Design and fabrication of High Impedance Surface based Wearable Antennas using Textile Material

Kavita Singh, Ajay Kumar Yadav

***Abstract*— This thesis paper concerned with the design and fabrication of textile wearable antennas integrated with artificial materials called High impedance surfaces (HIS). The Complete design cycle of wearable fabric antennas starting from material selection to prototype fabrication and antenna testing was carried out in this thesis. The use of HIS for antenna performance enhancement is growing at a rapid pace. In this paper a modified wearable form of HIS defined as non-uniform HIS is presented and successfully integrated with antenna for improved performance under low profile limitation. The HIS was also integrated with normal patch antenna to reduce its size and improve its gain and impedance bandwidth.**

***Index Terms*— Wearable Antenna, HIS, Electromagnetic Characteristics.**

I. INTRODUCTION

A. *Wearable Antennas*

Wearable antennas have drawn more and more attention in recent years due to the fact that they can be seamlessly integrated into clothing [1, 2-3] which is a desired feature for hands free applications and military applications requiring low visibility. More importantly wearable antennas can use all the space on clothing that can be utilized to improve quality of signal in wireless communications. Secondly multi path fading is one of the most severe problems in wireless communication since the signal strength drops as the mobile terminal moves over a distance comparable to wavelength. Antenna diversity is a very effective way to combat multipath fading. However antenna diversity requires at least half a wavelength separation between each antenna in the diversity system.[4-5] This is not possible on small form factor hand held units which limits the use of antenna diversity. On the other hand antenna diversity can be utilized on a large scale of a body worn wireless system [6]. Wearable textile antennas have also attracted consumer electronics industry because it fulfils the increasing demands from the rapidly evolving wireless world. Wearable antenna desirable features common to all applications require light weight, functional, robust, unobtrusive, inexpensive, zero maintenance and no setup requirements.

B. *High Impedance Surfaces (HIS)*

In 1999 [7] it was shown that by incorporating a periodic pattern on a conducting surface it is possible to alter its radio frequency surface properties. A smooth conducing surface has low surface impedance while with a specially designed geometry; the periodic structure can have high surface impedance. Such structures have therefore been named high impedance surfaces (HIS).

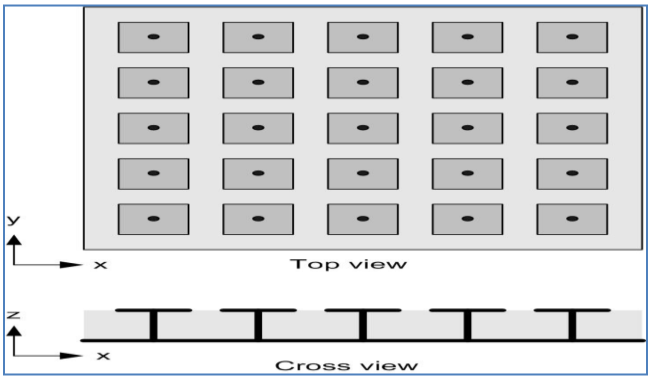

Fig.1 A mushroom like HIS structure top and cross view

The two main electromagnetic properties of HIS are:

• *In phase reflection or Artificial Magnetic conductor (AMC) behavior*. As discussed previously that PEC exhibits 180º phase shift while PMC, which doesn't exist in nature, has a reflection phase of 0º. The reflection phase of HIS varies from -180º to +180º with frequency. When it is between -90 to +90 the image currents are more in phase than out of phase. It means that in a certain frequency band, HIS behave as PMC. And therefore HIS showing such characteristics have been called Artificial Magnetic Conductor (AMC). This in phase reflection behaviour enables low profile antenna design using AMC as ground plane [8].

• *Surface wave suppression or Electromagnetic Band gap (EBG) behaviour*. The frequency band within HIS shows high surface impedance it doesn't allow free propagation of surface waves [9]. In other words there is a band gap for surface wave, hence the name Electromagnetic band gap (EBG). EBG structures have been integrated with antennas to improve the antenna Gain and reduce backward radiation [10,11].

II. LOW PROFILE WEARABLE ANTENNAS USING HIGH IMPEDANCE SURFACES

In this chapter a novel wearable antenna is introduced. For antennas to be integrated into everyday clothing it is desirable that they are compact in size (to lessen severe bending with movement of the body), and have low profile (to help wear ability if they are conformal to the skin). Microstrip patch antennas belong to a well known class of low profile antennas

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that have gained popularity in research and commercial use in the last few decades [12].

A. Three Layer Wearable Antenna for 2.4GHz WLAN Applications

A wearable antenna for WLAN (2.4-2.484GHz) was chosen as a useful and novel first application for the HIS researched thus far. In order to make use of the advantageous techniques discussed in previous sections there was a need to further modify the half wave dipole above a PEC.

Detail Design and Simulated Results

For integration into wearable clothing and to make feeding more practical the centre fed dipole driven element was modified to an end fed planar inverted L antenna. Also to appreciate the performance enhancement introduced by non uniform HIS the design stages are shown starting from the inverted L antenna without HIS to the inverted L antenna with uniform HIS and finally the optimal wearable design of inverted L antenna with non uniform HIS structure. The design stages of wearable inverted L antenna are shown in Figure 4-1. Using the analysis with the optimized results for the HIS iterations in a first design stage a textile 5×16 (≅λeff/4) conductive strip was chosen on top of 4.5mm thick Felt over a flexible PEC. This replaces the dipole antenna with an inverted planar L antenna.

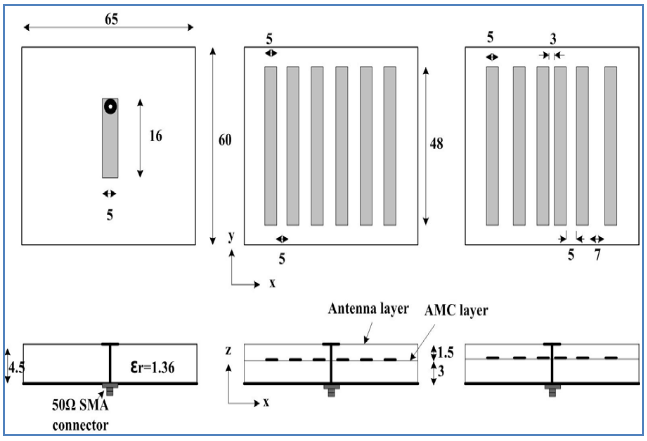


Fig.2 Design stages of low profile wearable inverted L antenna, top view and cross view.

B. A Low Profile Wearable Antenna for 2.4GHz WLAN

To simplify the fabrication process and also to further reduce the profile of wearable antenna the design shown in Figure 3 was also evaluated. It consisted of five metallic strips etched onto the conducting Polyester fabric. Only one layer of substrate was used and the radiating element was incorporated into the plane of the HIS elements. The total size of structure of this antennas was optimised to be 60×50×3(in millimetres) . The length and width of the strips was 48mm and 8mm respectively. For initial assessment of this HIS a uniform spacing between elements of 5mm was used. This topology is shown in fig and produced a phase return coefficient very similar to the one shown in Fig. In order to improve impedance match bandwidth the element spacing distribution was now tapered by closing the more central elements and expanding the outer. The optimised structure for the HIS is shown in Figure 3 along with the relevant dimensions.

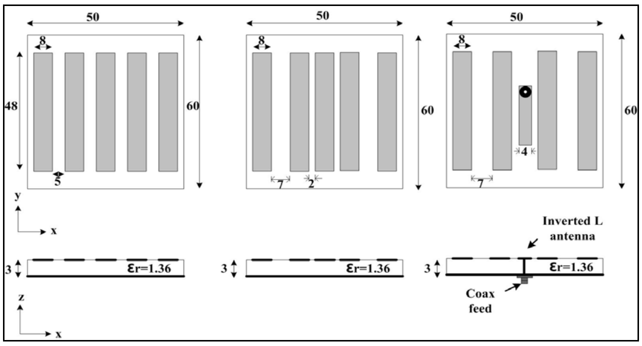
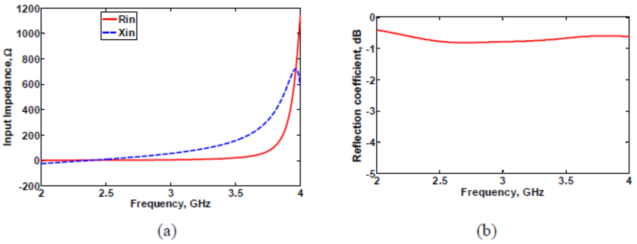


Fig.3 Design stages of modified low profile inverted L antenna Top view and Cross view

C. Synthesis of an Inverted L Antenna Integrated into an HIS

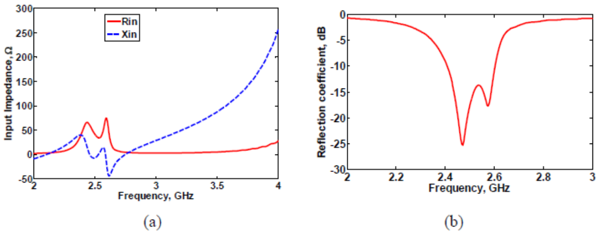
Synthesis began with the simulation of inverted L antenna without any HIS strips. The length of the strip was set to 23mm while the width was kept 4mm. The simulated input impedance and S11 results are shown in Figure 4



(a) (b)

Figure 4 Inverted L antenna. (a) Input impedance. (b) Reflection coefficient (S11).

The antenna is resonant at about 2.36GHz where the imaginary part of input impedance (Xin) is zero. The real part of input impedance (Rin) is only 2Ω which is difficult to match to a 50Ω source feed. The S11 result shown in Figure 4 clearly shows this behaviour as the minimum value of S11 is only -1dB at the resonant frequency. The peak value of input impedance is also very high ≅ 1200Ω. Note that as discovered previously the addition of the HIS alters the properties of the inverted L antenna substantially. First a uniform HIS was modelled as shown in Figure 4The imaginary part of input impedance (Xin) is zero at 2.46GHz. The real part of the input impedance (Rin) is close to 75Ω at this frequency. For fair comparison between uniform and non uniform version of the design the overall dimension of the structure was kept the same. Figure 4 shows the simulated input impedance and S11 results for the non uniform HIS version of wearable inverted L antenna.



(a) (b)

Fig.5 Inverted L with non uniform HIS. (a) Input impedance. (b) Reflection coefficient (S11).

The imaginary part of input impedance (Xin) is zero at 2.45GHz and 2.52GHz while the real part of the input impedance (Rin) is 60Ω and 35Ω respectively. The input resistance variation is small around the resonant frequency. Due to dual resonance behavior the input impedance bandwidth is increased as shown in Figure 4-4(b). The S11 value is about -25dB at 2.46GHz. The input match bandwidth for S11 < -10dB criteria is from 2.4GHz to 2.61GHz which is about 8.4% of the centre operating frequency. Hence non uniformity helps in increasing the input match bandwidth of this wearable antenna. Figure 6 shows the computed surface current distribution for this antenna at 2.44GHz. By comparing this current distribution with the previous antenna it can be seen that there is not 88 much difference in the current distribution of the two antennas. Thus radiation mechanism of both appears to be the same.

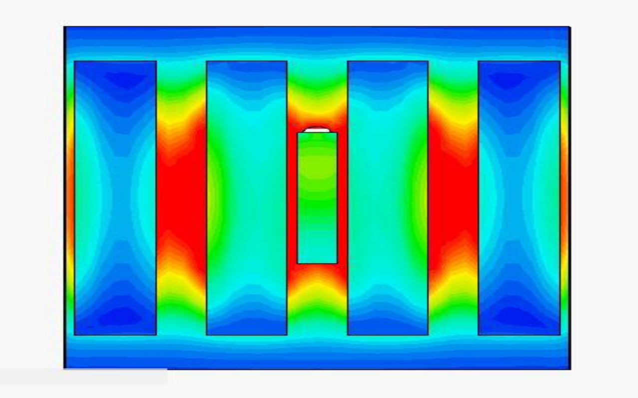


Fig.6 Computed surface current distribution of the antenna at 2.44GHz

III. WEARABLE ANTENNAS ON BODY PERFORMANCE

The human body affects the antenna performance in the following way : (1) the lossy tissues absorb the radiated power and hence degrades radiation efficiency and gain, (2) the high permittivity of tissues changes the guided wavelength and hence detune the resonant frequency (3) due to proximity of human body the antenna input impedance changes and hence degrades the impedance matching achieved for free space design. Apart from these detrimental effects occurring due to close interaction between antenna and human body there are some other factors that can affect the radiation performance of wearable antennas. Typically flexible antennas of the type discussed in this thesis will suffer some type of planar distortion in their dimensions due to conformability with the surface of the body. For example a wearable antenna may be placed on curved part of the body like arm or leg.

A. Wearable Inverted L Antenna Over HIS

The measured performance of wearable inverted L antenna over HIS was investigated in the results assumed that antenna was always planar and there were no interfering objects in the vicinity of antenna. In other words the results were valid for free space environment. In this section antenna under real life situations will be tested for their performance. Specifically the reflection coefficient (S11) result under bending condition for both E-plane and H-plane bending as well as on human body will be presented. The radiation pattern shape under bending condition will be explored to observe the change in radiation performance and the limitation for any bending plane.

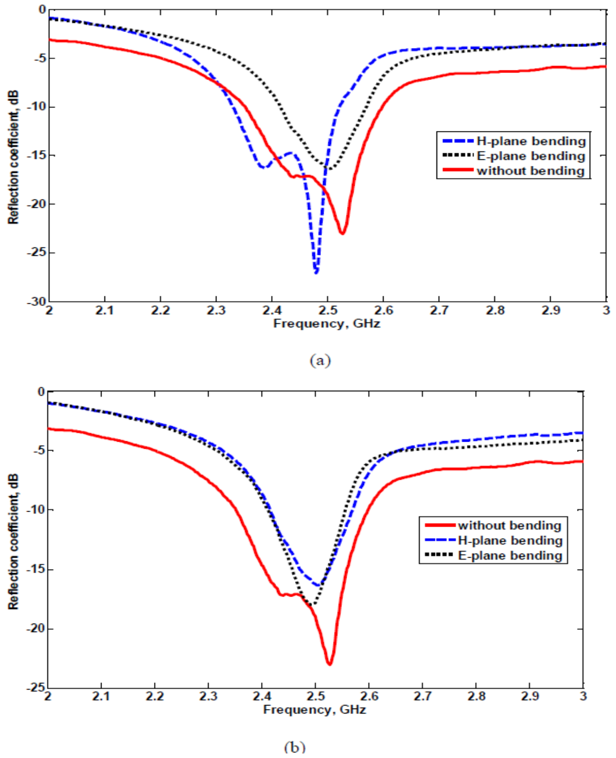
B. Input Match Results Under Bending Conditions

For these experiments two polystyrene foam cylinders with diameters of 70mm and 140mm were used. These dimensions are typical of the human body arm and leg respectively. Since the permittivity of polystyrene foam is close to that of free space and that the size of the cylinders was large compared to the AUT it is reasonable to assume that results showed effect of bending in isolation. For linearly polarized antennas the effect on antenna performance is different depending, along which of the two principal planes namely E-plane and H-plane, the antenna is bent. So the input matching and impedance bandwidth were measured for bending along both of these planes. Figure 6 shows the measurement setup for antenna bending using foam cylinders. The whole setup was placed inside the lab where it was insured that there were no interfering objects in front of the antenna. The height of the antenna from the ground was also quite high to reduce the effect of the ground on antenna performance. As the measurements were carried out in the same place for all test scenarios it is reasonable to assume that if there was any interference its effect would have been observed on all measurements. So any change in measured values would be due to the effect of bending. The antenna measured was the inverted L antenna integrated with HIS on a felt substrate. The total dimension of antenna was 65mm × 65mm×4.5mm. Cello tape was used to fix antenna conformably on the foam cylinder. As a result the edges of the antenna were deformed slightly. The results are therefore valid for the worst possible bending on the cylinder diameters used in this setup. [13-14]

Figure 7. Measurement setup for bending condition. (a) H-plane bending, (b) E-plane bending

The E-plane and H-plane bending results along with the non bending results for comparison purpose are shown in Figure

5-2. As can be seen the bending in general reduced the input match bandwidth.



(a)

(b)

Figure 8 Measured reflection coefficient (S11) results for inverted L over HIS wearable antenna bending on (a) 140mm cylinder (b) 70mm cylinder

The upward shift in operating frequency band for E-plane bending while downward shift for H-plane bending was observed on 140mm foam cylinder. The input match bandwidth was reduced from 2.35GHz-2.6GHz for the unbend case to 2.33GHz-2.52GHz for H-plane bending and 2.41GHz-2.57GHz for E-plane bending. Thus the E-plane bending is more significant for correct behaviour of this wearable antenna. When the antenna was bent around a smaller diameter 70mm cylinder the effect on input match due to E-plane and Hplane bending is almost the same. The H-plane bending input match was 2.4GHz-2.57GHz while E-Plane bending was 2.4GHz-2.55GHz One possible reason for worst E-plane bending effect on input match is due to the fact that E-plane bending affects the antenna's resonant length. The more the antenna is bent the more the resonant length is reduced and thus adversely affects the antenna's matching.[15] It is important to mention that this antenna was still able to operate in the desired 2.4GHz WLAN band even under bending conditions. This proves the reliability of this wearable antenna when conformed to any curved surface.

C. Input Match Results on Body

To see the affect of body on input match characteristics of wearable antenna it was measured by placing it close to human body. Due to probe fed connector the antenna was placed conformably in the region between arm and chest with the VNA cable coming from behind. Again it was ensured that no other interfering object was there other than the human body.

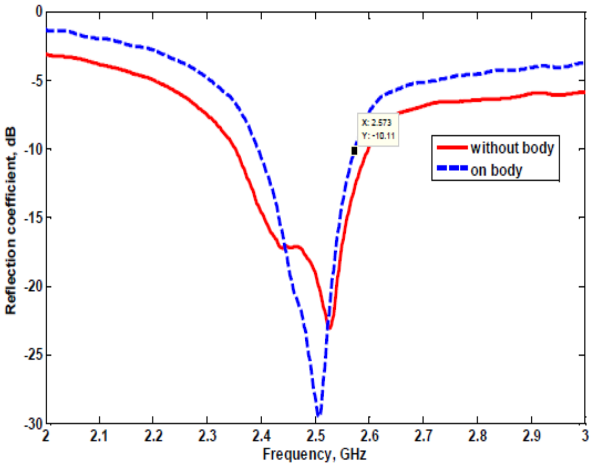


Figure 9. Measured reflection coefficient (S11) of inverted L over HIS wearable antenna with and without body

IV. CONCLUSIONS

The research in this paper concerns designing and fabricating fully textile wearable antennas integrated with novel HIS. The selection of materials and their characterization for wearable antenna design has received limited attention in scientific journals. In this thesis full classification of different techniques available for characterising electromagnetic properties of materials was given. The advantages and disadvantages of different methods clearly entioned. It was concluded that cavity method was best due to its accuracy and non destructive nature. The split post dielectric resonator (SPDR) working on the principle of cavity method and used in this research was demonstrated. Different fabric samples as potential wearable antenna substrates were then measured for the first time using SPDR. The accuracy of this device was verified with the values of the published results. To date wearable antennas were fabricated using copper tape or electro textiles using conventional knife cutting or laser ablation. In this research a novel technique was employed to fabricate wearable antennas using electro textile. The traditional printed circuit board (PCB) etching method was modified for the thin electro textiles. It was claimed this is the first time such a technique has been implemented in wearable antenna design.

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