A–8–4 THE TWO-WIRE SQUARE SPIRAL ANTENNA

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INTRODUCTION

A square spiral antenna is known as a counterpart of Archimedean round spiral. Up to the present time, much of the work on the square spiral has been experimental and the design of this antenna has been on the basis of current band theory[1] which gives simply a qualitative explanation of radiation characteristic. The purpose of this study is to give a fundamental treatment for this type of antenna from a design viewpoint. We solve Mei's integral equation[2] by the aid of computer. The numerical results including current distribution, input impedance, radiation pattern and axial ratio are presented with experimental results. It is shown that the square spiral radiates an excellent circularly-polarized-wave with a little dependence on the wire radius.

ANTENNA GEOMETRY

The geometry of two-wire square spiral is shown in Fig.1. Arms A and B of the spiral are wound by many linear filaments in a plane. The n th filament length l_n is defined by

$$l_n = \begin{cases} a & n=1 \\ 2a(n-1) & n=2,3,\ldots\ldots \end{cases} \qquad (1)$$

Then the position vector from the origin to an arbitrary point on n th filament is given by

$$\bar{r} = [-1]^q[[a(n-1)\sin n\pi/2 + (s-a(n-1)^2)\cos n\pi/2]\ \hat{x} + [-a(n-1)\cos n\pi/2 + (s-a(n-1)^2)\sin n\pi/2]\ \hat{y}]$$

$$\begin{cases} q=0 & \text{on arm A} \\ q=1 & \text{on arm B} \end{cases} \qquad (2)$$

where $\hat{x}$ and $\hat{y}$ are unit vectors of rectangular coordinate, and s the distance along the antenna arm from the feed point. Trigonometric function is used as a indicator showing 0 and ±1.

The tangential unit vector along n th filament is expressed by

$$\hat{s} = \cos n\pi/2\ \hat{x} + \sin n\pi/2\ \hat{y} \qquad (3)$$

on arms A and B.

INTEGRAL EQUATION

The unknown current distribution I(s') along the arm is determined from Mei's integral equation[2]. Because of the orthogonal property between arm filaments, the integral equation can be expressed by

$$\int_{\substack{\text{Antenna}\\ \text{length}}} I(s')\pi(s,s')ds' = B\cos ks - jV/2Z_0 \sin k|s| \qquad (4)$$

where $\pi(s,s') = f_1(s,s') + f_2(s,s') + f_3(s,s')$ (5)

$$f_1(s,s') = G(s,s')\,\hat{s}\cdot\hat{s}' \qquad (6)$$

$$f_2(s,s') = -\sum_{i=1}^{Q} G(c_i,s')(\hat{c}_i^{+}-\hat{c}_i^{-})\cdot\hat{s}'\cos k(s-c_i) \qquad (7)$$

$$f_3(s,s') = \begin{cases} \int_0^s G(t,s')\dfrac{1+jkD(t,s')}{D^2(t,s')}\dfrac{(x'-t_x)+\frac{dy'}{dx'}(y'-t_y)}{\sqrt{1+(\frac{dy'}{dx'})^2}}\cdot \\ \cdot\cos k(s-t)dt \quad ......m+n;\ \text{odd} \\ 0 \quad ....m+n;\ \text{even} \end{cases} \qquad (8)$$

$$G(s,s') = \frac{\exp(-jkD(s,s'))}{4\pi D(s,s')} \qquad (9)$$

$$D(s,s') = |\bar{r} - \bar{r}'| \qquad (10)$$

$k = 2\pi/\lambda$ (λ; free space wavelength)

and V is the driving voltage and Z_0 the intrinsic impedance of free space. $s'(x',y')$ and $t(t_x,t_y)$ are distances measured along the antenna arm from the feed point. c_i is the value of t at the i th bend, and $\hat{c}_i^-$ and $\hat{c}_i^+$ unit vectors before and after the i th bend, respectively. The summation limit Q in Eq.(7) is the number of bends the current has passed before it reaches s. In Eq.(8), tangential unit vectors $\hat{s}'$ and $\hat{t}$ exist on m th and n th filaments, respectively.

By expressing the integral in Eq.(4) as finite sums evaluated at points s_i (i=1,2,...N) and applying the boundary condition at the end of antenna, i.e., I(L)=0, we can obtain an (N+1)×(N+1) matrix equation for solving the current distribution approximately. As a basis function, the pulse function is adopted in this paper.

TREATMENT OF THE SINGULARITIES

The integration of $f_1(s,s')$ becomes singular as s' approaches s and can be integrated by well known treatment[3]. In addition, it should be noticed that singularities of $f_2(s,s')$ and $f_3(s,s')$, arising as $s'\to c_i$ in Eq.(7) and $t\to s'$ near the bend in Eq.(8), can be eliminated by the following properties[4][5],

$$\lim_{\varepsilon\to 0}\int_{c_i-\varepsilon}^{c_i+\varepsilon} G(c_i,s')[\hat{c}_i^{+}-\hat{c}_i^{-}]\cdot\hat{s}'ds' = 0 \qquad (11)$$

$$\lim_{\varepsilon\to 0}\left[\int_{c_i-\varepsilon}^{c_i}\int_{c_i}^{c_i+\varepsilon}\frac{\partial G(t,s')}{\partial s'}dtds' + \int_{c_i}^{c_i+\varepsilon}\int_{c_i-\varepsilon}^{c_i}\frac{\partial G(t,s')}{\partial s'}dtds'\right] = 0 \qquad (12)$$

This not only makes the computation simple but also indicates that the rectangular bend is not an essential factor in the opperation of a thin wire antenna. The variation of wire radius changes mainly the diagonal elements of matrix.

RADIATION CHARACTERISTICS

Once the current distribution is determined, the input impedance Z_{in} and the far-field pattern **E** can be caluculated by

$$Z_{in} = V/I(0) \tag{13}$$

$$\mathbf{E}(R,\theta,\phi) = -j\frac{Z_0 \exp(-jkR)}{2\lambda R} \int_{\substack{\text{Antenna}\\ \text{length}}} [(\hat{R}\times\mathbf{I}(s'))\times\hat{R}$$

$$\cdot\exp(jk\sin\theta(r_x\cos\phi + r_y\sin\phi))]ds' \tag{14}$$

where $\hat{R}$ is the radial unit vector. r_x and r_y are x and y components of the position vector Eq.(2), respectively.

From Eq.(14) the axial ratio is given by

$$A.R. = 10\log\frac{\Psi^2\sin^2\tau + 2\Psi\Xi\cos\delta\sin\tau\cos\tau + \Xi^2\cos^2\tau}{\Psi^2\cos^2\tau - 2\Psi\Xi\cos\delta\sin\tau\cos\tau + \Xi^2\sin^2\tau} \quad [\mathrm{dB}] \tag{15}$$

where $\tau = 0.5\tan^{-1}\dfrac{-2\Psi\Xi\cos\delta}{\Psi^2 - \Xi^2}$, $\Psi = |E_\phi|$, $\Xi = |E_\theta|$

and δ is the phase difference between field components E_ϕ and E_θ.

DESIGN EXAMPLE AND EXPERIMENTAL VERIFICATION

Let the number of filaments be 9 and the last filament length $l_9 = 8a$ ($a = 0.3077$cm). Then, at 3GHz the total armlength L becomes 2λ, i.e., L=20cm, and the distance between the outer filaments 0.5λ. From the point of view of the current band, the first mode is maintained. The typical current distribution along the spiral arm is shown in Fig.2. The driving voltage at the input of the antenna is one volt. The convergence of current distribution reaches a satisfactory state with 33 segments. It is found that current amplitude is decayed in an exponential type and that phase progression is nearly equal to the free space phase progression.

Fig.3 indicates the variation of the input impedance when the wire radius ρ is changed. The resistance value tends to increase as the wire radius decreases. On the other hand, the reactance value is very low. The measurement was performed at 3GHz by a conventional standing-wave method.

Fig.4 shows the radiation patterns. Since the patterns are symmetrical with respect to the spiral plane, only half of the pattern is shown. Component E_ϕ has a wider pattern than component E_θ radiating with half-power beamwidth about ±40 degrees. Significant change is not found in the radiation pattern itself even if the wire radius is varied. However, the dependence on the wire radius is somewhat found in axial ratio as shown in Fig.5. It is obvious that the square spiral radiates effectively circularly-polarized-wave, i.e., the axial ratio is about 1.0 dB in $0.003\lambda \leq \rho < 0.005\lambda$. In each case, there is remarkably good correlation between the experimental and theoretical results.

CONCLUSION

The numerical treatment of two-wire square spiral antenna has been presented from a design viewpoint. In the case of antenna configuration of total filaments 9, it is found that, (1) the current phase progression is nearly equal to the free space phase progression, (2) the antenna impedance is nearly pure resistance, (3) E_ϕ has a wider pattern than E_θ , and (4) the axial ratio has a little dependence on the wire radius. If $\rho=0.004\lambda$, then the radiation from the square spiral is circularly polarized with axial ratio 0.8 dB at 3GHz.

ACKNOWLEDGMENT The authors wish to thank Mr. Matsuegawa for fabrication of antenna. The numerical computations were carried out on HITAC-8800, the digital computer of Tokyo University.

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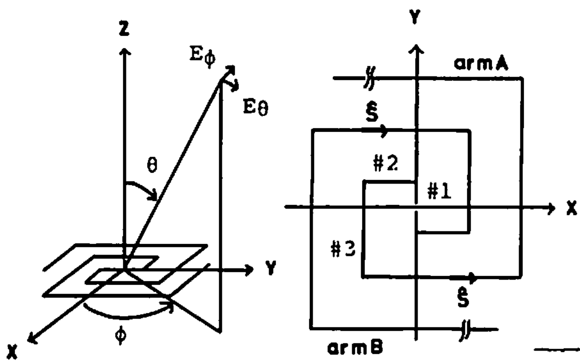

Fig.1. Configuration

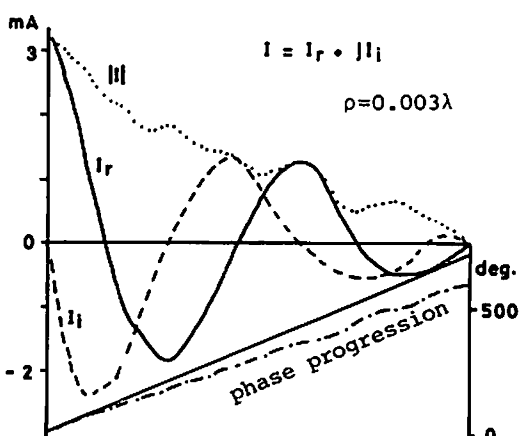

Fig.2. Current distribution

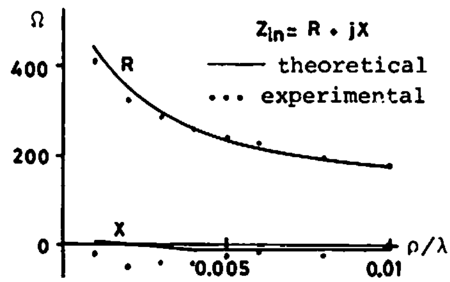

Fig.3. Input impedance

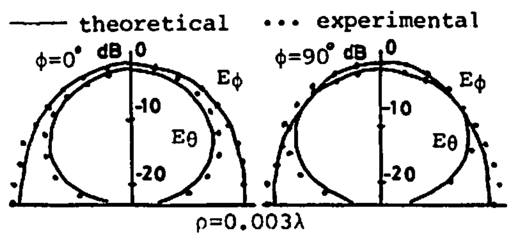

Fig.4. Radiation pattern

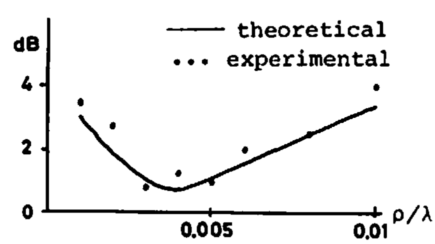

Fig.5. Axial ratio