https://dx.doi.org/10.4314/ijs.v25i2.6

EXPLORING THE GEOMETRY OF MINIATURIZED ARCHIMEDEAN SPIRAL ANTENNAS FOR SMALL AND PORTABLE MULTITASK DEVICES

Adenodi, R. A.
Department of Physics, Adeyemi Federal University of Education, Ondo, Nigeria.
Corresponding Author's Email: adenodiraph@gmail.com
(Received: 17th April, 2023; Accepted: 13th July, 2023)

ABSTRACT

The focus of miniaturization is the production of small and portable devices that can be carried in the pocket anywhere and anytime. Small and portable devices that perform multitask such the smartphone requires a portable and efficient antenna that operates in many frequency bands. A single planar miniaturized Archimedean spiral antenna, which operates in a frequency range that is determined by its inner and outer radii of its arc, has been adjourned to be a better candidate for these multiple tasks. This study examined the geometry of a miniaturized Archimedean spiral antenna of varying turns. An inner radius of 4.90 mm and a thickness of 0.0356 mm suitable for the printed antenna were previously chosen for the study. The length of the arc and the outer radius were determined for spiral turns ranging from 0.5 to 100 with an incremental step of 0.5. Results revealed the radial distance generating the spiral, the length of its arc, the outer radius, and the surface area were 4.97 mm, 15.51 mm, 4.97 mm and 77.16 mm^2 for 0.5 spiral turns, and 19.12 mm, 7,546.80 mm, 2,849.33 mm and 1,148.64 mm^2 for 100 spiral turns. Based on the outer radii, the frequency range of operation will be between 16.76 MHz and 9.60 GHz. The mathematical functions formulated through curve fitting described the relationship between the outer radius and arc length with a power function and the number of turns and frequency with an exponential function, while arc length and radial distance, area and number of turns, and area and pitch angle are described by polynomial functions. It is recommended that further analysis on the geometry of the minimized Archimedean spiral antenna be conducted.

Keywords: Archimedean spiral antenna, Pitch angle, Arc length, Radial distance, Geometry and varying turns.

INTRODUCTION

This spiral is named after the Greek Mathematician Archimedes who first created the planar two-dimensional curve by moving a point simultaneously away from the origin at a uniform linear speed and round the origin at a uniform angular speed. Archimedean spiral is a mathematical curve that expands outwards as it rotates around a central point. The spiral became famous after Edwin Turner in 1954, winding up the arms of a dipole antenna by into Archimedean spiral (Volakis *et al.*, 2010). The resulting antenna has some parameters which are contributing significantly to wireless communication. The spiral antenna is designed to radiate electromagnetic waves in a directional pattern, with the direction of radiation being perpendicular to the plane of the spiral. Miniaturization of Archimedean spiral antenna is achieved by reducing the size of the spiral conductor as well as its geometry. It is designed to be small, yet effective in performance. This antenna is widely used in many applications such as in smartphones, radar, aircraft, spacecraft, satellite (Baby and Michael, 2015), telemetry, global positioning system, differential global positioning system, navigation, wearable, and medical sensors and implants (Hadyat *et al.,* 2018), radiofrequency energy harvesting, radiofrequency identification (Amin *et al.,* 2012), remote sensing, to mention a few. Miniaturized Archimedean spiral antenna have numerous advantages which include but not limited to its small and portable size, high efficiency, directional radiation pattern, and ability to operate over a wide range of frequencies (Amin *et al.,* 2012).

According to Wang *et al.* (2019) and Zhang *et al.* (2021), the Archimedean spiral antenna can be fed at both the inner and outer ends. Depending on the specific application and the required frequency, any two points along the arc length may be selected to achieve the set goal. In recent years, miniaturized antennas have become an important research area due to the growing demand for portable, smaller, and more efficient devices. Therefore, the geometry of miniaturized Archimedean spiral antennas has become an important consideration for the design of such antennas. This study explores the geometry a of miniaturized Archimedean spiral antenna of varying turns. The parameters of the spiral are related by (Bunea *et al.*, 2020):

$$r = r_i + b\theta \quad (1)$$

where r is the radial distance of the points which move with a uniform linear speed from the origin, θ is the pitch angle produced as the points move at uniform angular speed round the origin and b is a constant value which denotes the growth rate of the curve, and is given by (Sharma and Bernhard, 2020):

$$b = \frac{r_o - r_i}{2\pi n} \quad (2)$$

where n is the number turns of the spiral, r_i and r_o are the radii of the inner and outer arms, respectively. The length of the Archimedean spiral's arc is represented by (Chen and Huff, 2014):

$$L = \int_{\theta_i}^{\theta_o} \sqrt{r^2 + \left(\frac{dr}{d\theta}\right)^2}\, d\theta \quad (3)$$

where θ_i is the initial pitch angle and $\theta_o = 2\pi n$ is the final pitch angle for n number of turns. If the spiral curve starts from the origin of the spiral, then $\theta_i = \theta^o$. For a two-arm Archimedean antenna, the two arms have the same dimension but one is 180 degrees out of phase with the other (Sharma and Bernhard, 2020). The maximum f_{ma} and minimum f_{mi} frequencies between which the antenna can operate are related to the inner and outer radii of the spiral by:

$$f_{ma} = \frac{c}{2\pi r_i} \quad (4a) \qquad f_{mi} = \frac{c}{2\pi r_o} \quad (4b)$$

where c is the speed of light in vacuum.

METHODOLOGY

An inner radius of 4.90 mm and a thickness of 0.0356 mm suitable for a printed antenna were previously chosen for the study. Each turn has an inner angular value $\theta_i = \theta^o$ and outer value of $\theta_o = 2\pi n$ where n varies from 0.5 to 100 in a step of 0.5. Therefore, θ_o value varies from π to 200π. The relationship

$$L = \int_{\theta_i}^{\theta_o} \sqrt{(r_i + b\theta)^2 + b^2}\, d\theta \quad (5)$$

was integrated to determine the length of arc. The study uses symbolic and numerical computation methods.

Computation

The symbolic module of Python was used to simplify the above polar formula, which makes the substitution easier. Integrating with the value of θ and b yields the relation present below.

$$\int_{\theta_i}^{\theta_o} \sqrt{(r_i + 2.263526 \times 10^{-5}\theta)^2 + 5.123549952676 \times 10^{-10}}\, d\theta \quad (6)$$

Thereafter, the value of r_i is imputed to yield the length of the arc and r_o. The script is made to run for all turns to produce the value of arc length and the radius at the end of the arc. The radial distance of the spiral is used to estimate the area the planer antenna will occupy within the device where it will be utilized. Mathematical functions that best describe the relationship between the arc length in terms of the radial distance, the outer radius in relation to the arc length, the area with respect to the number of turns, the number of turns as a function of the frequency and the area as a function of the pitch angle were deduced through curve fitting module of MATLAB (Hoxha and Meklachi, 2022). Due consideration was given to the residual plot to ensuring the best fitting functions.

RESULTS AND DISCUSSION

This effort is aimed to studying the geometry of Archimedean spiral antenna vis a vis the length of the arc, the area it will occupy within a device. Results reveal the radial distance, the arc length, the outer radius, and area are 4.97 mm, 15.51 mm, 4.97 mm, and 77.16 mm^2 for 0.5 spiral turns, and 19.12 mm, 7,546.80 mm, 2,849.33 mm and 1,148.64 mm^2 for 100 spiral turns. The antenna operates within the frequency range of 16.76 MHz and 9.60 GHz. A single-arm spiral antenna will require less space. The number of turns can be adjusted to select a range of frequencies within the range noted above for any particular application or set of applications and any two points along the arc length that will be suitable for the set application. Figure 1 presents a planar 25-turns two-arm Archimedean spiral antenna.

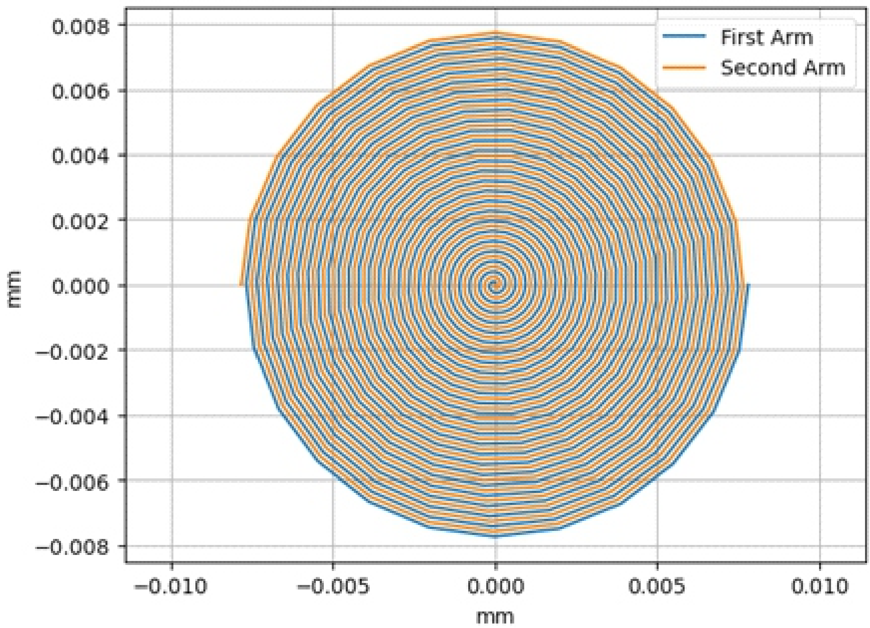

Figure 1: A planar 25-turns two-arm Archimedean spiral antenna.

The result of the curve fitting is presented as follows:

Arc length plotted as a function of the radial distance shown in Figure 2 is described by a polynomial function:

$$f(x) = -103.2x^4 + 15.16x^3 + 2.209 \times 10^4 x^2 - 785.5x + 6.453 \quad (7)$$

The goodness of fit is given by Sum of Square of Error (SSE): SSE = 1.03×10^{-13}, $R_2 = 1$, adjusted $R^2 = 1$ and $RMSE = 2.287 \times 10^{-8}$.

Outer radius plotted as a function of the arc length shown in Figure 3 is described by the power function:

$$f(x) = -0.2319x^{1.246} - 0.04958 \quad (8)$$

The goodness of fit is given by $SSE = 0.09013$, $R^2 = 0.9995$, adjusted $R^2 = 0.9995$ and $RMSE = 0.02128$.

The area plotted as a function of the number of turns shown in Figure 4 is described by the polynomial function

$$f(x) = 6.355 \times 10^{-8} x^2 + 4.379 \times 10^{-6} x + 7.544 \times 10^{-5} \quad (9)$$

The goodness of fit is given by $SSE = 1.62 \times 10^{-17}$, $R^2 = 1$, adjusted $R^2 = 1$ and $RMSE = 2.868 \times 10^{-10}$.

The number of turns plotted as a function of frequency shown in Figure 5 is described by the exponential function:

$$f(x) = 3.077 \times 10^5 x^{-0.4816} - 2.38 \quad (10)$$

The goodness of fit is given by $SSE = 38.82$, $R^2 = 0.9998$, adjusted $R^2 = 0.9998$ and $RMSE = 0.4439$.

Area plotted as a function of the pitch angle shown in Figure 6 is described by the polynomial function:

$$f(x) = 4.904 \times 10^{-13} x^2 - 1.216 \times 10^{-8} x + 7.544 \times 10^{-5} \quad (11)$$

The goodness of fit is given by $SSE = 1.62 \times 10^{-17}$, $R^2 = 1$, adjusted $R^2 = 1$ and $RMSE = 2.868 \times 10^{-10}$.

In all, the residuals exhibit a random distribution centered around the zero line. The SSE and RSME are very small while the R square and adjusted R square are high, making the goodness of fit very reliable.

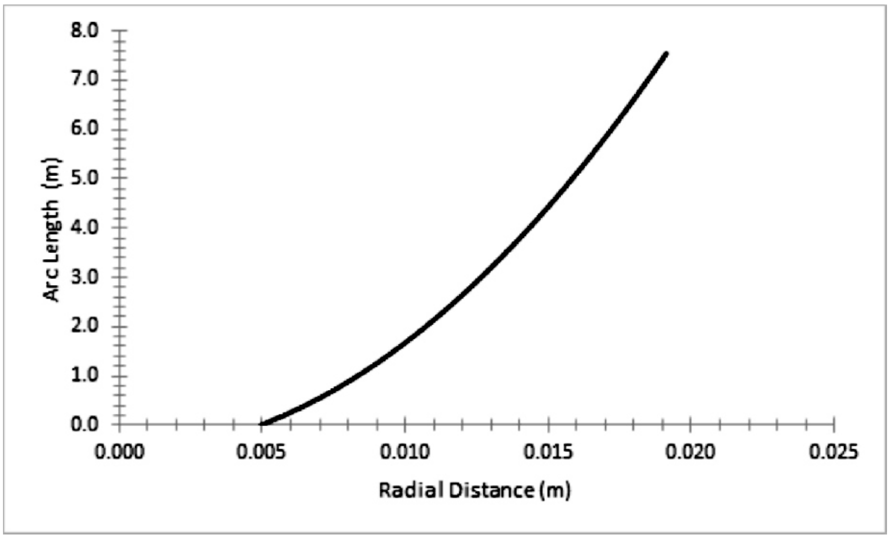

Figure 2: A plot of linear radius against arc length.

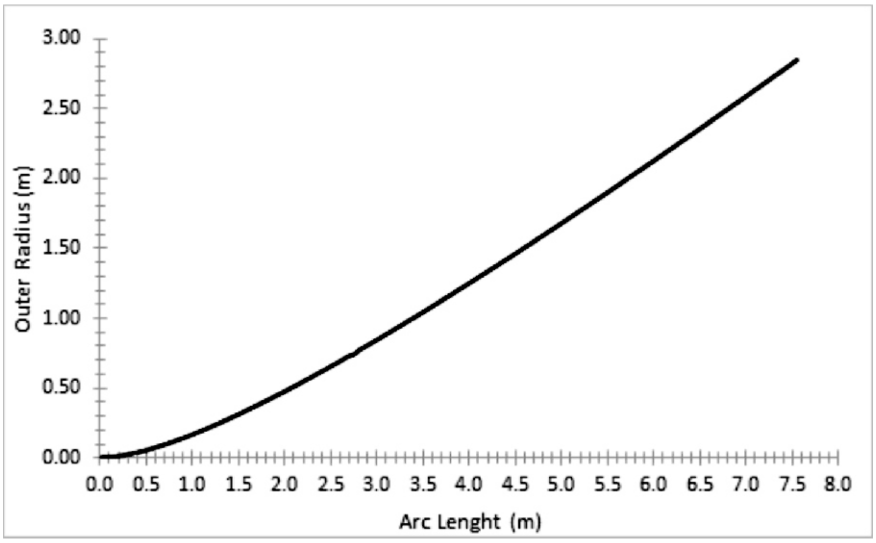

Figure 3: A plot of outer radius against arc length.

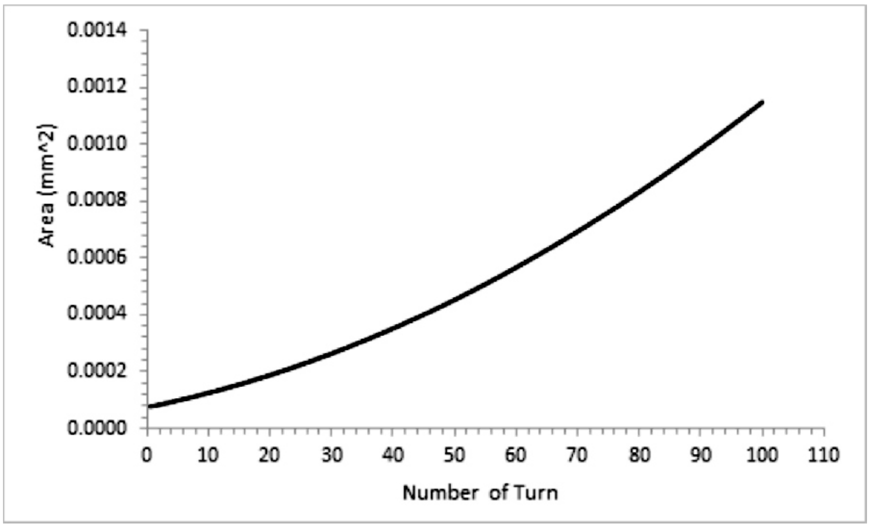

Figure 4: A plot of area against frequency.

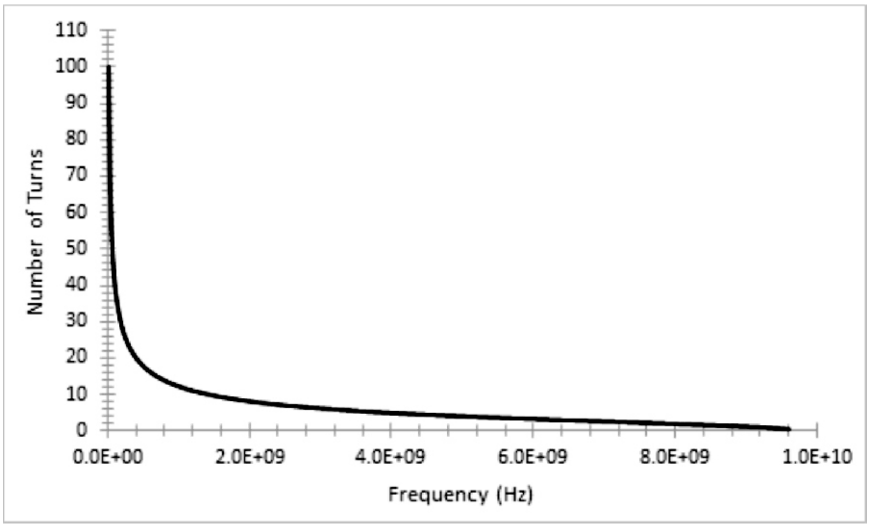

Figure 5: A plot of frequency against the number of turns.

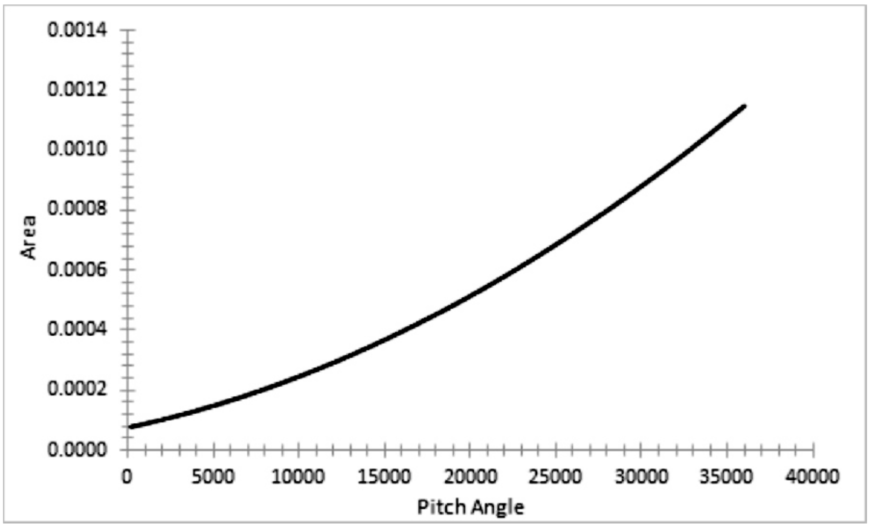

Figure 6: A plot of area against pitch angle.

CONCLUSION

This manuscript presents a study on the geometry of a miniaturized Archimedean spiral antenna with varying turns. The results demonstrate that the radial distance, arc length, outer radius, and area of the antenna can be adjusted according to the number of turns and frequency, providing versatility for different applications. These findings highlight the potential of miniaturized Archimedean spiral antennas for portable and efficient devices, contributing to our understanding of miniaturized antennas and their design considerations. Additionally, this research paves the way for advancements in wireless communication technology. Further analysis on the geometry of these antennas is recommended to explore their capabilities in various applications.

FUNDING

Fund for the study was provided by the researcher.

CONFLICT OF INTEREST

The author declares that there are no conflicts of interest regarding the publication of this study.

REFERENCE

Amin, Y., Chen, Q., Zheng, L. R. and Tenhunen H. 2012. Design and Fabrication of Wideband Archimedean Spiral Antenna-Based Ultralow Cost \Green" Modules for RFID Sensing and Wireless Applications. *Progress in Electromagnetics Research*, 130: 241–256.

Baby, L. and Michael, N. R. 2015. Self-Complementary Two Arm Archimedean Spiral Antenna for Aircraft Applications. *International Journal of Current Engineering and Technology,* 5 (5): 3435–3438.

Bunea, A-C., Neculoiu, D., Avram, M. A., and Iovea, M. 2020. Wideband Sub-Terahertz Coplanar Waveguide-Fed Spiral Antenna. *Romanian Journal of Information Science and Technology*, 23 (2): 140–156.

Chen, T-K and Huff, G. H. 2014. On the Constant Input Impedance of the Archimedean Spiral Antenna in Free-Space. *IEEE Transactions on Antennas and Propagation*, 62 (7), 3869–3872.

Hadyat, R., Rushendra, R., Elijah, A., Wulandar, I. Y. and Rahim, R. 2018. A Systematic Approach to Improving the Performance of Spiral Antenna. *Jurnal Telematilka,* 12 (2): 169–174.

Hoxha, I. and Meklachi, T. 2022. Data Fitting with Rational Functions: Scaled Null Space Methods with Applications of Fitting Large-Scale Shocks on Economic Variables and S-Parameters. *Algorithms,*15 (2): 57.
doi: 10.3390/a15020057

Sharma, P. and Bernhard, J. T. 2020. Analysis of Archimedean Spiral Slot Antennas in Infinite Ground Planes Using the Theory of Characteristic Modes. *IEEE Access,*10: 7082 – 7098.

Volakis, J. L., Chen, C-C and Fujimoto, K. 2010. Small Antenna: Miniaturization Techniques and Applications. McGraw-Hill, New York, 324 pp.

Wang, L., Chen, H., Guo, K., Shen, F. and Guo, Z. 2019. An Inner- and Outer-Fed Dual-Arm Archimedean Spiral Antenna for Generating Multiple Orbital Angular Momentum Modes. *Electronics*, 8 (2): 251 – 263.
doi: 10.3390/electronics8020251.

Zhang, L., Luo, N., Sun, Y., He, Y., Wong, S-W., Chu, P., Mao, C. and Gao, S. 2021. A Single-Turn Stacked Spiral Antenna with Ultrawide Bandwidth and Compact Size. *Communication IEEE Transactions on Antennas and Propagation*, 69 (3): 1740 – 1745.