Investigation of ON-to-ON Body and ON-to OFF Body Channel Characteristics in Static/Dynamic Human Body Model using High Gain Antennas

A Thesis submitted

in partial fulfilment for the degree of

Doctor of Philosophy

by

Elizabeth George

Department of Avionics Engineering

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

THIRUVANANTHAPURAM - 695 547

3 April 2023

Abstract

In the current world, the applicability of wearable devices is not just confined to modern devices like iWatches, fitness bands but also to the healthcare issues as well as safety/security, opening the way towards the vision of internet-of-things (IoT). Presently, body area network finds its importance in the field of sports, health care, multimedia and indoor data transmission system. Wireless communication bands like BCS (5-50Hz), MICS (402-405Hz), WMTS (420-450 Hz, 863-870 Hz), and the mostly used ISM bands (902-928 Hz, 950-956 Hz, 2.4-2.5 GHz) exist for deployment of Body Centric Wireless Communication Services (BCWCs). The ultra-wideband (UWB) technology, ranging from 3-10 GHz also provide some attractive features, like (i) low Power Spectral Density (PSD), (ii) low Interference, (iii) less prone to fading and (iv) high data rates. Hence, along with antennas operating in ISM bands, ultra-wideband antennas are also considered in this thesis. For designing a practical WBAN, it is important to investigate the consequences of on-body electromagnetic (EM) wave propagation while human body is at rest as well in motion. A number of obstacles are there when analysis is based on measurements alone. Hence, a good simulation technique, which is not costly as well as less time consuming is advantageous as it unmasks more comprehensive knowledge of the scenario. For this, a twelve cylinder body model is developed which features critical body parts and can be used to simulate rest as well as moving human body postures. The selection and design of the type of antennas to be used as well the orientation in which antenna is placed is of high importance since they increase the efficiency of the wireless link. The effect of varying orientation of ON-Body antennas is also discussed in the thesis. The work also investigates the gain enhancement techniques considering the OFF-Body antennas. The enhanced gain of an OFF-Body antenna results in a better link budget in case of ON-to OFF-body cases. The present PhD thesis investigates the enhancement of gain in three types of antennas, namely : i) E-shaped linearly polarized microstrip antenna ii) Dual fed square shaped circularly polarized antenna and iii) Dielectric resonator antenna (DRA). In the first two antennas a hybrid substrate is used for enhancing the gain and in the third case, a metasurafce lens is used to enhance the gain of the DRA. A systematic study of the EM wave propagation in ON-Body to ON-Body case as well as ON-Body to OFF-Body case is dealt in the thesis. This includes the investigation of creeping waves on a cylindrical body

model, time domain analysis using UWB antenna on three layered rectangular body model, study of propagation of EM waves during body movement using twelve cylinder body model as well as the study of transmission characteristics with and without the presence of human body while using 'Smart Bag'.

The work is systematically planned and summarized as follows:

- Gain enhancement of linearly and circularly polarized microstrip antenna as well as dielectric resonator antenna which has the potential to be used as OFF-Body antennas is simulated and practically realized.
- Human model which features the critical body segments such as head, shoulder, torso, upper arm, lower arm, thighs and calf is introduced for the study of double arm swing activity. Two cross-slot antennas (CSA) are designed and fabricated, for investigation of the double arm swing activity using the newly introduced twelve cylinder body model. The same CSA is used for creeping wave analysis on cylindrical single layered phantom. Simulations are done in CST Microwave studio suite and experiments are carried out using container filled with distilled water as phantom.
- Characterization of the channel between an ON-Body and OFF-Body UWB antenna in terms of Time Domain characteristics using short pulse electromagnetics is performed using extensive simulation. The experiments are also done by keeping UWB antennas on various positions of a volunteer.
- A smart bag is modelled in SOLIDWORKS and integrated with a patch antenna. The transmission characteristics of this 'Smart Bag' with and without the presence of twelve cylinder human body model is studied.