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REVIEW OF THE CURRENT DESIGN ON WEARABLE ANTENNA IN MEDICAL FIELD AND ITS CHALLENGES

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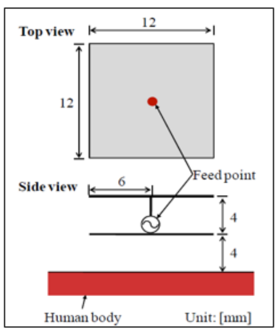
Graphical abstract



Abstract

Wearable device has become more popular nowadays. Wristband and glasses are now capable to sense and track our daily activities. It also becomes useful in medical field where physician can track their patient's activities and monitor their condition remotely. The wearable device is equipped with antenna to transmit the entire sensor's data to the monitoring system. The design of antenna is very important to ensure the wearer is comfortable when using the device for whole day without affecting the antenna performance. The paper aims to discuss on current design of wearable antenna in medical field and its current challenges. The advantages and disadvantages of certain design will also be highlighted. From the design and challenge discussed, the important factor for wearable antenna's design will be listed in the conclusion.

Keywords: Wearable device; on-body antenna; antenna design

1.0 INTRODUCTION

Wearable technology is an electronic and computer technologies that are incorporated into clothes or devices that can be worn on daily basis. The wearable devices can be glasses, watches, earrings, caps, and fabrics. These devices are not only capable to perform tasks like mobile phone and computers but also can provide sensory, tracking and scanning features. It can be seen as another major step in the trend of pervasive computing where information is accessible anywhere.

According to a report by Analysis Mason, the revenue of wearable devices is expected to reach more than USD$22 billion in 2020 compared to only than USD$3 billion in 2014 [1]. The complete graph is shown in Figure 1. This has shown that many manufactures starts to market new wearable devices in the near future.

Wearable devices have very broad application. Before it was introduced to consumer market, wearable devices are used in the military technology. Then, it has been applied in other field such as gaming, music, education, transportation, disabilities, fitness and health. In all of these fields, the priority is to incorporate the functions needed to a device that can be used comfortably in daily lives.

Health and medical field has shown great potential in wearable device application. The device is either worn or embedded to the body. It will capture and process the patient's data, do some required calculation and give the feedback to patient if needed. As an example, a wearable device for diabetes patient that can monitor glucose level in the blood. It will alert patient when the glucose level increases or decreases outside the healthy range. This will help patient to learn and adapt to a new healthy lifestyle.

The information collected is important as a record on patient's daily routine and how they react to the exercise and diets given by doctor. From the information, doctor and dietitian can plan effective treatment to the patient. It is more convenient for them if the information can be read anytime even though the patient is at home or workplace. For this purpose, the wearable device is equipped with antenna to transmit the collected data to other device such as smart phone or computer so that the data can be relayed to monitoring system.

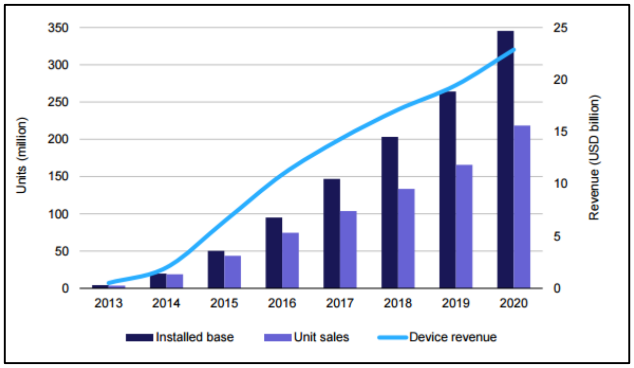


Figure1 Wearable device predicted sales and revenue 2013-2020 (source: Analysys Mason, 2014) [1]

The antenna design is important because the performance can be affected by the body motion. The antenna also suffers to gain variation and detuning, radiation pattern degradations, impedance mismatch, when operating near or on the human body [2]. According to Federal Communications Comission (FCC) and the European Radio communications Committee (ERC), implanted antenna must comply with the operating frequency for Medical Implant Communication Services (MICS) band (402-405 MHz) for biotelemetry applications [3].

This paper will review on the current design of wearable antennas for health and medical purpose and the challenge in developing the antenna. The paper is divided into two sections. First section will discuss on the antenna design and second section will focus on the challenge and limitation in designing the antenna.

2.0 CURRENT DESIGN

Even though wearable device are meant for devices that can be put on and taken off with ease, there are types of devices that are implanted to human body. It means that the antenna is embedded inside the human body. This section will discuss on both type of antenna's designs;i.e. on-body and implanted antenna.

2.1 On-Body Antenna

Ito *et al.* [4] had done an experiment to determine the suitable frequency range for specific applications. The frequency range selected is from HF to UHF band. The antenna was designed with 4mm thickness and the radiation pattern is omnidirectional at any frequency. During simulation, the antenna was placed 4mm from body surface as shown in Figure 2.

The experiment found that power transmission efficiency is better with low frequency at HF band. There is also a fluctuation of the received open voltage for the receiver at the wrist compared than other parts of body. The experiment only assumes that the human are homogenous, muscle tissue is equivalent and body is always in standing position. Therefore, the result may not accurate for all human conditions.

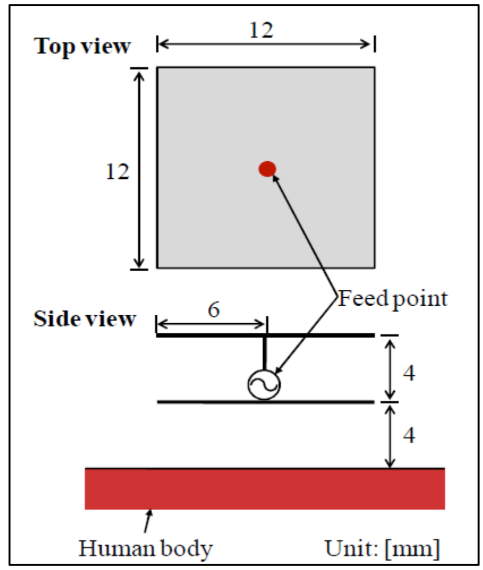


Figure 2 Antenna geometry [4]

Electromagnetic (EM) wave is one of the concerns that may affect human health. Kwak*et al*. [5]had proposed the antenna with electromagnetic bandgap (EBG) structure at WCDMA band. The antenna structure consists of Planar Inverted-F Antenna (PIFA), feeding structure and grounding pin connected to EBG structure as shown in Figure 3.

The simulation was done to the phantom to evaluate the EM effect to human body by testing specific absorption rate (SAR) value. SAR determines the rate at which energy is absorbed by human tissue when exposed to an electromagnetic field. The SAR average value for 1g of tissue should be less or equal to 1.6W/kg by IEEE C95.1-1999 standard and IEEE C95.1-2005 standard has outlined that the SAR average over 10g of tissue should be less or equal to 2W/kg [3]. From the result, the antenna can reduce SAR value more than 61% compared to conventional PIFA. Thus, the design can protect human from EM and at the same time satisfied WCDMA operation band.

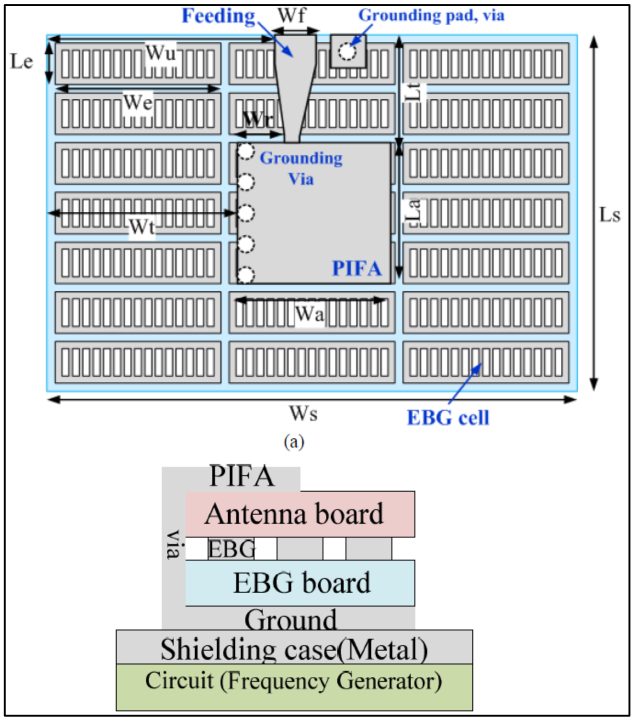


Figure 3 PIFA geometry (top and side view) [5]

Lin and Ito [6] introduced dual mode antenna where on-body mode will collect body data and off-body mode will send the data to external equipment. Figure 4 shows the structure of the antenna. The antenna is simulated with an arm phantom where on body mode using 10MHz and off-body mode at 2.4GHz frequency.

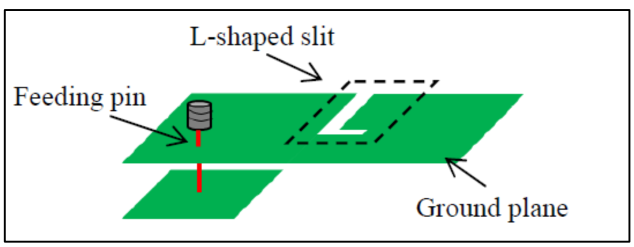


Figure 4 Structure for dual-mode antenna [6]

The results found both modes are suitable for its function. However for off-body modes, radiation toward human body is weak due to body absorption. The performance may not be consistent if the user always moving.

Rogier*et al.* [7] presents a textile antenna that is able to relay information on patient and video to the caregiver. It aims for reliability, invisibility and comfortable of the usage. It is designed for 2.54GHz and 4G frequency network. The antenna is equipped with solar cell for energy harvesting, making it different from the past textile antennas design.

Koo *et al.* [8] designed patch antenna with the dimension of 21mm x 36mm. The antenna is placed on flexible printed circuit board (FPCB) that consists of polyimide and thin copper layers. Figure 5 shows the geometry of the FPCB and antenna. For encapsulation purpose, Polydimethylsiloxane (PDMS)-based elastomer is used as separation between antenna and FPCB.

The antenna shows a directive radiation pattern with small back lobes; behaving like the conventional patch antenna patterns. The result shows that the peak gain for the antenna is about 0.68 dBi. This is acceptable for Medical Body Area Network (MBAN) application. Therefore the antenna is suitable to be used for extremely thin and flexible wireless bio-sensor system.

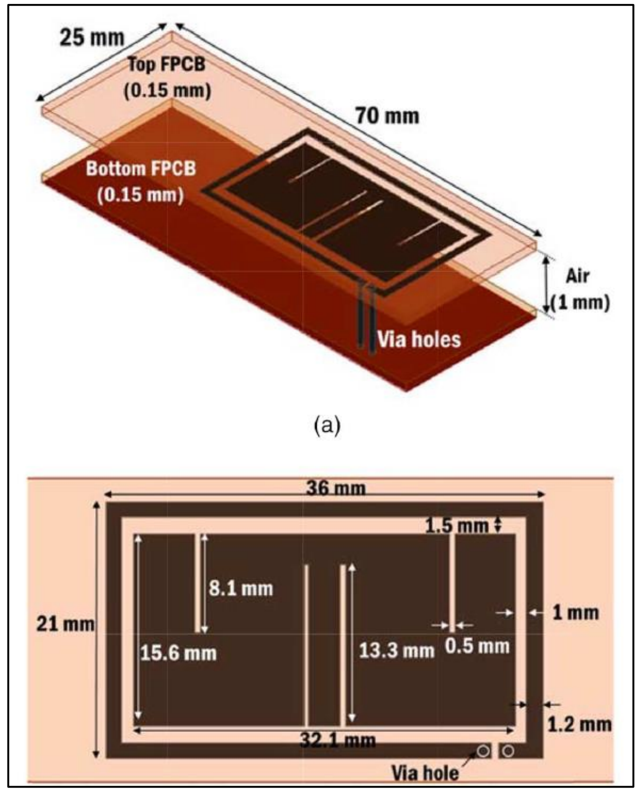


Figure 5 Geometry and dimension of the patch antenna [8]

Agneessens*et al.* [9] proposed another type of textile antenna using Quarter-Mode Substrate Integrated Waveguide topology. The design aims for off-body communications with 2.4GHz frequency. It has implemented Substrate Integrate Waveguides (SIW) in textile materials. To gain a miniature size and compact dimensions, quarter-mode miniaturization techniques is used.

The antenna tested at 2mm distance from human body. It achieves stable on-body performance with gain equals to 3.8 dBi. The radiation efficiency also reaches 81% in free space. SAR value is 0.45 mW/g averaged over 1 g of tissue, below the safe limit. It requires 500mW power for operation.

2.2 Implanted Antenna

Implanted antenna needs to consider human tissue layer so that human will not get injured. Wu *et al*. [3] had proposed an antenna with coin shaped in order to avoid sharp edges that may hurt the surrounding tissue. The volume of antenna is only 0.81mm^3. It used multi-layered structure composed of a ground plane and two circular patches. Figure 6 shows the configuration of the antenna. When implanted in human body, the antenna will covered by biocompatible material called parylene-C to isolate the conducting effect and reduce electromagnetic coupling with the body tissues.

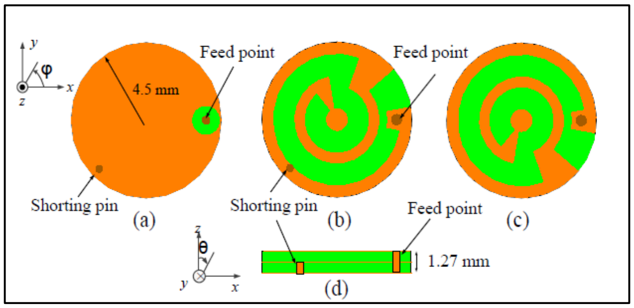


Figure 6 Proposed antenna geometry [3]

The antenna is simulated using ANSYS HFSS software. It is placed 10mm under muscle layer. From the simulation, the antenna achieved peak gain of -36.48 dB at 403Hz frequency. To satisfy with safety requirement by IEEE C95.1-2005, the delivered power for the antenna is limited to 25.73mW.This design is good for biomedical design due to its miniature size and resonant performance. However, it is still need improvement on the bandwidth capacities and robustness.

Due to the complexity of human body, medical implanted communication service (MICS) frequency band is used in most of the implant antennas design. It also provides better data rates than low and high frequency band. However, the antenna size is large to be embedded into human body. Lin *et al.* [10] introduced Radio-frequency identification (RFID) antenna that satisfies the ultra-high frequency (UHF) band standards.

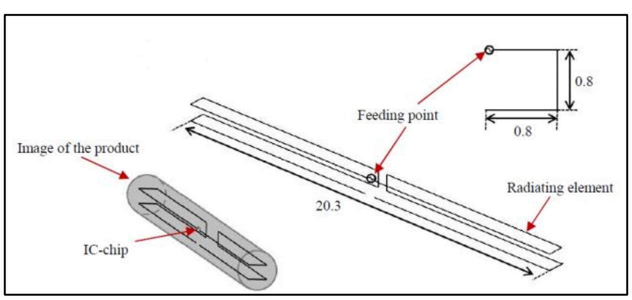


Figure 7 Configuration of the antenna [10]

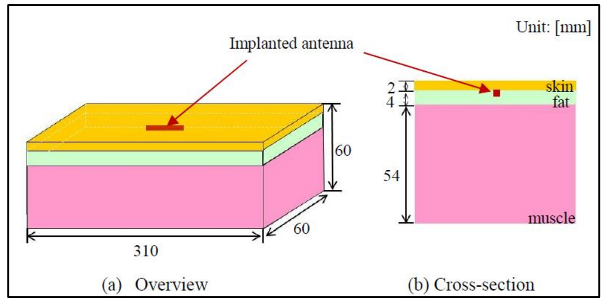


Figure 8 Numerical model of implanted antenna [10]

The antenna is a wire bent as a folded dipole antenna with the dimension of 20.3 mm × 0.8 mm × 0.8 mm. The size is practical for the antenna to be injected into human arm using syringe. Figure 7 shows the configuration of the antenna and figure 8 illustrates how the antenna implanted into three layer phantom that represents human arm.

From the result, the antenna can cover the UHF band of interest (951–956 MHz) as calculated. At 953 MHz frequency, maximum gains are about −23.5dBiin the yz-planes and −26.0 dBiinxz-planes. The use of the link budget also confirmed that the communication is possible when the antenna gain is more than −34 dBi.

Kumar and Shanmuganantham [11] proposed an implantable CPW fed monopole antenna for Industrial Scientific Medical (ISM) applications. To increase the distance of transmission signal, the antenna is designed in compact size. Figure 9 shows the antenna structure. The antenna was rectangular patch with a dimension of 18mm x 24mm and constructed on dielectric ceramic substrate with thickness of 1mm.

IE3D software was used to simulate the radiation characteristics of tissue implantable antenna mounted over human body. The simulation shows that the antenna shows has impedance around 50Ω in the frequency band of 2.4GHz. It also has lower return loss at -40dB and good VSWR at 1.03. The results conclude that the antenna is suitable for the ISM band frequency of 2.4 GHz for biomedical applications.

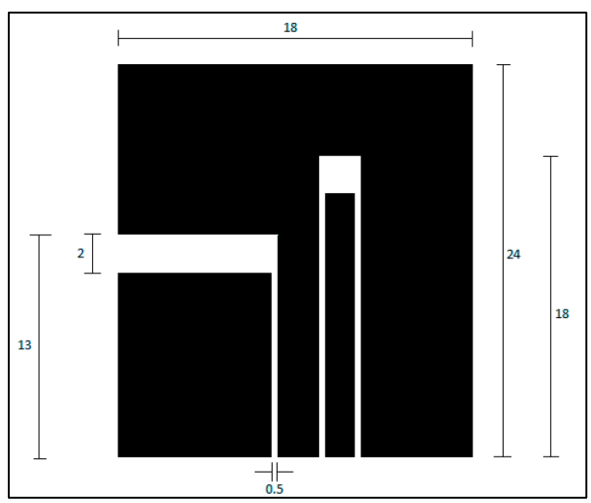


Figure 9 CPW fed antenna structure [11]

Al Amoudiet *al.*[12] noticed that most of antenna design suffers with low gain, low efficiency and narrow bandwidth. To increase communication efficiency, more power is required. Therefore, they proposed an implanted probe antenna without dielectric coat. The performance is enhanced by using external frequency selective services (FSS) and a strip line as shown in figure 10.

Results show that the configurations increase the efficiency of the antenna nearly 5%. Radiation efficiency is 14.1%, 160% better than normal probe antenna efficiency. Power consumption also reduced 10 times to only 0.02275W. The proposed antenna shows a directive radiation pattern with low back lobes. Even though the results are promising, the external components may cause discomfort to the user.

PIFA and micro-strip patch antennas are electric field antennas. Minimizing the antenna size will increase the near zone electric field, resulting higher SAR value. Ibraheem, and Manteghi [13] proposed Electrically Coupled Loop Antenna (ECLA), a magnetic field antenna to overcome the problem. ECLA has a capability to tune the frequency by tuning the antenna dimension.

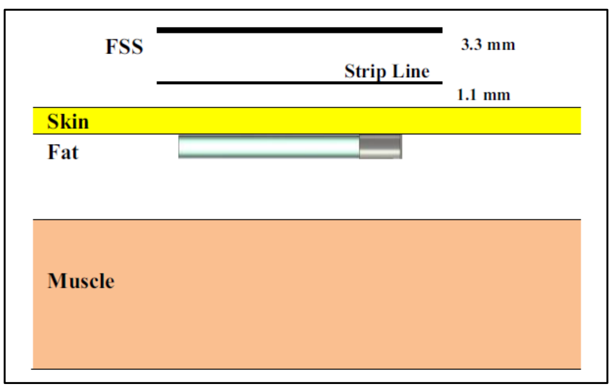


Figure 10 Implanted antenna with FSS and strip line [12]

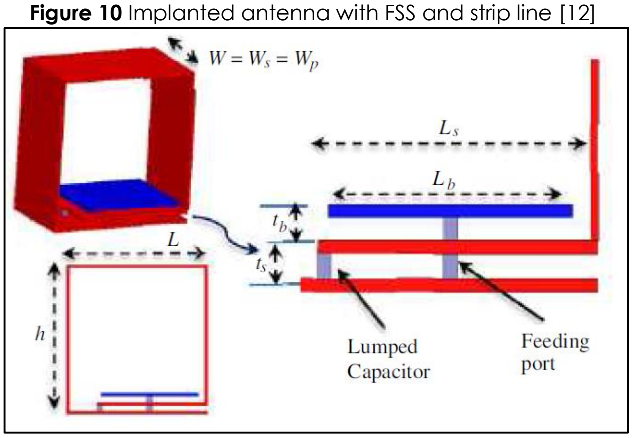


Figure 11 Front and magnified view of ECLA structure [13]

Simulation was done using HFSS software for ECLA antenna with a dimension of 5mm x 5mm x 3mm as shown in figure 11. The simulation was done on one layer model and three layer spherical model to compare antenna efficiency and SAR between PIFA antennas and ECLA in different dimension. Besides, the effect of insulation layer on SAR was observed. The insulation layer is needed to prevent rejection of antenna by human body.

Results show that ECLA can maintain the smallest SAR value in the human body when the dimension is reduced compared to PIFA antenna. The SAR value also can be reduced by increasing the thickness of insulation layer.

Another antenna design that focusing on SAR reduction was done by Mirrahimiet *al.* [14]. They used the meandered antenna in the MICS frequency band that consists of four rectangular strips with the dimension of 15 mm × 3.8 mm. The strips are connected electrically. Simulation was done using two human body models: homogenous tissue model and three layer tissue model. The performance of the antenna is calculated using finite-difference time-domain (FDTD) method

From the initial meandered antenna design, two novel antennas had been proposed. First proposed antenna only used two strips of non-uniform radiators with the width of 5mm and 12mm, respectively. On the other hand, second antenna used four strips with non-uniform radiator. Figure 12 illustrates both antenna dimensions.

Simulation results show that first antenna SAR distribution in term of 1g tissue is equal to 180W/kg and radiated power is 73µW. While, second antenna SAR distribution is equal to 178W/kg and radiated power is 78µW. Both antennas are better than meandered antenna and the second design is better than the first one.

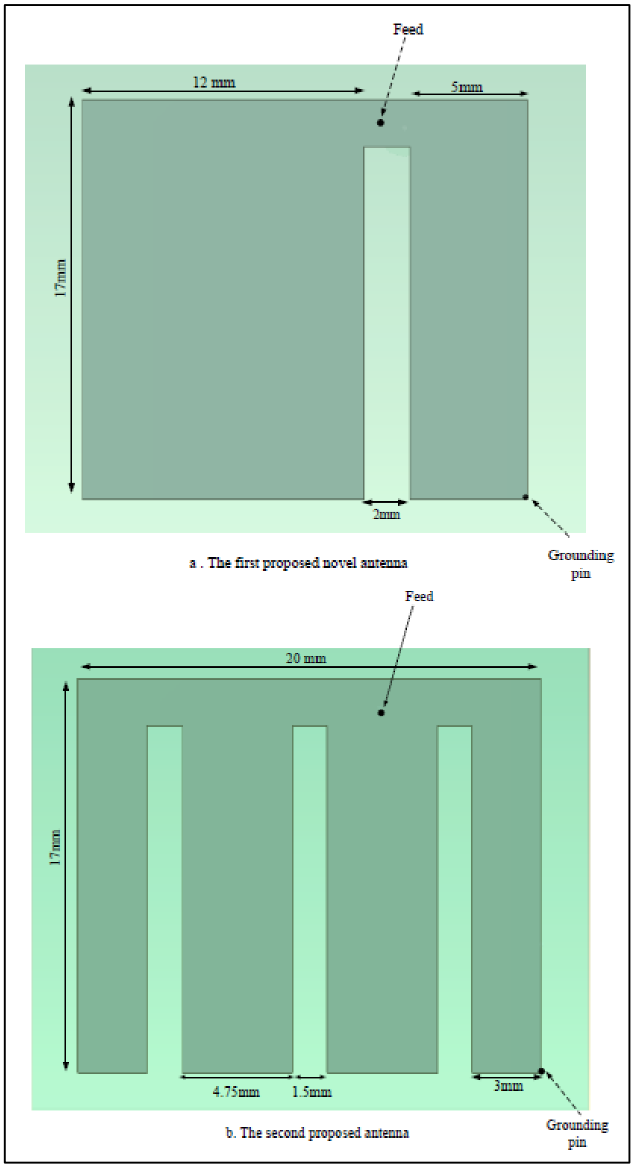


Figure 12 Two proposed antenna design for SAR reduction [14]

3.0 CHALLENGES

In medical field, the wearable device needs to perform continuous measurement and transmit the data to the monitoring system [15]. The transmitted data must be accurate and reliable to ensure the quality of life of the patients can be improved [16]. To achieve it, a few challenges are identified.

First challenge is on power efficiency. The operation of wearable device is fully depending on battery power. The main energy consumption is from transmitting packet data. Therefore, it is important to have a design with optimal energy consumption to ensure the data can be transmitted for longer period. Another challenge is radiation degradation due to human body tissues and human motion. Human bodies are different from one to another. It is important to identify the component in the tissues that need to be considered for antenna design. The movement of body parts also will reduce antenna performance. We cannot restrict the movement, therefore we need to identify which body part that are less effected by movement.

Wireless communication is easily effected by environmental factors such as temporal physical obstructions [17]. Signal can be degraded due to interference from other wireless device. This can prevent the data to be efficiently transmitted and reduce the performance of the device in terms of reliability and energy efficiency. It is become more challenging when the signal also can be distorted by human body. These factors need to be addressed to ensure the antenna bandwidth and throughput can be optimally designed.

Final challenge is on the antenna form factor and the safety of the user. The antenna must be at miniature size and do not have any sharp edges than can hurt the user. Besides physically safe, it must also be safe in term of EM wave and heat dissipation during operation. User must be comfortable when using the device.

4.0 CONCLUSIONS

The antenna design for medical application need to comply with safety standard and SAR value must be less than safety limit. Even though the antenna structure can be patch type, textile or implanted antenna, the priority is to achieve best performance during its operation. The challenge such as power consumption, bandwidth, throughput and safety must be considered during the design. The review is done to give brief idea for new researchers on the current design of on-body an implanted antenna based on different objectives and purposes.

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