Novel Quadrifilar Helical Antenna for RFID Applications Using Genetic Algorithms

M. O. Akinsolu[1], **A. Ali**[1], **A. Atojok**[1], **E. Ibrahim**[1,2], **I. T. E. Elfergani**[3], **R. A. Abd-Alhameed**[1], **Abubakar Sadiq Hussaini**[1,3,5], **J. M. Noras**[1], **and Jonathan Rodriguez**[3,4]

[1]University of Bradford, Bradford, West Yorkshire, BD7 1DP, UK
[2]College of Electronic Technology Bani Walid, Libya
[3]Instituto de Telecomunicacoes, Aveiro, Portugal
[4]Universidade de Aveiro, Portugal
[5]School of Information Technology & Communications, American University of Nigeria, Nigeria

Abstract— For excellent tag-read communication in RFID applications, an interrogator equipped with an antenna having a circularly polarised radiation pattern is required. The antenna must also maintain a low profile and be compact for ease of installation. A more compact QHA is developed by linearly-shifting its helical elements for minimal optimum quadrature-distance. As a result, a novel QHA design, a "linearly-shifted quadrifilar helical antenna" (LSQHA) is proposed to operate at 900 MHz RFID applications using Genetic Algorithm (GA) driver with the industry-standard NEC-2 computational analysis program. Performance of the GA-optimised antenna shows that it has a 3 dB beamwidth of 90 degrees and a total gain of 13.1 dBi at the design frequency of 900 MHz. The proposed antenna excellently meets VSWR and return loss requirements within the frequency boundary of (875–912.5) MHz. The performance also shows that the proposed LSQHA is circularly polarised.

1. INTRODUCTION

Antennas constitute a very important part of Radio Frequency Identification (RFID) systems [1]. Coming in various forms and types, they are usually designed and intended to ensure maximum effective and efficient communication links between tags or transponders and their associated readers or interrogators. One of the primary challenges in the design and development of antennas in RFID applications as it is in other wireless applications is having an antenna with optimised parametric features that are desirable and in consonance with laid down specifications and functional requirements [1, 2].

RFID systems which connote the physical interaction between a tag and a reader for automatic identification operate within the global bandwidth of (860–960) MHz as specified by the International Standards Organisation (ISO) [3]. RFID systems function by adopting a non-contact application of radio-frequency that does not require a line-of-sight channels [4]. In order to optimise an RFID system, the orientation of the tags and associated readers must be fully established through the polarisation characteristics of their corresponding antennas. RFID tags are often designed to have linearly polarised dipoles [5].

The quadrifilar helical antenna (QHA) (example see Figure 1) has been identified by previous works as a suitable antenna for omnidirectional tag reading in RFID and other wireless applications, due to its ability to give circular polarisation over a wide angular area [6, 7]. Another excellent property of QHAs in terms of the symmetry of their geometry is their ability to give a cardioid-shaped radiation pattern regardless of the axial length and diameter [8]. It has also been established that the inherent cardioid-shaped radiation patterns of QHAs can be made conical by extending the resonant fractional turns of the QHA to an integral number for improved characteristics [9].

The QHA (Figure 1) is capable of providing an excellent beamwidth pattern with desirable circular polarisation, making it a good choice in RFID applications [2]. However, optimum caution is needed in the design and development of QHAs to realise the specified axial ratio and front to back power ratio. One of the notable pitfalls in the design and development of QHAs is the overall axial length of antenna, which is often too bulky for many practical installations and applications To address this problem, a global optimisation technique was employed to constrain the geometrical parameters of the conventional QHA. The selected global optimisation technique, genetic algorithm (GA) has been exemplified as an effective and efficient tool in RF and EM engineering optimisation [10]. In addition GA has been used in previous works to achieve low profile, compact designs for QHAs in other wireless communications applications [6, 7].

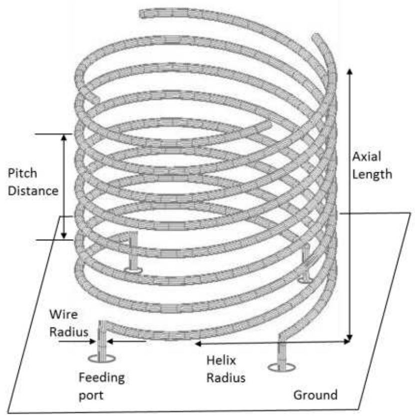


Figure 1: Basic geometry of the QHA.

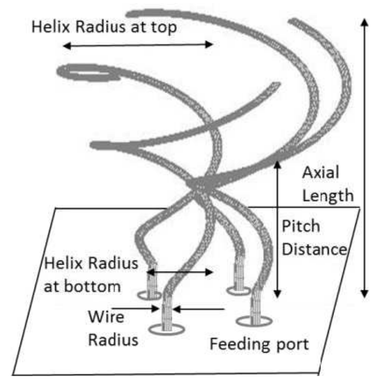


Figure 2: Geometry of the linearly-shifted quadrifilar helical antenna (LSQHA).

The novel QHA antenna is named linearly-shifted quadrifilar helical antenna (LSQHA) because its elements are linearly-shifted and made compact to cover the global BW 860–960 MHz as revealed in Figure 2. With reference to its helical elements and as can be observed, the proposed LSQHA design does not take the form of the conventional QHA. Specifying a finite ground and feeding of the LSQHA via an integrated feed network is proposed, to avoid the intricacy and losses associated with multiple feed points of a centre feed. At the risk of repetition, the novel antenna structure is achieved by linearly-shifting the helical elements of the conventional QHA by 90° using a defined phase quadrature distance. This design is expected to reduce the axial length and overall volumetric equivalent of the LSQHA, while retaining good axial ratio, high power gain and wide beamwidth coverage.

2. ANTENNA DESIGN STRUCTURE

The design and optimisation of the proposed linearly-shifted quadrifilar helical antenna in RFID applications was conducted using a GA driver synchronised with the industry-standard Numerical Electromagnetic Code (NEC-2). The GA driver is initialised by a set of initial solutions or parameters defined for the proposed LSQHA. Parametric iterations are then executed with the conjunctive running of the GA driver and the NEC-2 computational analysis program. As adopted in this work, the source codes for the GA driver synchronised with the industry-standard NEC-2 were written in FORTRAN [11, 12]. The codes were intuitively modified to randomly generate and evaluate antenna samples.

To achieve optimum results, the initial geometrical and parametric solution of the proposed LSQHA was defined for optimisation with GA based on established findings in [6, 7]. In this process, real-valued GA chromosomes were defined. Antenna parameters such as the, VSWR, axial ratio (AR) and total forward gain (G_T) were optimised at an operating frequency of 900 MHz in consonance with the EPC Global RFID Tag/Reader specifications [13]. Individual antenna samples were generated using the industry-standard NEC-2 source code and corresponding results were juxtaposed with the desired fitness function.

A summary of the GA input parameters, antenna variables and best solutions for the proposed LSQHA design is detailed in Table 1. The LSQHA was designed to provide a very high forward gain and circular polarisation within the RFID global bandwidth of (860–960) MHz. As evident, the proposed design differs from the conventional QHA in Figure 1 in that its helical elements were configured to be linearly-shifted at 90° from each other using a defined phase quadrature distance. This was deemed necessary in an effort to achieve a very compact design and lower the overall profile of the proposed antenna. In the study undertaken, the LSQHA offered a better performance with its helical elements shifted.

The simulation logic and GA optimisation model were structured in such a way that an optimum linear distance between the four helical elements of the LSQHA was sought while shifting them by 90° in phase-quadrature. Optimal parametric features for the proposed LSQHA antenna, with an excellent VSWR and AR, were found within the maximum number of GA generations specified (250): the antenna's parameters for the optimum design are detailed in Table 1. The performance of the proposed LSQHA has been analysed and verified using freeware antenna modeller

Table 1: Summary of GA input parameters and antenna variables.

GA PARAMETERS		QUADRIFILAR HELICAL ANTENNA DESIGN PARAMETERS			
	Input Values		**Minimum Value (m)**	**Maximum Value (m)**	**Optimum Value (m)**
Population Size	10	**Pitch Distance**	0.0033	0.0721	0.0558
Number of Parents	5	**Axial Length**	0.045	0.10	0.0885
Probability of mutation	0.02	**Radius of Helix (Top)**	0.01	0.035	0.035
Maximum Generation	250	**Radius of Helix (Bottom)**	0.01	0.035	0.0342
Probability of Crossover	0.5	**Linear Quadrature Distance Between Helical Elements**	0.035	0.07	0.0501
Probability of Creep	0.04	**Fixed Radius of Wires**	0.0005	0.0005	0.0005
Number of Possibilities	32768	**Fixed Distance above ground**	0.01	0.01	0.01

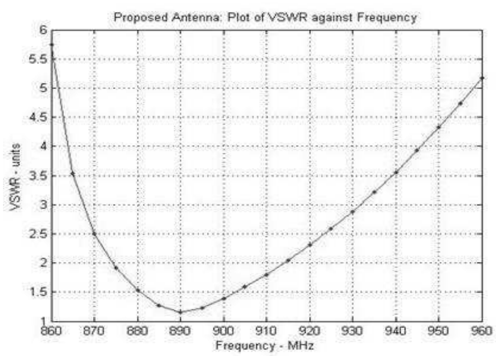


Figure 3: Computed VSWR for the proposed LSQHA.

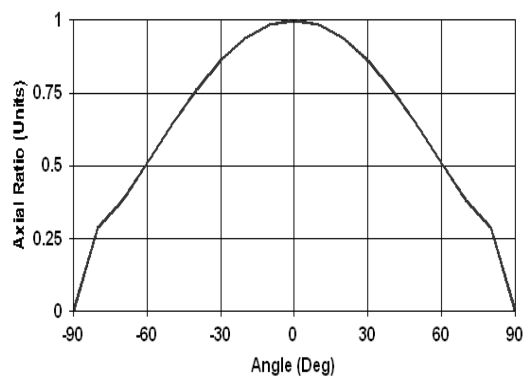


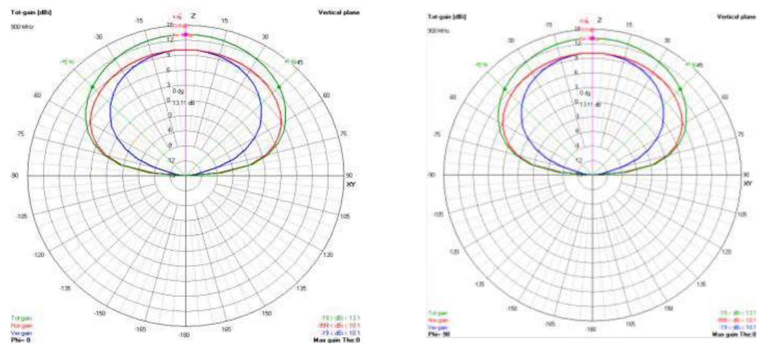
Figure 4: Axia ratio of the LSQHA.

and simulation software [14].

Evidently, the overall profile of the optimal design of LSQHA showcases the effectiveness of the compactness achieved by employing the logic and architecture illustrated in Figure 2. In contrast to the conventional QHA design (see Figure 1), the LSQHA was configured to have its helical elements more closely fitted together in volume and space. The LSQHA offers a more compact design in terms of its surface area, while retaining a good axial ratio and a very good beamwidth. Critical analysis of the performance of the optimal LSQHA was conducted to ascertain parametric features in terms of bandwidth, axial ratio coverage and antenna gain. The proposed LSQHA was found to have an optimum axial length of 8.85 cm as revealed in Figure 3.

The VSWR at the input ports of the optimised LSQHA antenna was calculated using an electromagnetic modelling software package and evaluated to be 1.39 at the EPC Global RFID Tag/Reader frequency of 900 MHz respectively as shown in Figure 3. As can be seen, the optimised antenna appears to have excellent impedance matching that covers most of the bandwidth specified for RFID communications (875–912.5) MHz.

Figure 4 confirms the excellent circularly-polarised characteristic of the proposed antenna over a good elevation angle mostly prominent in the counter-clockwise direction (left hand). Figure 5(a) and Figure 5(b) depict the measured power gain radiation patterns of the proposed LSQHA at an operating frequency of 900 MHz for two vertical cut planes at $\Phi = 0°$ and $\Phi = 90°$ respectively. The



(a) (b)

Figure 5: Computed gain radiation patterns of the proposed antenna for two vertical cut planes; (a) $\Phi = 0°$ and (b) $\Phi = 90°$.

proposed antenna shows approximately $\pm 45°$ elevation angle range for an axial ratio less than 3 dB that is, a 3 dB beamwidth of 90°. Also, the proposed LQHSA revealed a total forward isotropic gain of 13.1 dBi.

3. CONCLUSIONS

A novel 'linearly-shifted quadrifilar helical antenna' (LSQHA) circularly polarized with a high forward isotropic gain and VSWR specifications desirable in RFID applications has been proposed. The proposed antenna is intended for deployment in RFID systems, as the reader or interrogator antenna, where the orientation and polarisation of the associated tag antennas cannot be precisely predicted. The design and optimisation of the proposed antenna using Genetic Algorithm method have been well appreciated and showcased, the specified objective being deployed for antenna design within the RFID global bandwidth of (860–960) MHz. The performance of the optimal selected antenna structure was validated using 4NEC-2. The results confirm the proposed antenna has a 3 dB beamwidth of 90° with a resonant frequency at about 890 MHz and an acceptable total forward gain of 13.1 dBi at the design frequency of 900 MHz. The optimal design reached was found to be compact and of an excellent profile. These results tell that the proposed antenna can easily be configured to sample commercial RFID readers or interrogators. On the whole, Genetic Algorithm global optimisation method has also proved its advantage in quickly finding optimal solutions for RF and EM designs.

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