# Analysis and Design of a Partitioned Circular Loop Antenna for Omni-directional Radiation

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***Abstract*** **-A novel printed antenna configured with circular loop geometry of approximately one wavelength perimeter is designed for operation at 5.8 GHz with near omni-directional radiation pattern. The loop is partitioned into multiple segments and loaded with capacitive elements at selected locations so as to decrease phase variations in the current flow and thereby increase the radiation efficiency. A total of five capacitors are used to achieve stable current flow, resulting in phase variations of < 12°. The performance of the loop antenna is first analyzed as a transmitter in free space using a method of moments (MoM) solver for thin-wire structures, and then validated using 3-D finite element method (FEM) and MoM solvers. The simulated radiation pattern for the thin-wire model in the plane of the loop is close to omni-directional with directive gain of 1.46 dBi. A printed circuit antenna model is then designed with alternating top- and bottom-layer conductors of annular geometry on a thin substrate, with regions of conductor overlap functioning as physical capacitors. Simulations of the printed antenna demonstrate omni-directional radiation in the azimuthal plane, with peak directive gain of 1.66 dBi, peak directivity of 1.69 dB, radiation efficiency of 0.98, and input impedance close to 50 Ω. Performance measurement data for a fabricated printed circular loop antenna (in process) will be shown during presentation for comparison and validation.**

**Keywords-Loop antenna; partitioned; omni-directional; current; phase variations**

## I. INTRODUCTION

The historical popularity of the loop antenna with microwave and radiofrequency (RF) engineers is demonstrated by its omnipresent representation in the literature [1]-[2], and this popularity is due primarily to its simplicity of design and fabrication, ease of integration in front-end transceivers for wireless communication systems, and low cost of manufacture. However, its performance in comparison to other types of antennas is deficient with respect to such parameters as gain, bandwidth, impedance, and radiation pattern. One well- known problem occurs when the perimeter of a loop antenna is small with respect to the wavelength, where the minute radiation resistance becomes impractical for matching to a 50 ohm transmission line. Alternatively, when the loop perimeter is of the order of one wavelength or larger, the radiation efficiency is degraded because the current in the loop undergoes large phase variations [3]. This results in an inefficient radiator, as well as a shift of the direction of maximum radiation from the plane of the loop to a plane that is normal to the loop, which may be undesirable for the intended wireless application.

It has been shown previously for square loop geometry [4] that the phase variations of the current can be minimized by partitioning the loop into smaller segments and inserting lumped capacitors in series arrangement to achieve omni-directional radiation. This paper presents the design and analysis of a partitioned circular loop antenna of nearly one wavelength in circumference and its simulated performance. The dimensions of a thin-wire antenna model are converted to an equivalent printed model with overlapping conductors of annular geometry on a low-loss dielectric substrate. The design procedure for the wire and printed antennas is discussed, and simulation results using method of moments (MoM) and finite element method (FEM) software packages are presented. Measurements of the antenna's return loss and far-field radiation patterns will be shown during the presentation to compare the performance of the printed partitioned circular loop antenna with the simulation results for validation purposes.

## II. WIRE LOOP ANTENNA MODEL

A thin-wire circular loop antenna of radius $r$ = 7.0 mm and circumference $C \cong 44.0$ mm ($0.85\lambda_0$) was designed for operation at 5.8 GHz and analyzed using the MoM software package *Analysis of Wire Antennas and Scatterers* (AWAS) [5]. The loop was centered in the $xy$-plane at $z$ = 0 and modeled with copper wire segments of radius $a$ = 0.5 mm. A total of 24 nodes defining 24 wire segments comprise the antenna geometry, as shown in Fig. 1. Nodes were spaced every 15° for achieving a smooth circular symmetry and the insertion of series lumped capacitors at selected locations. The wire segments have arc lengths of $s$ = 1.83 mm and a corresponding aspect ratio of $s/a \cong 3.7$. A voltage generator of 1.0 V was fixed at node 1 (port 1) with a characteristic impedance of 50 ohms.

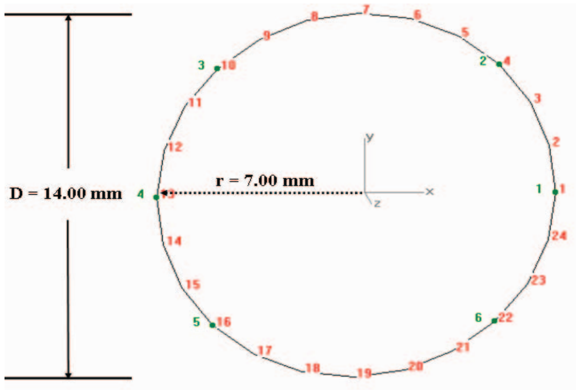



Figure 1. Thin wire model of partitioned circular loop antenna with wire nodes (red) and lumped series ports (green) indicated.

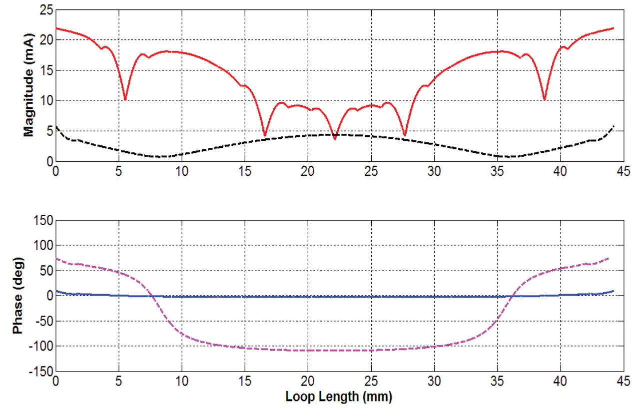



Figure 3. Simulated current magnitude and phase on thin wire circular loop antenna with (solid) and without (dashed) lumped capacitors (5.8 GHz).

Five capacitive elements were inserted at the following node locations to cancel out the net inductance of the wire loop: 0.086 pF (nodes 4 and 22), 0.042 pF (nodes 10 and 16), and 0.047 pF (node 13). The antenna was simulated in transmission mode in free space from 1 to 10 GHz, resulting in an input impedance of 49.3 – *j* 0.05 Ω, a corresponding input admittance of 20.3 + *j* 0.02 mS, and a return loss of 43.4 dB at 5.8 GHz, as shown in Fig. 2.

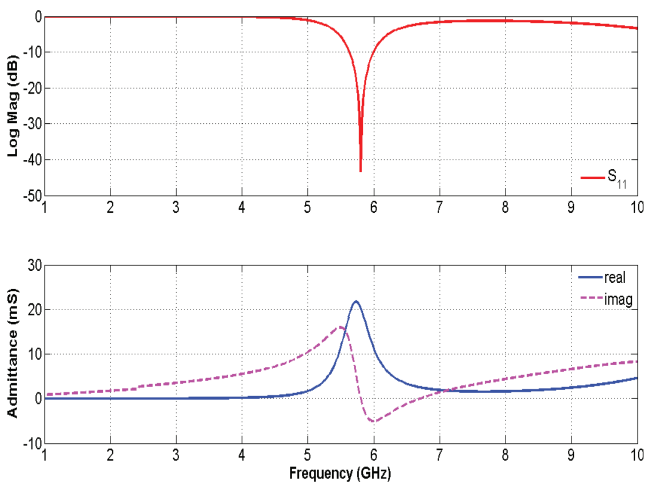
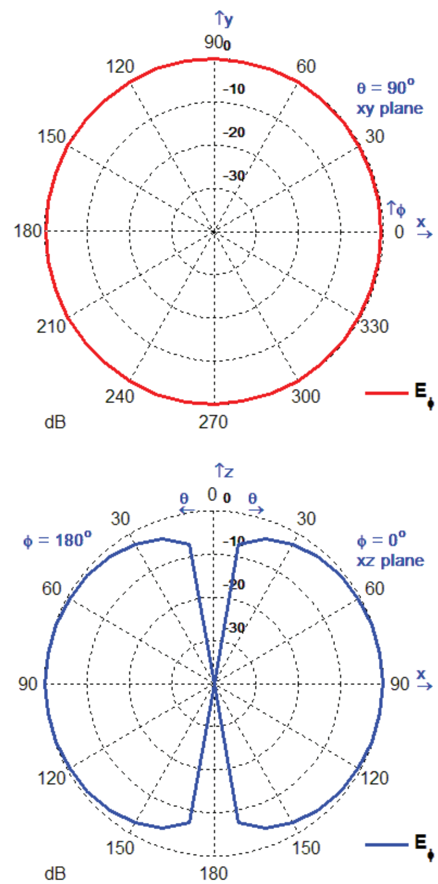



Figure 2. Simulated return loss and input admittance for the thin wire partitioned circular loop antenna (5.8 GHz).

The simulated current magnitude and phase on the thin wire loop antenna, with and without lumped capacitors, are plotted in Fig. 3. The total phase shift with capacitive loading is on the order of 12°, which indicates good stability of the current phase over the entire length of the loop. The net phase shift in the current around the circular loop is equivalent to that found for the partitioned square loop antenna [4], and this result is reasonable if one considers that the magnetic coupling between the wire segments of each respective loop geometry increases when the perimeter of the loop antenna decreases, generating a stronger magnetic field parallel to the *z*-axis of the loop.

The simulated far-field radiation patterns demonstrate omni-directionality in the *xy*-plane, as shown in Fig. 4. The cross-polarization components are negligible due to the symmetry of the wire loop and therefore are not shown. The maximum directive gain is calculated as 1.46 dBi at 5.8 GHz



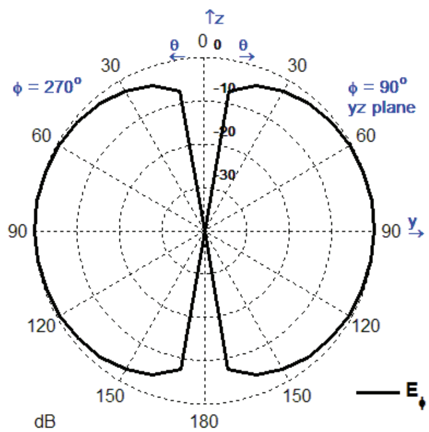



Figure 4. Simulated far-field radiation patterns in three planes for the thin-wire partitioned circular loop antenna (5.8 GHz).

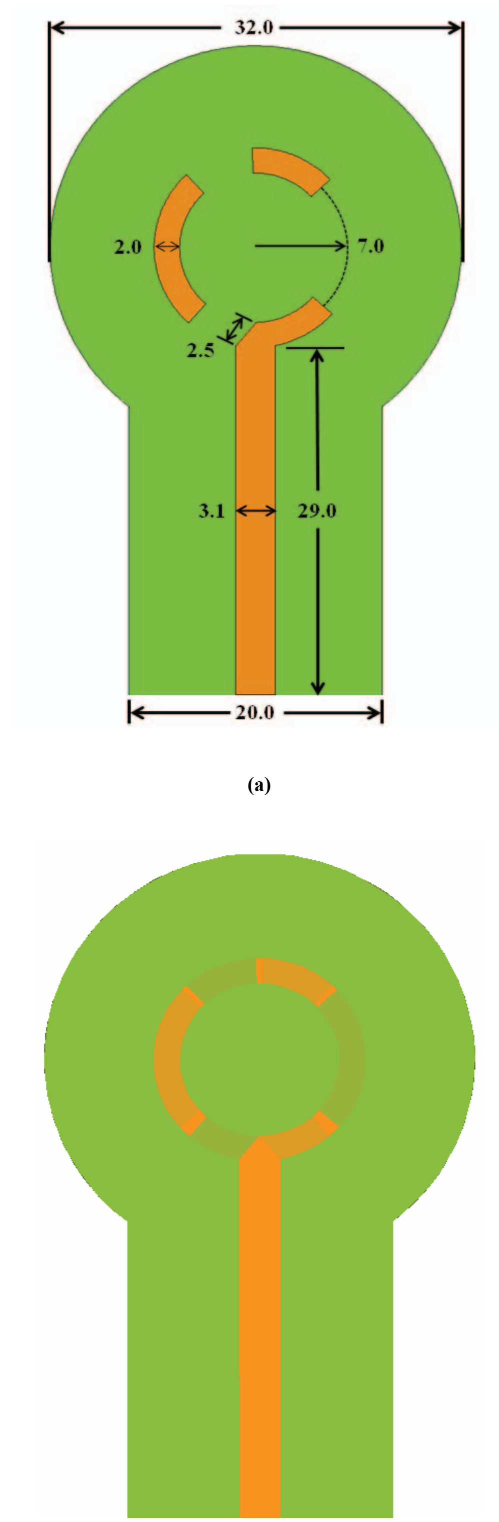
The antenna bandwidth is determined from the simulated return loss to be 6.2 % with respect to the 10-dB threshold level, and thus the radiator is inherently narrowband.

## III. PRINTED LOOP ANTENNA MODEL

A printed square loop antenna was designed by converting the loop wire conductors to a strip width of 2.0 mm using a cylinder-to-ribbon current equivalence approximation relation $w \cong 2d$ [6], where $d$ is the wire diameter The antenna is realized on a substrate with alternating top and bottom layer conductors using Rogers RT/Duroid 5880 with $\varepsilon_r = 2.2$, substrate height $h = 0.787$ mm (31 mil), $\tan \delta = 0.0004$, and conductor thickness $t = 0.035$ mm. The capacitances are realized by overlapping the end sections of annular conducting strips on opposite sides of the substrate. The areas of overlap were centered at 45°, 135°, 180°, 225°, and 315°, respectively, rotating CCW from the feed port position. The angular area for each capacitor was computed using the relation

$$\theta_n = 2hC_n / (r_0^2 - r_i^2)\, \varepsilon, \qquad (1)$$

where $C_n$ ($n$ = 1, 2,…5) is the physical capacitance for each location in the loop as determined from the thin-wire model; $r_0$ and $r_i$ are the outer and inner radii, respectively, of the printed loop strip conductors ($r_{center} = 7.0$ mm); and $\varepsilon = \varepsilon_r\varepsilon_0$, where $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m is the permittivity of free space. A scale factor was applied to each capacitance to account for fringing field effects near the regions of conductor overlap. Fig. 5 shows the design dimensions of a printed partitioned circular loop antenna with matching feed line in which the angular areas of strips are configured for the capacitor values. The design is highly sensitive to the values of the individual capacitances and therefore further optimization of these values is required in the printed model by application of the scaling factor, which is critical to achieving the desired center frequency of operation and omni-directional radiation pattern in the $xy$-plane. Simulation of the printed model using a commercial FEM solver [7] shows resonance at the design frequency.




(a)

(b)

Figure 5. Design dimensions for the printed circular loop antenna with annular conducting strips (units are in mm): (a) Top view and (b) Transparent view.

Fig. 6 shows the simulated return loss (34.8 dB) for the printed circular loop antenna, with a 10-dB bandwidth of 6%.

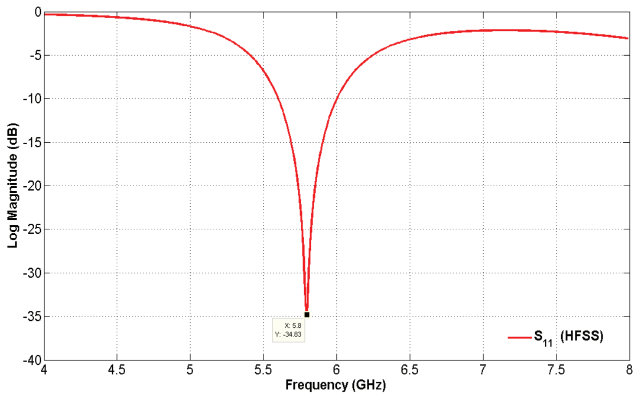



Figure 6. Simulated return loss for the printed circular loop antenna (5.8 GHz).

An independent simulation of the printed circular loop antenna model is then performed using the FEKO 3-D electromagnetic solver in order to confirm the results of the FEM simulation [8]. An embedded edge port is used to excite the antenna at 1 V due to finite substrate dimensions. The Surface Equivalence Principle (SEP) is used with adaptive frequency sweeps from 4.8 to 6.8 GHz. The electric and equivalent magnetic surface currents are then calculated at 5.8 GHz, as shown in Fig. 7. The opaque view shows the strips and annular areas of capacitance.

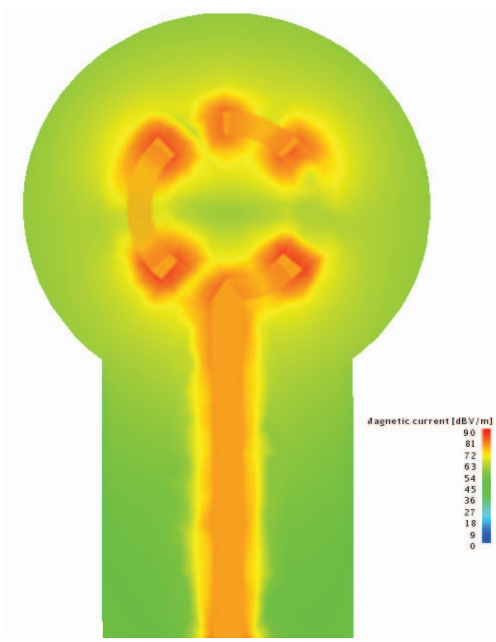



Figure 7. Equivalent magnetic surface current for the printed circular loop antenna with annular capacitors using FEKO 3-D solver (5.8 GHz).

The simulated far-field 3-D pattern is shown in isometric view in Fig. 8 as encompassing the printed antenna model.

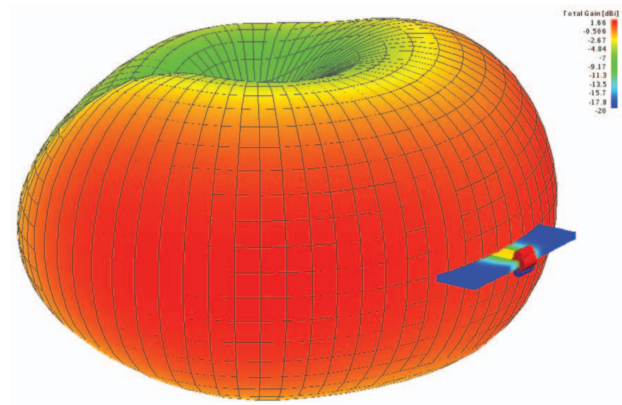



Figure 8. Simulated 3-D far-field radiation pattern for the printed circular loop antenna using FEKO 3-D solver (5.8 GHz).

The far-field radiation pattern is nearly omni-directional with a directive gain of 1.66 dBi, with pattern degradation opposite the feed source location on the order of ≤ 1 dB.

## IV. CONCLUSION

A novel printed loop antenna has been designed and simulated by partitioning the structure and inserting physical capacitors at selected locations by overlapping conducting strips of annular geometry for smoothing the current phase. The antenna has a simulated directive far-field gain of 1.66 dBi at 5.8 GHz, with nearly omni-directional radiation in the *xy*-plane. The printed loop antenna has potential use as a low-power transceiver for both WLAN and RFID applications.

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