AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics & Electrical Communication Engineering

Wearable Antennas for Medical Applications

A Thesis submitted in partial fulfillment of the requirements of the degree of

Doctor of Philosophy in Electrical Engineering

(Electronics & Electrical Communication Engineering Department)

by

Mohamed Sayed Zaky El Atrash

Masters of Science in Wireless Mobile Communications Systems Engineering

(Electronics Engineering and Electrical Communications)

Faculty of Engineering, University of Greenwich, 2014

Supervised By

Prof. Dr. Hadia Elhennawy

Prof. Dr. Mahmoud Abdelrahman Abdalla

Cairo - (2020)

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Date: 23/11/ 2020

Statement

This thesis is submitted as a partial fulfilment of Philosophy in Electronics & Electrical Communication Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Thesis Abstract

Antennas should possess certain features and properties to be characterized as wearable, where they are placed all over the body; for instance, wrist, chest, back, thigh, and abdomen, etc. depending on the application targeted. Such characteristics include flexibility, compact size, high gain, low Specific Absorption Rate (SAR), and uni-directional radiation pattern.

With that said, presented in this thesis are three design approaches for wearable antennas, which are designed, fabricated, evaluated and measured in free space and within the vicinity of the human body. The objectives of the different wearable design approaches are to introduce different single/dual-frequency bands with small wearable antennas profile in addition to preserve a high antenna gain and efficiency, as well as, low SAR. Through the fabrication process, all reported antennas have been fabricated using (1) Rogers Ultralam 3850 substrate, which is based on the flexible Liquid Crystal Polymer (LCP) and (2) textile substrate to demonstrate the flexibility features needed for the wearable biomedical antennas.

The first antenna approach is an asymmetric meander line-based antenna operating at 2.4 GHz. Such methodology led to a size reduction of 67.7% in comparison to a printed straight monopole antenna at 2.4 GHz. By extending the Co-Planar Waveguide (CPW) ground planes around the Asymmetric Meander-Line Antenna (AMLA), forming a U-shaped extended ground, and coupling it to the AMLA, gain enhancements were achieved at the desired resonant frequency of 2.4 GHz. The antenna was evaluated at different separations from the human wrist, where performance parameters; such as, realized gain, total efficiency, and SAR were analyzed; thus, leading to the optimum performance. Despite the absence of a backing isolating structure, to de-couple the antenna from the human wrist, the AMLA, spaced by 10 mm from the human wrist, exhibited a SAR level of 1.58 W/kg. Hence, it complies with the American and European standards.

Afterwards, the antenna was backed by a textile-based 1×2 Artificial Magnetic Conductor (AMC) to maintain flexibility, enhance the gain, and reduce the SAR when evaluated at 3 mm from the human hand. According to a comparative study in terms of the AMC material, it was chosen to be based on textiles, as the integrated design achieved optimum results. The integrated design operated at the desired 2.4 GHz and outclassed the AMLA, in the absence of an isolating structure, in terms of gain in free space and within the

vicinity of the human hand at both flat and bent circumstances. Courtesy of the backing reflector, the integrated design attained low SAR levels and complies with both standards.

Further enhancement of single-band antenna properties in terms of size was attained by incorporating a metamaterial Composite Right/Left Handed (CRLH) cell as the second antenna radiator. The antenna was backed by an all-textile 2×2 AMC to enhance the gain and reduce the SAR. For this design, a textile material was specifically selected for the AMC to maintain overall design flexibility and for integration with clothes. The antenna is ultra-thin, compact, highly efficient, and operates at 2.45 GHz of the Industrial, Scientific, and Medical (ISM)-band. The antenna physical size is 25 mm × 25 mm with a realized gain of 2.34 dBi and total efficiency of 87% in free space. In free space, the low profile integrated design exhibited a gain of 7.63 dBi (enhancement of 5.29 dB) and a total efficiency of 96.4%. The integrated design achieved gain and total efficiency enhancements by 14.88 dB and 72.4%, respectively, as well as, lower SAR levels, in comparison to the CRLH antenna, without an isolating structure, for human loading cases. In addition, the CRLH antenna and AMC array structure were fabricated and measurements were undertaken, which agreed well with the simulated results. Therefore, the integrated design is highly suggested to be recognized medical applications

The third antenna was a slotted triangular-shaped antenna backed by a 4×4 AMC array. The objectives were to design a dual-band and small-sized antenna to radiate at 3.5 GHz and 5.8 GHz for WiMAX and ISM-bands, respectively. Furthermore, make use of an AMC structure to enhance the antenna gain and efficiency, as well as, reduce SAR, when evaluated within the vicinity of the human body. The antenna radiator size is compact with a size reduction of 70% in comparison to the conventional square-shaped monopole antenna at 3.5 GHz. Whether in free space or at close distances to the human thigh and abdomen, enhancements in terms of realized gain, total efficiency, Front-to-Back Ratio (FBR), and SAR values were attained courtesy of the incorporated de-coupling AMC array structure, in comparison to the monopole antenna, with the absence of the isolator.

Subsequently, a similar design was designed with the differences being in the usage of textile materials and reduction of the AMC array size from 4×4 to 2×2. The rationale behind transitioning into an all-textile design is highlighted when compared with a similar but polyimide-based design. Moreover, demonstrated are the evaluations in flat and bent conditions within the vicinity of the human hand. In addition, the fabricated all-textile prototype is integrated into a wristband where measurements are conducted on a subject's wrist in such an arrangement. Such a scenario replicates a wristband worn by athletes for monitoring the health conditions; such as, blood pressure and pulse rate, at the wrist. The vital signs are then transmitted wirelessly to a physician for diagnosing purposes.

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