Partitioned Square Loop Antenna

Veysel Demir, Roger Hasse, Darko Kajfez, and Atef Elsherbeni

Department of Electrical Engineering
The University of Mississippi, University, MS 38677-1848, USA
vdemir@olemiss.edu, rhasse@olemiss.edu, eedarko@olemiss.edu, atef@olemiss.edu

Abstract: A novel antenna design is presented for nominal operation at 5.8 GHz. The antenna employs square loop geometry of perimeter one wavelength. The loop is partitioned with capacitive elements at strategic locations in order to minimize phase variations in the current flow and thereby enhance the radiation efficiency. Five capacitive elements are used to achieve optimal current flow, resulting in phase variations smaller than ± 6°. The performance of the antenna is first analyzed with the wire-antenna simulation software, and later validated using a finite difference time domain (FDTD) package. The calculated radiation pattern in the plane of the loop is close to omnidirectional with directive gain of 1.5 dB. A printed circuit antenna is manufactured with alternating top- and bottom-layer conductors, with the overlapped regions acting as physical capacitors. The measured radiation patterns confirm the predicted omnidirectional behavior in the equatorial plane and a good match to 50 Ohm impedance.

Keywords: Loop antenna, partitioned, current phase, omnidirectional

1. Introduction

The loop antenna has proven to be one of the most practical and adaptable types of antennas [1], with circular and rectangular geometries representing the most popular configurations. However, when the perimeter of the loop antenna is small with respect to the wavelength, its radiation impedance is extremely small and thus inconvenient for matching to a 50 Ohm value. On the other hand when the perimeter is of the order of one wavelength or larger, the current flowing in the loop exhibits phase changes that ultimately degrade the radiation efficiency [2]. This results not only in the antenna functioning as a poor radiator but also in a shift of the radiation pattern from in the plane of the loop to a maximum along its z-directed axis, which may not be desirable for the intended application.

It is possible to minimize the phase variation of the current by partitioning the loop into several sections small in comparison with wavelength, and inserting the lumped capacitive elements in series. The resulting antenna structure is simple and can be investigated using a thin-wire model radiating into free space. The physical dimensions are then converted to an equivalent printed model on a dielectric substrate. The procedure used to design both the wire and printed antennas is discussed, while simulation results using a finite difference time domain (FDTD) package are presented which validate the final printed design. Measurements of the return loss and radiation patterns are also presented to compare the performance of the partitioned loop antenna with the simulation results.
2. Wire Antenna Model

A thin-wire square loop antenna of radius 0.5 mm and side $s = \lambda/4$ mm was designed and simulated using the commercial software package Analysis of Wire Antennas and Scatterers (AWAS) [3]. The loop antenna was centered in the $xy$ plane at $z = 0$ and modeled with copper wire segments. A total of 6 wire segments comprise the antenna geometry (see Fig. 1). Since the aspect ratio is $\approx 26$ (relatively thick antenna), three polynomial coefficients per wavelength were used to model the current and charge distributions along segments 1, 3, 4, and 6, respectively, while five coefficients were used for segments 2 and 5 in the numerical solution of the two-potential equation [4].

![Fig. 1. Thin-wire model for partitioned loop antenna with source, nodes and segments indicated.](image)

An ideal voltage generator of emf 1.0 V was fixed between segments 1 and 6 (node 1) with a nominal port impedance of 50 $\Omega$. Concentrated capacitive loadings were positioned at the four corners and between segments 3 and 4 (node 4) directly opposite the source. Five capacitive elements ranging from 0.046-0.069 pF were used.

![Fig. 2. Return loss and input admittance for wire partitioned loop antenna at 5.8 GHz.](image)
to minimize the current phase variations. The antenna was simulated in transmission mode in free space from 1 to 10 GHz using a total of 450 points, and optimization of the capacitor values yielded an input impedance of $50.64 - j 1.96 \, \Omega$, a corresponding input admittance of $19.72 + j 0.0076 \, \text{mS}$, and a return loss of -34 dB at 5.8 GHz as shown in Fig. 2.

The simulated current magnitude and phase variations on each wire segment of the loop are plotted in Fig. 3, with phase variations in the range of $\pm 6^\circ$, indicating good current stability over the entire loop length.

![Fig. 3. Current magnitude and phase on wire segments of partitioned loop antenna at 5.8 GHz.](image)

The normalized directive gain pattern in the far field is nearly omnidirectional in the $xy$ plane with a maximum gain of 1.5 dB and shows $\leq 1$ dB of variation (see Fig. 4 below).

![Fig. 4. Normalized far-field directive gain pattern for wire partitioned loop antenna at 5.8 GHz.](image)
3. Printed Loop Model

A printed square loop antenna as illustrated in Fig. 5 was designed by converting the loop wire conductors, using a cylinder-to-ribbon current equivalence approximation \( w \approx 2d [5] \), to a strip width of 2.0 mm. 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 \( h = 0.787 \text{ mm} \) (31 mil), and \( \tan \delta = 0.0004 \). The capacitances are realized by overlapping the end sections of strips on opposite sides of the substrate. The areas of overlap for the five physical capacitors were computed as

\[
A = \frac{hc}{\varepsilon_0 \varepsilon_r}
\]

with areas corresponding to 1.84 \( \mu \text{m}^2 \) (0.046 pF), 2.63 \( \mu \text{m}^2 \) (0.065 pF), and 2.80 \( \mu \text{m}^2 \) (0.069 pF), respectively. Figure 6.a shows the dimensions of a partitioned loop antenna with a feeding line in which the overlapping areas of strips are approximated to these calculated values. Simulation of this antenna using a custom FDTD solver verified that it operates at 5.8 GHz.

This antenna has been fabricated using a LPKF ProtoMat C100/HF milling machine and the measured return loss demonstrates that the antenna operates at a center frequency of 6.02 GHz with –19.6 dB return loss. The exact values of the individual capacitances proved to be very critical to the antenna center frequency. The partitioned loop antenna dimensions had to be slightly modified using FDTD in order to lower the center frequency of antenna operation. The new dimensions are illustrated in Fig. 6.b.

A new antenna has been fabricated using the modified dimensions. Figure 7 shows the back and front views of this antenna. Measurement of the return loss is performed using a HP 8510C vector network analyzer and the measured results are compared to simulated results as shown in Fig. 8. The measurement shows good performance of –18 dB return loss at 5.8 GHz. Radiation patterns of the fabricated antenna have been measured in an anechoic chamber and the results are compared to FDTD simulation results at 5.8 GHz. Figure 9 shows directivity patterns obtained by FDTD in three principle planes, whereas Fig. 10 shows the measured radiation patterns. A good agreement can be observed between the calculated and measured patterns. Radiation is omni-directional in the xy-plane with \( \phi \)-polarization.

![Fig. 5. Schematic of partitioned loop antenna on a substrate.](image-url)
Fig. 6. Dimensions of the partitioned loop antenna in millimeters; a) initial design, b) modified design.

Fig. 7. Partitioned loop antenna; a) front view, b) back view.
Fig. 8. Measured and simulated return losses for partitioned loop antenna.

Fig. 9. Directivity patterns calculated by FDTD at 5.8 GHz.
4. Conclusions

A novel loop antenna design is presented which utilizes capacitive elements at strategic locations in order to minimize phase variations in the current flow and thereby enhance the radiation efficiency. Initial design parameters are obtained using AWAS, a thin-wire antenna MoM solver, and then a partitioned loop antenna is designed on a planar substrate and optimized using FDTD. The design is fabricated and return loss and radiation pattern measurements are performed. The radiation pattern measurements reveal that the antenna provides the desired omni-directional radiation characteristics. The return loss measurements show that the antenna is extremely sensitive to fabrication imperfections; therefore the proposed design methodology shall be improved in order to minimize sensitivity to fabrication tolerances.

References