ARCHIMEDEAN SPIRAL ANTENNA EMBEDDED WITH FREQUENCY SELECTIVE SURFACE FOR WIDEBAND APPLICATIONS

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"Special to my dear parents; Hawa Jama Ali and Allahyarhamu Mohamud Shire Mohamed for their prayers and support for me. Not to forget for my lovely wife, Sa'diya Ahmed Mohamed, your support keeps me up alive and my lovely kids, Mohamud and Munir"

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ABSTRACT

The potential applications such as satellite communication systems, critical military communications, radar warning systems and direction finding systems demand for high gain, uniform unidirectional radiation pattern and wideband antenna ranging from 3.1 GHz to 10.6 GHz. An Archimedean spiral antenna is the most potential candidate in the above mentioned applications as the antenna meets most of the above requirements. However, the practical implementation of spiral antenna is challenged by its bidirectional patterns, relatively low gain and the need for balanced feeding structures. A moveable ground plane is proposed as the backing technique of the spiral antenna by placing it at quarter wavelength behind spiral arms. Despite, the effects of the ground plane on the antenna's wideband properties, to enable the realization of a conformal antenna without the loss of the antenna's broadband characteristics, a radian sphere theory is proposed for bandwidth improvement. Microstrip to parallel strip line balun is proposed as the feeding structure of the spiral antenna. This balun has very large bandwidth ranging from 2 GHz to 14 GHz. However, the separation of the ground plane and the spiral arms at quarter wavelength at lower frequencies deteriorate the radiation patterns at middle and higher frequencies. In order to improve the patterns, frequency selective structure is proposed to embed in the cavity of the spiral antenna. The optimized frequency selective surface improves the radiation pattern while maintaining the other parameters such as the gain, bandwidth and axial ratio. All the proposed designs are fabricated and measured. Both simulated and measured results have shown good agreements. Finally, the results show that the proposed Archimedean spiral antenna is the most suitable candidate for above mentioned applications because good circularly polarized unidirectional radiation patterns and high gain of 8 dB to 11.2 dB with bandwidth of more than 140% is obtained.

ABSTRAK

Aplikasi berpotensi seperti sistem komunikasi satelit, komunikasi tentera kritikal, sistem amaran radar dan sistem mencari arah mempunyai permintaan untuk keuntungan tinggi, corak sinaran satu arah seragam dan jalur lebar antena daripada 3.1 GHz kepada 10.6 GHz. Antena lingkaran Archimedes adalah calon yang paling berpotensi untuk memenuhi sebahagian besar daripada keperluan aplikasi tersebut.Walau bagaimanapun, pelaksanaan prototaip antena lingkaran sangat mencabar disebabkan oleh corak dwiarah, agak keuntungan yang rendah dan keperluan teknik pengujaan yang seimbang. Satah pembunian bergerak dicadangkan sebagai teknik sokongan antena lingkaran dengan meletakkannya pada jarak suku daripada panjang gelombang di belakang lingkaran.Kesan penggunaan satah pembumian terhadap ciri-ciri jalur lebar adalah untuk membolehkan antenna komformal direalisasikan tanpa kehilangan ciri-ciri jalur lebar itu,teori sfera radian adalah dicadangkan untuk peningkatan jalur lebar. Mikrojalur ke balun talian jalur selari dicadangkan sebagai teknik pengujaan antena lingkaran. Balun ini mempunyai lebar jalur yang sangat besar di antara 2 GHz hingga 14 GHz. Walau bagaimanapun, pemisahan satah pembumian dan lengan antena lingkaran pada panjang gelombang suku pada frekuensi rendah memberi kesan buruk pada corak sinaran pada frekuensi pertengahan dan tinggi.Untuk meningkatkan corak sinaran, struktur frekuensi terpilih dicadangkan untuk menanamkan rongga di dalam antena lingkaran. Nilai optimum struktur frequensi terpilih memperbaiki corak sinaran sambil mengekalkan parameter lain seperti keuntungan, jalur lebar dan nisbah paksi. Semua reka bentuk yang dicadangkan menjalani proses fabrikasi dan pengukuran. Kedua-dua keputusan simulasi dan pengukuran menunjukkan persamaan yang baik. Akhirnya, keputusan menunjukkan antena lingkaran Archimedes yang dicadangkan itu adalah calon yang paling sesuai untuk aplikasi yang dinyatakan di atas kerana baik keliling polarisasi corak sinaran satu arah dan keuntungan tinggi 8 dB kepada 11.2 dB dengan lebar jalur lebih daripada 140% diperolehi.

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Proceedings

i. A. M Shire and F. C. Seman "Effects of dielectric substrate on performance of UWB Archimedean Spiral Antenna" Space Science and Communication (IconSpace), 2013 IEEE International Conference Pages 412-415.

ii. Abdirahman Mohamud Shire and Fauziahanim Che Seman "Analysis of the Active Region of Archimedean Spiral Antenna" Chapter 25, Notes Electrical Eng., Vol. 315, et al: Advanced Computer and Communication Engineering Technology.

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iv. F. B. Zarrabi, A. M. Shire, M. Rahimi and N. P. Gandji "Ultrawideband tapered patch antenna with fractal slots for dual notch application" Microwave Optical Technology Letters, Vol. 56, 2014, Pages:1344-1348.

v. F. C. Seman and A. M Shire "Archimedean Spiral Antenna on Moveable Ground Plane for UWB Applications" (Under Review at APRN Journal; indexed in SCOPUS).

vi. A. M Shire and F. C. Seman "Numerical Analysis of Frequency Selective Surface Using Equivalent Circuit Method" (Under Review at electronic letters)

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List of Awards

i. GOLD PRIZE "Archimedean Spiral Antenna on Moveable Ground Plane" Exhibited at the Seoul International Invention Fair (SIIF) 2014, in Seoul, South Korea.

ii. SILVER MEDAL "Archimedean Spiral Antenna on Moveable Ground Plane" Invention and Innovation Awards for Malaysia Technology Expo (MTE) 2014, in Kuala Lumpur, Malaysia.

iii. BRONZE MEDAL "Archimedean Spiral Antenna on Moveable Ground Plane for UWB Applications" Exhibited at Research and Innovation Fest (R & I) 2013, in University Tun Hussein Onn Malaysia (UTHM).

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CHAPTER I

INTRODUCTION

1.1 Introduction

Wide band is a transmission technology in which information is transmitted over large operating bandwidth. Such technology has been utilized for decades mostly for military related systems because more information and applications can be carried through the radio frequency channels with a high data rate and accuracy [1]. Wideband applications are numerous including ground penetrating radar systems, military communications, satellite communications, direction finding systems, vehicular radar systems and wireless communications [2]. In order to make the transmission and reception of an wide band system over the frequency range of 3.1 GHz to10.6 GHz; it is required to have a high gain antenna, with good impedance matching and VSWR less than 2 throughout the entire band [2-3]. Therefore, Archimedean spiral antenna is good candidate to be used in wideband applications since it has met the above mentioned requirements. Archimedean spiral antenna has received huge interest over the last two decades due to its wide impedance bandwidth, high efficiency, nearly unidirectional

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radiation pattern, low profile, stable impedance characteristic and circular polarization over the last two decades [4].

There are three different designs of spiral antennas. The first design of spiral antenna is by shaping it as a single arm spiral antenna, which is designed for some narrow-band applications. The second design is the two arm case, which is the minimum number of arms needed for single-mode broadband operation. The third design is the multi arm case, which is designed when two broadband modes are needed. This means, in order to achieve two broadband modes at least three arms are required. Therefore, in this research the second design which is the two arm case is discussed due to its advantages over the other two cases. It is because the two arm Archimedean spiral antenna has better axial ratio than the single arm Archimedean spiral antenna, which means the two arm case has better circular polarization compared to the single arm case. The two arm spiral antenna has a simple feed (e.g. Microstrip to parallel strip balun) and less complex geometry design compared to the multi arm spiral. It is because the multi arms spiral has complex geometry design and feeding systems such as a beam feeding network.

In summary, several optimizations techniques are proposed in this study such as loading lower permittivity dielectric substrate, radian sphere concept, reducing mutual coupling, moveable ground plane and embedding frequency selective surface structure in the cavity of the spiral. Therefore, these five optimization techniques leads to the invention of a new design of two arm Archimedean spiral antenna backed by cavity with large bandwidth, high gain, unidirectional pattern with circular polarization and with higher efficiency.

1.2 Problems Statement

A common approach used to cover a large frequency range which encompasses many different communication systems is to employ a separate antenna for each system.

An advantage of this approach is that it meets the specific needs of each communication system. However, when a platform such as an airplane, ship or automobile requires the use of many communication systems, this approach has several problems such as space, payload, cost and electromagnetic compatibility/interference (EMC/EMI). Therefore, there is a significant interest in antennas which possess compact size, have multi-functional characteristics, have large bandwidth (>20%) and have high gain.

In the design of an antenna that meets the above requirements, there are several challenges that must be taken into account. First of all, the antenna must have sufficient bandwidth to facilitate the integration of multiple antennas into a single aperture. Since the applications of interest require bandwidths in excess of 10:1, this work focuses on wide-band antenna such as the Archimedean spiral antenna. Since the spiral antenna belongs to the class of frequency independent antennas, it is easily capable of bandwidth greater than 10:1 [5]. Such antennas are considered frequency independent because their pattern, impedance and other parameters vary little with frequency as compared to a multi-band antenna which can exhibit considerable variation. These characteristics make the spiral an ideal candidate for replacing a variety of antennas. Apart from the advantages of spiral antenna, there are disadvantages in spiral antenna, such as the spiral antenna has a low gain and bidirectional radiation pattern. There are several techniques to get rid of the bidirectional radiation pattern, such as by using an absorber-filled cavity, a lossy cavity, and conducting ground plane.

Therefore, in this project a technique is proposed to get rid of this problem, which is to construct a moveable ground plane, which maintains quarter wavelength spacing between the spiral and the ground plane in the vicinity of the active region of the spiral. However, by introducing this technique; antenna's patterns at higher frequencies deteriorate. In order to improve the patterns and to minimize the splitting of the patterns at higher frequencies; a frequency selective surface structure is embedded between the spiral antenna and the ground plane. This new design can substantially enhances the radiation pattern properties of the antenna since the reflected field is in phase with that directly radiated by the antenna itself. In addition, by embedding the FSS structure in the

design minimizes the gain fluctuations caused by the ground plane. However, FSS structure together with the ground plane reduces the antenna's bandwidth. One way to minimize the FSS reduction of the bandwidth is applying the radian sphere theory in order to make the antenna electrically larger and to obtain larger bandwidth.

As a result of the optimized techniques such as the ground plane (for unidirectional radiation pattern), radian sphere theory (for maintaining wideband bandwidth) and embedding FSS in the cavity of the spiral antenna (for better performance of radiation pattern), it is expected to come up with new spiral antenna prototype, which has enhanced unidirectional radiation pattern, wide bandwidth (at least 100% of bandwidth of return loss better than -10dB) and high gain which enables the antenna to detect the enemy radar in a large range of distance compared to the present radar systems.

1.3 Research Contribution

Throughout this research work several major contributions have been achieved for Archimedean spiral antenna performance. In this section a summary of these major contributions are presented:

1. A prototype of wideband Archimedean spiral antenna has been designed with enhanced performance based on *Radian sphere theory*.
2. Universal design of spiral antenna has been used which leads to the elimination of multiple antennas configurations on wideband systems.
3. A tapered microstrip to parallel strip lines balun is proposed with new tapered design based on mathematical formulation is proposed as a feeding technique for wideband antennas.
4. Comprehensive study is carried out for different structures of frequency selective surface in order to improve the antenna's performance.

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5. Band stop frequency selective surface design based numerical synthesis is developed.

1.4 Objectives of Study

This project has the following objectives:

i. To design wideband Archimedean spiral antenna on a moveable ground plane placed at a quarter wavelengths for selected design frequencies in order to achieve high gain antenna with circularly polarized unidirectional radiation pattern.

ii. To design and embed frequency selective surface structure in the Archimedean spiral antenna cavity in order to improve antenna's radiation pattern performance.

1.5 Scope of Study

This project focuses on the performance investigations of Archimedean spiral antenna based on radian sphere theory, FSS structures and microstrip to parallel strip balun within wideband frequency range (3.1-10.6GHz). The effects of the dielectric materials (free space ε_r=1, Rogers RT 5870 ε_r=2.33, FR-4 ε_r= 4.3 and Rogers RO3030 ε_r=10.2) and moveable ground plane placed at quarter wavelengths for selected design frequencies including 2GHz, 3.1GHz, 5GHz, 6.85GHz and 10.6GHz on the performance of the spiral antenna are investigated, in order to achieve a bandwidth of 100% at the return loss of the antenna; which below -10dB, high gain of up to 10dB and unidirectional radiation pattern with circular polarization using discrete port as the

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