URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Composite Excitation for a Two-Arm Spiral Antenna

Hisamatsu Nakano*(1), Toru Kawano(2), Tomoki Abe(1), Junji Yamauchi(1), and Amit Mehta(3)
(1) Hosei University, Tokyo, Japan
(2) National Defense Academy, Kanagawa, Japan
(3) Swansea University, Swansea, UK

Abstract

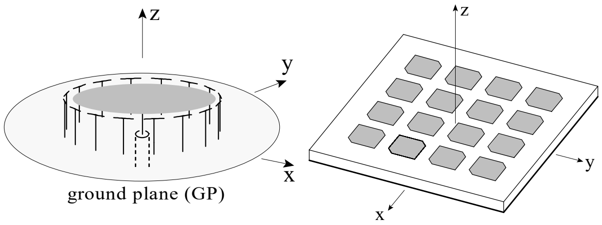
This paper describes novel movement of the direction of the maximum radiation from a two-arm spiral antenna. Antenna feed points F1 and F2 are excited with V1 volts and V2 volts, respectively, where the phase of V1 is 0 degrees and the phase of V2 is 180 degrees plus a deviation angle of α_{dev} degrees. This is treated as a superimposition of the excitation from a pair of out-of-phase voltage sources (OutPVSs) and the excitation from a pair of in-phase voltage sources (InPVSs). The OutPVSs generate a circularly polarized (CP) beam in the broadside direction, while the InPVSs generate a CP conical beam around the vertical center axis normal to the antenna plane. It is found that a change in voltage V2 relative to voltage V1 moves the direction of the CP maximum radiation in a specific direction. The 3-D radiation is presented, as well as other antenna characteristics.

1. Introduction

An antenna, shown in Fig. 1(a), is composed of an excited circular disc and sixteen low-profile T-shaped parasitic elements, each having an on-off switching circuit that changes the end of the parasitic element to either an open-circuited state or a short-circuited state with respect to a ground plane (GP) [1]. The antenna beam can move in sixteen different azimuth directions using the switching circuits, where five consecutive parasitic elements at a time are held in an open-circuited state, with the remaining eleven elements held in a short-circuited state.

The abovementioned antenna is a modified version of the antenna in [2], which is composed of an excited central monopole and six parasitic monopoles, each having a reactive load. The antenna forms a beam in a specific direction by changing the values of reactive loads. Note that the antennas in [3]-[6] are also fabricated using the antenna concept presented in [2]. It is emphasized that the antennas in [1]-[6] radiate a linearly polarized (LP) beam.

A question arises as to how a circularly polarized (CP) beam can be realized in a specific direction. A solution to this question is shown in Fig. 1(b), where CP patches, each having a phase shifter, are arrayed on a plane. In this case, a CP beam can be moved around the antenna axis (z-axis) with the help of the phase shifters. However, it is difficult to move a CP beam using a small number of patch elements; in the extreme, the beam from a single patch cannot be moved. Hence, a further question emerges as to whether a single antenna element can realize a movable CP beam.



(a) (b)

Figure 1. Antenna that can move its beam. (a) Linearly polarized Disc-T antenna. (b) Circularly polarized phased array antenna.

This paper presents an answer to this question, using a two-arm Archimedean spiral antenna [7], which is known as a CP antenna. Note that the spiral arms in this paper are defined by the Archimedean function, which differs from the equiangular function defining an equiangular spiral antenna.

The two-arm Archimedean spiral antenna was introduced by Kaiser in 1960 [7]. He qualitatively explained the radiation mechanism using electric current bands created along the spiral arms. In this explanation, traveling wave currents are assumed to be distributed along the arms, while neglecting mutual coupling effects (MCPEs) between spiral arms. Later, in 1978 [8], the existence of the traveling wave currents were confirmed by solving an integral equation [9], which took MCPEs into account. Since then, numerous novel findings on the spiral antenna and its application have been reported, for example, in [10]-[12].

Recently, a metamaterial-based spiral antenna (located in the x-y plane) has been reported and the radiation under unbalanced mode excitation has been investigated [13]. The investigation reveals a gain reduction in the antenna axis direction (in the z-direction). The gain reduction is due to asymmetric radiation with respect to the z-axis. Note that the concept of this asymmetrical radiation is used in this paper.

This paper comprises four sections. Section 2 presents a spiral antenna structure. The discussion of the movement of the maximum radiation is performed in section 3. Section 4 summarizes the results of the research.

2. Structure

Investigation is performed using a frequency of 4 GHz. Fig. 2 shows a two-arm Archimedean spiral antenna, where antenna arms I and II are excited from points F1 and F2, respectively. The position vector from the antenna center (coordinate origin) to a point on arm I is specified by radial vector $\mathbf{R}(r, \phi, \theta) = \mathbf{R}(a\phi, \phi, 90^\circ)$, where “a” is the Archimedean spiral constant. Arm II is specified by vector $-\mathbf{R}$. The spiral antenna diameter is given as $D = 2r_{max}$, where r_{max} is the radial distance to the arm end. The diameter, D, in this paper is selected to be 70 mm.

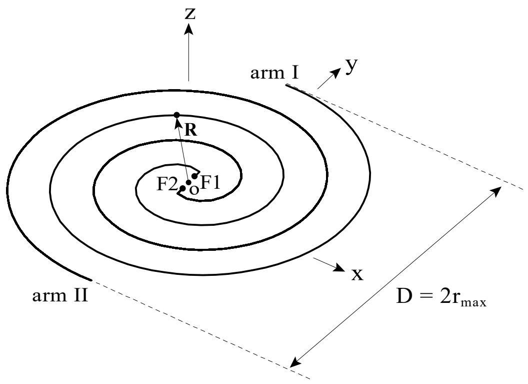


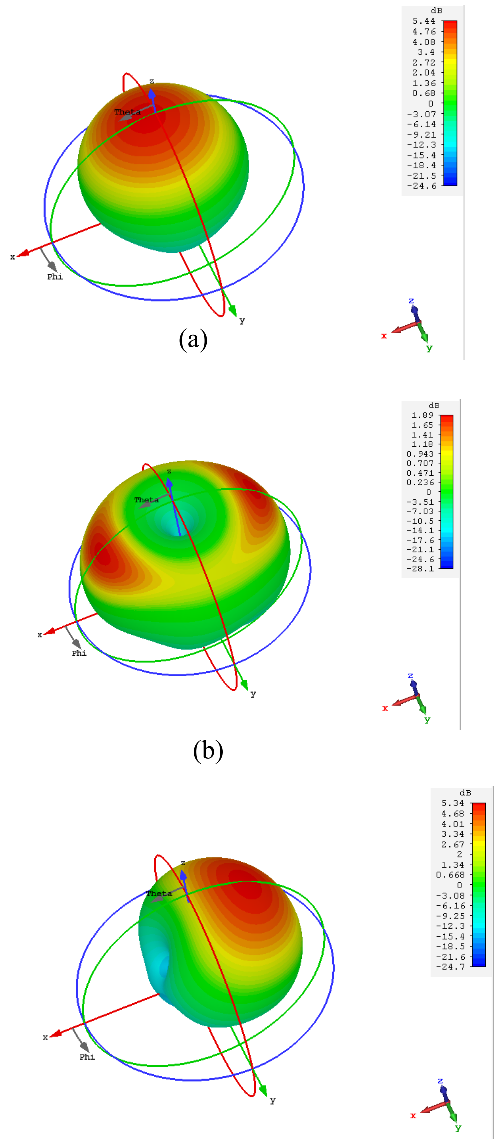
Figure 2. Archimedean spiral antenna.

3. Discussion

Radiation in a specific direction is formed by superimposing a conical beam onto an axial beam. For the axial beam generation, a pair of out-of-phase voltage sources (OutPVSs) with amplitude $|V_{out\text{-}p}|$ volts is applied to feed points F1 and F2. Fig. 3(a) shows the 3-D radiation for $|V_{out\text{-}p}| = 1$ volt, where the radiated fields at symmetric field points with respect to the z-axis have a 0°-phase difference (in phase).

For the conical beam generation, a pair of in-phase voltage sources (InPVSs), both having amplitude $|V_{in\text{-}p}|$ volts, is applied to the feed points. Fig. 3(b) shows the 3-D radiation for a voltage of $|V_{in\text{-}p}| = 1$ volt. Note that the phase at symmetric field points with respect to the z-axis has a 180° difference (opposite phase).

The superimposition of the radiation from the out-of-phase excitation and the in-phase excitation is illustrated in Fig. 3(c). It is found that the CP maximum radiation is formed away from the z-axis, due to the phase relationship between the two radiation fields at symmetric field points with respect to the z-axis.



(a)

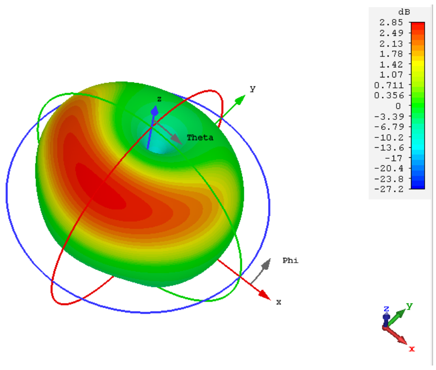
(b)

(c)

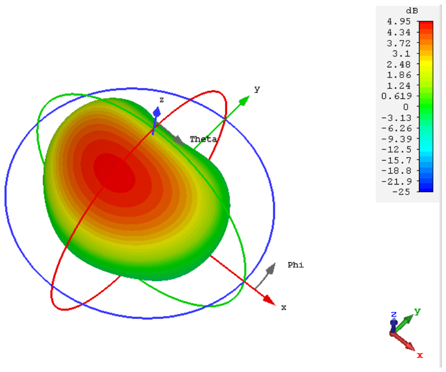
Figure 3. 3-D radiation. (a) Out-of-phase excitation. (b) In-phase excitation. (c) Superimposition of the radiation by out-of-phase excitation and the radiation by in-phase excitation.

Based on the above results, further consideration is devoted to moving the direction of the CP maximum radiation. We excite F1 and F2 using voltage sources V1 and V2, respectively. Note that the excitation voltage at F1 is always set to be $V1 = |V1|\angle V1 = 1\angle 0^\circ$ throughout this paper and the phase for V2 is expressed as $\angle V2 = 180^\circ + \alpha_{dev}$, where α_{dev} is called the deviation angle.

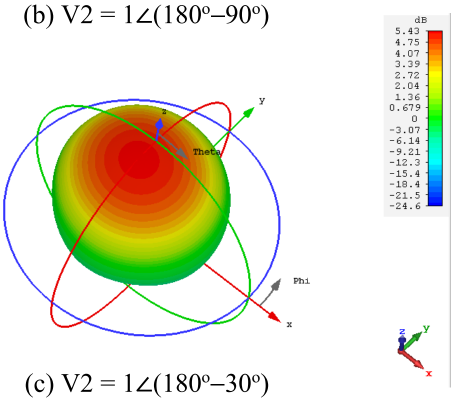
First, we analyze the case where amplitude $|V2|$ is fixed ($|V2| = |V1|$) and phase $\angle V2$ is changed with deviation angle α_{dev}. This excitation is called the phase-dependent excitation (PhaseDepEX). A detailed theoretical analysis starts with decomposing PhaseDepEX into two excitation components: out-of-phase excitation component $V_{out\text{-}p}$ and in-phase excitation component $V_{in\text{-}p}$. It is found that the phase difference, $|\angle V_{out\text{-}p} - \angle V_{in\text{-}p}|$, is constant, regardless of the change in deviation angle α_{dev}. This result infers that the maximum radiation will move in the elevation plane at a specific azimuth angle. Fig. 4 confirms this movement of the maximum radiation in the elevation plane, which is obtained using an EM solver [14].



(a) V2 = 1∠(180°–150°)



(b) V2 = 1∠(180°–90°)

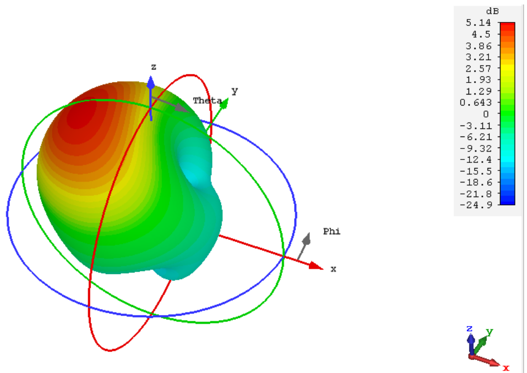


(c) V2 = 1∠(180°–30°)

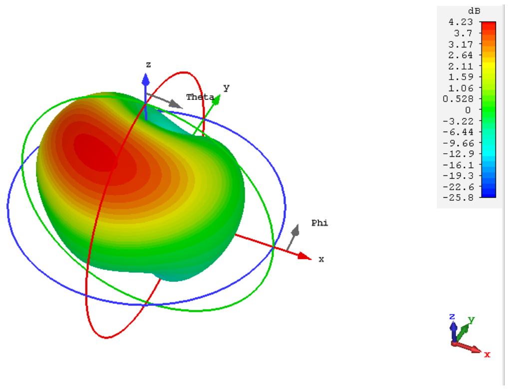
Figure 4. Movement of the maximum radiation in the elevation plane.

Note that the axial ratio in the direction of the maximum radiation is less than 3 dB, as desired, and the VSWR is less than 2.

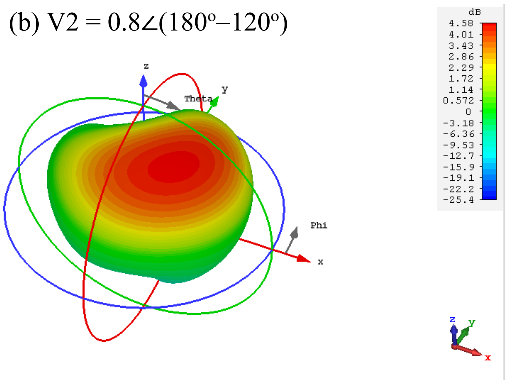
Second, we consider the case where amplitude $|V2|$ is changed and phase $\angle V2$ is fixed. To distinguish this excitation from the previous excitation, it is called the amplitude-dependent excitation (AmpDepEX). The analysis of AmpDepEX shows that phase difference $\angle V_{out-p} - \angle V_{in\text{-}p}$ changes according to the change in $|V2|$. Therefore, it is expected that the maximum radiation will move around the z-axis. Fig. 5 shows the results when V2 = $|V2| \angle (180° – 120°)$. It is found that the maximum radiation rotates around the z-axis, as expected. The axial



(a) V2 = 0.2∠(180°–120°)



(b) V2 = 0.8∠(180°–120°)



(c) V2 = 2∠(180°–120°)

Figure 5. Movement of the maximum radiation in the azimuth direction.

ratio in the direction of maximum radiation is less than 3 dB; the VSWR is less than 2, as with the first case.

4. Conclusions

Movement of the maximum radiation formed by a single spiral antenna has been discussed, focusing on the voltage excitation. Two input voltage sources are recognized as a superimposition of a pair of OutPVSs and a pair of InPVSs. The former pair forms an axial beam and the latter pair forms a conical beam. The addition of these two beams points the maximum radiation in a specific direction. It is found that the maximum radiation can be moved in the elevation plane by PhaseDepEX. Movement of the maximum radiation in the azimuth direction is obtained by AmpDepEX. It is also found that, at 4 GHz, the axial ratio in the direction of the maximum radiation is less than 3 dB and the VSWR is less than 2.

5. Acknowledgement

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

6. References

1. H. Nakano, Y. Kameta, T. Kawano, A. Mehta, A. Pal, A. Skippins, and J. Yamauchi, “Antenna System Composed of T-shaped Elements Coupled to an Open Radial Waveguide,” *IEEE Trans. Antennas Propagat.*, **AP-66**, 2, February 2018, pp. 550-563.

2. R. F. Harrington, “Reactively Controlled Directive Arrays,” *IEEE Trans. Antennas Propag.*, **AP-26**, 3, May 1978, pp. 390-395.

3. N. L. Scott, M. O. Leonard-Taylor, and R. G. Vaughan, “Diversity Gain from a Single-port Adaptive Antenna Using Switched Parasitic Elements Illustrated with a Wire and Monopole Prototype,” *IEEE Trans. Antennas Propag.*, **AP-47**, 6, Jun. 1999, pp. 1066-1070.

4. T. Ohira and K. Gyoda, “Electronically Steerable Passive Array Radiator Antennas for Low-cost Analog Adaptive Beamforming,” in Proc. IEEE Int. Conf. Phased Array Syst. Technol., May 2000, pp. 101-104.

5. K. Murata et al., “Beam Scan Antenna,” in Proc. IEICE Gen. Conf., Osaka, Japan, Mar. 2005, p. B-1-155.

6. H. Nakano, R. Aoki, R. Kobayashi, and J. Yamauchi, “A Patch Antenna Surrounded by Parasitic Y Elements for Beam Scanning,” in Proc. IEEE Antennas Propag. Soc. Int. Symp., vol. 3, Abuquerque, NM, USA, Jul. 2006, pp. 2317-2320.

7. J. A. Kaiser, “The Archimedean Two-wire Spiral Antenna,” *IRE Trans. Antennas Propagat.*, **AP-8**, 3, May 1960, pp. 312-323.

8. H. Nakano and J. Yamauchi, “The Two-wire Square Spiral Antenna,” Proc. ISAP, Sendai, Japan, 1978, pp.137-140.

9. H. Nakano, *Low-profile Natural and Metamaterial Antennas*, *IEEE Press*, *Wiley*, 2016.

10. H. Nakano and K. Nakayama, “A Curved Spiral Antenna above a Conducting Cylinder,” *IEEE Trans. Antennas Propag.*, **AP-47**, 1, January 1999, pp. 3-8.

11. B. Kramer, C. Chen, and J. Volakis, “Size Reduction of a Low-profile Spiral Antenna Using Inductive and Dielectric Loading,” *IEEE AWPL*, 7, July 2008, pp. 22-25.

12. M. Radway, T. Cencich, and D. Filipovic, “Pattern Purity of Coiled-arm Spiral Antennas,” *IEEE Trans. Antennas Propag.*, **AP-59**, 3, March 2011, pp. 758-766.

13. H. Nakano, K. Anjo, and J. Yamauchi, “Simple Equations for Estimating Decrease in Broadside Radiation from a Metaspiral Antenna,” *IEEE AWPL*, 15, 2016, pp. 1951-1954.

14. CST. https://www.cst.com/applications/mwandrf