

A Low Profile Loop Antenna Design for Automotive Applications

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ABSTRACT

This paper proposes a novel antenna design for automotive communication applications. The antenna design combines a resonant Alford loop with folded dipole elements to allow for efficiencies that are higher than electrically small loop antenna designs. The Alford loop provides the horizontal polarization and omnidirectional pattern coverage on the horizon which is desired for remote keyless entry and other narrowband automotive applications. With the use of folded dipole elements, the design allows for low profile mounting desired by automotive styling.

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INTRODUCTION

Omnidirectional diversity antenna systems are becoming important to various vehicle communication applications. For automotive styling purposes, it is also valuable for antenna designs to have a low profile as they are placed on the vehicle.

Electrically small loop antennas are favorable for their simplicity and their radiation pattern. However, these electrically small loops need matching networks to operate and have relatively low efficiency. The efficiency is further reduced when these loops are placed close to a ground plane, meaning that much higher input powers are needed to reach the necessary application range requirements.

This design favors efficiency and range over simplicity for the purpose of narrowband applications while maintaining the omnidirectional radiation pattern and horizontal polarization of an electrically small loop. It attempts to solve the issue of having a low profile for automotive styling by staying close to the ground plane.

Electrically Small Loop

An electrically small loop produces the horizontally polarized radiation pattern that is desired as shown in [figure 1](#) and [figure 2](#). However, the efficiency of an electrically small loop is reduced from an already low number around 25.3% due to low radiation resistance relative to Ohmic losses ([Figure A1](#)), to an even lower number around 2.9% when placed .075 wavelengths above a ground plane ([Figure A2](#)) as shown in [Appendix A](#).

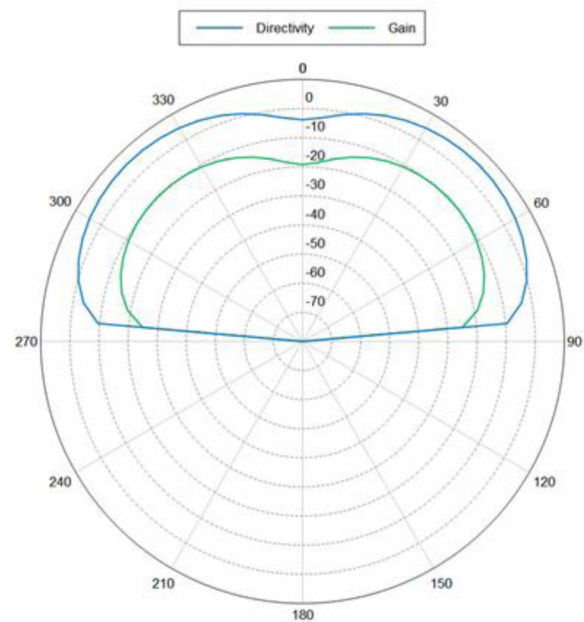


Figure 1. Radiation pattern of electrically small loop, ~ 0.1 wavelength circumference, 0.075 wavelengths above ground plane (Gain in dBIL)

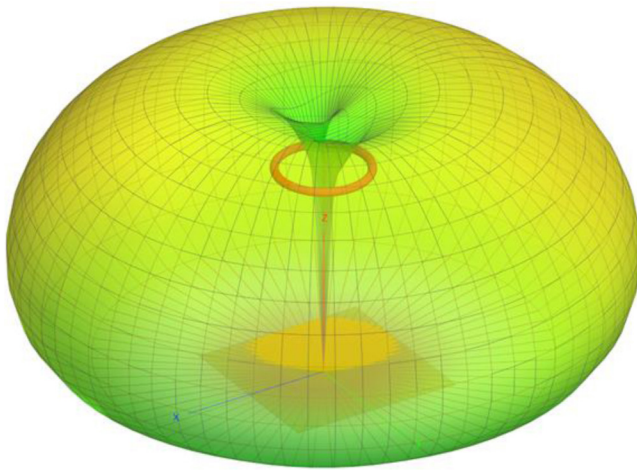


Figure 2. 3D Radiation pattern of electrically small loop, ~ 0.1 wavelength circumference, 0.075 wavelengths above ground plane.

Folded Dipole

A folded dipole radiates a pattern similar to a single dipole, but has an input impedance that can be changed as a function of the size of the conductors. This means that a good impedance match can be designed directly into the antenna, and a high antenna efficiency can be achieved. From the *Antenna Engineering Handbook* by Volakis [1], the step-up impedance ratio for transforming the input impedance, $(1+a)^2$, can be found to a good approximation by equation 1 where d is the distance between the conductors and ρ is the radius of each conductor as shown in figure 3.

$$a = \frac{\ln(d/\rho_1)}{\ln(d/\rho_2)} \quad (1)$$

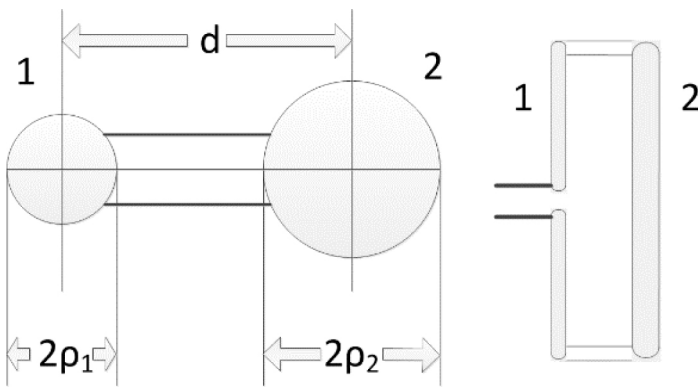


Figure 3. Folded dipole dimension diagram showing different conductor thicknesses, ρ_1 and ρ_2 , and distance between conducting elements, d .

Alford Loop

From *Modern Antenna Design* by Milligan [2], “An Alford loop feeds two dipoles curved into a loop that radiates an omnidirectional pattern with horizontal polarization when located horizontally over a ground plane.” An Alford loop has a 1 wavelength circumference, but has a similar radiation pattern as that of an electrically small loop.

Combination of Designs

When the elements of the folded dipole and the Alford loop are combined, the desired impedance match can be achieved using the properties of a folded dipole, and the desired radiation pattern can be reached from the Alford loop shape. This is more desirable than an electrically small loop because the electrically small loop needs a matching circuit to increase efficiency, whereas a good match and high efficiency is designed into this folded dipole, Alford loop hybrid.

Specifically, the folded dipole element matches the real part of the input impedance to 50Ω . There is no imaginary component of the input impedance because the Alford loop is a resonant loop antenna. Current is constant across the loop so a near magnetic dipole pattern is achieved.

DESIGN

This paper looks at two potential implementations of this antenna design, a two-feed Wilkinson divider implementation as described in figure 4 and shown in figure 5, and a single-feed implementation as described in figure 6 and shown in figure 7 taking advantage of the folded dipole elements being highly coupled. This eliminates the power divider by replacing one feed point with a short to ground, and is less complex than the power divider implementation. The single-feed implementation will have a slight asymmetry in its radiation pattern due to the current not being fed symmetrically to the loop.

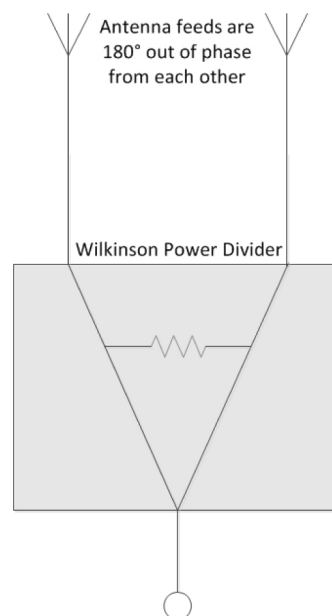


Figure 4. Diagram of two-feed Wilkinson Divider implementation

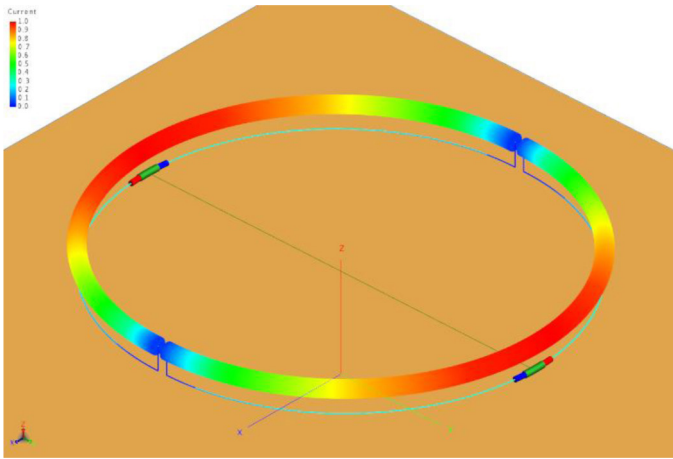


Figure 5. Two-feed folded dipole, Alford loop hybrid antenna with rough current distribution

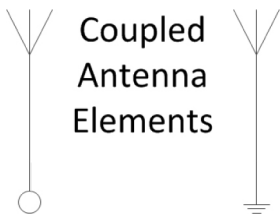


Figure 6. Diagram of single-feed folded dipole, Alford loop implementation

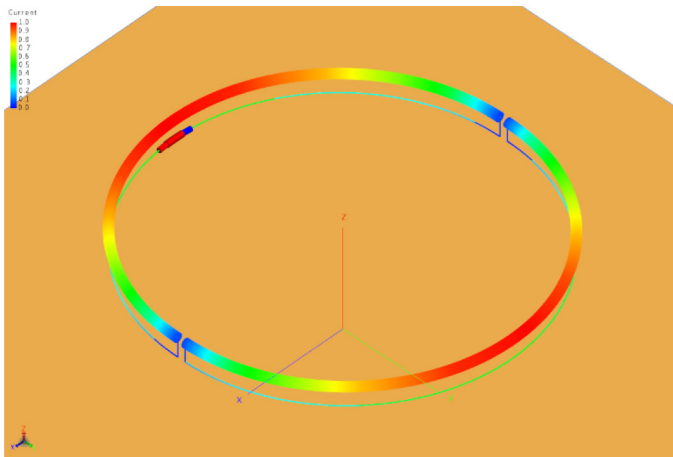


Figure 7. Single-feed folded dipole, Alford loop hybrid antenna with rough current distribution

PERFORMANCE

Efficiency

The biggest advantage of this design is that it has efficiencies above 80% in band as shown in figure A3 and figure A4 in [Appendix A](#), significantly higher than the ~3% efficiency of an electrically small loop .075 wavelengths above a ground plane as shown in figure A2 in [Appendix A](#).

Radiation Pattern

This design gives the desired magnetic dipole or loop antenna radiation pattern as shown in [Figure 8](#) and [Figure 9](#). It should be noted that there is a slight asymmetry in the single-feed hybrid antenna implementation radiation pattern due to the asymmetry in the feed points.

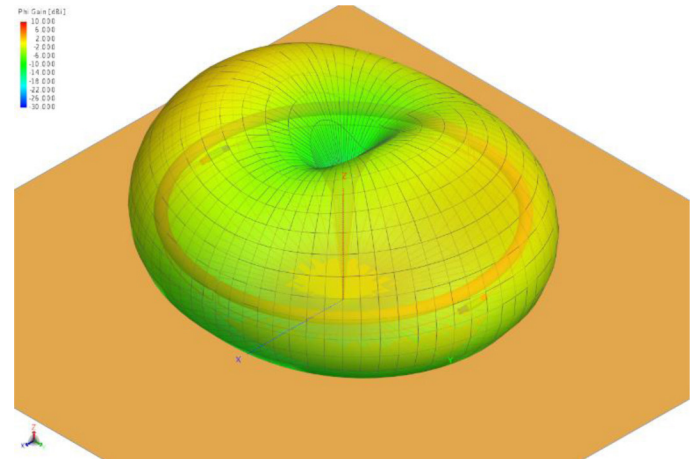


Figure 8. Two-feed folded dipole, Alford loop hybrid antenna radiation pattern. (Gain in dB/L)

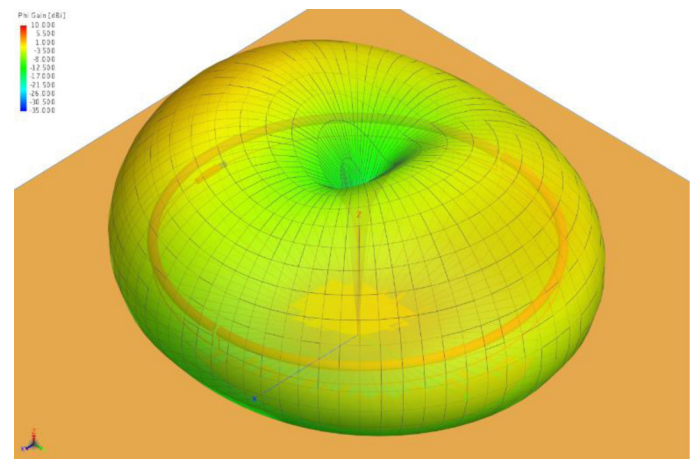


Figure 9. Single-feed folded dipole, Alford loop hybrid antenna radiation pattern. (Gain in dB/L)

Drawbacks of Design

One disadvantage of this design is that it has a narrow bandwidth. Plots of the bandwidth for each hybrid antenna implementation are given in [Appendix B](#). The bandwidth could be increased by raising the conducting elements farther above the ground plane. This design is also larger and more complex than an electrically small loop. It also has some phi degradation (ripple) relative to an ideal loop as shown in [Appendix D](#).