An Archimedean Spiral Antenna
Backed by a Modified EBG Reflector

H. Nakano, R. Kobayashi, H. Umetsu, S. Sasaki, and J. Yamauchi
College of Engineering, Hosei University,
Koganei, Tokyo, Japan 184-8584, nakano@k.hosei.ac.jp

1. Introduction

An Archimedean spiral antenna radiates a bi-directional beam in the direction normal to the
spiral plane [1]. This bi-directional beam is transformed into a unidirectional beam to realize a high
gain for use in communications applications. Conventionally, the unidirectional beam has been
realized using a PEC reflector (a PEC plate or a PEC cavity). Note that the use of a PEC reflector
deteriorates the inherent wideband characteristics of the input impedance and axial ratio of the
Archimedean spiral antenna [2].

It is known that the inherent wideband characteristics of the spiral are restored if the space
between the spiral and the PEC reflector is filled with an absorbing material [3]. However, this
significantly decreases the radiation efficiency.

This paper discusses the use of an EBG reflector [4] [5] with the Archimedean spiral antenna to
obtain a unidirectional beam. For purposes of this discussion, the EBG reflector is assumed to be
lossless. Note that such a lossless EBG reflector does not deteriorate the radiation efficiency. The
discussion assumes that the distance between the spiral and the EBG reflector surface is extremely
small. This configuration realizes a low antenna profile.

The use of an EBG reflector with the equiangular spiral has been reported in [6]. Clearly, the
shape of the arm of the Archimedean spiral differs from that of the equiangular spiral. Therefore, it
is useful to analyze the input impedance and axial ratio of the Archimedean spiral. The analysis of
these two characteristics is performed over a frequency range of 3 GHz to 10 GHz.

2. Configuration

Fig. 1 shows the configuration of an Archimedean spiral antenna backed by an EBG reflector.
The spiral has two arms, and each arm’s radial distance from the center of the spiral is defined by
the Archimedean function \( r = a_s \phi_w \), where \( a_s \) is the spiral constant and \( \phi_w \) is the winding angle. The
circumference of the spiral is defined as \( c = 2\pi r_{\text{max}} \) with \( r_{\text{max}} = a_s \phi_{\text{end}} \) where \( \phi_{\text{end}} \) is the winding angle
at the end of the spiral. Each of the spiral arms is made of a strip line of width \( w \). The distance from
the top surface of the EBG reflector to the spiral is \( H' \).

The patches used for the EBG reflectors in this paper are shown in Fig. 2; they are composed of
\( n \) patches above a ground plane of area \( S_{\text{EBG}} \times S_{\text{EBG}} \). Each patch is printed on a dielectric substrate
of relative permittivity \( \varepsilon_r \) and thickness \( B \), and is short-circuited to the ground plane. The number of
patches in Figs. 2(a) and 2(b) are \( n = N_{\text{max}}^2 \) and \( n = N_{\text{max}}^2 - n_{\text{rmv}}^2 \), respectively. Note that, in the
following discussion, the EBG reflectors in Figs. 2(a) and (b) are referred to as the original EBG
reflector and the modified EBG reflector, respectively.

3. Discussion

Analysis is performed using the FDTD method based on Yee’s mesh. The antenna configuration,
including the EBG-reflector, is symmetric with respect to the z-axis and hence the electric and
magnetic fields, \( \mathbf{E} \) and \( \mathbf{H} \), in an analysis space of \((N_x\Delta x) \times (N_y\Delta y) \times (N_z\Delta z)\) are obtained from those in
half of the analysis space, i.e., \((0.5N_x\Delta x) \times (N_y\Delta y) \times (N_z\Delta z)\), using the following symmetry
conditions:
The use of the symmetry conditions reduces the computation time. The antenna characteristics, including the input impedance, radiation pattern, and axial ratio, are calculated on the basis of $\mathbf{E}$ and $\mathbf{H}$ obtained using the FDTD method.

For the analysis, the following parameters are fixed throughout this paper: spiral constant $a_s = 1.273$ mm/rad, winding angle $\phi_w = 8\pi$ rad, arm width $w = 2$ mm, side length $S_{\text{EBG}} = 142$ mm, substrate thickness $B = 4$ mm, permittivity $\varepsilon_r = 2.2$, height $H' = 7$ mm, and number of patches $N_{\text{max}}^2 = 12^2$. The number of patches removed to create the modified EBG reflector $n_{\text{rmv}}^2$ is varied subject to the objectives of the analysis.
The axial ratio of the spiral depends on \( n_{rv}^2 \). Fig. 3 shows the axial ratio as a function of frequency: Figs. 3(a) and (b) are for \( n_{rv}^2 = 0 \) and \( 2^2 \), respectively. Note that the EBG reflector for \( n_{rv}^2 = 0 \) is the original EBG reflector. When \( n_{rv}^2 = 2^2 \), the axial ratio exhibits a wideband characteristic.

As more patches are removed (\( n_{rv}^2 \) is increased), the input impedance deteriorates. This implies that the number of patches removed must be chosen to maintain the wideband characteristics of both the input impedance and the axial ratio. Fig. 4 shows the input impedance for \( n_{rv}^2 = 2^2 \), together with that for \( n_{rv}^2 = 0 \).

The radiation field is decomposed into two waves: a right-hand circularly polarized wave (\( E_R \)) and a left-hand circularly polarized wave (\( E_L \)). Fig. 5(a) shows the radiation pattern for \( n_{rv}^2 = 2^2 \). For comparison, Fig. 5(b) shows the radiation pattern in the absence of patches (\( n_{rv}^2 = N_{max}^2 \)). It is found that the unidirectional radiation beam for \( n_{rv}^2 = 2^2 \) is circularly polarized around the z-axis, while that for \( n_{rv}^2 = N_{max}^2 \) is linearly polarized.

4. Conclusions

A low-profile Archimedeans spiral antenna backed by an EBG reflector is analyzed, where the EBG reflector is composed of \( n = N_{max}^2 - n_{rv}^2 \) patches, with each patch short-circuited to the ground plane. The antenna height from the top surface of the EBG reflector to the spiral is extremely small: 0.07 wavelength at 3 GHz. The analysis is performed, while changing the number of patches removed from the reflector (\( n_{rv}^2 \)). First, the axial ratio as a function of frequency is investigated. The investigation shows that the axial ratio is a function of \( n_{rv}^2 \). Second, the input impedance is analyzed. The analysis results reveal that, as \( n_{rv}^2 \) is increased, the input impedance deteriorates at low frequencies. Based on the obtained frequency responses, it is concluded that the number of removed patches must be chosen such that the wideband characteristics of both the axial ratio and the input impedance are maintained.

Acknowledgments

The authors thank V. Shkawrytko for his assistance in the preparation of this manuscript.

References

Figure 3: Axial ratio. (a) $n_{\text{rmv}}^2 = 0$. (b) $n_{\text{rmv}}^2 = 2^2$.

Figure 4: Input impedance. (a) $n_{\text{rmv}}^2 = 0$. (b) $n_{\text{rmv}}^2 = 2^2$.

Figure 5: Radiation pattern. (a) $n_{\text{rmv}}^2 = 2^2$. (b) $n_{\text{rmv}}^2 = N_{\text{max}}^2$. 

$f = 3$ GHz

$E_R$ 

$E_L$ 

$0^\circ$ 

$30^\circ$ 

$60^\circ$ 

$90^\circ$ 

$0$ 

$30^\circ$ 

$60^\circ$ 

$90^\circ$ 

$x$ 

$z$ 

$\theta$ 

$\phi$

(a) 

(b)