Roof-Mounted Vehicle Single-Arm Spiral Antenna Without a Balun Circuit

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Abstract

The deterioration in the antenna characteristics that are observed when a single-arm spiral antenna is located in front of a shallow conducting cavity can be mitigated by using an absorbing strip (ABS), which is placed behind the outer arm filaments. The use of lumped resistor elements connected to the arm end results in wideband antenna characteristics similar to those of the spiral with the ABS. A comparison between the spiral with the ABS and with the resistors shows that the former provides antenna characteristics in the lower frequency region that are more stable than the characteristics of the latter.

1. Introduction

It is known that a two-arm spiral antenna in free space excited in the balanced mode exhibits wideband frequency characteristics with respect to the input impedance and axial ratio [1]-[3]. Conventionally, the balanced-mode spiral is excited using a coaxial line, into which a wideband balun circuit is inserted, in order to retain the inherent wideband characteristics of the spiral. It is noted that designing and fabricating a wideband balun circuit [4][5] is complicated and has been an issue for antenna engineers.

This paper presents one solution to the balun issue, proposing a new spiral antenna that does not require a balun circuit. The new spiral is composed of one arm and is backed by a conducting cavity, which transforms the bidirectional beam of the spiral in free space into a unidirectional beam. The analysis of the new spiral is performed using the finite-difference time-domain method (FDTDM)[6][7].

First, we analyze the input impedance (hence the VSWR) and the axial ratio, with the antenna height as a parameter. The analysis reveals how these two characteristics vary as the antenna height is decreased. The variation is explained using the current distribution. Second, an absorbing strip (ABS) is placed under the outer spiral arm filaments [8]-[10]. The effect of the ABS on the current distribution is discussed. Third, a resistor is used instead of the ABS [11] and the effects of the resistor on the axial ratio and the input impedance are revealed. In addition, two resistors are then used [12] and the effects on the antenna characteristics are investigated.

2. Discussion

Fig. 1(a) shows the structure of a single-arm spiral antenna. The radial distance from the center of the spiral to a point on the arm, r, is defined by $a\phi'$, where "a" is the spiral constant and ϕ' is the winding angle. The spiral arm width is chosen to be small compared with the operating wavelength. To realize a unidirectional beam, the spiral is backed by a conducting cavity, whose diameter and height are D_{cav} and h_{cav}, respectively. The excitation of the spiral is achieved using a coaxial line, where the inner conductor is connected to the center of the spiral and the outer conductor is connected to a small disc inside the cavity. This excitation does not need a balun circuit.

Analysis is performed over a frequency range of 2 GHz ($\equiv f_L$) to 10 GHz ($\equiv f_H$). Throughout this paper, the antenna circumference defined by $2\pi a\phi_{max}$ and the cavity circumference πD_{cav} are fixed to be 1.42 wavelengths and 1.68 wavelengths at the lowest frequency f_L, respectively.

We analyze the frequency response of the axial ratio with the cavity height h_{cav} as a parameter. The investigation reveals that the axial ratio becomes higher in the lower frequency region as h_{cav} is decreased. Fig. 1(b) shows an example for the frequency response of the axial ratio, where the cavity height is $0.07\lambda_3$ (λ_3 is the free space wavelength at 3 GHz).

The input impedance (hence the VSWR) with the cavity height h_{cav} as a parameter is also analyzed. It is found that, as h_{cav} is decreased, the VSWR becomes larger. The representative frequency response of the VSWR is shown in Fig. 1(c), where the cavity height is the same as that used in Fig. 1(b); $h_{cav} = 0.07\lambda_3$.

We conclude that, as the cavity height is decreased, the spiral loses its wideband antenna characteristics. This is due to the fact that the spiral has a standing wave current distribution at the lower frequency region. In other words, the

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spiral has reflected currents that radiate a circularly polarized (CP) wave with a rotational sense that is opposite to the CP wave generated by the out-going current from the feed point.

For a low-profile spiral (having a cavity height of $h_{cav} = 0.07\lambda_3$), it is essential to reduce the reflected current for the antenna to operate as a CP antenna over a wide frequency range. For this, we use an absorbing strip (ABS), which is placed behind the outer spiral arm filaments, as shown in Fig. 2(a). Note that the ABS ranges over an arc angle of ϕ_{ABS} [8]-[10]. Fig. 2(b) shows the axial ratio when the arc angle ϕ_{ABS} is chosen to be 360^o, that is, the ABS has a ring-shaped structure. A comparison of Fig. 1(b) and Fig. 2(b) reveals that the ABS helps mitigate the deterioration in the axial ratio of the lower frequency region. Mitigation of the deterioration of the VSWR in the lower frequency region is also found in Fig. 2(c). It is clear that the spiral with the ABS has a wideband VSWR characteristic. Note that the input resistance is approximately 50 ohms, which leads to easy matching to a 50-ohm coaxial feed line.

Next, we consider using lumped resistor elements instead of the absorbing strip, as shown in Fig. 3(a). An analysis shows that the axial ratio when one resistor is inserted between the arm end and the cavity wall (ground plate) is improved, compared with that shown in Fig. 1(b). Note that the use of this resistor is optimized for absorbing the even mode current. Further analysis reveals that the axial ratio is also improved when a resistor for absorbing the odd-mode current is inserted between the arm end point and a point on the neighboring arm. Based on these findings, we use two resistors for the single-arm spiral and obtain the results shown in Fig. 3(b). It is observed that these two resistors help mitigate the deterioration of the axial ratio caused by the presence of the shallow cavity.

Furthermore, use of the two resistors provides a stable input impedance (hence the VSWR) characteristic, as shown in Fig. 3(c). It can be said that the insertion of resistors is useful for absorbing the undesirable reflected current at the antenna arm end. However, it is noted that the frequency response of the VSWR in the lower frequency region for the spiral having two resistors is slightly inferior to that of the spiral using the ABS. The axial ratio in the lower frequency region is also slightly inferior to that of the spiral having the ABS.

3. Conclusions

The frequency response for the antenna characteristics of a cavity-backed single-arm spiral is investigated, with the antenna height as a parameter. It is found that the axial ratio and the input impedance deteriorate as the antenna height is decreased. This deterioration is mitigated by loading the antenna arm with an absorbing strip (ABS), which is placed behind the outer spiral arm filaments. Subsequently, another mitigation technique, where two lumped resistor elements are used, is investigated. It is revealed that wideband characteristics similar to those of the spiral with the ABS are obtained. A detailed comparison between the spiral with ABS and with resistors shows that the former is slightly superior to the latter with respect to mitigation of the frequency response deterioration in the lower frequency region.

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5. References

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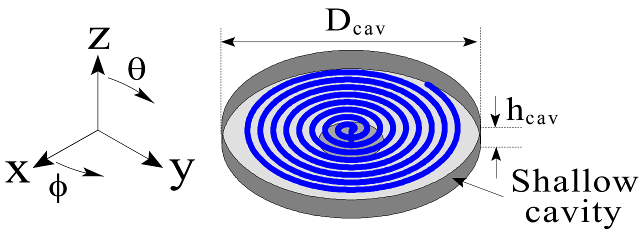
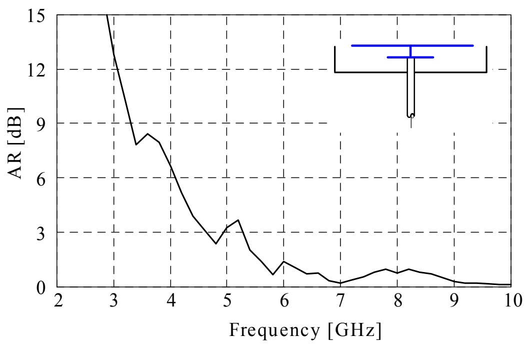


(a)



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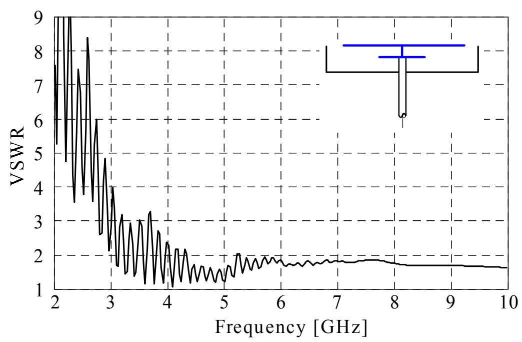

(c)

Fig. 1 Single-arm spiral antenna. (a) Structure. (b) Axial ratio. (c) VSWR.

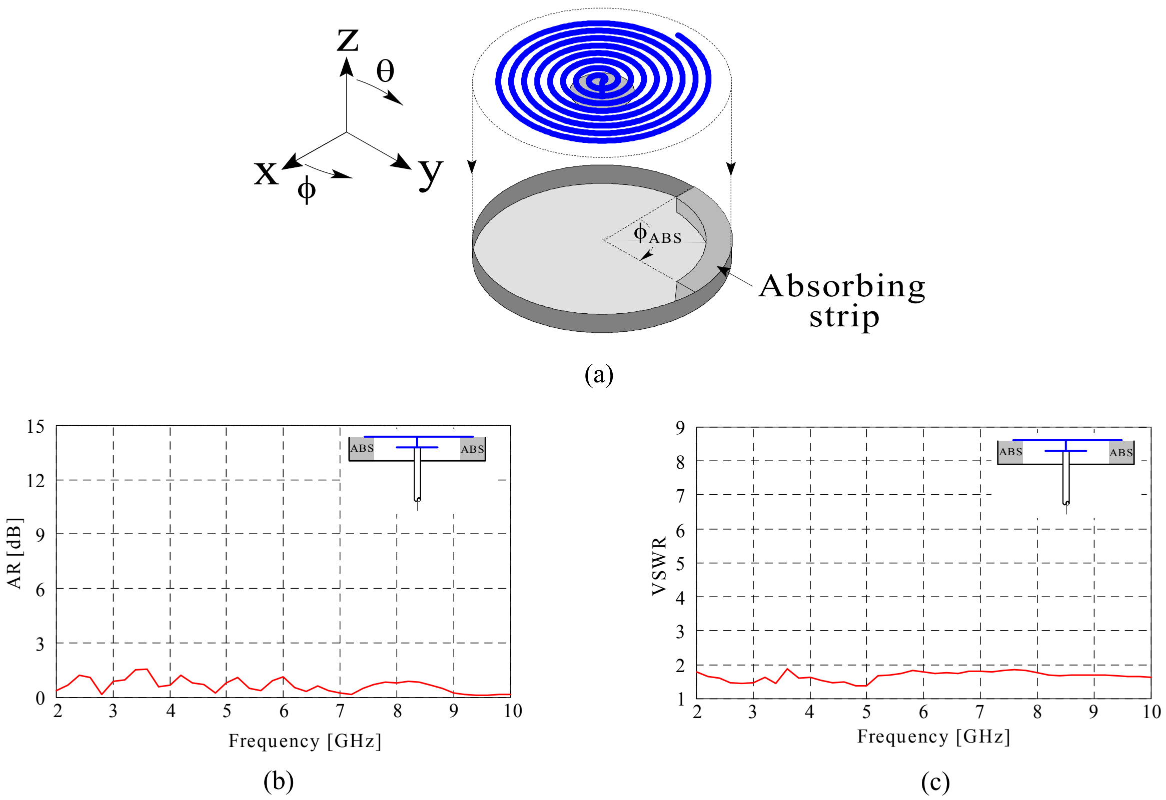

Fig. 2 Single-arm spiral antenna with absorbing strip. (a) Structure. (b) Axial ratio. (c) VSWR.

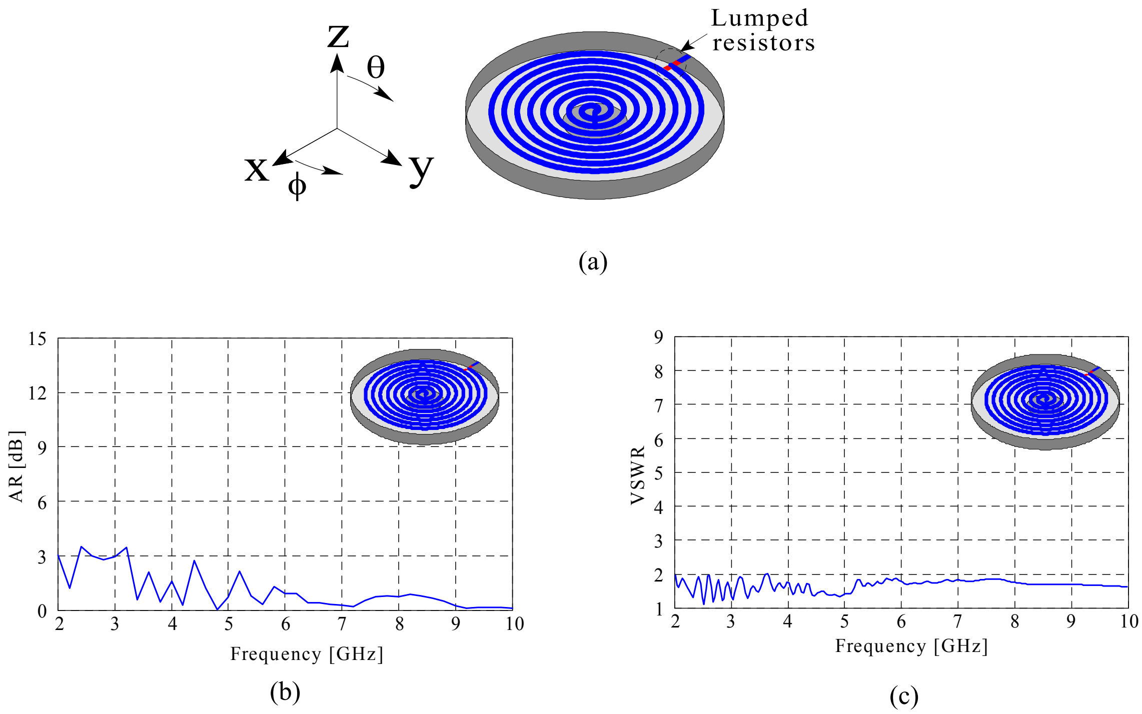

Fig. 3 Single-arm spiral antenna with lumped resistors. (a) Structure. (b) Axial ratio. (c) VSWR.