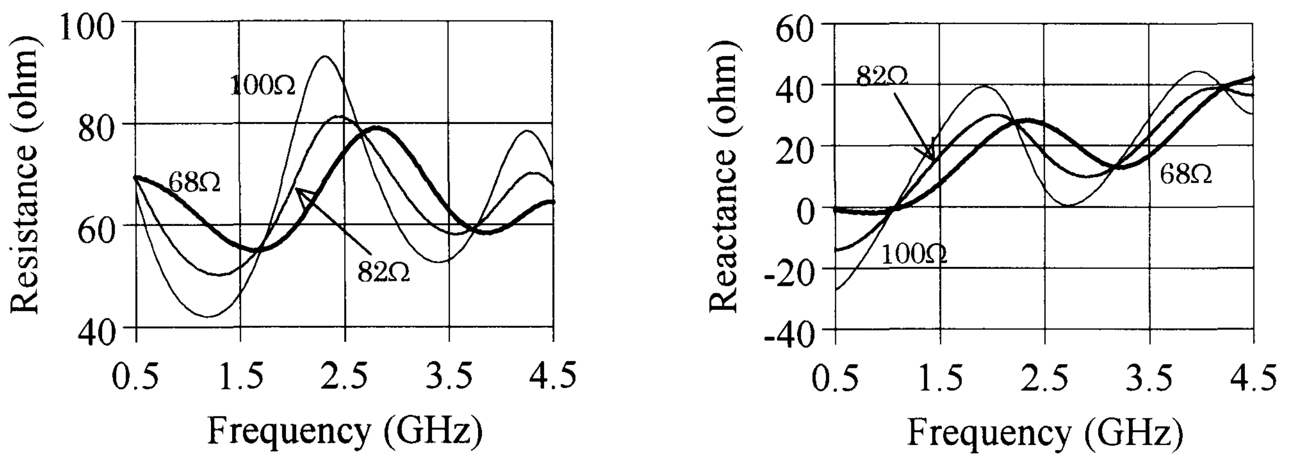


Fig. 4 Calculated input impedance characteristics. W=36mm

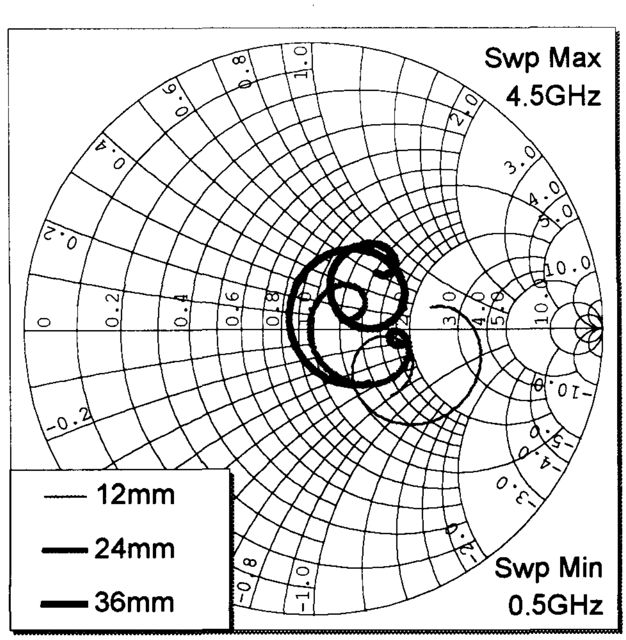
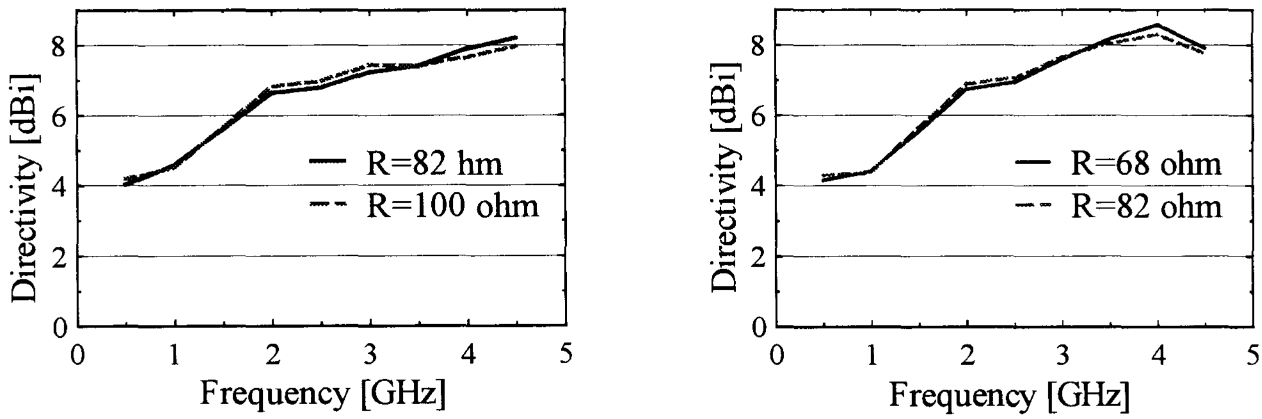


Fig. 5 Calculated input impedance characteristics. R=100Ω



(a) W=24mm (b) W=36mm

Fig. 6 Calculated directivity characteristics.

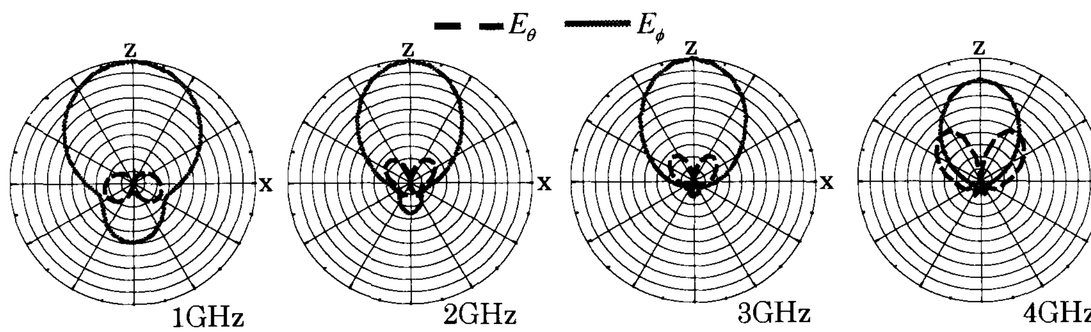


Fig. 7 Calculated electric field radiation patterns in xz-plane. W=36mm, R=68Ω

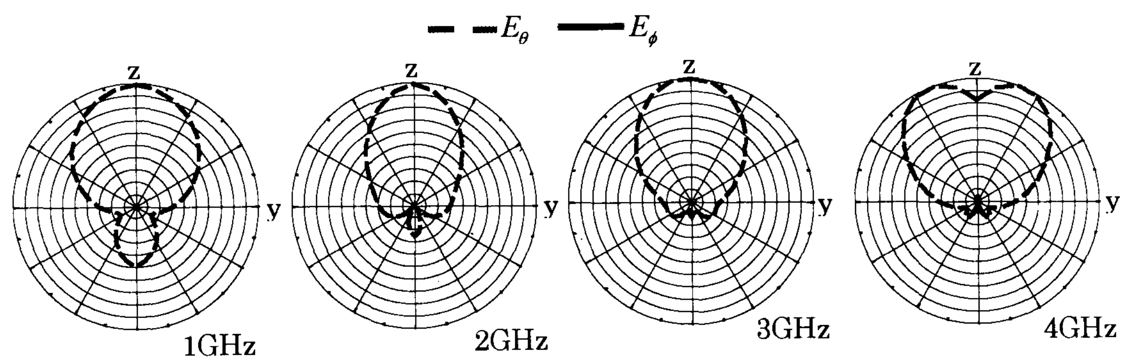


Fig. 8 Calculated electric field radiation patterns in yz-plane. W=36mm, R=68Ω

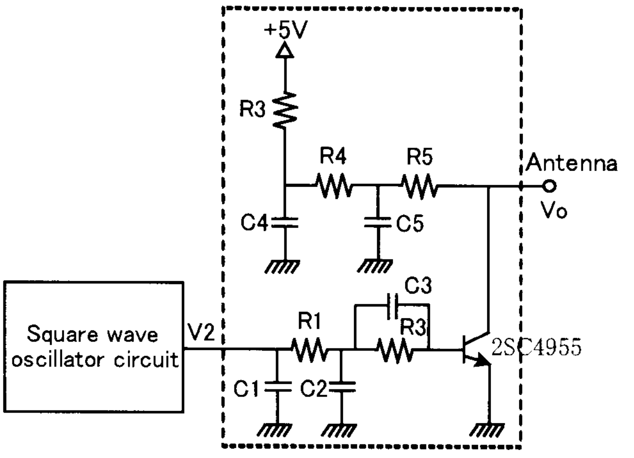


Fig. 9 Amplifier circuit of transmitting antenna

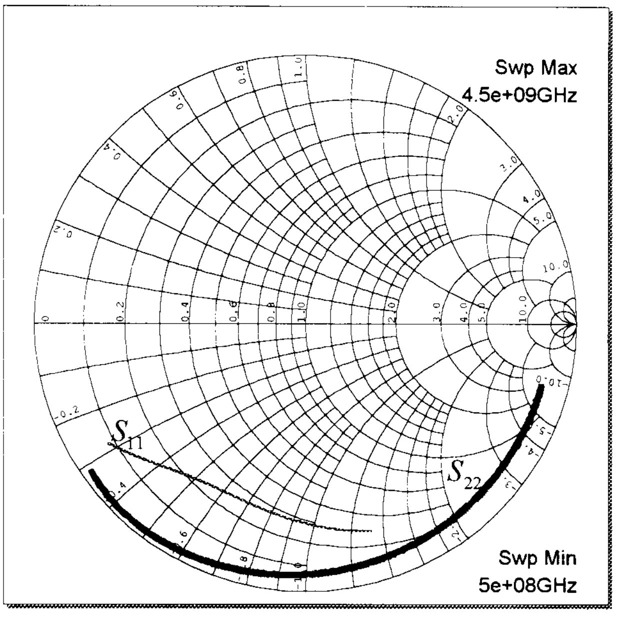


Fig. 10 Calculated scattering parameters of amplifier circuit.

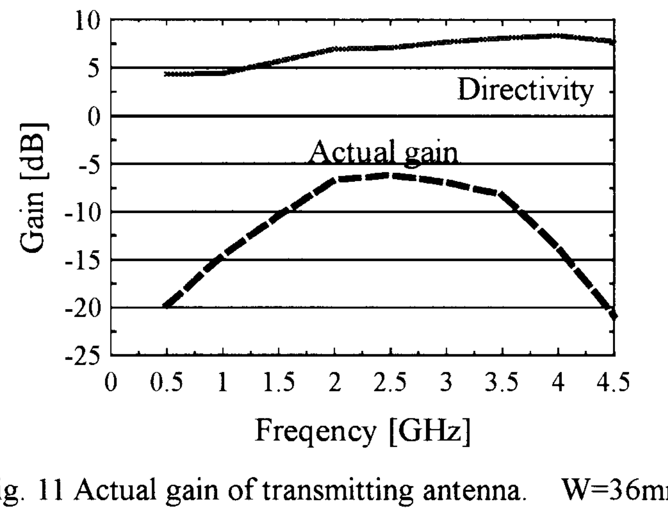


Fig. 11 Actual gain of transmitting antenna. W=36mm, R=68Ω