LP Radiation from a Metamaterial-based Loop Antenna

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Abstract – **A loop antenna whose electrical peripheral length is equal to two (C_{peri} = 2) at two different frequencies is investigated. The antenna arm of this loop is composed of numerous cells, each having one inductive and two capacitive elements, so that the current on the loop has a negative propagation phase constant in addition to its inherent positive propagation phase constant. The radiation pattern shows a dual-peak pattern. The VSWR is small at the two frequencies where C_{peri} = 2, as desired.**

Index Terms — **Loop antenna, dual-peak radiation, linearly polarized wave, negative propagation phase constant.**

I. Introduction

Antenna characteristics, such as the radiation pattern, gain and input impedance, can be calculated using the current on the antenna conductors. Hence, it is essential that the current be analyzed either theoretically or experimentally. For a theoretical analysis, the current can formulated as an unknown function within an integral equation and solved using the method of moments (MoM) [1][2].

Fig. 1(a) shows a loop antenna printed on a dielectric substrate [3][4], where the loop peripheral length normalized to the operating guided wavelength λ_g (*electrical loop peripheral length* C_{peri}) is equal to one; C_{peri} =1. Theoretical analysis [4] shows that the current along the loop has a maximal value at two points, feed point F and middle point M, and the loop radiates a linearly polarized (LP) wave whose maximum field intensity is in the z-direction, i.e., the loop forms an LP broadside beam. Note that the frequency where the loop peripheral length C_{peri} equals one (C_{peri} =1) is uniquely determined once the antenna size (physical loop peripheral length) is fixed.

Fig. 1(b) also shows a loop antenna supported by a low dielectric substrate ($\varepsilon_r \approx 1$), where a perturbation element is added to the loop [5]. Theoretical analysis for C_{peri} = 2 shows that the current along the loop flows in a traveling wave fashion and the loop radiates a circularly polarized (CP) wave in the positive z-space, where the maximum field intensity is off the z-axis, i.e., the loop forms a CP conical beam. Note that the physical loop peripheral length uniquely determines the frequency at which C_{peri} = 2.

A question arises as to whether C_{peri} equal to 2 can be obtained at *two* frequencies, even when the physical loop peripheral length is fixed. If this were possible, then the loop antenna's use could be extended to dual-band antenna applications.

A clue to the answer to this question is found in the recent literature [6]-[8], where the metamaterial concept is utilized; i.e., the antenna arm is constructed in such a way as to support a current with a negative propagation phase constant in addition to a current with the inherent positive propagation phase constant. These propagation phase constants are obtained at two different frequencies where the radiation zone corresponds to C_{peri} = 1. If this can be extended such that C_{peri} equals 2 at two frequencies, then we will have obtained an answer to our question.

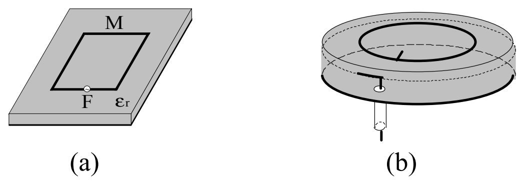

Fig. 1. Loop antennas. (a) LP loop printed on a dielectric substrate. (b) CP loop printed on a dielectric substrate.

This paper presents a novel loop antenna that realizes C_{peri} = 2 at two different frequencies. We focus on the generation of an LP beam, because generation of a CP beam has already been reported [5]. The antenna radiation characteristics are analyzed and presented, where the analysis is performed using an EM solver based on a finite integration technique (MW studio).

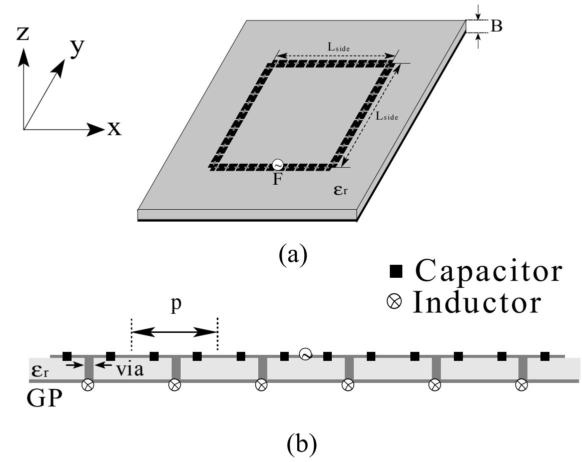

Fig. 2. LP Loop antenna composed of numerous cells. (a) Perspective view. (b) Side view.

II. DISCUSSION

Fig. 2 shows the configuration and coordinate system for the loop antenna to be considered here. The loop is square with a side length of L_{side} and is printed on a dielectric substrate of relative permittivity ε_r and thickness B. The loop is excited using a delta-gap voltage source embedded in the antenna arm.

The antenna arm is not continuous, unlike conventional loop antenna arms. The arm is composed of numerous segments (strip cells) with capacitive and inductive elements inserted into the cells. The unit cell of the arm is equivalently modeled by a parallel transmission line [9]-[11], which is specified by a series impedance Z' per unit length and a shunt admittance Y' per unit length. The propagation constant $\gamma = \alpha + j\beta$ for this transmission line is given by

$$\gamma = \sqrt{Z'Y'} \quad (1)$$

A frequency f_T that satisfies $Z' = Y' = 0$ is defined as the *transition frequency*, where $\beta = 0$ and the guided wave length λ_g is infinitely long. A negative propagation phase constant is obtained below f_T and a positive propagation phase constant is obtained above f_T. For radiation, these frequencies below and above f_T, denoted as f_{N2} and f_{H2}, respectively, must be within the fast wave frequency region of f_L to f_U. In addition, for our purpose, the electrical loop peripheral length must correspond to $C_{peri} = 2$ at f_{N2} and f_{H2}.

The antenna is designed such that the transition frequency is f_T = 3 GHz and the fast wave frequency region ranges from f_L = 2.4 GHz and f_U = 4.6 GHz. Fig. 3 shows the representative radiation patterns at f_{N2} and f_{H2}, both in the x-z plane. The radiation forms a dual-peak pattern. At f_{N2}, the co-polarization component (co-pol) in the x-z plane is E_ϕ and the cross polarization (x-pol) component is E_θ. This relationship between the co-pol and x-pol components is the same at f_{H2}.

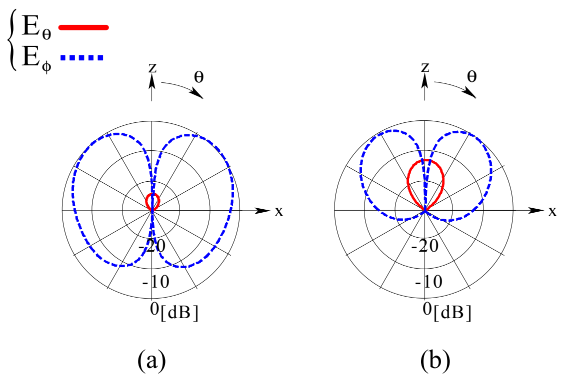

Fig. 3. Radiation pattern. (a) At f_{N2}. (b) At f_{H2}.

Fig. 4 shows the VSWR frequency response around frequencies f_{N2} and f_{H2}. It is found that a small VSWR is obtained, as desired. The bandwidth for a VSWR = 3 criterion is 1.2% around f_{N2} and 2.7% around f_{H2}.

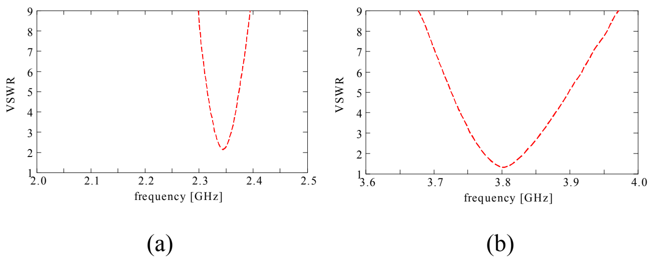

Fig. 4. Frequency response of the VSWR. (a) Around f_{N2}. (b) Around f_{H2}.

III. CONCLUSIONS

A novel loop antenna is presented. A negative propagation phase constant is created by subdividing the loop arm into numerous cells and inserting reactive elements into the cells. Thus, an electrical loop peripheral length of C_{peri} = 2 at two different frequencies, f_{N2} (< transition frequency f_T) and f_{H2} (>f_T), is obtained. The radiation at these frequencies forms a dual-peak radiation pattern. The relationship between the co-pol and x-pol components at f_{N2} is the same as that at f_{H2}. The VSWR is small at f_{N2} and f_{H2}, making impedance matching straightforward.

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