High-ε Ceramic Lens Antenna with Novel Beam Scanning Mechanism

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Abstract

This paper proposes a thin lens antenna using high-ε ceramic and a new beam scanning technique. The scanning mechanism mainly consists of 0dB coupler using NRD guide (Non-Radiative Dielectric waveguide). The lens antenna with the excellent performance and the wide angular beam scanning is realized. The experimental results of the radiation patterns are also shown.

1. Introduction

In Recent years, there has been considerable interest in developing millimeter-wave radar system for the adaptive cruise control (ACC) of automobiles. This system requires the antenna which have the characteristics as follows; wide scanning angle, high angular resolution, high scanning rate, small size, and high antenna gain. Several antennas with scanning mechanisms have been proposed previously [2]-[6]. However, they didn't satisfy all the requirements simultaneously.

We describe thin lens antenna with novel beam scanning mechanism, which can simultaneously resolve all of the problems listed above.

2. High-ε ceramic lens

The lens is designed by the ray analysis method [7] on condition that the diameter is 88mm and tanδ of the lens material is 1.0×10^{-3}. In this design, the reflection loss is considered on the surface of the lens, and the radiation pattern of a feeder is chosen to get the maximum antenna gain. Figure 1 shows the relationship between the dielectric constant of lens material and the calculated antenna efficiency, and the calculated total thickness of the antenna (the sum of the thickness of the lens and the focal length) for the different Fb/D (the ratio of the focal length to the diameter). From this figure, we have chosen the ceramic lens with high-dielectric constant of 6.6 and Fb/D of 0.3 in consideration of the efficiency and the total thickness of the antenna. To suppress the reflection on the surface of the lens, the lens is coated with polypropylene (εr=2.2) on the surface as the antireflection coating. The thickness of the coating is 0.7mm (about a quarter wavelength). The thickness of the lens and the focal length are 17mm and 26mm, respectively. Figure 2 shows the measured radiation pattern of the lens antenna in azimuth plane at 76.5GHz. The antenna gain of 34.1dBi (antenna efficiency of 52.2%), the beamwidth of 3.0º and the sidelobe level of less than -23dB is realized. Optimizing the radiation pattern of the feeder and the shape of the lens improves these characteristics.

3. Beam scanning mechanism

In order to realize the high angular resolution, we have chosen the continuously moving mechanism of a feeder. We adopt the sliding feeder using 0dB coupler. Figure 3 shows the basic construction of the beam scanning mechanism. This can make the lens antenna to scan the beam continuously.

3.1 0dB coupler using NRD guide

Figure 4 shows the structure of 0dB coupler. The 0dB coupler consists of two parts, a fixed and a movable part. The fixed part is connected to the RF module and the antenna feed is set on the movable part. These parts are separated by a constant small gap, keeping non-contact. The beam scanning is achieved by sliding the position of the movable part with the antenna feed, keeping close coupling.

The designing process of 0dB coupler is described below. The power dividing ratio of a coupler is given as follows. a_1 shows the complex amplitude of primary transmission line and a_2 shows of secondary one.

$$|a_1|^2 = \cos^2 \frac{\sqrt{(\beta_1-\beta_2)^2+4k^2}}{2} l + \frac{(\beta_1-\beta_2)^2}{(\beta_1-\beta_2)^2+4k^2} \sin^2 \frac{\sqrt{(\beta_1-\beta_2)^2+4k^2}}{2} l \qquad \text{----(1)}$$

$$|a_2|^2 = \frac{4k^2}{(\beta_1-\beta_2)^2+4k^2} \sin^2 \frac{\sqrt{(\beta_1-\beta_2)^2+4k^2}}{2} l \qquad \text{----(2)}$$

$$k \text{ (coupling coefficient)} = \frac{\sqrt{(\beta_o-\beta_e)^2-(\beta_1-\beta_2)^2}}{2} \qquad \text{----(3)}$$

where l is a coupling length, β_1, β_2 is a phase constant of each transmission line and β_o, β_e is a phase constant of odd, even mode, respectively. The relationship of the equation (1) and (2) satisfy the equation (4).

$$|a_1|^2 + |a_2|^2 = 1 \qquad \text{----(4)}$$

The condition of 0dB coupler realization is $|a_2|^2 = 1$. When taking into consideration, only the coupling of the transmission lines, that is, $\beta_1 = \beta_2$, the condition of 0dB coupler is therefore attained in the equation (5).

$$kl = \pi/2 + n\pi \qquad \text{----(5)}$$

The minimum coupling length L of 0dB coupler is derived by

$$L = \frac{\pi}{|\beta_0 - \beta_e|} \qquad \text{----(6)}$$

This result shows the shorter coupling length is caused from the larger difference between β_o and β_e. NRD guide has the larger difference between β_o and β_e than the waveguide. Therefore, it can make the coupling length L of the 0dB coupler to be shorter and smaller than that of the conventional waveguide. In NRD guide, LSM_{01} mode with low transmission loss is used. These β_o, β_e are calculated by 2-dimensional FEM.

Figure 5 shows the relationship between coupling length l and the transmission (S_{21}) and the coupling (S_{31}) values calculated by Ansoft-HFSS at 76.5GHz. Figure 6 shows the measurement model of 0dB coupler and the definition of each port and the position of the movable part, Figure 7 the measured frequency response and Figure 8 the relationship between the position of the movable part and the measured S parameter S_{31}, S_{11} at 76.5GHz, respectively. The results show that this method enables to slide the position of the movable part, keeping 0dB coupling. The coupling value (S_{31}) is less than 0.8dB within the movable range (±7mm) at 76.5GHz. The movable part weighs less than 4.0 g. As compared with the one of the mechanical scanning technique proposed previously [5], this is much lighter and smaller, indicating that this method can realize the high scanning rate.

3.2 Lens Antenna using 0dB coupler

The dimensions of this antenna are 88mm in diameter and 47mm thickness, realizing the small size lens antenna with scanning mechanism. The circular horn is used as a primary feed, where the TM_{11} mode is transformed from LSM_{01} mode in NRD guide. Figure 9 shows the measured radiation diagram of the beam scanning antenna at the scanning angle of 0º, ±5º, ±10º. This figure shows the data in azimuth plane at 76.5GHz. The sidelobe level is less than -15dB within the beam angle of ±10º. The deviation of the antenna gain within ±10º angle is less than 1dB.

4. Conclusion

The thin lens antenna using high-ε ceramic and the new beam scanning technique using NRD guide are presented. We describe the principle and the design method of NRD-type 0dB coupler. This lens antenna enables the wide scanning angle, high angular resolution, high scanning rate, small size, and high antenna gain simultaneously. This is expected to be applicable for automotive ACC radar applications.

Acknowledgment

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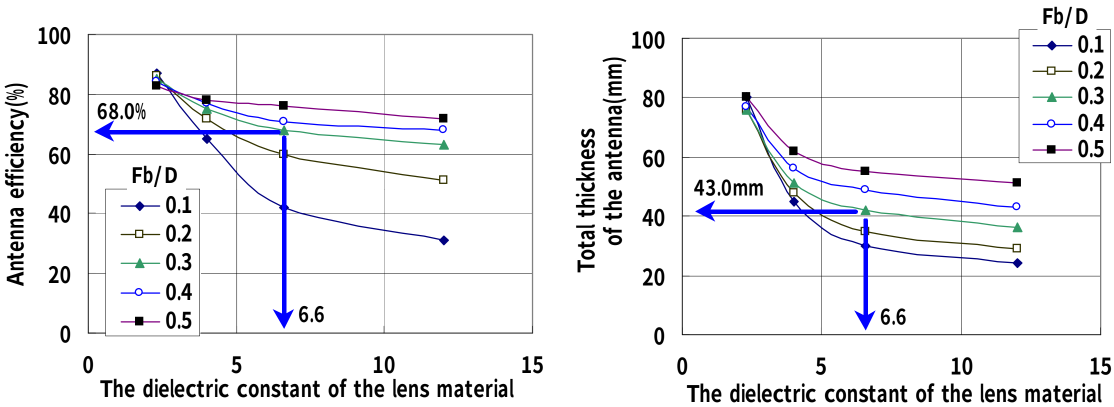

Fig. 1 The relationship between the dielectric constant of lens material and the antenna efficiency, the total thickness of the antenna for the different Fb/D (calculated results)

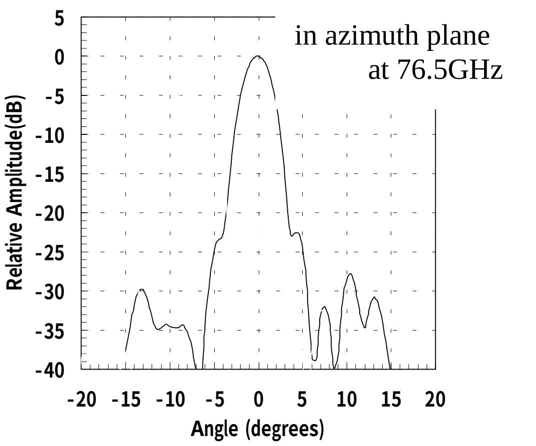

Fig. 2 The measured radiation pattern of the ceramic lens antenna

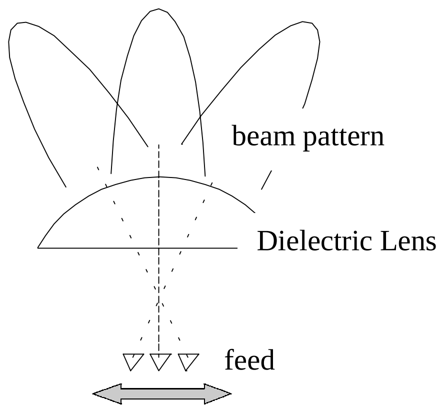

Fig. 3 The beam scanning mechanism

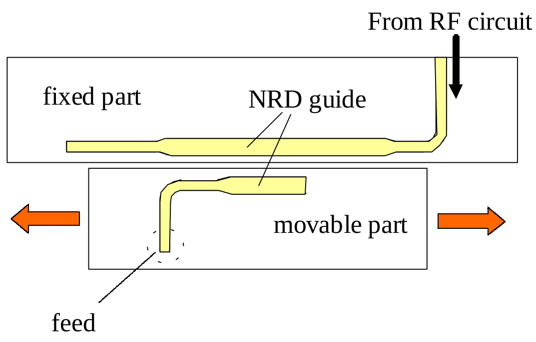

Fig. 4 The structure of NRD-type 0dB coupler

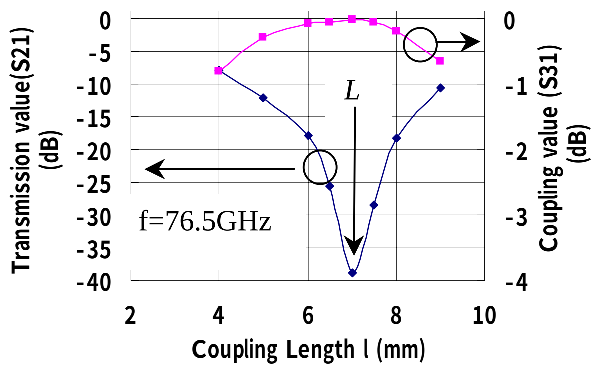

Fig. 5 The relationship between the coupling length *l* and the transmission (S_{21}), the coupling values (S_{31}) (calculated results)

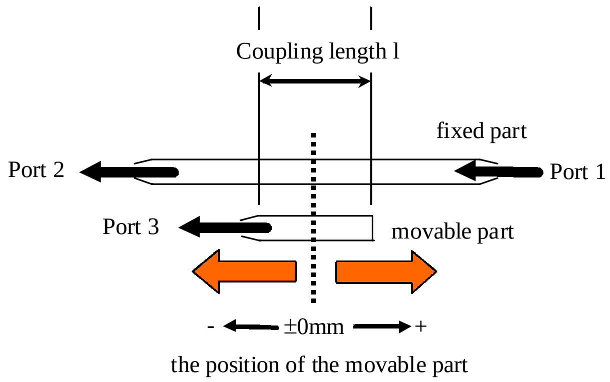

Fig. 6 The measurement model of 0dB coupler and the definition of each port and the position of the movable part

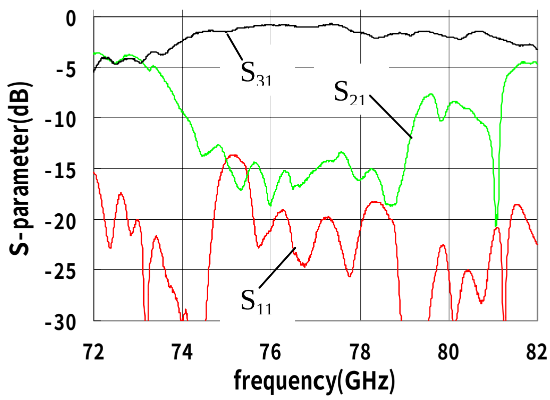

Fig. 7 The measured frequency response of 0dB coupler

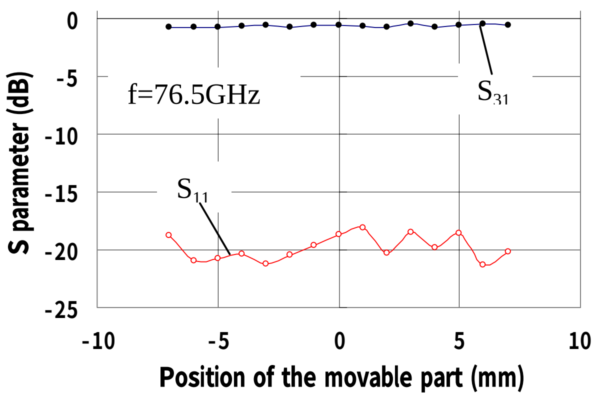

Fig. 8 The relationship between the position of the movable part and measured S_{11}, S_{31}

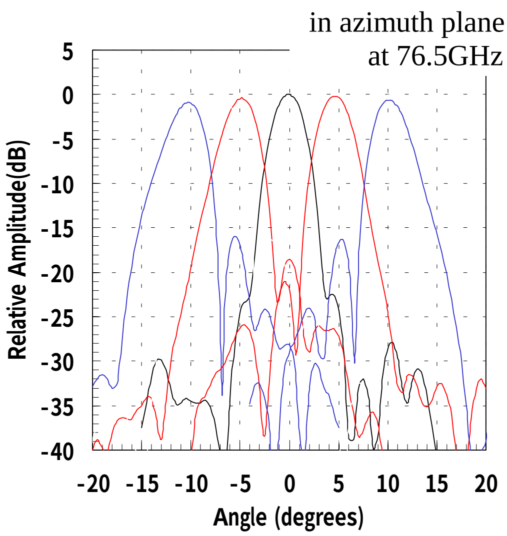

Fig. 9 The measured radiation diagram of the ceramic lens antenna using 0dB coupler