Body-Worn Diversity Antennas for Squad Area Networks (SAN)

***D. Psychoudakis*[1], *G.Y. Lee*[1], *C-C Chen*[1] *and J. L. Volakis*[1]**

[1]ElectroScience Lab, ECE Dept., The Ohio State University, 1320 Kinnear Rd, Columbus, OH. 43212, USA,
E-mail: dpsycho@ece.osu.edu, lee.3168@osu.edu, chen.118@osu.edu, volakis@ece.osu.edu

Abstract

We present a Body-Worn antenna system for communications in the 225*MHz*-380*MHz* band. The antenna consists of multiple broadband dipole elements appropriately positioned on the human body. Measurements are given for a human body phantom for validation and a series of simulations are carried out using Multiple-Input Multiple-Output (MIMO) techniques to estimate optimum positioning and orientation for improved channel capacity.

1. Introduction

Body-worn antennas are gaining greater interest due to the many impending wireless applications. However, they present us with several due to their low gain and high losses. Several papers have shown planar designs fabricated on conductive textile material [1-5] for body-worn applications. These designs range from simple body-worn patch antennas [1, 2] to dual band and broadband designs [3-5] with electromagnetic band gap (EBG) substrates used in some cases [5]. A common theme in all these designs is the combating of high dielectric body. Typically, the radiating element is shielded from the body by employing a ground plane or an EBG backing. Such a ground plane aims to increase antenna efficiency, but is not as effective since all reported wearable antenna gains remain close to -10*dBi*. Thus, without significantly increasing gain, the ground plane backings shield-off the radiating element from the high permittivity substrate (emulated by the body). Therefore, it would be desirable to eliminate the ground plane for increased miniaturization. Indeed, it was shown in [6] that without a ground plane, the body can be used to exploit miniaturization without significantly reducing efficiency. Additionally, by excluding the metallic backing, the antenna can be thinner and more flexible.

Another challenge associated with body-worn antennas is the pattern degradation caused by the irregular body shape or clothing. To alleviate these issues use of MIMO techniques can be adapted to increase effective gain. In this case, the body is treated as a fading channel. Specifically, by using polarization and spatial diversity, we may select the best position and antenna orientation for increased gain and improved coverage.

In this paper, we present a wearable antenna operating in the 225*MHz*-370*MHz* band that avoids use of a ground plane altogether. Moreover, the antenna is printed on a flexible FR-4 substrate (4*mils* thick) enabling ease of mounting conformal to the body. A human body phantom was also built and used to test the antenna for gain and pattern performance. These measurements and simulations are aimed at validating our design. MIMO was then considered to evaluate the best mounting scenarios for improved channel capacity and increased coverage.

2. Body-Worn Antenna Design

The proposed antenna design is derived from a flare dipole and is depicted in Fig. 1. It is a modified version of the design in [7]. Starting with the design in [7], we first reduced its length from 35.56*cm* to 30.48*cm* and its

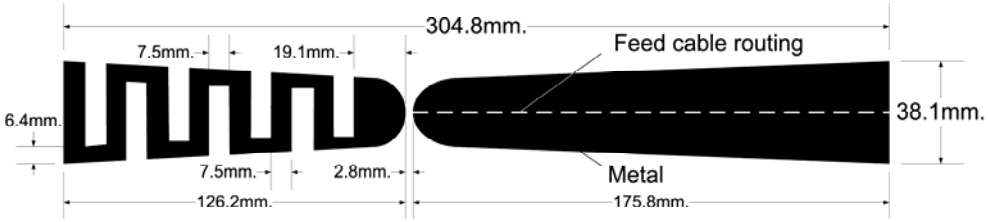

Fig. 1: Wearable UHF flare dipole with the meandered arm to the left.

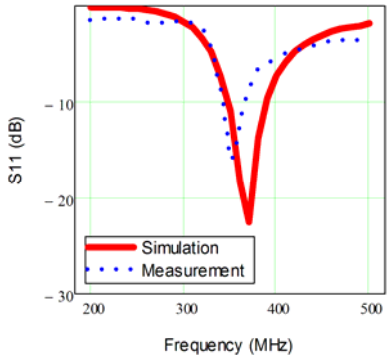

Fig. 2: Input impedance for the free standing meandered flare dipole antenna.

width to 3.81*cm* (from 22.86*cm*). The initial flare dipole operated from 200*MHz* to above 1*GHz* due to its enlarged width. However, for this application the bandwidth is much smaller (225*MHz*-370*MHz*), allowing us to reduce the size of the body-worn flare dipole without adversely affecting performance. To further reduce its length, a meandering scheme was adapted as in Fig. 1 at the expense of bandwidth. However, meandering was done only to one arm so that a balun feed can be accommodated.

The return loss for the free standing version of the designed meandered dipole is shown in Fig. 2. As shown, the measured return loss is in reasonable agreement with the Finite Element – Boundary Integral (FE-BI) solution [8]. Specifically, the resonance is shifted towards the high end of the operation band in anticipation for mounting on the human body.

For this and all other measurements, the dipole was fed by a coaxial cable that was soldered to the non-meandered section near the dipole gap. The coax was then stripped and connected to the meandered section. As seen in Fig. 3, the inner conductor of the coaxial cable is soldered to the meandered arm and the ground conductor to the longer arm.

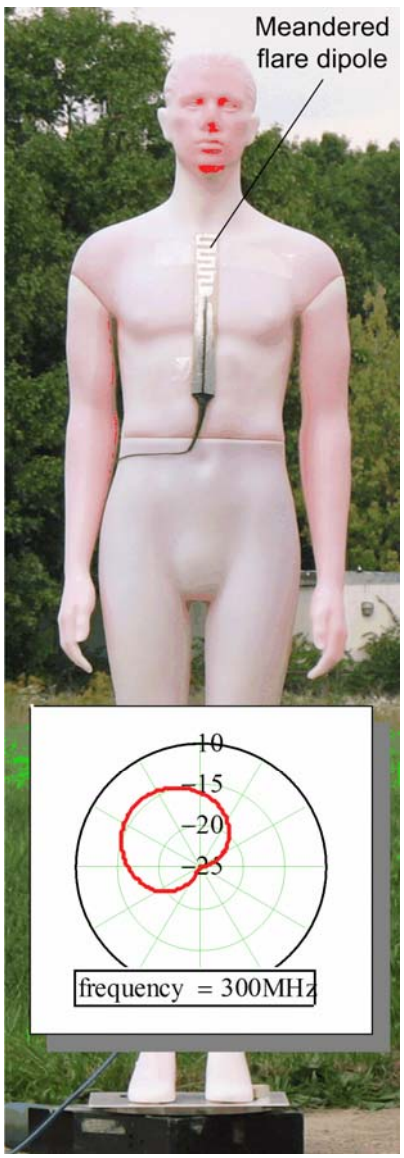

Fig. 3: Human body phantom with the meandered flare mounted on the front torso.

3. Body Phantom

To evaluate the antenna performance on the human body and to find the optimal mounting locations, we constructed a human phantom from a retail plastic mannequin. The mannequin's wall thickness varies between 3*mm* to 8*mm* and is made of plastic with $\varepsilon_r \approx 2$. To emulate the human body, the mannequin was opened and filled with liquid emulating human tissue (the red tint of the phantom in Fig. 3). The liquid used had a measured $\varepsilon_r = 67$ and $\tan\delta = 0.7$ at 300*MHz*. This permittivity value is slightly higher than nominal but the $\tan\delta$ is slightly lower.

4. Measurements

The human body phantom was used in a series of measurements to establish optimal mounting locations and achieve best azimuth coverage. Initially, measurements were carried out with a single antenna placed at the front and center of the torso area (see Fig. 3). The gain patterns for this setup are shown at the bottom of Fig. 3. We immediately notice the 5°-10° tilt in the main lobe. This is due to the asymmetry of the mannequin's arms (apparent in Fig. 3). This was also verified by measuring the pattern with the arms removed.

The next step aimed at measurements with a second antenna. Specifically, two identical antennas were placed on the back and the front. This pair was fed by a single cable that was split via a hybrid to accommodate each antenna. Simulations using this configuration show that the two elements are connected out-of-phase. Thus, the horizontal plane (H-plane) pattern has two major lobes at the front and back. Alternatively, when the two elements are fed in-phase the pattern becomes more omnidirectional. These two modes, identified as the differential (DF) and common (CM) mode, respectively, can be potentially switched through a radio unit.

Fig. 4 shows the pattern for the Differential and Common mode configurations in a 3D rendering that includes frequency dependence. The pattern irregularities in Fig. 4 are due to the human phantom asymmetry as well

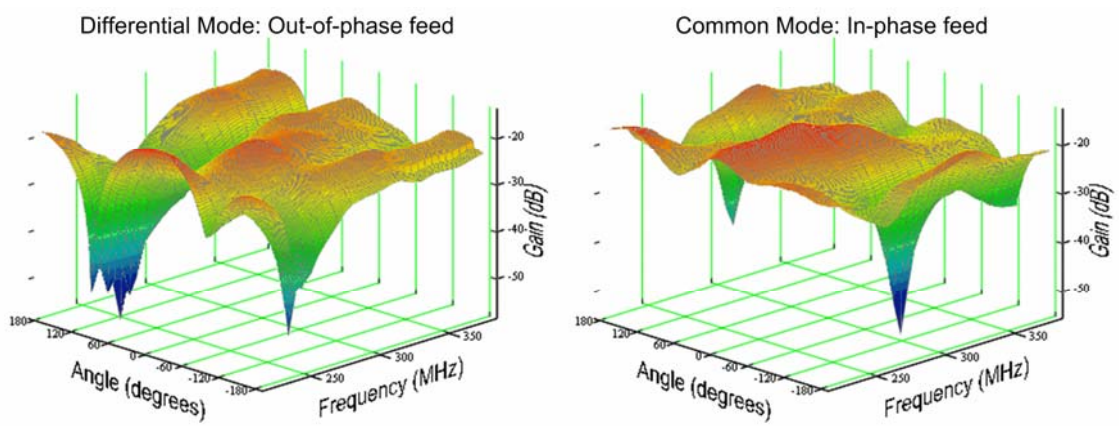

Fig. 4: Measured horizontal plane patterns for the dual element configuration on human body (front and back torso) for two feed configurations.

as possible asymmetries due to positioning of the hybrid and cables. The rough and uneven ground was also a contributor. However, the trend of having a uniform pattern for the Common mode and two distinct lobes in the Differential mode is quite prominent as depicted by the nulls to the left of Fig. 4.

5. Mounting on Hydration Unit

A hydration unit provided by the US army was proposed as a possible and practical mounting platform. Pattern measurements were carried out and compared to FEKO simulations for validity. One such comparison is shown in in Fig. 5. The simulation clearly matches the measurement when a ground plane is used. This simulation setup is used to evaluate the channel capacity when using two or more antennas.

6. Channel Capacity Evaluation

Fig. 7 shows the polarization diversity performance of the two antennas. The simulation setup (Fig. 6) consists of an antenna in the front that is rotated 0°, 45° and 90° with respect to the vertical element mounted on the back. The two antennas are fed independently and receive a signal from a vertical polarized transmitter located at

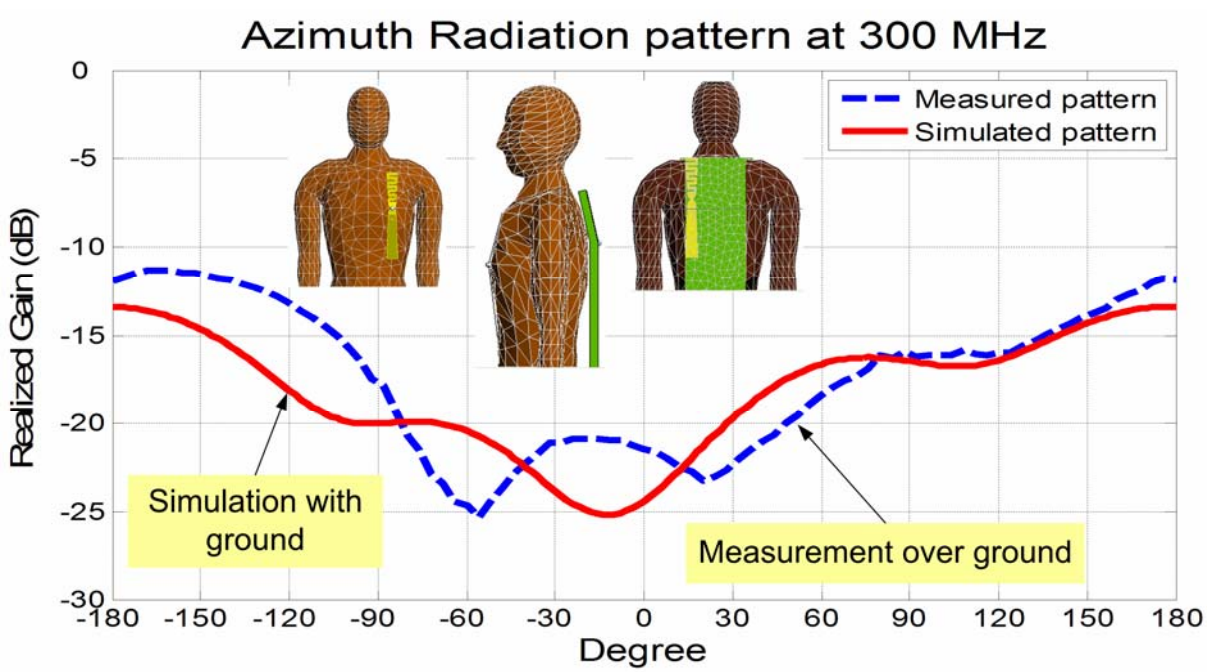

Fig. 5: Mounting on hydration unit (left) and measured horizontal plane gain pattern (right).

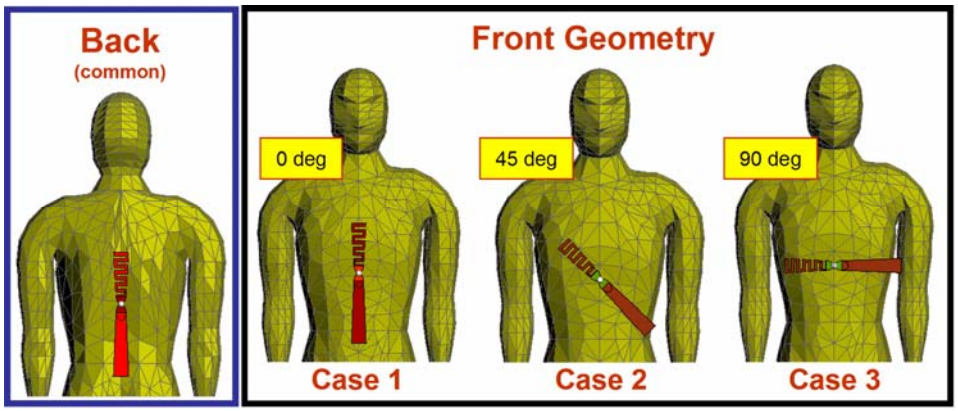

Fig. 6: Antenna configurations for polarization diversity study.

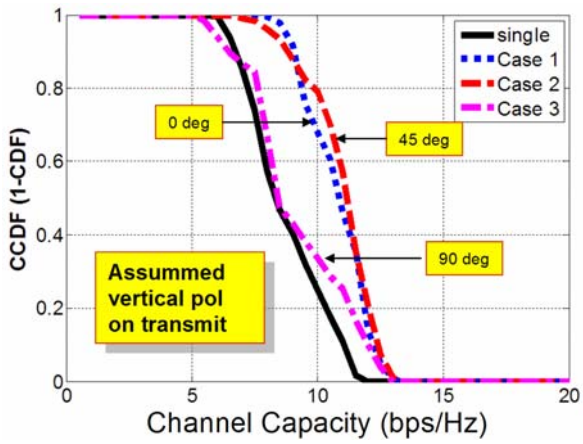

Fig. 7: Channel capacity estimates for antenna configuration depicted in Fig. 6.

infinity. Using this configuration we proceeded to calculate the channel capacity curves in Fig. 7. It is clear that for a vertically polarized transmitter, the receiving antennas oriented at 0° and 45° give the highest capacity. The 90° oriented antenna is associated with a capacity closer to the single antenna case.

7. Conclusions and Future Work

A body-worn, meandered flare dipole was designed for operation at UHF frequencies. Measurements and simulations provided reference for its performance and applicability. Some mounting options were discussed and additional configurations will be discussed at the conference. A brief polarization diversity study was also carried out to evaluate channel capacity improvements. As is evident from the given patterns, the body-worn antenna is highly sensitive to its location and mounting. Considering the posture, clothing and human body variation it is evident that wearable antennas require a statistical performance evaluation.

8. References

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