Jurnal
Teknologi

Full Paper

A NOVEL EXPERIMENTAL PROCEDURE FOR DIGITIZING FLEXIBLE WEARABLE ANTENNAS FOR BODY AREA NETWORKS (BANS)

Article history
Received
25 October 2015
Received in revised form
14 December 2015
Accepted
9 February 2016

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Abstract

This paper considers the performance of a square microstrip patch antenna designed from two layers of non-flexible conducting material (copper) separated by foam or other material which is deformable and having an approximate relative permittivity, $\varepsilon r \approx 1$. The antenna can be incorporated into smart clothing for multi band reception and transmission in Body Area Networks (BANs). An empirical technique is presented for obtaining the shape of the antenna when it has been deformed due to body movement or by applying force at two adjacent edges. The reflection coefficient, radiation pattern and surface currents of the wearable antenna under consideration are analyzed under various bending conditions. It is found that H-plane bending did not significantly affect performance of the patch. The antenna can be used in multi-band body worn wireless applications.

Keywords: Patch antenna, smart clothing, body area networks, multi-band

1.0 INTRODUCTION

The main purpose of this paper is to describe a new empirical technique for measuring and digitizing a crumpled patch antenna with a deformable foam core and inflexible conductors. There is a growing interest in the body worn communication systems and hence wearable antennas are becoming important [1-5]. In wearable applications it is very difficult to keep the antenna flat all the time especially when the antenna is made of deformable materials. Textile antennas as a result of human activities are subjected to bending, deformation and crumpling [6-9]. In addition these types of antenna are routinely exposed to harsh environmental conditions and often have to survive machine washing. Nevertheless, the benefit of these devices has been exploited in numerous applications such as astronomical applications [8] and fire rescue operations [9]. The bending and crumpling that occurs when wearable antennas are worn on the body is frequently reported to cause resonance shift in the antenna which is observable by examining the input characteristic [5, 6]. It has also been noted that a reduction in the bandwidth occurs. Ha et al. [10] studied the performance of wearable antennas used in WLAN applications at 5.5 GHz and in this case it was found that input impedance and radiation pattern was not severely affected by varying crumpling or bending conditions, although there was a small reduction in the forward gain. The performance of a body-worn textile antennas used in the 2.45 GHz WLAN band has also been studied under different bending conditions in the E-plane [11]. We conclude therefore that there is a significant amount of knowledge already about some specific antenna types and their properties when they are distorted.

The current paper considers a novel situation, the H-plane bending of another antenna type- a square patch with flexible core. However, another contribution is on the methodology for bending the antenna which differs from other approaches reported thus far. For example, in past work, such as [11] the amount of bending is adjusted by wrapping the antenna around a cylindrical structure of differing radii [11]. Whilst a cylindrical shape appears to be a reasonable approximation for an antenna mounted on part of uniform body, it is arguably not such a good approximation for a loose textile. We consider here the situation where the antenna does not lie flat on the body. A photographic empirical technique is described here which captures the shape of the textile and from this a simple model is derived for the shape of the upper and lower conductors in the flexible patch antenna. The proposed technique can be used in the design of wearable antennas [12-14].

The rest of the paper is arranged as follows: Section 2 demonstrates the geometry and design methodology of the antenna. Results are discussed in Section 3 while the paper is concluded in Section 4.

2.0 GEOMETRY AND DESIGN METHODOLOGY

2.1 Geometry of the antenna.

The geometry of a wearable square patch antenna is shown in Figure 1.

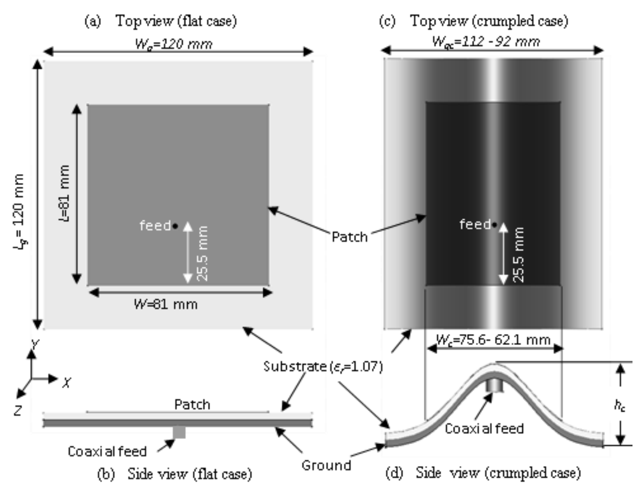

Figure 1 Flat planar device and an example digitized crumpled antenna

The length and width of the metal patch are denoted by *L* and *W* respectively. A low dielectric substrate of ε_r=1.07 is inserted between patch and ground and has thickness of 3 mm. The length and width of the metal ground and substrate are identical and designated by L_g and W_g respectively. The patch is assumed to be centered on the z-axis and is fed with a coaxial cable (RG405/U), 15 mm off the centre in the –Y direction. A generalized diagram is drawn for the crumpled case in which the shape of the patch varies in accordance with the crumpling factor (ζ). The subscript 'c' is used to differentiate the crumpled case from the normal (flat case). The crumpling factor is given by:

$$\zeta = \frac{w_{gc}}{w_g} = \frac{w_c}{w} \qquad (1)$$

2.2 Methodology

In order to determine effects of bending a photographic method was employed to obtain an exact side view image of the antenna. The image was subsequently digitized and a mathematical model of the fit was arrived at. The optimum fit averaged over a number of measurements using a proprietary program designed for digitizing graphs was obtained with a Gaussian curve with the form:

$$y = h_c\, e^{-\alpha\, x^2} \qquad (2)$$

where, h_c is maximum height of the top of the patch due to crumpling (Figure 1) and the parameter $\alpha=3/W_{gc}$ (W_{gc} expressed in mm) was obtained for the material in use. The curve described by (2) was subsequently used for numerical models of crumpled patches and simulations were produced. This was repeated for several values of W_{gc}.

3.0 RESULTS

The simulated values of S_{11} for the given patch antenna under different crumpling conditions are plotted in Figure 2. The degree of crumpling is expressed in terms of the crumpling factor ζ. The first resonant frequency, f_0 appears independent of the crumpling factor at 1.65 GHz. However significant variations were observed in the higher resonance frequencies and bandwidths obtained also varied with increased crumpling (Figure 2). A conventional patch antenna is primarily operated at its first resonant frequency; therefore the effects of crumpling on the radiation patterns of these antennas in the *H*-plane appear viable in body worn communication systems or in smart-clothing applications.

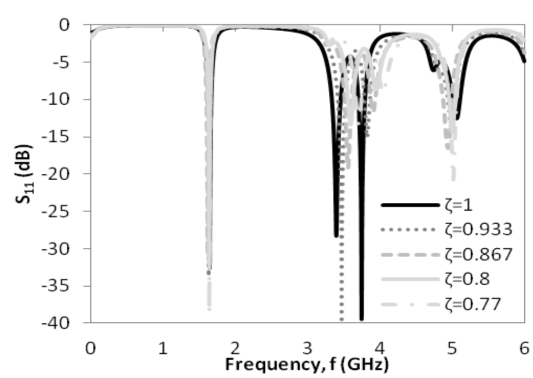

Figure 2 S_{11} for different crumpling conditions

The 3-dimensional pattern of the patch antenna at the designed frequency (1.65 GHz) shows maximum boresight gain (6.6 dBi) along the y-axis (Figure 3).

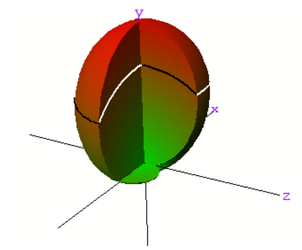

Figure 3 Three-dimensional radiation pattern of patch antenna

The co and cross-polar components of the *E* and *H*-plane radiation patterns of the patch antenna are depicted in Figure 4 and 5 respectively. A slight increase in the beam width of the co-polar field component is observed in both planes as a function of crumpling factor, which is beneficial in circumstances where more angular coverage is required. On the other hand the cross-polar discrimination is adversely affected as a function of crumpling, i.e. the magnitude of the cross-polar component is increased with crumpling however the cross polar performance remains below -37 dB (Figure 4) and -28 dB (Figure 5) for *E* and *H* plane patterns respectively. The radiation efficiency is slightly decreased as a result of crumpling in the *H*-plane, i.e., 84. 9, 84, 81.61, 79.6 and 78.3 % for ζ=1, 0.93, 0.867, 0.8 and 0.77 respectively.

The space domain electric fields of the un-crumpled (*ξ*=1) and extremely crumpled (*ξ*=0.77) patch antenna at four resonant points are demonstrated in Figure 6 and 7 respectively. In both cases (un-crumpled and crumpled), the two slots of the patch antenna radiates electromagnetic energy into space at first, second and third resonance frequencies. At the fourth resonant point (5.07 GHz), the strength of the electric field in the two radiating slots is slightly reduced due to impedance mismatch. The purpose of space domain *E*-field snap shots it to demonstrate the radiation of the patch antenna in flat and bended condition.

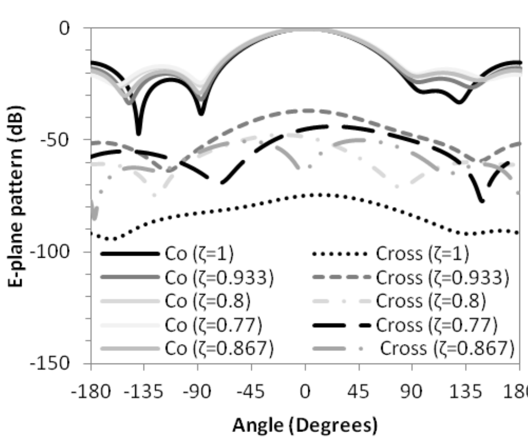

Figure 4 E-plane radiation pattern

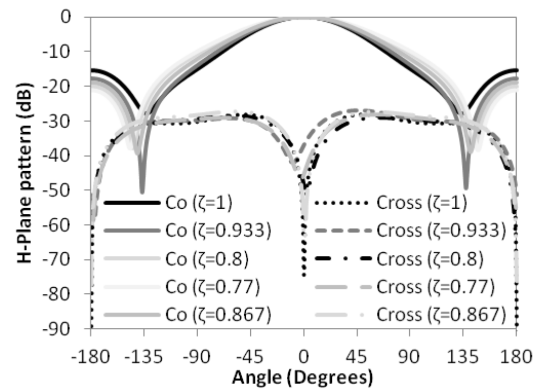

Figure 5 H-Plane radiation pattern

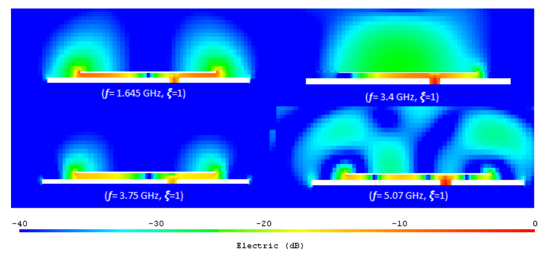

Figure 6 Space-domain electric field comparison of the un-crumpled patch antenna (ξ=1) at different resonance frequencies (viewed in YZ-plane)

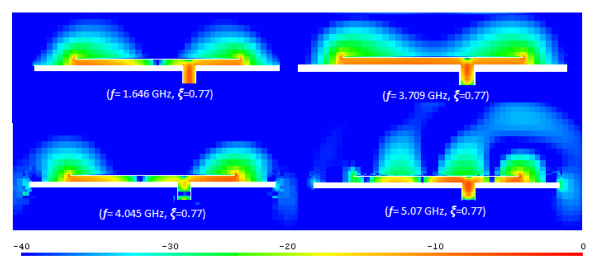

Figure 7 Space-domain electric field comparison of the crumpled patch antenna (ξ=0.77) at different resonance frequencies (viewed in the YZ-plane)

4.0 CONCLUSION

A new mathematical description of a crumpled antenna using a Gaussian curve has been proposed based on empirical methods. By means of example this model has been used to demonstrate the effect of crumpling in one direction on a patch antenna. No significant change in the impedance at the driving point for the first resonant frequency of the antenna was observed. The patch crumpling decreases the gain, broadens antenna beamwidth at first resonance point (1.646 GHz). The space domain electric field radiations of the patch antenna in the normal and extremely crumpled (23 % bent) conditions demonstrate that the antenna radiates at all resonant frequency. The antenna can be used in multi-band wearable applications. Metamaterial surfaces can be incorporated as a ground plane to enhance the radiation efficiency of the antenna under crumpled conditions.

Acknowledgement

We are grateful to James. A. Flint, Loughborough University, UK for his support in Numerical analysis of the antennas.

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