Broadband Slot Spiral Antenna with External Feed and Microstrip-to-Slotline Transition

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I. Introduction

As the demand for spread spectrum and multifunction RF systems increases, antennas that are capable of wideband/multiband operation are becoming more and more desirable in recent years. Spiral antennas with inherent broadband nature meet the requirements for automotive applications [1]. Recently, slot spiral antennas with or without reflecting cavity have been widely studied [2]-[5]. In this work, we propose a new design of slot spiral antenna with external feed combined with wideband microstrip-to-slotline transition and backed with a reflecting cavity for unidirectional radiation and gain enhancement. A new approach to identify the active region of spiral antenna will also be presented.

II. Antenna Design

The Archimedean spiral can be expressed as $r = r_0 + a\phi$, where a is the growing rate and r_0 is the initial radius. The concept of active region states that the far-field radiation is mainly contributed from the region of about one-wavelength circumference and balanced feed is required for mode 1 operation. The current and phase distributions are the figure of merits to identify the traveling wave characteristics of spiral antennas. In this work, we propose a new approach to identify the active region. First define two arm-to-arm phase differences, labeled as inner phase difference (IPD) and outer phase difference (OPD) with respect to the reference arm as shown in Fig.1. The phase distribution along the spiral arm is obtained by considering the slotline dispersive characteristics and spiral geometry. This approach is verified by full-wave simulation using HFSS, as shown in Fig.2. The simulated results show that constant phase occurs due to standing wave near the end of spiral arm. The difference between the calculated and simulated phase are significant but the trend is consistent and can be improved by employing more accurate slotline dispersive models. Fig.4 shows the simulated current distributions. Fig.4(b) shows that the active region is roughly located between the two points with zero phase difference associated with IPD and OPD, respectively. The predicted active region is very close to that predicted by using current band theory. Notice that the active region is accompanied by decaying current amplitude. Since our approach is more straightforward, it will be used throughout this work.

Fig.3 shows the proposed slot spiral antenna with external feed by incorporating the wideband microstrip-to-slotline transition and backed with a reflecting cavity. The spiral growing rate is 0.8117 mm/rad, slot width is 0.3 mm and spiral turns is 3.2. The spiral radius $R_{\max}$ and $R_{\min}$ is approximately 18 and 2 mm for mode 1 operation over 2 to 6 GHz. The arm-to-arm spacing is 7.5 times of slot width to reduce the arm-to-arm coupling. An additional thin-film dielectric can be added between the spiral substrate and reflecting cavity in order to miniaturize the antenna size. The radius of reflecting cavity is 35mm and its depth is 10 mm. The feeding network is consisted of microstrip power divider, impedance taper line and two wideband microstrip-to-slotline transition with radial stubs. A Klopfenstein taper is designed as impedance transformer.

The radius of radial stubs is approximately $\lambda_g/6$ of the microstrip and slotline. The size of antenna is 90×90 mm² and is built on an FR4 substrate with $\epsilon_r = 4.4$, $\tan\delta = 0.022$ and $h = 1.6$ mm.

III. Simulation Results and Discussion

Fig. 6 shows the simulated return loss of proposed slot spiral antennas. The bandwidth of 10 dB return loss covers 2.2 to 8 GHz due to the traveling wave characteristics with decaying current distribution as shown in Fig.4(a). The phase progression, as shown in Fig.2, also shows the traveling wave characteristics with insignificant standing wave near the end of spiral arm at 3 GHz. The real and imaginary part of currents also maintains a 90° phase difference. Fig.5 shows the LHCP radiation patterns at 3.3 and 4GHz, respectively. Notice that the radiation patterns are similar with broaden beams at lower operating frequencies. The radiation patterns at higher frequencies are degraded due to the standing wave near the end of spiral arm. The radiation patterns are close to omnidirectional in the horizontal plane. Fig.7 shows the simulated broadside gain. Approximately 3 dBi is obtained over 3 to 5 GHz. The gain degradation at low frequencies are mainly due to the poor input matching and the gain degradation at higher frequencies are mainly due to the standing wave near the end of spiral arm. EM absorber materials can be placed within the cavity to reduce reflection. In addition, spiral antennas with dual-mode operation for satellite and terrestrial applications attract more and more attentions. Another novel design of broadband 180° hybrid feeding network used for dual modes operation is under development.

Acknowledgment: This work is sponsored by the National Science Council, ROC, under contract NSC 92-2213-E-002-070.

IV. Conclusions

A new design of broadband slot spiral antenna is proposed. The simulated results show that return loss bandwidth covers from 2.2 to 8 GHz. The gain performance is approximately 3 dBi over 3 to 5 GHz. A new active region identification approach is also proposed and verified with HFSS simulation, which can be used to identify the size reduction ratio of meandered spiral.

V. References

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Fig. 1: Definition of IPD and OPD, with arm 1 as the reference arm.

Fig. 2: Calculated phase progression compared with HFSS simulation at 3 GHz.

Fig. 3: Proposed slot spiral antenna.

(a)

(b)

Fig. 4 (a) Simulated current distribution, (b) calculated phase difference at 3 GHz.

Fig. 5: Simulated radiation patterns at (a) 3.3 GHz and (b) 4 GHz.

Fig. 6: Simulated return loss.

Fig. 7: Simulated broadside gain.