Two Resistors Loaded Ultra-Wideband Small Spiral Antenna Backed by a Cavity

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Abstract

Spiral antennas have ultra-wideband characteristics such as a nearly constant input impedance, antenna gain, and low axial ratio. However, when a reflector such as a conducting plane or a cavity is used, its performances are degraded due to the reflections from the end of the spiral arms. In particular, this effect is remarkable at low frequencies where the antenna becomes small in comparison to the wavelength. In this paper, we propose a new type of small spiral antenna which has a pair of resistors and experimentally verify its ultra-wideband characteristics.

1. INTRODUCTION

Circularly polarized waves are widely used in the field of radar, satellite and mobile communication. A spiral antenna [1][2] is a good candidate for such applications since it features a low profile and ultra-wideband characteristics. A spiral antenna is classified as a traveling wave type antenna. The waves propagates from the feeding point, which is the center of the spiral antenna, to the ends of its arms, and are gradually radiated to space.

In practical applications, a spiral antenna is required to radiate to only one side; hence, a reflector such as a conducting plane or a cavity is placed behind it. However, when a spiral antenna with a reflector is miniaturized, a small amount of residual power that was not radiated reflects at the point of spiral truncation and propagates in the opposite direction toward the feed point. Thus, the reflected components radiate a cross-polarized wave and the axial ratio characteristic is deteriorated. Moreover, if the components reach the feeding point, the VSWR performance become worse. In particular, this effect is remarkable at low frequencies where the antenna becomes small in comparison to the wavelength.

Therefore, a conventional antenna was made larger in comparison with the wavelength, and the antenna's outer circumference becomes approximately 2-3λ, where λ is the wavelength of the operating frequency. Alternatively, another report suggests that the current amplitude distribution at the end of the spiral arms can be just minimum, and that the amount of reflection can be decreased if the outer circumference is of the order of 1.4λ [3]. However, making the antenna larger in comparison with the wavelength contradicts the requirement of antenna miniaturization; further, in array antennas, the element pitch is large at high frequencies and the problem of generating a grating lobe arises. It is difficult to obtain a wideband characteristic by using the method of adjusting the outer circumference of an antenna.

On the other hand, some papers report that a microwave absorber was installed in a spiral antenna with a reflector; this miniaturized the outer circumference to about 1.5λ_L, where λ_L is the wavelength of the lowest operating frequency, and the ultra-wideband characteristic was obtained [4][5]. Wang [4] used a ring of absorbing material at the truncated edge of the spiral on the reflecting conductor, and an ultra-wideband characteristic of 6:1 was achieved although with a very low attitude. However, it is difficult to select a lossy medium that has the wideband absorption performance, and manufacturing of the antenna is deteriorated from the viewpoint of the placing the selected medium. Penney [5] installed the cavity behind the antenna and inserted multilayered resistive sheets. In this case, the antenna gain decreases because the co-polarized waves in addition to the cross-polarized waves are absorbed.

To overcome the difficulty, in this paper, we propose a new type of small spiral antenna that has a pair of resistors and show its ultra-wideband characteristics. The antenna structure and design procedure of the two resistors are presented. Further, we actually fabricate the antenna element and experimentally verify its performances.

2. DESIGN OF TWO RESISTORS

The square spiral antenna that is composed of two arms is illustrated in Fig. 1. The outer circumference of the square spiral antenna is 0.96λ_L, and the cavity depth is 0.09λ_L. The antenna is fed at the center of the spiral, and the wideband tapered balun formed by a microstrip line is used for impedance matching.

The following two electric modes that exist at the section of the spiral truncation are considered. One is an odd mode between the tips of the spiral arm and the adjoined spiral arm, and another is an even mode between the tips of the spiral arm and the ground conductor (cavity). To supress these two modes, we use a resistor R_o for the odd mode and a resistor R_e for the even mode, as shown in Fig. 1. Land is placed at an opposite side in which the resistor R_e is connected, and the land and cavity are shorted via a through hole.

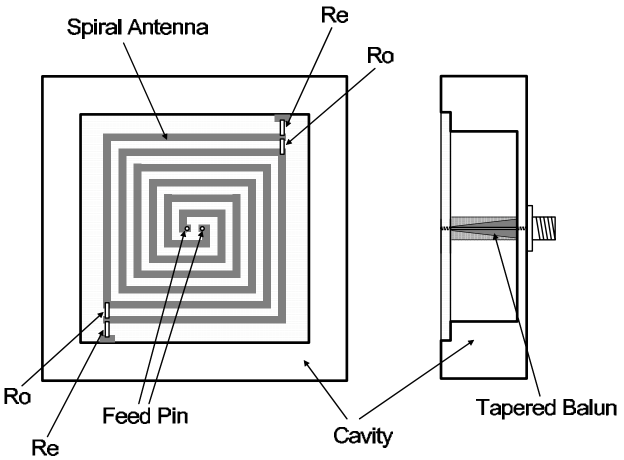


Fig. 1: Two resistors loaded spiral antenna backed by a cavity

The two resistors are chosen in the following manner. The point of the spiral truncation is replaced by the coupled microstrip line, as shown in Fig. 2. The width and the interval S between the two lines and height H from the ground conductor is set similarly to the spiral antenna. Fig. 2 shows the FDTD calculation model; (a) represents the odd mode calculation, and (b) represents the even mode calculation. These two lines are fed at one side, and the other sides are inserted in the PML absorbing boundary condition; they become equivalently infinite. To prevent the influence of the feeding structure in calculating the characteristic impedance of the line, the observation point of the voltage and current is set in a position that is sufficiently distant from the feeding point. In Fig. 2, the subscript "inc" shows the feeding point and "obs" shows the observation point. Fig. 3 shows the calculation result. The even and odd mode characteristic impedances are $Z_e = 300\ \Omega$ and $Z_o = 50\ \Omega$, respectively.

A. Design of R_e

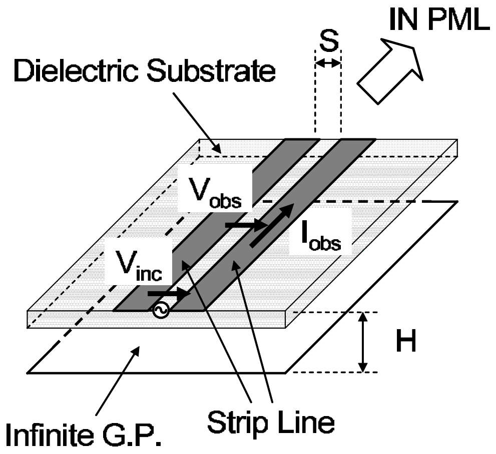
For the even mode, the resistor R_e should be equal to Z_e. Although a resistor R_o is undetermined here, the even mode is unaffected by R_o because both strips are at the same potential and no current flow occures.

B. Design of R_o

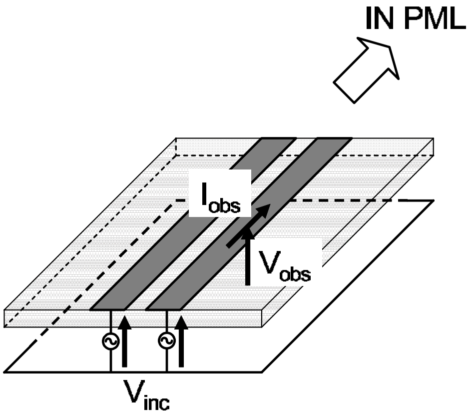
For the odd mode, it is considered that an electric wall equivalently exists in the middle of the two strips. When an electric wall is assumed to be a potential basis, R_e, determined above, and $R_o/2$ are connected in parallel at the tip of the spiral arm. Thus, the resistor R_o is determined to satisfy the following equation:

$$1/Z_o = 1/R_e + 1/(R_o/2) \qquad (1)$$

Therefore, R_e and R_o are determined to be 300 Ω and 120 Ω, respectively.



(a) For Odd Mode



(b) For Even Mode

Fig. 2: FDTD calculation model of coupled microstrip line

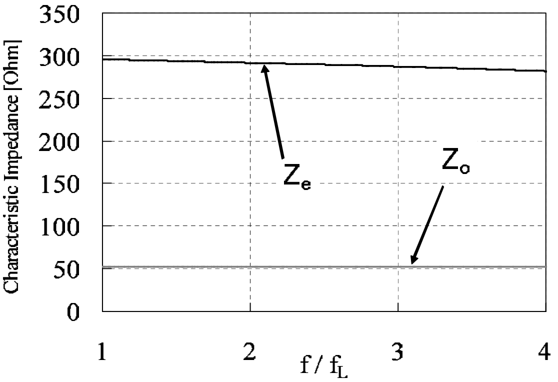


Fig. 3: Characteristic impedance of coupled microstrip line

3. RESULTS

We fabricated the antenna element based on the design procedure described above, and the measurement result is presented here.

A. *Effect of two resistors*

Fig. 4 shows the VSWR performance versus frequency (normalized by f_L), and Fig. 5 shows the axial ratio. In both figures, the case with and without two resistors are compared. It is seen that two resistors are effective from f_L to $2f_L$ in the VSWR and from f_L to $3f_L$ in the axial ratio. In particular, the effect on the axial ratio is large and an ultra-wideband characteristic is obtained.

Next, the antenna gain frequency characteristic is shown in Fig. 6. It is seen that the antenna gain has hardly changed regardless of the presence of the resistors. Thus, it can be said that the antenna gain does not decrease even if the resistors are used. This is because the resistors only remove the residual power that does not contribute to the radiation.

B. *The effect of each resistor R_e and R_o*

Here, the effect of each resistor R_e and R_o is examined. According to the frequency, either the even or the odd mode becomes dominant because the length of the two spiral lines from the feeding point to the connection point (both ends where R_o is connected) of the resistors is different. The result of the phase difference at both ends of R_o, which is calculated from the difference of the length (electrical length) of the two lines considering excitation by an opposite phase at the feeding point, is shown in Fig. 7. The electrical length is calculated by using an effective permittivity that is calculated from the coupled microstrip line model, as shown in Fig. 2. It is diplayed up to $2f_L$ because two resistors are effective at a lower frequency. Up to a frequency of $1.2f_L$, the phase difference at the two points becomes in phase and it is guessed that R_e is effective. On the other hand, at a frequency of $1.2f_L$ or more, the phase difference at the two points becomes out of phase and it is guessed that R_o is effective.

The measurement result is shown in Fig. 8 and 9 when either R_e or R_o is placed, respectively. The VSWR and axial ratio frequency response as a comparison of the cases "with resistors" and "without resistors" are shown. From Fig. 8, the resistor R_e is effective up to the frequency of $1.2f_L$; this is similar to the result of "with resistores." Further, it is understood that the resistor R_e is not effective over $1.2f_L$; this is identical to the result of "without resistores." On the other hand, it can be seen from Fig. 9 that R_o is only effective at more than $1.2f_L$.

Therefore, it can be said that it is necessary to choose these two resistors appropriately in consideration of the two modes required to obtain its ultra-wideband characteristics.

4. CONCLUSIONS

We proposed a new termination technique for small spiral antennas backed by a cavity. We showed its design procedure and experimentally verified its ultra-wideband characteristics. Moreover, we showed that resistor using only one is not sufficient and confirmed the necessity of two resistors.

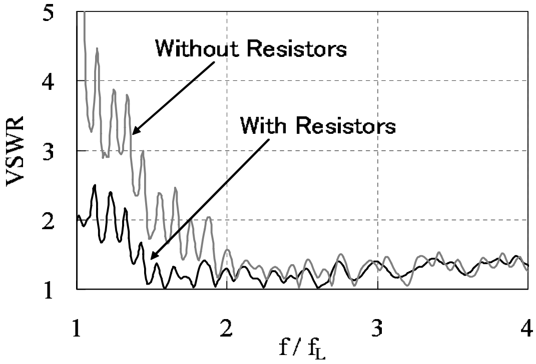


Fig. 4: VSWR

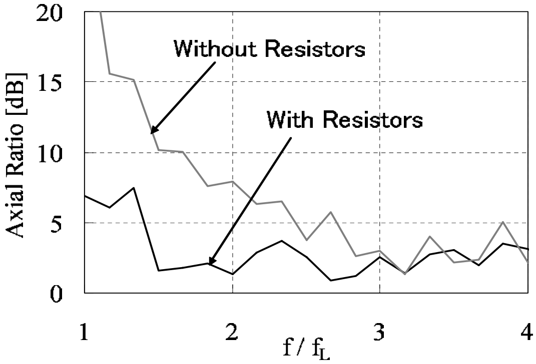


Fig. 5: Axial ratio

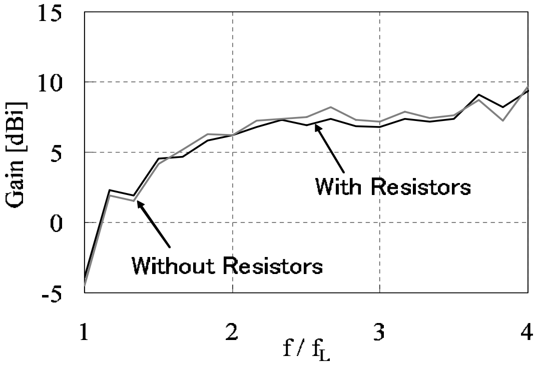


Fig. 6: Antenna gain

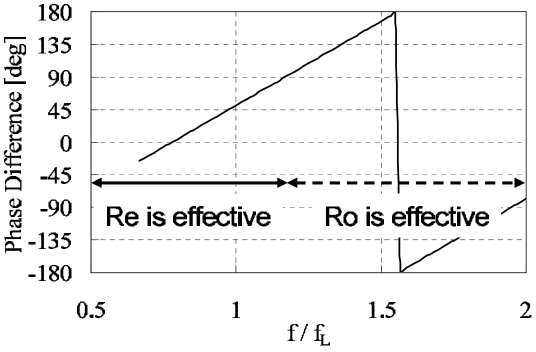
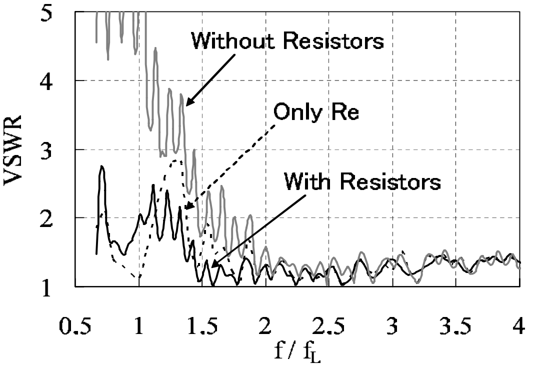
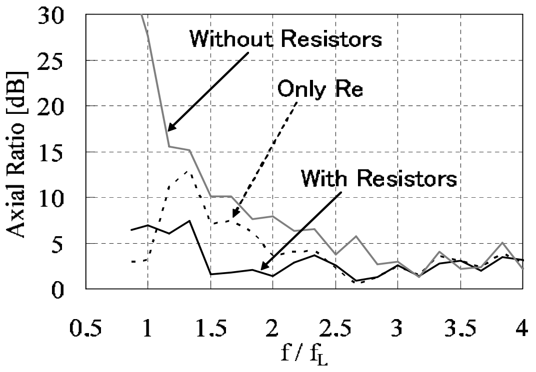


Fig. 7: Phase difference at the spiral arm



(a) VSWR



(b) Axial Ratio

Fig. 8: Only R_e

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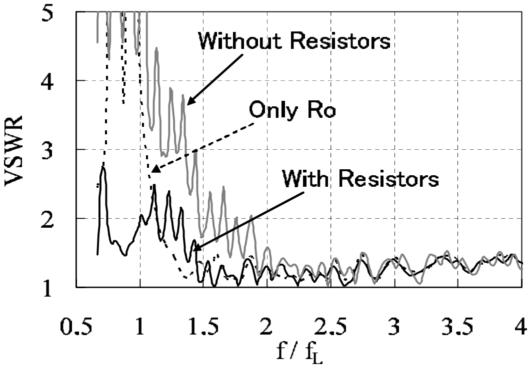
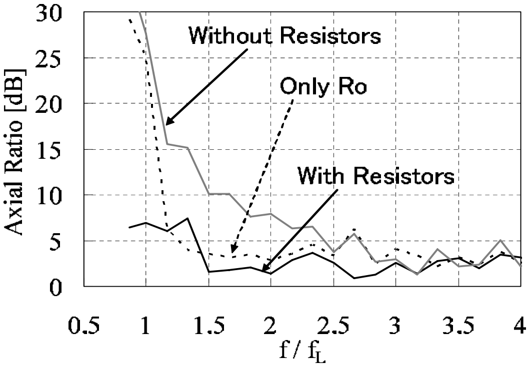


(a) VSWR



(b) Axial Ratio

Fig. 9: Only R_o

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