“An Electrically Small Loop Antenna With Usefully Isotropic Radiation And Common Mode Feed”

Francis E. Parsche

Harris Corporation, Special Antennas Group
PO Box 37, Mail Stop HTC-3463
Melbourne, FL 32902
fparsche@harris.com

***Abstract*—An electrically small circular loop antenna with an isotropic radiation pattern to within ± 1.9 dBi is described. The scalable design operated at the 1575.42 Megahertz Global Positioning System L1 frequency. Means are provided to separately adjust driving resistance and reactance. Common mode currents radiate beneficially as part of loop structure. As the radiation pattern is sufficiently spherical, the design permits wireless systems to operate without aiming or orientation. Applications may include radio frequency identification (RFID) tags, radiolocation receivers, tumbling satellites or personal communications.**

Keywords—antenna; isotropic; electrically small; loop; half wave loop; spherical radiation pattern; unaimed; unoriented; personal communications; tracking tag; RFID; global positioning system GPS; tumbling satellite; balun; common mode.

I. Introduction

Many antenna systems are not aimed or oriented in use, such as antennas for wildlife tracking, tumbling satellites, and personal communications. There is a need therefore for practical antennas having usefully isotropic radiation.

Antennas can be organized as to dipoles and loops based on the divergence or curl electric current, with spirals and helices providing hybrid forms. Many shapes are called loops but the canonical loop antenna is a circle of wire [1]. Euclidian geometries, such as the circle have been known through the centuries for optimization and a circular loop encloses the greatest physical area for the least conductor length. The vanishing small loop is absent radial *electric* near fields [2] while the vanishing small dipole is absent radial *magnetic* near fields [3]. So a small loop may have reduced dielectric heating losses when body worn.

Yet in spite of the advantages, the circular wire loop antenna can be difficult to implement: the driving point resistance of a simple gap fed circular loop is not 50 ohms at any resonance frequency. Robust baluns can be needed: the radiation resistance from unbalanced coaxial cable currents may easily exceed small loop radiation resistance. Practical means to implement antennas with usefully isotropic radiation are necessary; this paper shows how to accomplish this from an electrically small loop.

II. Design Description

FIG. 1 depicts a schematic view of the present article: a circular loop antenna with planar / 2.5 D shape, usefully isotropic radiation and 50 ohm coaxial feed without need of a balun:

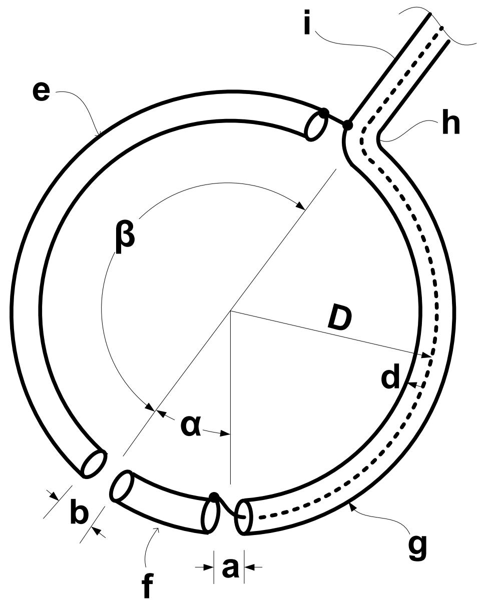

FIG. 1: Antenna Schematic

The design may be formed from a circular ring of RG-405 coaxial cable. Table 1 provides design dimensions, which will be used throughout the paper unless otherwise stated:

TABLE I.

Design Dimensions			
Variable	***Parameter Desciption***	***Physical Dimensions at 1575 MHz***	***Electrical Dimensions at 1575 MHz***
-	Loop major circumference	3.372 inches	$0.45\lambda_{air}$
D	Loop major radius	0.537 inches	$0.072\lambda_{air}$
d	Loop minor radius	0.0425 inches	$0.0575\lambda_{air}$
a	Feed gap / driving discontinuity width	0.085 inches	$0.011\lambda_{air}$
b	Matching gap / matching discontinutiy width	0.085 inches	$0.011\lambda_{air}$

i	Coaxial cable egress segment	5.0 inches	$0.67\lambda_{air}$
α	Matching gap angle	32 degrees	-
β	Coaxial cable egress angle	180 degrees	-

The design is not dependent on any specific length for the cable egress segment length (i). Five inches was chosen for this example.

III. THEORY

Electrically small circular loops with uniform current distributions have broadside radiation pattern nulls [4]. In order to fill those nulls for usefully spherical radiation, a stationary sinusoidal loop current distribution was synthesized by sizing the loop for half wave resonance and separating charge across an added matching gap (b). This causes a dipole moment in the loop which renders needed broadside as well as coplanar radiation.

The design provides for independent control of antenna driving resistance without appreciably changing antenna resonance frequency, reactance, or radiation pattern. This is accomplished by adjustment of the spacing between loop gaps, e.g. changing the matching gap angle α of FIG. 1. At loop half wave circumference resonance, and for $10^{o} < \alpha < 350^{o}$, driving resistance r may be calculated according to the formula:

$$r \approx 8 + 12 \left| \mathrm{COT}\ (\alpha/2) \right| \text{ ohms}$$

Where:

r = the driving resistance at gap (a) at resonance in ohms
α = the matching gap angle in degrees

This relationship response arises as loop feed gap resistance r is proportional to loop feed gap voltage E divided by loop feed gap current I, with E varying as COS (α/2) and I as SIN (α/2).

Loop segment (g) between the matching gap (a) and the transmission line exit point (h) is formed by common mode currents flowing on the exterior of the segment (g) coaxial cable shield. To reduce unwanted common mode current radiation from the egress segment (i), the coaxial cable exits the loop at the location of loop current symmetry (and maxima). So, at any given time, one loop half is capacitively *pulling* displacement current onto the egress cable shield while the other loop half is *pushing* displacement current onto the egress cable shield.

Matching gap (b) location determines the location of the loop current maxima, while feed gap (a) location does not appreciably affect this. Adjusting matching gap (b) width provides a practical method for fine tuning. Spreading the gap raises the resonant frequency and reducing the gap width lowers the resonant frequency. The design is relatively insensitive to changes in feed gap (a) width.

IV. SIMULATED PERFORMANCE

The design was analyzed by finite element simulation in the HFSS software by Ansys Inc. of Pittsburgh, PA. The simulation included the 5 inch long coaxial feed line egress segment (i). No baluns or common mode chokes were used. All electrical conductors were copper. The simulator excitation port was located at feed gap (a), where the center conductor exited the shield tube. Coaxial transmission line losses are not included. Reviewing several manufacturers' data, those losses would have been between 0.1 to 0.2 dB for RG-405.

It is difficult to impractical to physically measure coaxial cable outer surface RF currents so simulation was used to map current amplitude distribution on the conductive structures. FIG. 2 depicts this map for the Table 1 geometry antenna in an IEEE-145 radiation pattern coordinate system:

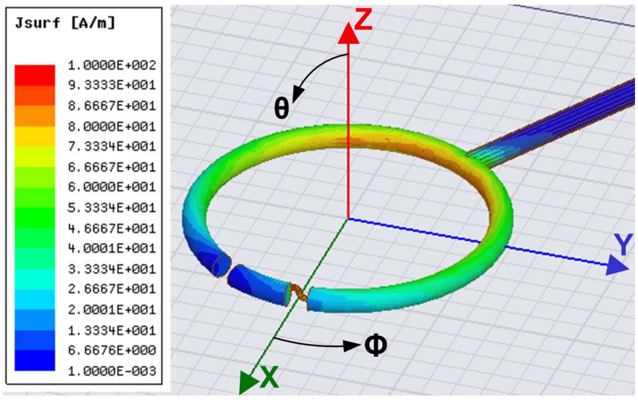

FIG. 2: Simulation Geometry, Current Amplitude Distribution and Pattern Coordinate System

Driving point impedance across gap (a) is provided in FIG. 3, VSWR in FIG. 4, and the driving resistance as a function of varying matching gap α as FIG. 5:

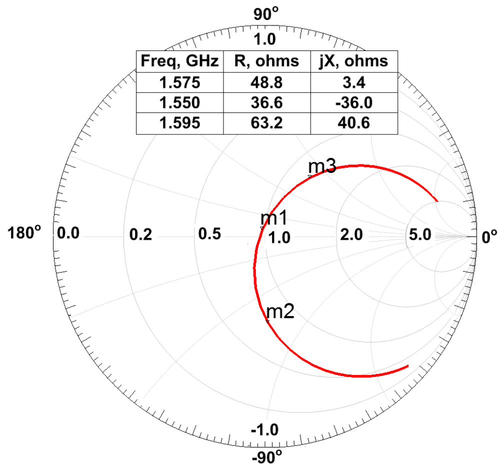

FIG. 3: Normalized Smith Chart Driving Point Impedance At Gap (a)

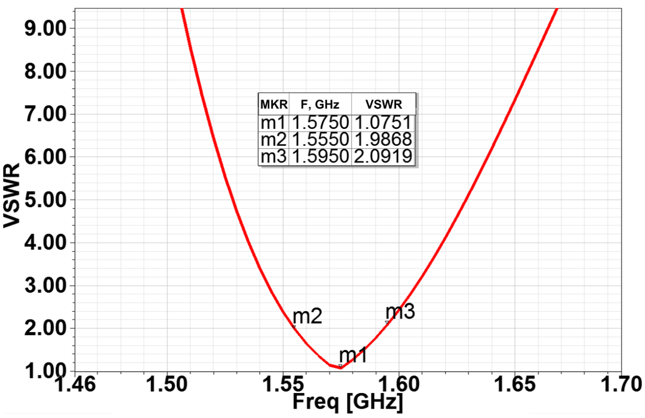

FIG. 4: VSWR In A 50 Ohm System

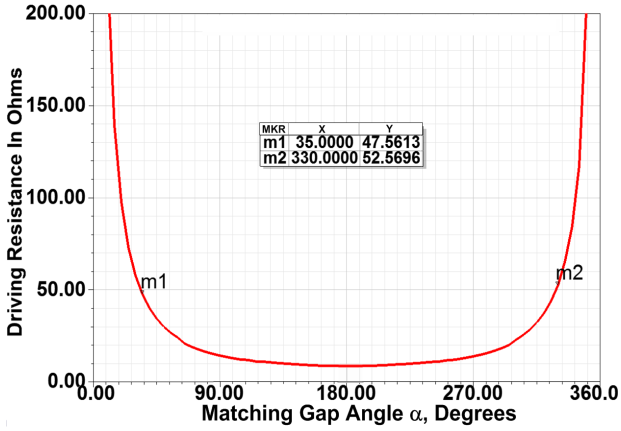

FIG. 5: Driving Resistance Response Versus Matching Gap Angle α

FIGs 6 through 9 are 1575 MHz the principle plane free space radiation patterns as realized gain in dBi for total fields:

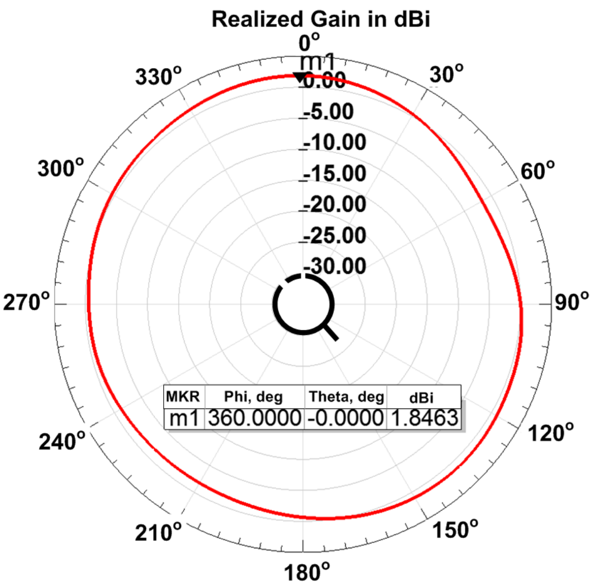

FIG. 6: XY Plane Far Field Radiation Pattern Cut

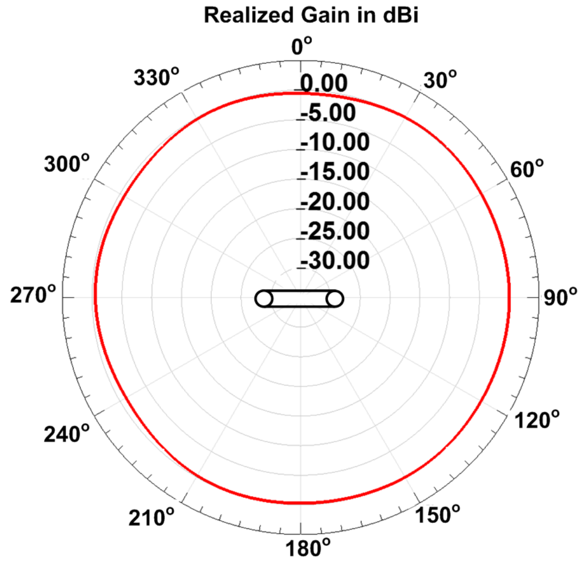

FIG 7: YZ Plane Far Field Radiation Pattern Cut

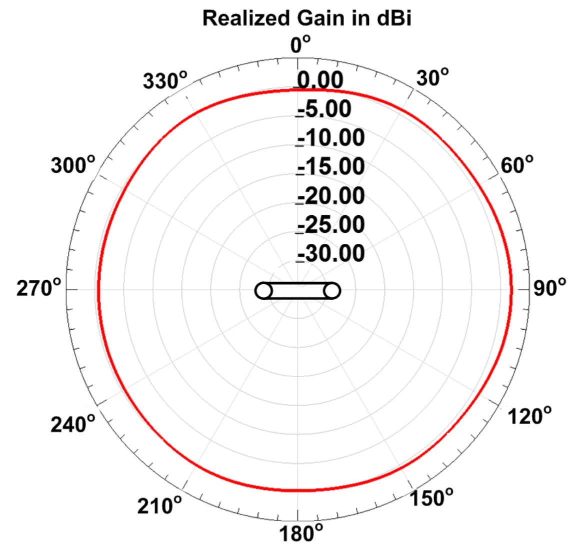

FIG. 8: ZX Plane Far Field Radiation Pattern Cut

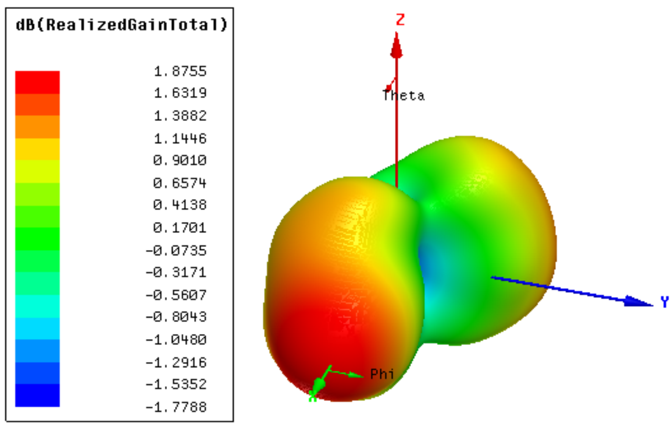

FIG. 9: 3D Far Field Radiation Plot Having Greatly Expanded Scale

Over all possible pattern look angles the maximum realized gain was 1.9 dBi and the minimum realized gain was -1.8 dBi so the radiation pattern was spherical to within ± 1.9 dBi. If the present loop antenna were linked with a circularly polarized antenna, the maximum possible loop aiming plus orientation fading would be -6.8 dB, reconciling as -3 dB of polarization mismatch fading (circular on linear) and 3.8 dB fading for loop radiation pattern minima. This is usefully isotropic radiation for many wireless systems.

Far field polarization is horizontal when the loop is in the horizontal plane. Broadside and along the +Z axis, the E field strength maxima peaked at phi equals 148 degrees corresponding to the axis of a dipole moment extant across the matching gap (b). The 3 dB realized gain bandwidth was 105 MHz or 6.9 %.

RADIATION EFFICIENCY

The radiation efficiency of a Table 1 configuration physical prototype was measured using the Wheeler Cap Method [5]. The shielding cap comprised a 1.70" diameter by 1.80" tall cylindrical can made of 0.010" copper foil with all seams were soldered to prevent radiation. The reflection coefficient magnitude Wheeler Capped $|\Gamma_{WC}|$ was measured to be 0.91 and reflection coefficient magnitude in free space $|\Gamma_{FS}|$ was measured to be 0.04. Wheeler's efficiency formula allows calculation of radiation efficiency as follows:

$$\eta = [\,|\Gamma_{WC}|^2 - |\Gamma_{FS}|^2 / 1 - |\Gamma_{FS}|^2\,] \text{ x } 100\ \%$$

The physical measurements therefore indicate a radiation efficiency of 83 %.

The physical prototype antenna is shown as FIG. 10 and the Wheeler Cap in FIG. 11:

FIG. 10: Physical Prototype

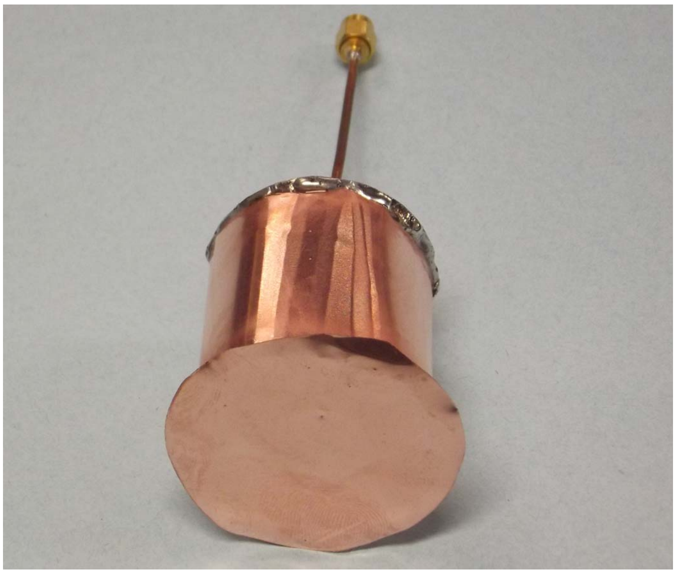

FIG. 11: Wheeler Cap With Antenna Sealed Inside

SUMMARY

An electrically small circular loop antenna having two gaps has been shown to provide 83 % efficient radiation with a pattern shape within + - 1.9 dBi of spherical. A coaxial common mode current formed a portion of loop conductor, with the distance between two loop gaps providing a simple, wide range adjustment of driving resistance. The design radiates coaxial cable common mode (outer shield) currents beneficially. The antenna can permit many wireless systems to operate without the need for aiming or orientation, such as tracking tags, GPS location receivers, and personal communications devices.

REFERENCES

[1] John L. Volakis; "Antenna Engineering Handbook", 4th ed., McGraw Hill, 2007, Fig. 5-1, pp 5-3.

[2] Constantine Balanis, "Antenna Theory", 3rd ed., Wiley 2005, pp 236-237, equations 5-18(a-c).

[3] Constantine Balanis, "Antenna Theory", 3rd ed., Wiley 2005, pp 153-154, equations 4-8(a-b) and 4-10(a-c).

[4] John D. Kraus; "Antennas For All Applictions", 3rd ed., McGraw Hill, 2003, FIG. 7-7, pp 204.

[5] H.A.Wheeler "The Radiansphere Around A Small Antenna", Proc.Of The IRE, vol. 47, pp. 1325-1341, August 1959.