Performance Comparison between Archimedean and Equiangular Spiral Antenna

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***Abstract*—Spiral antennas are commonly used in communication systems due to their compact size, wide bandwidth and circularly-polarized radiation. This paper shows the design, simulation and analysis of two different types of spiral antenna; the Archimedean and Equiangular spiral. The spirals were designed to be working in the frequency range of 1–4 GHz using the CST Microwave Studio (CST MWS) software. These spiral antennas were designed and analyzed in two conditions; with and without a ground plane. Performance comparisons between the spirals were analyzed in terms of active region, current distribution, return loss S_{11}, gain and radiation pattern.**

***Index Terms*—Archimedean Spiral Antennas; Equiangular Spiral Antennas; Frequency-Independent Antennas; Self-Complementary Antennas; UWB Antennas.**

I. Introduction

As the technology in communication field is massively growing, antennas have become one of the essential elements in the communication systems. An antenna (also known as an aerial) is a device to transmit and/or to receive electromagnetic waves and is often used in radio and television transmitter or receiver [1]. There are many types of antenna available such as dipoles, monopoles, loops, patches, and travelling wave antennas.

Spiral antenna belongs to the travelling wave antenna category, and has been used for various applications in communication systems. The spirals can be classified into several geometries; Archimedean, Equiangular (also known as Log Periodic), square and star spirals. These antennas were originated from a dipole antenna, where instead of leaving the arms straight, the wires are wrapped around each other and form into a spiral [2]. The spirals are commonly used in the defense of military system for sensing applications, GPS, satellites, radars, TV signal transmissions and LTE [3]. These antennas are usually small in size, have a large bandwidth and exhibit circular polarization with low axial ratio [4]. In satellite communication system, Archimedean and Equiangular spiral geometries have been widely used since these antennas provide a very wide bandwidth. Spiral antennas also belong to the frequency-independent antenna class where the geometries of these antennas are specified by angles instead of linear dimensions. Spiral antennas start to radiate when the circumference of the spiral is equal to a wavelength, $C = \lambda$. This specific region is called the 'active region' [5,6].

The performances between Archimedean and Equiangular spirals have always been compared to each other in previous literatures [7,8]. Archimedean is said to have a better control of circuitry of radiated signal at low frequency near cut off [7], but relies on close spaced turns for good operation [8]. Equiangular however, can be built with only 1.5 or 2 turns and having low circuit losses at low frequencies [8]. However, none have made a clear comparison between these two in the same literature. Therefore in this paper, the comparison between the Archimedean and Equiangular spirals is addressed. The performance is compared in terms of active region, current distribution, return loss S_{11}, gain and radiation pattern. Both spirals are analyzed in two conditions; with and without a ground plane (free space).

II. Design of Spiral Antenna

A two-arm, Archimedean and Equiangular spiral antennas were designed to be working in the frequency range of 1–4 GHz using CST MWS software [9]. The geometry designs for the Archimedean and Equiangular antennas are shown in Figure 1 and Figure 2, respectively. First, the antennas are designed and simulated in free space (without a ground plane). A ground plane is then added to the back of the spirals in order to enhance the gain of the antennas, and also to provide a unidirectional radiation with high front-to-back ratio [10,11]. An infinite ground plane would provide the best performance in reducing backlobe energy [10], but to make it realizable, the size of the ground plane should be at least the same size as the antenna. Here, the diameter of the ground plane is designed to be slightly larger than the spiral, enough to cover the active region from 1–4 GHz. Moreover, the ground plane is placed a quarter-wavelength away from the spiral at each of the targeted frequencies (i.e. $\lambda/4_{@1GHz}$, $\lambda/4_{@2.5GHz}$, and $\lambda/4_{@4GHz}$) to prevent mismatch and pattern degradation and reduction in gain. At this distance, a short circuit impedance (presented by the ground plane) is transformed to an open circuit at the spiral centre feed point [10,11].

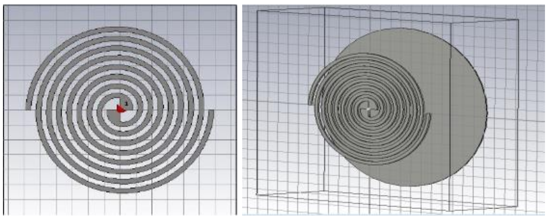


Figure 1: The geometrical parameters of the Archimedean spiral antenna in free space (left) and on a ground plane (right); spiral outer radius r_o = 44.7 mm, spiral inner radius r_i = 11.9 mm, spiral spacing s = 2.11 mm, spiral width w = 6.33 mm, spiral number of turns N = 4, spiral thickness t = 1 mm, ground plane outer radius r_{oGP} = 50 mm, and ground plane thickness t_{GP} = 1 mm.

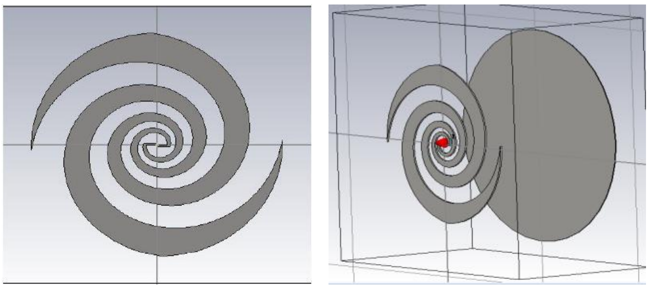


Figure 2: The geometrical parameters of the Equiangular spiral antenna in free space (left) and on a ground plane (right); spiral outer radius r_o = 44.7 mm, spiral inner radius r_i = 11.9 mm, a = 0.2, δ = 90°, spiral number of turns N = 4, spiral thickness t = 1 mm, ground plane outer radius r_{oGP} = 50 mm, and ground plane thickness t_{GP} = 1 mm.

III. Simulation Results

The simulated results were analyzed at three different frequencies; 1 GHz, 2.5 GHz and 4 GHz, which are the lowest, center and highest of the frequency range 1–4 GHz. Table 1 shows the location of the active region (C = λ) within the proposed spiral geometries and the corresponding outer radius of the spiral.

Table 1
The Circumference (mm) of the Active Region andtThe Corresponding Outer Radius (mm) of The Spiral At 1 GHz, 2.5 GHz and 4 GHz.

Frequency	Active region	Outer radius, r_o
1 GHz	300 mm	47.7 mm
2.5 GHz	120 mm	19.1 mm
4 GHz	75 mm	11.9 mm

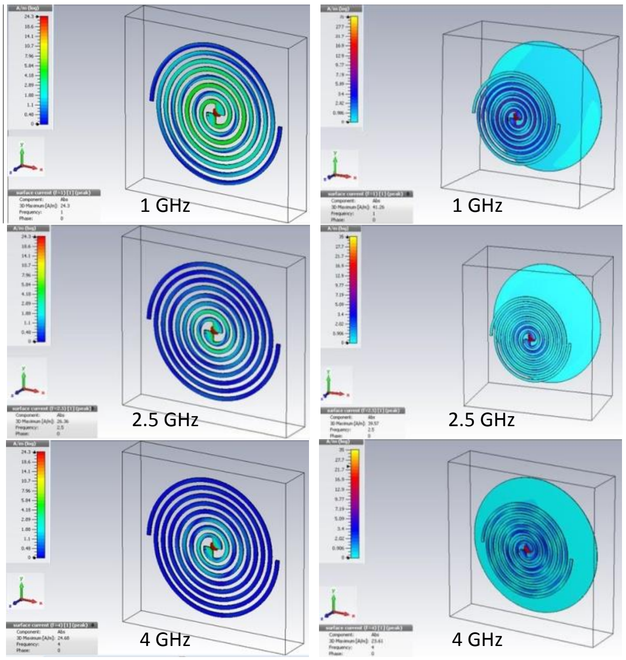


Figure 3: Simulated current distribution of Archimedean spiral antenna in free space (left) and on a ground plane (right) with λ/4 separation distance at 1 GHz, 2.5 GHz and 4 GHz.

The spiral outer radius for the active region of frequency 1 GHz, 2.5 GHz and 4 GHz was calculated to be 47.7 mm, 19.1 mm and 11.9 mm, respectively. Figure 3 and Figure 4 show the simulated current distribution of both Archimedean and Equiangular in free space and on a ground plane, which shows the location of the active region within the spiral geometry [6]. The return loss, S_{11} for the Archimedean and Equiangular spiral antennas in free space and on a ground plane can be observed in Figure 5 and Figure 6. Both spirals radiated perfectly in free space as the S_{11} along the operating frequency range of 1 GHz to 4 GHz is below than -10 dB.

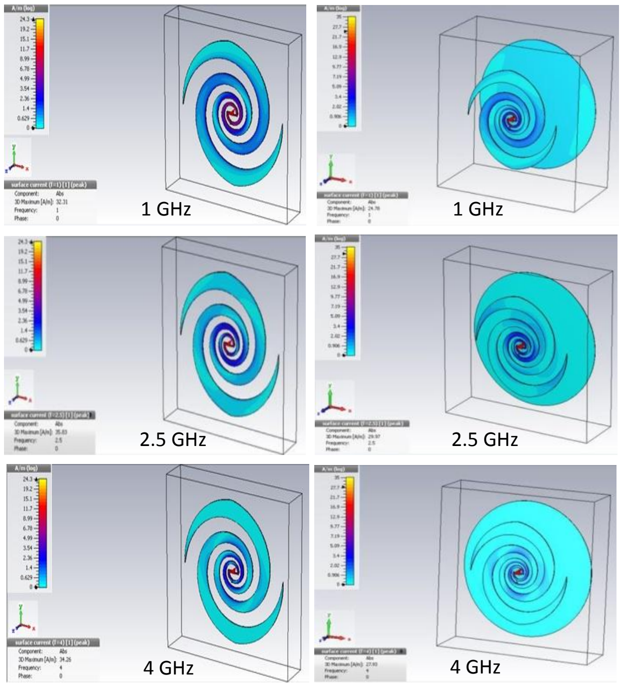
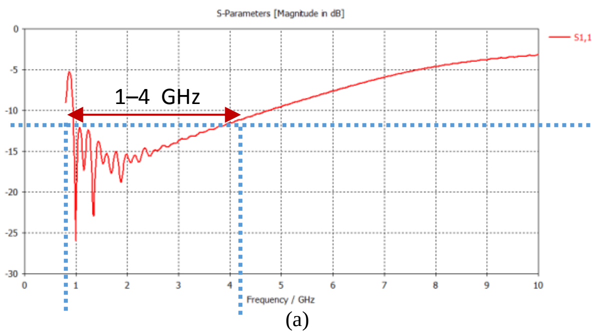
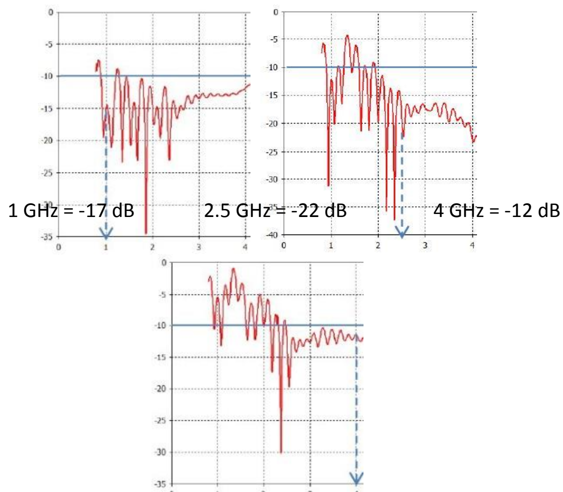


Figure 4: Simulated current distribution of Equiangular spiral antenna in free space (left) and on a ground plane (right) with λ/4 separation distance at 1 GHz, 2.5 GHz and 4 GHz.

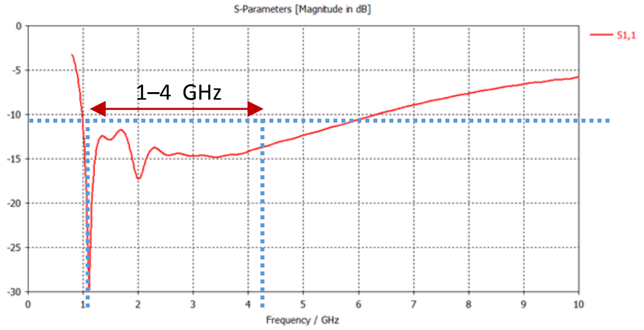


(a)

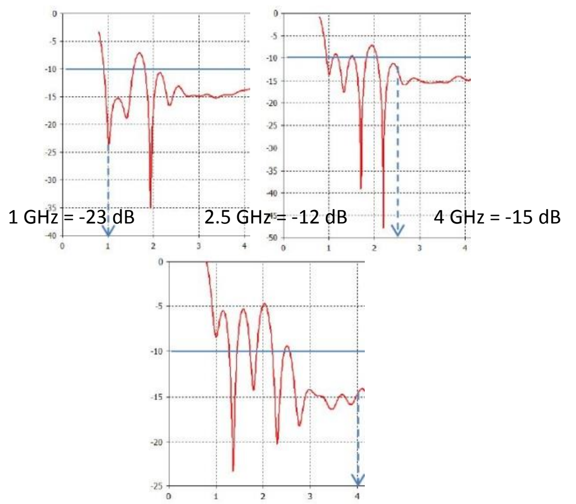


(b)

Figure 5: Simulated return loss, S_{11} (<-10 dB) of Archimedean spiral antenna in (a) free space at 1–4 GHz, and (b) on a ground plane (right) with λ/4 separation distance at 1 GHz, 2.5 GHz and 4 GHz.



(a)



(b)

Figure 6: Simulated return loss, S_{11} (<-10 dB) of Equiangular spiral antenna in (a) free space at 1–4 GHz, and (b) on a ground plane (right) with $\lambda/4$ separation distance at 1 GHz, 2.5 GHz and 4 GHz.

Next, a ground plane is inserted $\lambda/4$ below the spirals at 1 GHz, 2.5 GHz and 4 GHz. This step is performed to provide a unidirectional radiation and to increase the gain of the antennas [10]. As shown in Figure 5(b) and Figure 6(b), both spirals radiated perfectly as the S_{11} at all the targeted frequencies are below than -10 dB. Table 2(a) and 2(b) also summarized the simulated gain of the antennas in free space and with the presence of a ground plane. In free space, the gain of the Archimedean spiral is shown to be 2.6 dB (1 GHz), 5.7 dB (2.5 GHz) and 6.4 dB (4 GHz), while the gain for Equiangular spiral are 1.7 dB (1 GHz), 5.9 dB (2.5 GHz) and 6.2 dB (4 GHz). It can be observed that the gain increases when a ground plane is added to the back of the antenna.

Table 2
Performance Comparison between Archimedean and Equiangular Spiral Antenna in Terms of Return Loss S_{11}, Gain, and Radiation Pattern at 1 GHz, 2.5 GHz, and 4 GHz (A) in Free Space, and (B) an a Ground Plane with $\Lambda/4$ Separation Distance at Each Frequency.

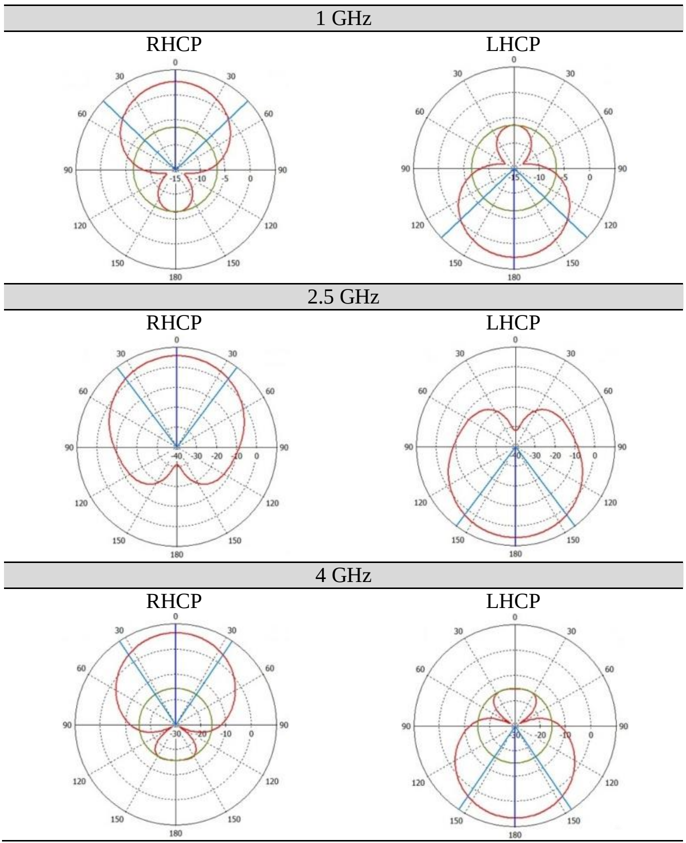
Parameter	Archimedean			Equiangular		
	1 GHz	2.5 GHz	4 GHz	1 GHz	2.5 GHz	4 GHz
S_{11}	-24 dB	-15 dB	-12 dB	-15 dB	-14 dB	-14 dB
Gain	2.6 dB	5.7 dB	6.4 dB	1.7 dB	5.9 dB	6.2 dB
Pattern	Bi-dir.	Bi-dir.	Bi-dir.	Bi-dir.	Bi-dir.	Bi-dir.

(a) Free space

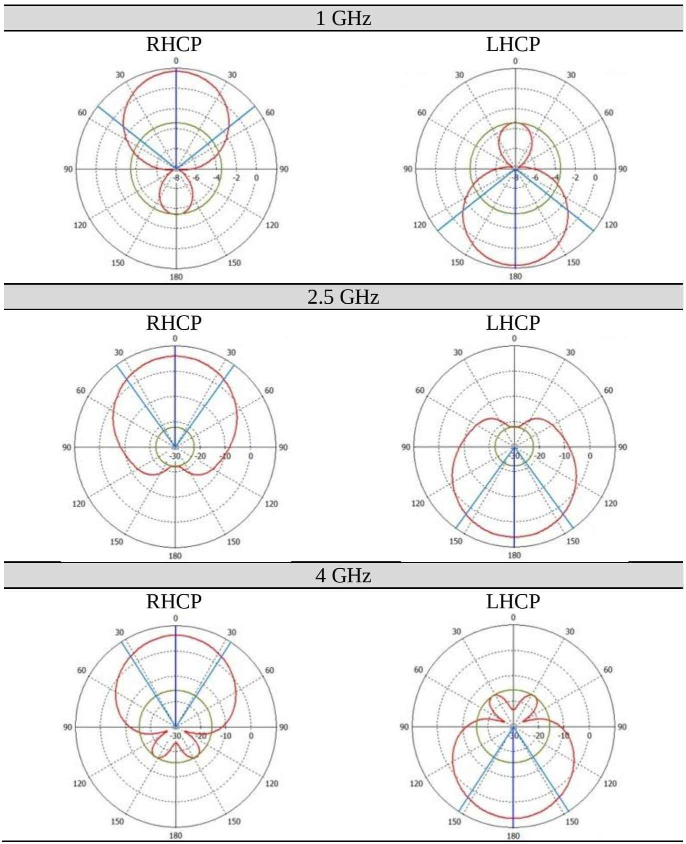
Parameter	Archimedean			Equiangular		
	1 GHz	2.5 GHz	4 GHz	1 GHz	2.5 GHz	4 GHz
S_{11}	-17 dB	-22 dB	-12 dB	-23 dB	-12 dB	-15 dB
Gain	7.8 dB	9.4 dB	8.9 dB	7.2 dB	9.5 dB	7.1 dB
Pattern	Uni-dir	Uni-dir	Uni-dir	Uni-dir	Uni-dir	Uni-dir

(b) Ground plane

Table 3
Simulated Radiation Pattern (RHCP and LHCP) of (a) Archimedean, and (b) Equiangular Spiral Antenna at 1 GHz, 2.5 GHz and 4 GHz in Free Space.

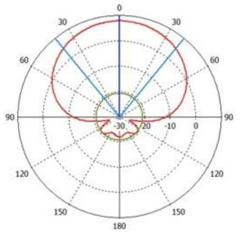
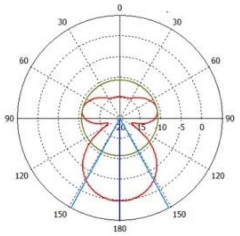
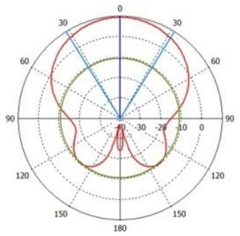
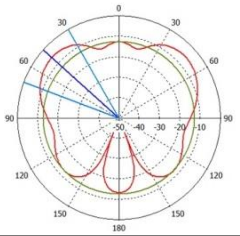
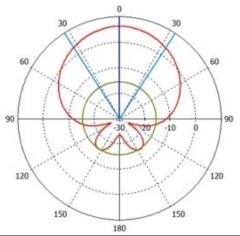
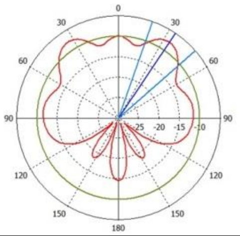


(a) Free space: Archimedean

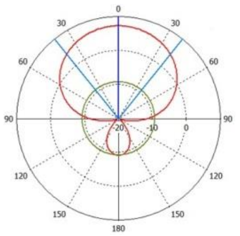
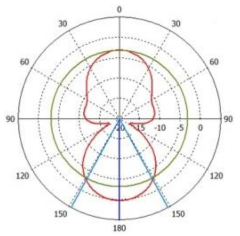
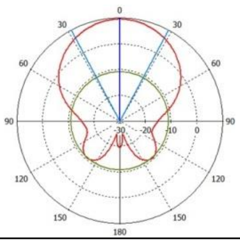
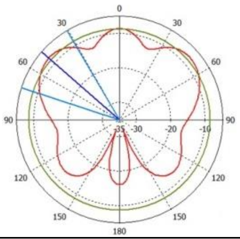
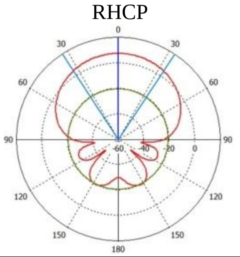
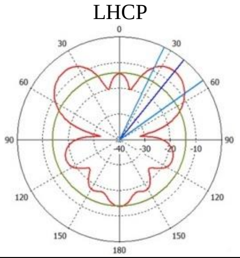


(b) Free space: Equiangular

Table 4
Simulated Radiation Pattern (RHCP and LHCP) of (a) Archimedean, and (b) Equiangular Spiral Antenna at 1 GHz, 2.5 GHz and 4 GHz with Ground plane.

1 GHz	
RHCP	LHCP
	
2.5 GHz	
RHCP	LHCP
	
4 GHz	
RHCP	LHCP
	

(a) Ground plane with $\lambda/4$ separation distance: Archimedean

1 GHz	
RHCP	LHCP
	
2.5 GHz	
RHCP	LHCP
	
4 GHz	
RHCP	LHCP
	

b) Ground plane with $\lambda/4$ separation distance: Equiangular

The gain for the Archimedean spiral increased to 7.8 dB (1 GHz), 9.4 dB (2.5 GHz) and 8.9 dB (4 GHz), while the gain for the Equiangular spiral increased to 7.2 dB (1 GHz), 9.5 dB (2.5 GHz) and 7.1 dB (4 GHz). Table 3 and Table 4 show the radiation patterns of the Archimedean and Equiangular spiral antenna in free space and with a ground plane. It can be observed from Table 3 that the spirals exhibit bidirectional radiation pattern with equal gain on the right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP). The power in the lower hemisphere is then reflected to the upper hemisphere with the addition of a ground plane at $\lambda/4$ separation distance, which provides a unidirectional radiation pattern (see Table 4).

IV. Conclusion

The design and simulation of a two-arm, four turn Archimedean and Equiangular spiral antenna in the frequency range of 1–4 GHz has been performed. The antenna performances such as active region, current distribution return loss S_{11}, gain and radiation pattern of the two spirals have been studied and investigated. Archimedean spiral is said to have a better control of circuitry of radiated signal at low frequency near cut off [7,8]. This can be seen by the result obtained in this paper at 1 GHz, where the return loss of Archimedean is shown to be better, with S_{11} = -24 dB and gain = 2.6 dB, compared to Equiangular with S_{11} = -15 dB and gain = 1.7 dB. Nevertheless, the return loss of Equiangular at this particular frequency is still in the acceptable region of S_{11} <-10 dB. Moreover, the current distribution of the Archimedean is shown to have a distinct and clearer surface current, which makes it easier to detect the exact location of the active region. This characteristic is important if active region is taken into consideration, such as in the design of a conical or a stepped ground plane for wideband spiral antennas [11]. Thus, it can be concluded that the choice of spiral depends on whether an excellent low frequency performance and active region location is required, or researchers can opt for Equiangular design which are simpler and require less number of turns compared to Archimedean.

Acknowledgment

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