Design and Evaluation of Flexible CPW-fed UltraWide Band (UWB) Textile Antennas

^{1,2}Ping Jack Soh, ¹Guy A.E Vandenbosch, ¹Javier Higuera-Oro,

¹ESAT-TELEMIC Research Division

Katholieke Universiteit Leuven

3001 Leuven, BELGIUM

[pingjack.soh, guy.vandenbosch]@esat.kuleuven.be, xhiguer@gmail.com

²School of Computer and Communication Engineering

Universiti Malaysia Perlis (UniMAP)

02000 Kuala Perlis, Perlis, MALAYSIA

Abstract— Two new antenna designs for Ultra Wideband (UWB) applications are proposed and discussed. The structures feature a rectangular radiator with circular or rectangular slots. A coplanar waveguide (CPW) feed is utilized to feed power to both antenna topologies. The main aim of this work is to design, fabricate and evaluate the two antennas' performance, both in free space and on body. The analyses of the structures are carried out using CST Microwave Studio, before being fabricated using ShieldIt Super® conductive textile and felt substrates. A comprehensive dimensional analysis is presented before detailing out the experimental results in this work.

Keywords—ultrawideband (UWB) antenna, textile antenna, coplanar waveguide (CPW) feed, slot antenna

I. INTRODUCTION

The introduction of Ultra Wideband (UWB) by the FCC has triggered much attention due to its properties such as low power consumption, high secured data rate support and simple configuration over conventional wireless communication systems [1]. The various applications of the UWB radio include position and tracking, collision avoidance radar for usage in commerce, military and government sectors.

In the recent years, the need for small and broad bandwidth antennas have triggered research efforts in miniaturization of UWB antennas. Contemporary researchers have been working towards this objective using cost effective materials, the selection of planar printed structures, application of high permittivity material and antenna geometry modifications [2]. The main limitation of the microstrip antenna's narrow bandwidth is effectively eliminated by the use of slots – either on the patch radiator, or on the ground planes. Combination of the co-planar waveguide (CPW) feed and a variety of slot shapes – tapered dipole [1], rectangular [3], triangular [4], circular and elliptical [5], and its variants – has been proven to provide a miniaturized and wideband antenna structure. This is achieved by slotting and tapering dimensions on its structure, which in turn will modify the impedance value.

However, less effort has been put into designing flexible antennas for UWB. Flexible textile antennas are

ergonomically more suitable for on-body operation compared to conventional metallic structures, e.g rigid copper plates or tapes which are worn [6]. Moreover, in wearable applications, flat surfaces cannot be guaranteed. Thus, an important antenna requirement is its ability to work with good robustness against environmental, positional and location changes when being worn. One of such investigations is a CPW-fed flexible rectangular monopole antenna [7] was designed using 0.5 oz copper on PET film. On the other hand, CPW-fed UWB slot antennas' performance has also been investigated in [8]. However, both investigations applied conventional, non-flexible materials for their antennas for on-body evaluations. The proposed work analyses two types of CPW-fed slotted antennas, which aims to be integrated on body. Besides basic antenna evaluation work, investigation has also been extended to assess the antennas' robustness under worn conditions.

II. MATERIALS AND ANTENNA DESIGN

The proposed antennas, manufactured fully using textiles, are built from several types of materials. The conducting parts of the antenna (i.e patch radiator and ground plane) are constructed using ShieldIt™ Super from LessEMF Inc USA. ShieldIt, which is a ripstop, woven polyester textile coated with copper and nickel, possesses a high conductivity (i.e surface resistivity, $R_s < 0.05 \Omega/\text{sq}$). The thickness, t , is 0.17 mm, and its estimated weight is 230 g/m². Its substrate is a 3 mm thick felt fabric, with a relative permittivity ϵ_r of 1.43 and loss tangent ($\tan\delta$) of 0.025 at 2.4 GHz [9]. Fastening of the conductive textile onto the felt substrate is simplified by the fact that it comes with an adhesive backing. A silver conductive epoxy, model 129-4 from EpoTek Inc was used to connect the SMA connector onto the CPW line without soldering.

The antenna structure consists of a rectangular patch; a CPW feed line, and two trapezoidal ground planes. The patch is dimensioned at $RadW \times RadL$, placed on a substrate dimensioned at $SubW \times SubL$. This patch is fed by a CPW line with width and length of TLW and TLL . Trapezoidal ground planes are placed on both sides of the feed line. Its width is labeled as GW , with two different side lengths of $GL1$ and $GL2$

Figure 1. Dimensions and parameters of the two proposed CPW-fed antenna

Figure 2. Fabricated prototypes of both circular slot CPW antenna (CCPW) and rectangular slot CPW antenna (RCPW)

creating the trapezoidal ground. Gap between feed line and ground, which is used to create the CPW line, is labeled as GW_{Gap} . Two types of slots are investigated in this work; (1) a rectangular patch with two identical rectangular slots (RCPW), dimensioned at $SlotW \times SlotL$; and (2) a rectangular patch with a circular slot (CCPW), and its radius labeled as $Radius$. The dimensions of both antennas are shown in Fig. 1 and 2.

The antennas' common dimensions, i.e., the rectangular patch and CPW line dimensions have been calculated using conventional design equations [10]. This resulted in the initial values of $RadW = 19.9$ mm, $RadL = 15.4$ mm, $TLW = 2$ mm, $GW_{Gap} = 0.1$ mm. The antennas' are then optimized using commercial simulator CST Microwave Studio. After extensive optimization, the common dimensions for both the structures are: $GW = 15$ mm, $GW_{Gap} = 0.2$ mm, $GL1 = 14.5$ mm, $GL2 = 8.5$ mm, $TLW = 1.3$ mm, $TLL = 15.1$ mm, $RadW = 18$ mm, $RadL = 18.5$ mm, $SubW = 34$ mm and $SubL = 42$ mm. For the antenna with rectangular slots, its slot dimensions are $SlotW = 5$ mm, $SlotL = 11$ mm, while the circular slot's radius in the second antenna is $Radius = 4$ mm.

III. DIMENSIONAL ANALYSIS

Due to the simple cutting tools that are used to fabricate the textile antenna, it is critical that an analysis of dimensional variation is carried out. This is to ensure any variation in antenna fabrication could be predicted. Also, this practice is useful in identifying sensitive parameters, which are prone to cause antenna degradation as a result of the variations. This investigation is carried out through simulation of RCPW. Each parameter is varied by ± 2 mm, wherever possible, while analyzing its reflection coefficient (S_{11}), bandwidth (BW) and center frequency (f_c).

Figure 3. BW and f_c with varying transmission line size (TLW and TLL), and radiator's size (RadW and RadL) in mm

Figure 4. BW and f_c with varying ground plane size (GW, GL1 and GL2), and gap (GWGap) in mm

Figure 5. BW and f_c with varying slot width and length (SlotW and SlotL), and position (SlotPosX and SlotPosY) in mm

In this investigation, BW is defined as the -10 dB limits of the antennas' S_{11} , while f_c is taken as the center of the BW . Analyzing results, the parameters affecting the antennas' performance could be grouped into three categories: high influence, medium influence and low influence parameters. Parameters related to the radiator and transmission line's dimensions, $RadW$, $RadL$, TLW and TLL , are seen to be critical in determining the resulting BW and f_c of the antenna. Besides that, two ground plane dimensions, $GL1$ and $GWGap$ are also grouped into the same category. Parameters with medium influence on the antenna's performance are GW , $SubH$ and $SlotL$, while dimensions with least influence are related to the slot positions ($SlotPosX$ and $SlotPosY$), substrate size ($SubW \times SubL$), $GL2$ and $SlotW$. This can be seen in Figs. 3 to 5. BW and f_c changes are presented according to the four antenna sections – transmission line and radiator related parameters in Fig. 3, ground plane related dimensions in Fig. 4 and slot dimensions in Fig. 5.

Referring to Fig. 3, the variation of TLL is seen to change the antenna performance drastically, by more than 3 GHz BW and 1 GHz f_c for every 1 mm increment. TLW , on the other hand, was almost constant with a decreasing length, but BW dropped by almost 1 GHz with every mm increment. A high rate of change is also seen for both $RadW$ and $RadL$. For $RadL$, its BW varied by about 100 MHz or less per mm increments, while a quarter the rate of change is observed for f_c . On the other hand, its decrease in length caused more than 500 MHz of decrease in BW and f_c per mm change. Decrement in $RadW$, meanwhile, resulted in about 300 MHz decrement in BW and 100 MHz in f_c , while higher rate of change of 500 MHz BW and 200 MHz in f_c is seen for positive length increments.

Fig. 4 shows the significant changes contributed by the changes in $GL1$ and $GWGap$, the two dimensions which are close to the transmission line. Contrary to the parameters in Fig. 3, changes here are more significant when the dimensions are decreased. An abrupt BW and f_c reduction of more than 1.5 GHz is seen when $GL1$ is decreased by only 1 mm. Similar can be said for $GWGap$, but it only took 0.1 mm change to cause such change. BW varied more than 1 GHz and f_c more than 500 MHz when $GWGap$ is incremented. However, $GL2$ and GW did not cause much change in BW and f_c , with less than 100 MHz per mm variation.

As seen in Fig. 5, every millimeter increment in $SlotW$, $SlotPosX$ and $SlotPosY$ did not cause much change in BW and f_c . All BW changes are 200 MHz or less, and f_c smaller than 100 MHz per mm. $SlotL$, on the other hand, caused a larger change of 200 MHz in BW and 100 MHz in f_c , with every millimeter deviation. As a summary, parameters that are critical in the design of the proposed antenna structure are related to the CPW transmission line, including the nearby ground plane dimensions and the radiator. Fabrication will have to be carried out with care, since small parameters variation on $GL1$ and $GWGap$ are seen to be affecting the performance significantly.

IV. RESULTS AND DISCUSSION

The fabrication process starts with the cutting of the textiles using the optimized simulation dimensions. The textile, which

comes with an adhesive backing, is then secured onto the felt substrate by ironing. Then, a 50 Ω SMA connector is connected to the textile antennas using the conductive epoxy. Due to the difficulty expected when using the simple fabrication tools, two methods of CPW line fabrication are tested. In the first method, the CPW line-radiator structure and ground plane structure is cut individually before being secured onto the fleece. The best effort is put in to accurately form the required 0.2 mm $GWGap$ through manual measurement. This resulting prototype is named as prototype 1 ($P1$). The second method is to cut an overall CPW-radiator-ground plane structure and securing it first onto the substrate. $GWGap$ is then cut away after fastening to create the CPW line. This antenna is then labeled as prototype 2 ($P2$).

Performance of both circular slot CPW antenna ($CCPW1$ and $CCPW2$) and rectangular slot CPW antenna ($RCPW1$ and $RCPW2$) in Fig. 6 clearly shows the significance of the fabrication method. Despite the obvious frequency shift, prototypes $CCPW2$ and $RCPW2$, which are fabricated using the second method, are better in agreement with simulations. This is due to the improved accuracy when cutting out $GWGap$ after securing the textile onto the substrate. Besides similarity in S_{11} trend, both $P2$ prototypes also created larger BWs compared to $P1$ s at the desired UWB frequency band. $P1$ s, however, are seen to resonate at frequencies higher than 11 GHz, which is out of the investigation range. Total BW produced by $RCPW1$ and $RCPW2$ is quite consistent, between 5.4 GHz and 5.8 GHz, while $CCPW1$ and $CCPW2$ generated about 6.4 GHz and 7.2 GHz BW , respectively. All these BWs are, however, less than values predicted by simulation, which is more than 9 GHz in a single band. Measured antennas in free space, meanwhile, produced three separate bands for $RCPW1$, and two bands for all other prototypes. Aside from the inaccuracies caused by fabrication, it is predicted that the substrate is more lossy in practice compared to the values inserted into the simulation model. Moreover, a simplified, ideal port is used in simulations, since modeling a detailed connector will require longer simulation time and resources.

An evaluation of the on body performance is then carried out. The textile antennas are secured onto a 1.2 mm thick fleece

Figure 6. Simulated and measured S_{11} for rectangular and circular slot antenna prototypes

Figure 7. Measured on body S_{11} for rectangular slot CPW antenna (RCPW2) Figure 8. Measured on body S_{11} for circular slot CPW antenna (CCPW2)

TABLE I. MEASURED ON BODY PERFORMANCE SUMMARY

Properties	Type	FS	BH	BV	CH	CV	SH	SV
No of resonant bands (meas)	CCPW	2	2	2	3	4	3	3
	RCPW	2	3	2	3	4	2	3
Total BW (Meas) (GHz)	CCPW	7.21	7.22	7.21	6.51	6.06	6.44	7.05
	RCPW	5.78	5.68	6.31	6.16	5.60	6.41	5.26

Legend: FS = free space; BH = back horizontal; BV = back vertical; CH = chest horizontal; CV = chest vertical; SH = shoulder horizontal; SV = shoulder vertical

jacket before being worn on a human user and measured in an anechoic chamber. A male test subject with height and weight of 1.75 m and 70 kg, respectively, stood at the center of the chamber during measurements, away from the walls. Antenna placements on three different on-body locations are evaluated, on the chest, shoulder and back. For each location, antennas are also evaluated horizontally and vertically. The results of this evaluation are shown in Fig. 7 for RCPW2 and Fig. 8 for CCPW2, the two better performing prototypes when measured

in free space. It can be observed that on body placement degraded the antennas' S_{11} at most locations, except when placed on the back of the human user. Besides, the dielectric coupling to the body has also introduced an additional f_c down-shifting for all antennas. This is due to coupling of the waves to the skin and muscle layers under the antenna. This coupling, however, is expected to introduce a significant efficiency and gain degradation, as reported in [11]. The best on body location for antenna placement is on the back of the upper human torso, as summarized in Table I.

V. CONCLUSIONS

Two slotted, CPW-fed UWB antennas have been designed and investigated. Evaluation of the antennas using slightly different fabrication methods has been carried out, and proved to be significant in determining the antenna performance. Though initial evaluation in free space is not satisfactory, on body placement has improved its reflection properties. The best on body location is found to be on the back of the user, which produced bandwidths of up to 7.22 GHz for CCPW2 and 6.31 GHz for RCPW2, respectively. Fabrication of the CPW line using textiles has proved to be challenging when only basic manual cutting tools are utilized.

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