A Dielectric Biconvex Lens Design for High-gain Spiral Antenna

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***Abstract*— This paper describes a design for a high-gain antenna that combines a dielectric lens and a spiral radiator. The gain of the proposed spiral antenna with a biconvex lens was remarkably increased compared with that of a conventional spiral antenna with an added conical cavity wall. The narrow beam width was reasonably achieved using the optimized biconvex lens. The author confirmed that the beam width and the average gain are greatly influenced not by the lens thickness but by the focal length.**

I. INTRODUCTION

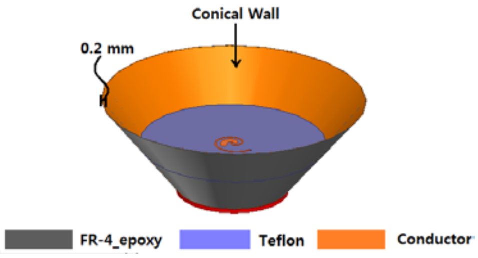
Recently, the small memory chips composed of minimal semi-conductors, which contain important information, can be used illegally. Accordingly, the detection of hidden devices to be used for illegal purposes becomes difficult because of complex hiding methods. The detection of a tiny chip made by a semiconductor has been made possible by the development of a nonlinear junction detector (NLJD) [1]-[3]. To stave off terror threat by various explosive substances, a wireless multi-mode threat detector (MMTD) system or the explosives trace detection (ETD) system has also been developed. The high-gain circular polarization antenna is mainly used for the NLJD system application [4], [5]. The antenna for the MMTD system requires a sharp beam for high resolution.

The author proposed a high-gain spiral antenna with a novel Archimedean spiral slit on the ground plane to achieve circular polarization and designed a new cavity [5] added to the conical wall to realize the high gain. To realize a higher gain and a better resolution, a biconvex dielectric lens was considered and discussed in this paper.

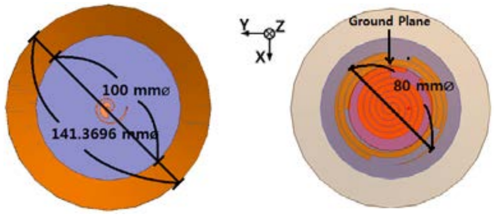
II. CONVENTIONAL ANTENNA

A. *Configuration of Conventional Spiral Antenna*

Fig. 1 shows the conventional antenna structure [5] and a compensated structure specification obtained by the new simulation. Fig. 1 (a) shows the spiral antenna structure composed of a conical wall and a reflection plate as the metal cap. The conical wall thickness with FR-4_epoxy is 0.2 mm, and the inner conical wall is the conductor, as shown in Fig. 1 (a). The diameters of the radiating plane and the conical wall are 100 mm and 141.3696 mm, respectively, as shown in Fig. 1 (b). The conical wall height between the metal cap and the radiating plane is 25 mm.



(a) Conventional spiral antenna structure



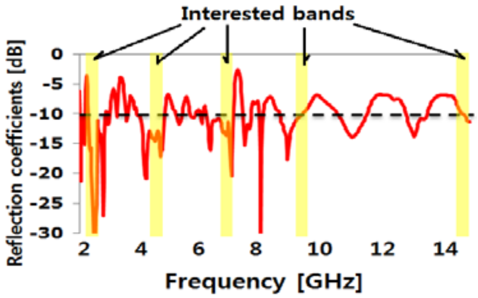
(b) Radiating plane (c) Spiral slit on the ground plane

Fig. 1. The compensated structure and specification of a conventional spiral antenna structure

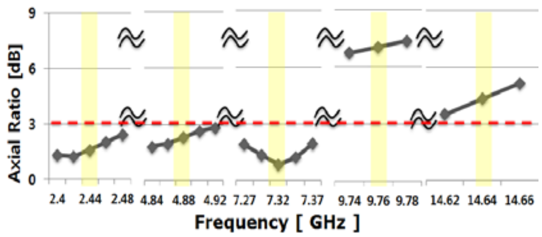
The substrate of the antenna was considered for the Teflon dielectric material, with a relative permittivity of 2.1 and a substrate height of 0.6 mm. The diameter of the optimized Archimedean spiral slit on the ground plane as shown in Fig. 1 (c) is 80 mm.

B. Simulation of the compensated structure

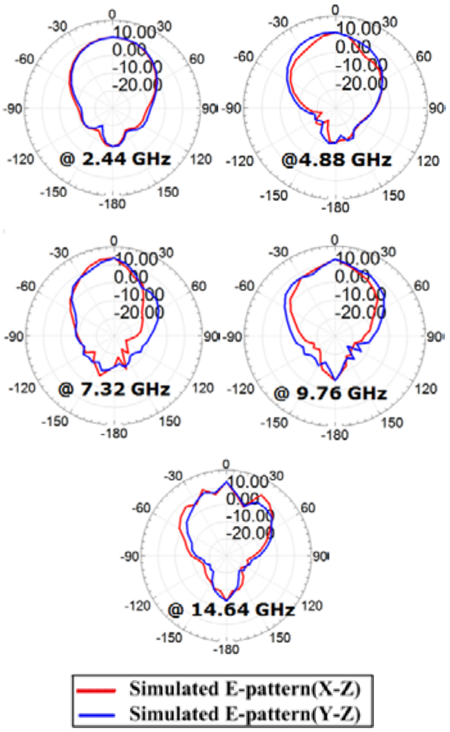
Fig. 2 shows the simulated results of a compensated spiral antenna, as shown in Fig. 1. Fig. 2 (a) presents the multi-resonance characteristics with respect to the compensated structure of the conventional spiral antenna. The simulated reflection coefficients of the compensated antenna appeared at about -10 dB below in the interested bands of the NLJD system and the MMTD system. These results are similar to those in reference [5]. The center frequencies of 9.76 GHz and 14.64 GHz, and the linear polarization were considered for the MMTD application. Fig. 2 (b) shows the simulated axial ratio, where θ = 90 ° and ø = 0 °. The average axial ratio at the NLJD bands is about 1.6 dB, and it shows excellent circular polarization characteristics at the NLJD bands. Fig. 2 (c) shows the patterns of the XZ plane and the YZ plane are denoted by the solid red line and the solid blue line, respectively. Fig. 2 (d) shows the simulated gain comparison between the conventional antenna [5] and the proposed compensated spiral antenna. The gain of the compensated antenna seems similar to that of the conventional antenna at the NLJD bands.



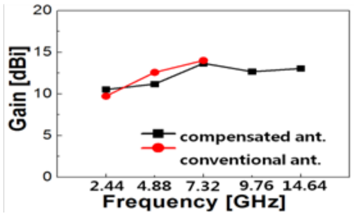
(a) Simulated reflection coefficients



(b) Simulated axial ratio



(c) Simulated radiation patterns



(d) Gain comparison with the conventional antenna

Fig. 2. Simulated results of the compensated spiral antenna

III. DIELECTRIC LENS DESIGN

A. Biconvex lens design

The dielectric lens was considered for gain improvement and beam width control [6]. Fig. 3 shows the compensated spiral antenna structure of Fig. 1 added with a dielectric biconvex lens. Optimum lens parameters, such as the diameter (D), thickness (T), and focal length (L) between the bottom surface of lens and the spiral radiator, are required to obtain a high gain and a sharp beam. This lens is located in the compensated spiral antenna. A biconvex sphere shape of the lens is easily determined by two circular equations.

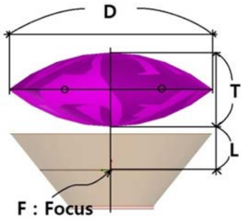
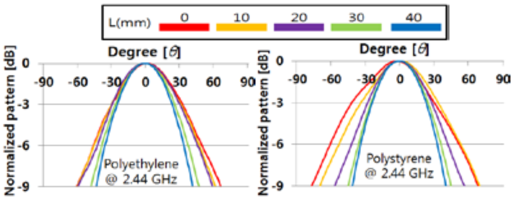


Fig. 3. The compensated antenna with a biconvex lens

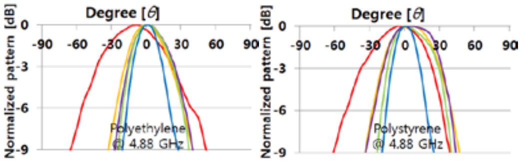
B. *Antenna Simulations*

Dielectric materials such as polyethylene and polystyrene are used as the material for biconvex lenses in design. To optimize the parameters of D, T, and L determined by the relative permittivity of the lens material, the beam width patterns of the spiral radiator combined with a polyethylene lens and a polystyrene lens were simulated by a commercial tool.

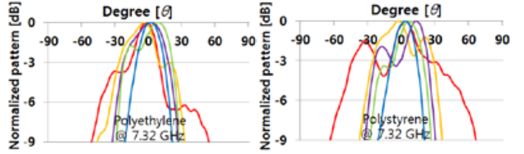
Fig. 4 shows the simulated results of the normalized patterns of beam width with respect to polyethylene and polystyrene as the dielectric materials of the biconvex lens at the interested bands. The dielectric constants of polyethylene and polystyrene are 2.26 and 2.6, respectively. D and T are fixed at 143.4 mm and 51.8 mm, respectively, in the simulation. L is changed from 0 to 40 mm, as shown in Fig. 4. The 3 dB beam width mostly depends on the distance between the bottom surface of the lens and the spiral radiator, and more on the operating frequency than on the dielectric constant of polyethylene and polystyrene. The more the operating frequency is generated to a higher frequency, the more the 3dB beam width becomes sharper with high gain. That is, beam width is determined by L and the operating frequency. As polystyrene is a well-known plastic and its manufacturing process is relatively easy, polystyrene was selected for simulation hereafter.



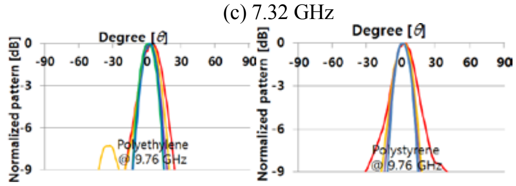
(a) 2.44 GHz



(b) 4.88 GHz



(c) 7.32 GHz



(d) 9.76 GHz

Fig. 4. Normalized patterns of beam width at the interested bands

Fig. 5 shows the normalized simulation patterns of the beam width with respect to polystyrene as the dielectric material of the biconvex lens at the interested bands. D and T in the simulation are 143.4 mm and 51.8 mm, respectively. L is changed from 50 mm to 90 mm, as shown in Fig. 5.

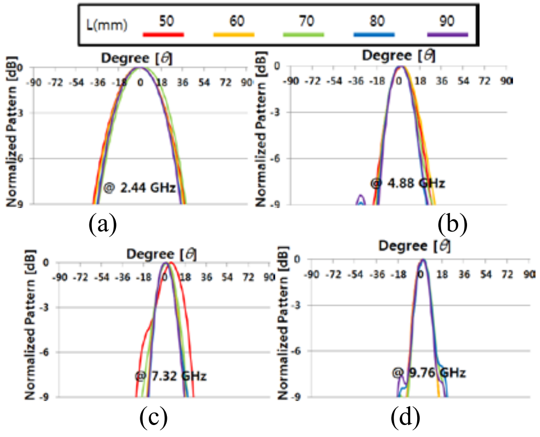
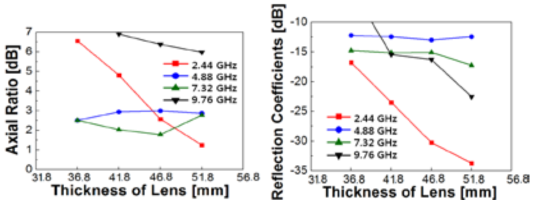


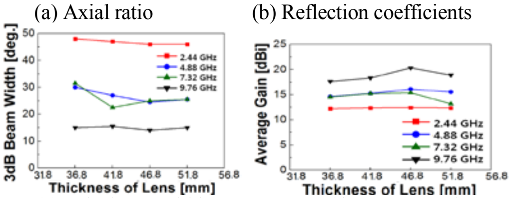
Fig. 5. Normalized simulation beam patterns of polystyrene lens with respect to the focal length variation at the interested bands

The 3 dB beam width generally depends on the operating frequency than on the focal length. Once the focal length is longer than 50 mm, a variation of the beam width does not almost occur and not so serious. When the focal length is longer than 80 mm, a side lobe appears at 4.88 GHz and 9.76 GHz. Therefore, the focal length of 50 mm, which can realize a small-sized antenna, is determined as the optimum value. When L = 50 mm and D = 143.4 mm, the antenna characteristics of the spiral radiator combined with a polystyrene lens are simulated and designed to optimize the biconvex lens thickness.

Fig. 6 shows the simulation results with respect to the polystyrene lens thickness variation at the interested bands.



(a) Axial ratio (b) Reflection coefficients



(c) 3 dB beam width (d) Average gain

Fig. 6. The simulation results with respect to the polystyrene lens thickness variation at the interested bands

Fig. 6 (a) shows the simulated axial ratio as a function of lens thickness. An axial ratio is changed by the lens thickness. When T = 51.8 mm and 2.44 GHz, the simulated axial ratio of 3 dB below, which is similar to that of the conventional antenna, is observed at the NLJD band. As a linear polarization is required at the MMTD band, a remarkable linear polarization is radiated at 9.76 GHz. Fig. 6 (b) shows the simulated reflection coefficients as a function of lens thickness. The reflection coefficients of -10 dB below are obtained at the interested bands. The 3 dB beam width is rapidly narrowed by a biconvex lens except for 2.44 GHz, as shown in Fig. 6 (c). This narrow beam width contributes to the gain improvement. The more the frequency is moved to high, the more the beam width is changed to sharp. This phenomenon is related to antenna gain, as shown in Fig. 6 (d). If the beam width has a wide angle, the gain shows a relatively low level. That is, the beam width and the average gain are not seriously influenced by lens thickness. The simulated gain of the spiral antenna with a polystyrene biconvex lens appears at about 2 dBi higher than the conventional spiral antenna at 4.88 GHz and 9.76 GHz.

IV. CONCLUSION

This paper presents a fundamental design for a high-gain spiral antenna combined with a dielectric biconvex lens for the NLJD and MMTD applications. The characteristics of a compensated antenna are similar to those of a conventional spiral antenna with an added conical cavity wall. To optimize a biconvex lens, the lens parameters D, T, and L are determined by the relative permittivity of the dielectric lens. The selected material of the lens is polystyrene, which has an electric constant of 2.6. The optimized values of D, T, and L are 143.4, 51.8, and 50 mm, respectively. The simulated gain of a spiral radiator combined with a polystyrene lens appears to be about 2 dBi higher than that of the conventional spiral antenna. The sharp beam width is obtained in comparison with the conventional one because of the use of a dielectric biconvex lens. Beam width and average gain are confirmed to be seriously influenced not by lens thickness but by focal length. Fabrication and measurement will be carried out in near future study.

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