Radiation from a Metahelical Antenna

H. Nakano, M. Tanaka, and J. Yamauchi
Hosei University
Koganei
Tokyo, Japan

***Abstract*- A novel helical antenna, designated as the metahelical antenna, is proposed, where the helical arm has electromagnetic right-handed (RH) and left-handed (LH) properties. The antenna design process is described. It is found that the metahelical antenna radiates a circularly polarized (CP) wave within two frequency bands. The rotational sense of the CP wave within one of the frequency bands is opposite to that of the CP wave within the other frequency band. The VSWR is less than 2, as desired, when the gain is at the maximum value.**

I. INTRODUCTION

A conventional helical antenna [see Fig. 1(a)] radiates a circularly polarized (CP) wave in the forward direction under the conditions that (i) the arm peripheral length S is approximately one guided wavelength ($1\lambda_g$) [1][2], and (ii) the current on the helical arm flows toward the arm end with no current reflected toward the feed point. This radiation is called end-fire radiation.

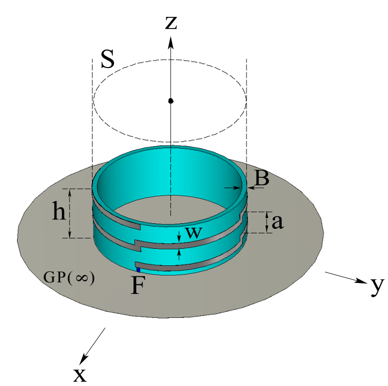
The current distribution for the conventional end-fire helical antenna was revealed experimentally by Kraus [1]; it was later revealed theoretically by Nakano, with the solution of an integral equation [3] using the method of moments [4]. It was found that the current distribution has two distinct regions: the C-current region and the S-current region [5]. The C-current region generates a CP wave, and the S-current region acts as a director for the electromagnetic wave from the C-current region. An array composed of low-profile helical antennas having only the C-current region has been used in Japan for direct broadcasting satellite antennas and as the primary feed for a Cassegrain reflector (VERA project by NAOJ). Such an array has also been adopted for use on the Mercury magnetospheric orbiter (BepiColombo project by JAXA and ESA).

The aforementioned conventional end-fire helical antenna, shown in Fig. 1(a), radiates a CP wave of either left-handed (LH) or right-handed (RH) polarization, determined by the arm winding direction (either clockwise or counter clockwise). This paper presents a novel end-fire helical antenna, shown in Fig. 1(b), which differs from the conventional end-fire helical antenna in that it radiates an LH CP wave within a specific frequency band and an RH CP wave within a different frequency band. This antenna is designated as the metahelical antenna and is distinguished from the conventional helical antenna. The radiation characteristics of the metahelical antenna are presented and discussed in this paper.

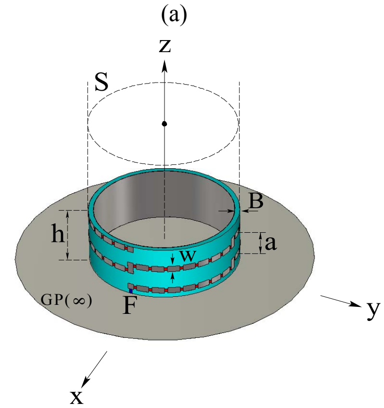
II. STRUCTURE

Figs. 1(a) and (b) show the conventional helical antenna and the novel helical antenna, respectively. The conventional antenna consists of a continuous arm wound on a dielectric layer, while the novel antenna has a noncontinuous arm wound on a grounded dielectric layer. Both antennas are upright above a conducting plate [ground plate (GP)].

The noncontinuous arm of the novel antenna is composed of segments, each having length L_{seg}, and each being loaded by an inductor (inductance L_L). Neighboring segments, separated by a gap g, are connected through a capacitor (capacitance C_L). The length L_{seg} + g is designated as the periodicity P. Note that the width and pitch of the helical arm are denoted as w and a, respectively, and the grounded substrate has a thickness of B and a permittivity of ε_r. The notation for the other structural parameters is included in Fig. 1.



(a)



(b)

Figure 1: Helical antennas. (a) Conventional helical antenna. (b) Novel helical antenna.

III. Discussion

The parameters for the metahelical antenna are determined using the following three steps. First, the relative permittivity ε_r and thickness B of the grounded dielectric layer are specified. Second, the width w of the helical arm printed on this dielectric layer is determined, so that the helical arm without gaps (g = 0) and without the C_L and L_L loading has a specified intrinsic impedance of Z_R. Third, values of C_L and L_L are determined such that a specified balanced frequency of f_{bal} is obtained for a given segment length L_{seg} and gap g.

Thus, parameters w, C_L, and L_L are determined for a given ε_r, B, L_{seg}, g, and f_{bal}. Using these parameters, the dispersive relation between β/k_0 and the operating frequency f is revealed, where β is the phase constant for the current flowing along the helical arm and k_0 is the phase constant for electromagnetic wave propagation in free space. The radiation occurs between frequencies f_L and f_U, where f_L and f_U are the lower and upper frequency bounds for a fast wave.

A negative phase constant ($\beta/k_0 < 0$) appears below the balanced frequency f_{bal} [6] in the dispersion diagram. This predicts that the metahelical antenna will radiate an LH CP wave when the peripheral length of the arm, normalized to the guided wavelength, is approximately one. Conversely, the metahelical antenna will radiate an RH CP wave above f_{bal}, due to a positive phase constant ($\beta/k_0 > 0$) when the normalized peripheral length is approximately one, as in the LH CP radiation. Note that the guided wavelength λ_g normalized to the free-space wavelength λ for LH CP radiation differs from that for RH CP radiation.

Analysis is performed by increasing the number of helical turns N up to N = 6. As N is increased, the gain in the bore sight direction (z-direction) increases. When the number of helical turns is N > 2, the maximum gain for principal LH CP radiation, $G_{max\text{-}LH}$, for our antenna model, having a balanced frequency of f_{bal} = 3 GHz, appears at a frequency of approximately 2.5 GHz $\equiv f_{N\text{-}LH}$, and the maximum gain for principal RH CP radiation, $G_{max\text{-}RH}$, appears at a frequency of approximately 3.6 GHz $\equiv f_{H\text{-}RH}$. Note that $f_{N\text{-}LH}$ is a frequency below the balanced frequency f_{bal}, and $f_{H\text{-}RH}$ is a frequency above f_{bal}. This is consistent with the aforementioned prediction.

The radiation field is decomposed into two components: an LH CP wave component E_L and an RH CP wave component E_R. It is found that, as the number of helical turns N is increased, the cross-polarization component becomes smaller. This is illustrated in Fig. 2, where the radiation patterns for N = 2 and N = 6 are compared. Note that these radiation patterns are obtained at a frequency above the balanced frequency f_{bal}.

The helical arm is not symmetric with respect to the z-axis. Asymmetry is seen in the cross-polarization component, indicated in Fig. 2 by the dotted line. On the other hand, as N is increased, the principal component becomes relatively symmetric with respect to the z-axis (see the solid line). Although the principal LH CP radiation pattern is not shown in Fig. 2, it is found that the principal RH CP and LH CP radiation patterns for the same number of helical turns N have different half-power beam widths, due to the dispersive characteristic of the antenna arm.

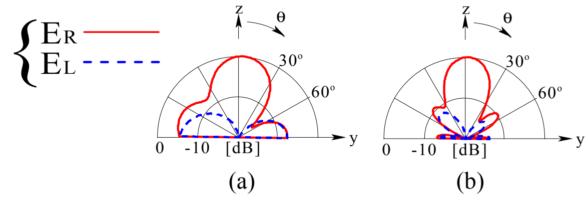


Figure 2: Comparison of the radiation patterns. (a) Number of helical turns N = 2. (b) N = 6.

The input impedance Z_{in} for the number of helical turns N > 2 is investigated at the frequency where the LH CP radiation shows maximum gain. It is found that the VSWR relative to 50 ohms, calculated based on Z_{in}, is less than 2, as desired. A similar frequency response for the VSWR is obtained at the frequency where the RH CP radiation shows maximum gain.

IV. Conclusions

A novel helical antenna, designated as the metahelical antenna, has been proposed. The metahelical antenna has two electromagnetic properties: the LH and RH properties. With these properties, the metahelical antenna radiates both LH CP and RH CP waves in the bore-sight direction (i.e., axial mode radiation), when the peripheral length of the helical arm corresponds to one guided wavelength. These axial-mode counter-CP waves, which cannot be obtained by conventional axial-mode helical antennas, occur within a low frequency band below the balanced frequency and a high frequency band above the balanced frequency. In other words, the metahelical antenna acts as a dual-band counter CP radiation element. The radiation pattern within the low frequency band is wider than that within the high frequency band. The VSWR is low within these frequency bands, as desired.

Acknowledgment

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

References

[1] J. D. Kraus, *Antennas* (second edition), Chapter 7, McGraw-Hill, 1988.
[2] H. Nakano, *Helical and spiral antennas*, Research Studies Press, Hertfordshire, England, 1987
[3] E. Yamashita edit, *Analysis methods for electromagnetic wave problems*, Chapter 3, Artech House, Boston, 1996.
[4] R. F. Harrington, *Field Computation by Moment Methods*, Macmillan, New York, 1968.
[5] H. Nakano, J. Yamauchi, and H. Mimaki, "Backfire radiation from a monofilar helix with a small ground plane," IEEE Trans., Antennas and Propagat., vol. 36, no. 10, pp. 1359-1364, October 1988.
[6] N. Engahta and R. Ziolkowski, *Metamaterials*, Wiley, 2006.