SAR Levels for Irradiation by a Crumpled 900 MHz Flexible Diamond Dipole

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Article Info	ABSTRACT
	In this work, the antenna performance and Specific Absorption Rate (SAR) levels in a homogeneous phantom exposed to 900 MHz flexible diamond dipole antenna are investigated under different crumpling deformation conditions. The numerical simulations of the realistic complex two dimensional crumpling are performed by using Finite Integration Technique (FIT) which is applied in Computer Simulation Technology (CST) Microwave Studio. The validation of results with the industry standard DASY4 robot SAR measurement system is made possible with the use of homogenous phantom model. The 1 g, 10 g and point SAR are enhanced by 28.33 %, 36.75 % and 9.55 % respectively due to the antenna crumpling deformation. The short length ripple investigated in this paper shows the highest relative SAR increment.

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1.   INTRODUCTION

Wireless body area networks (WBANs) are an increasingly growing research and show great promise for monitoring and communication in diverse applications such as healthcare, public safety and defence. In body centric environment, practically the wearable antenna is directly integrated into clothing. Such environment is particularly challenging as the antenna is placed very close to human body. The antenna performance degradation such as frequency detuning, bandwidth reduction and radiation distortions when placed close to lossy human body are expected [1].

Apart from that, it is difficult to maintain the antenna in a flat form due to the anatomical shape and changes of human body's posture as well as its movements. The wearable antenna is prone to bending, crumpling or even twisting. Due to that, study on the effect of bending and crumpling is necessary to be carried out.

Moreover, as mentioned earlier, wearable antennas are often operated in close proximity to users and thus raise public concerns regarding the penetration of electromagnetic radiation onto the human's flesh. Plus, the users are exposed to the radiation for longer duration. The electromagnetic radiation that penetrates into human flesh is measured by Specific Absorption Rate (SAR). The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has published one of the globally accepted guidelines for radiation safety of humans [2]. The limit for local SAR general public exposure is 2 W/kg spatial-averaged over any volume of 10 g of tissue and time-averaged over any period of 6 min whereas the Institute of Electrical and Electronics Engineers (IEEE/ANSI) sets the maximum SAR limit to 1.6 W/kg, averaged over 1 g and a period of 30 min [3]. These guidelines provide reference levels for field strength and basic restrictions in

terms of localised peak SAR and whole body averaged SAR [2],[3]. The maximum safety limit should not be exceeded to prevent any adverse health effect.

The effects of bending and crumpling of textile antennas have been widely studied [1],[4]–[24]. Unfortunately, most of the previous study only focusing on the effect of bending and crumpling towards the antenna performance in free space scenario and neglected the presence of human body. Furthermore, despite the vast literature on SAR analysis, there are only a limited literatures [8],[10]–[12] on the effect of bending and crumpling on the SAR levels. Therefore, radiation safety must be assured for these users of WBANs to prevent any adverse health effect.

2. RESEARCH METHOD

2.1. Antenna Under Test (Flexible Diamond Dipole)

This section presents the design of textile diamond dipole antenna which made of flexible GTS laminating film. Figure 1(a) illustrates the geometry of the diamond dipole. The laminating film has to undergo etching process in order to make this antenna. The fabricated antenna is illustrated in Figure 2(b). Diamond dipole antenna has been chosen as antenna under test (AUT) due to its bigger bandwidth compared to common straight dipole. Based on previous work in [25], in most of the crumpled cases of dipole, the antenna resonant frequency is significantly detuned when placed close to the human phantom. Therefore, in this study, the design and optimization process of the diamond dipole is carried out in the presence of homogenous phantom in order to ensure the AUT will function satisfactorily at 900 MHz while the SAR levels inside the phantom are computed.

Next, the antenna is symmetrically crumpled by varying the length of ripple, l as depicted by Figure 1(b) and (c). The middle part of the antenna which is the port position is kept constant throughout the crumpling process. The height of the ripple, h is also kept constant at 11 mm. Smaller l indicated a more extreme deformation case while larger l represents moderate deformation cases. Figure 2(a) shows the simulated crumpled AUT in the CST Microwave Studio computational platform, while Figure 2(b) demonstrates the AUT compressed experimentally in between two complementary Rohacell formers ($\varepsilon_r = 1.06$) to form the crumple.
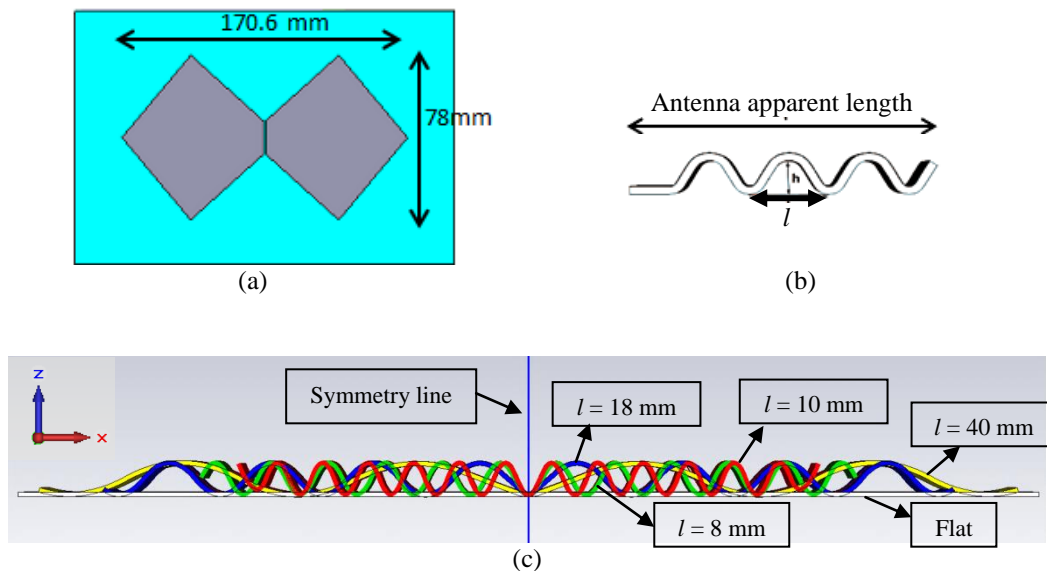

Figure 1. (a) Flexible diamond dipole antenna dimension; (b) Crumpling parameter (c) Symmetrically crumpled lengths
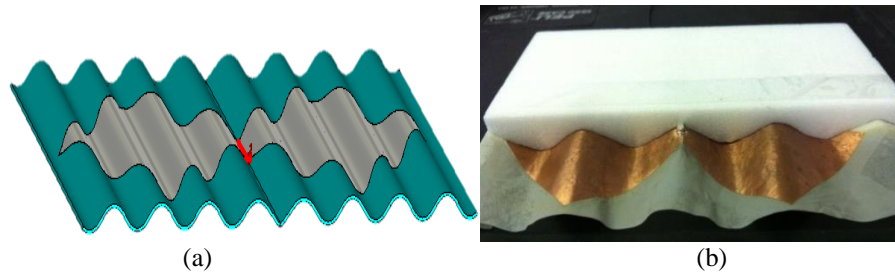
Figure 2. (a) Simulated crumpled AUT; (b) fabricated prototype of AUT crumpled in between two Rohacell foam

2.2. Crumpled AUT Mounted on Homogenous Phantom

As the wearable textile antenna is to be mounted and operated in the vicinity of human body, therefore it is imperative to assess the effects of antenna crumpled conditions in close proximity of human body. A simple homogenous body model is used in this work in order to comprehensively study the relative SAR enhancement behavior due to the antenna crumpling alone. This is due to the fact that the variation of the thickness of tissue layers in the exposed region and also the anatomical shape variations of human body model may affect the SAR results [16]. Besides, the validation of results with the industry standard DASY4 robot SAR measurement system is made possible with the use of homogenous phantom model [26]. Therefore, the crumpled antenna is placed on a simple homogenous trunk model with permittivity, ε_r of 53.64 and conductivity, σ of 1.77 S/m as shown in Figure 3 (a). The electrical properties of the phantom model are the same as the average muscle properties recommended by IEEE and Federal Communications Commision (FCC) [27].

In addition to that, the antenna position and distance from the body, d is kept constant for all crumpling cases investigated in order to comprehensively study the effect of antenna crumpling. In this paper, the AUT is mounted at 1.8 mm away from the phantom model considering the thickness of the cloth and the air gap that exist in realistic scenario of WBANs. The antenna with flat surface (no ripple) as illustrated in Figure 3 (b) is used as the reference to study the relative SAR enhancement behavior.

Moreover, Hexahedral Fast Perfect Boundary Approximation (FPBA) mesh technology is used in these simulations. A global number of 10 lines per wavelength were set in the mesh settings throughout the study. By optimizing the local mesh setting have generated around 68 million fine-size mesh cells to model the regions around the diamond dipole and human model. The simulations are run for several times by increasing the number of mesh cells until stability is achieved. This is done in order to increase the precision level of the results obtained.
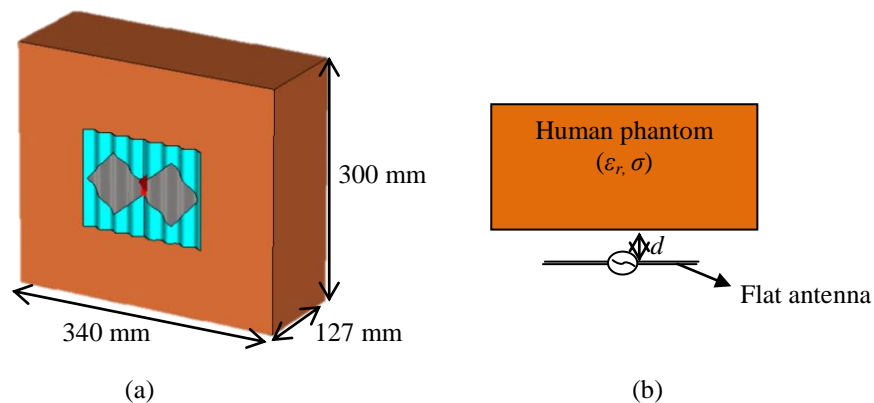

Figure 3. (a) Depictions of AUT placed on a simple homogenous phantom; (b) normal flat antenna placed at fixed distance, d from homogenous phantom

3. RESULTS AND ANALYSIS

In the first section, the effects of crumpling towards the antenna resonant frequency are discussed. The next section discusses the efficiency, gain and SAR levels inside the homogenous phantom by comparing the value with flat case.

3.1. Antenna Resonant Characteristics

The original operating frequency for the AUT is 800 MHz with a return loss value of -25.83 dB under normal flat and free space condition. The S11 achieves -10 dB matched across 714 - 934 MHz frequency band. Figure 4 illustrates that in on-body environment, the antenna resonant frequency is shifted to higher frequency as the amount of crumpling increases. Besides that, it can be observed that the antenna - 10 dB bandwidth is significantly reduced when the AUT mounted close to the homogenous phantom is crumpled. This is true for all crumpling cases investigated. Meanwhile, the return loss value of the AUT at the frequency of 900 MHz is shown in Table 1. It is clearly shown that the antenna remains operated acceptably below -10 dB for all crumpling cases except for the most extreme deformation case, l=8 mm.
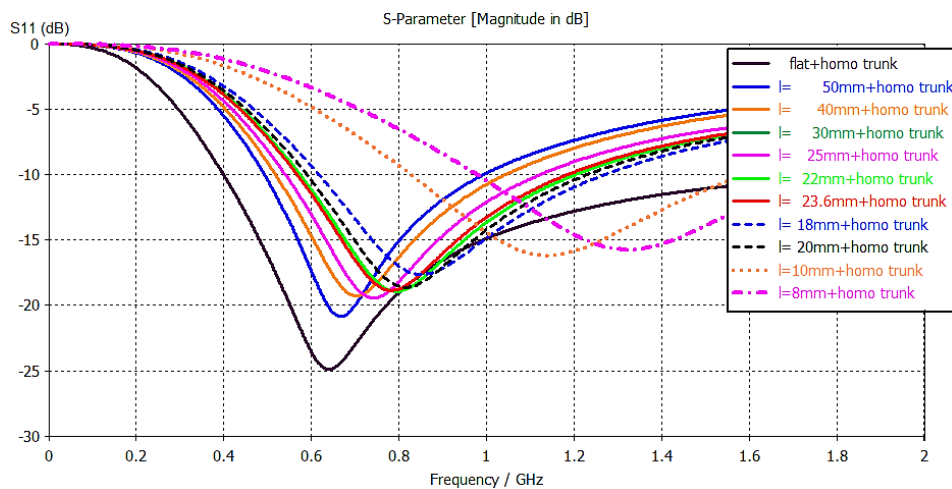

Figure 4. Effects of various crumpling condition on the S11 in on-body environment

Table 1. The AUT

	Return Loss at 0.9 GHz (dB)
FLAT	-16.57
l=50mm	-11.95
l=40mm	-13.03
l=30mm	-14.70
l=25mm	-14.70
l=23.6mm	-16.05
l=22mm	-16.54
l=21mm	-16.70
l=20mm	-17.08
l=18mm	-17.19
l=10mm	-11.90
l=8mm	-8.41

3.2. Antenna Efficiency

Figure 5 summarizes the effect of antenna crumpling on the radiation efficiency and gain when the AUT is mounted close to the body phantom. Surprisingly, the results show that the AUT radiation efficiency is the lowest when the normal flat antenna is attached to the human phantom. The antenna efficiency has dropped by 97.14 % compared to the original flat and free space condition. As the crumpling deformation become more intense, the AUT efficiency slightly dropped. The same trend can be seen for the antenna gain.
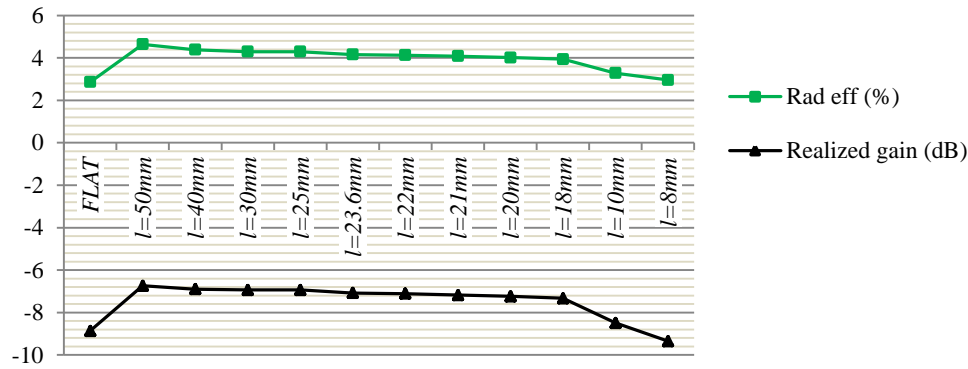
Figure 5. Effects of various crumpling condition on the AUT radiation efficiency and gain in on-body environment

3.3. SAR

As a post processing result, 10 g, 1 g and averaged point SAR values are computed according to the IEEE C95.3 standard averaging method at the frequency of 900 MHz. The simulation results are normalized to 1 W accepted power. The results for the SAR levels inside homogenous model are presented in this section.

Figure 6 illustrates the peak value of 10 g, 1 g and point SAR inside the homogenous trunk model for different crumpling cases. Generally, the 10 g SAR values in this paper behave in a very similar way to the 1 g SAR values, except that the amplitudes are approximately half the 1 g SAR values. Figure 7 also shows that the highest peak 1g, 10 g and point SAR are observed when the AUT is crumpled with smallest l (l=8mm), which is 36.75 %, 28.33 % and 9.55 % increment for 10 g, 1 g and point SAR compared to flat case. The SAR averaged over a 10 g mass start to increase from (l = 21 mm). Whereas the SAR averaged over a 1 g mass and point SAR start to increase when the antenna is crumpled with (l = 10 mm). The increment of SAR can also be expressed in terms of the percentage of antenna crumpled.

$$\% \ \text{Crumpled} \ = \ \left[\frac{\text{Original length – apparent length}}{\text{original length}} \right] \times 100 \ \% \tag{1}$$

Therefore, it shows that antenna crumpled by 13.64 % increases the 10 g SAR, while the 1 g and point SAR are increased when the antenna is 35.84 % crumpled. The differences occur because of the variation of the SAR distribution inside the 10 g and 1 g cube of mass.

Besides that, the results show that the increment in the amount of antenna curvature will also increases the SAR values. This is valid after the antenna is crumpled by percentage of crumpling mentioned earlier.

Therefore, it can be inferred that for 900 MHz diamond dipole positioned approximately 1.8 mm from the homogenous trunk phantom, the crumpling could have a substantial effect if the crumpling deformation percentage is higher than 13.64 % for 10 g SAR and 35.84 % for the 1 g and point SAR. However, the concern on the radiation that goes towards human sensitive organ would not be the issued here as there is no significant enhancement in the energy penetration depth even for the most crumpled cases.
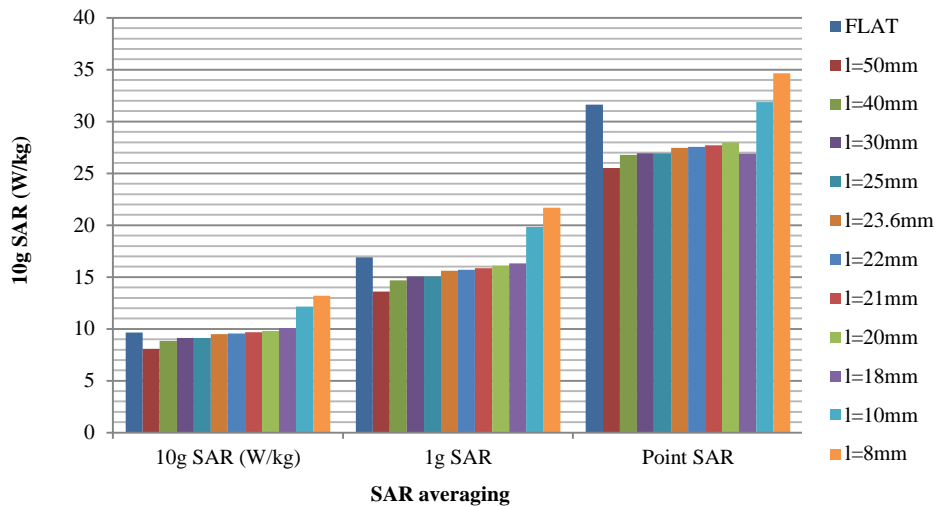
Figure 6. Effects of various crumpling condition on the SAR levels in on-body environment for peak 1 g, 10 g and point SAR averaging mass

4. CONCLUSION

A numerical computation using CST Microwave Studio is applied to investigate the crumpling effect towards the AUT performance and SAR levels. The SAR levels inside human phantoms exposed to a radiation excited by diamond dipole at 900 MHz has shown substantial relative increment. The 10 g SAR was found to increase by up to 1.4 times and the 1 g SAR by approximately 1.3 times compared to flat case. Therefore, it is better to keep the amount of crumpling lower due to this crumpling effect. Also, note that the effects of the crumpling on SAR may vary depending on several factors such as frequency, types of antenna and also the position of the antenna, hence it is worth for further research and will be investigated in future work.

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