Effect of Milli Bends on Reflection Coefficient of a Wearable Antenna using FDTD Method

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Abstract: A wearable antenna is supposed to be a part of the clothing used for communication purpose. The wearable antenna can undergo different cases of bending and crumpling. This paper describes the effect of milli bends on reflection coefficient S_{11} along the patch length of a wearable antenna using Finite Difference Time Domain (FDTD) Method. In this work, milli bends at particular angle in the beginning, middle and end of a wearable patch antenna are considered. Three milli bends along the length of wearable antenna are modeled using FDTD method and their effect on reflection coefficient is presented. Results demonstrated the noticeable change in the reflection coefficient and resonant frequency of the antenna.

Keywords: Finite Difference Time Domain Method, Wearable Antenna, Milli Bends.

Introduction

Two and three dimensional scattering problems have been solved using finite difference time domain method [1]-[3]. Finite difference time domain method can be used to compute time domain and frequency domain characteristics of a patch antenna [4]-[5]. Bending of the wearable patch antenna could result in the shift of the resonant frequency [6]. The effect of bending on reflection coefficient and resonant frequency is most dominating along the length of the wearable patch antenna [7]. A bend of size of milli meter is considered as milli bend. The ground plane, substrate and patch undergone a milli bend can be accurately modeled with staircase scheme using the finite difference time domain method. The wearable antenna may be excited using a broad band pulse and by taking Discrete Fourier Transform of the transient results various frequency domain parameters can be computed over the frequency range of interest. In this paper, the scattering parameters of a wearable patch antenna with milli bends along patch length have been calculated and compared using finite difference time domain method. The finite difference time domain method has been chosen over other existing simulators because it allows the simple, straightforward and efficient staircase modeling of a milli bend in a wearable patch antenna. A PML as ABC [8]-[9] is used for the truncation of the computational space.

Maxwell's Equations and FDTD Method

The governing Maxwell's curl equations may be written as:

$$\nabla \times E = -\mu \frac{\partial H}{\partial t} \qquad (1)$$

$$\nabla \times H = \varepsilon \frac{\partial E}{\partial t} \qquad (2)$$

The FDTD method provides the discrete solution of Maxwell's equations directly in time domain. Yee first presented the discrete solution to the above stated continuous Maxwell's equation [1]. The discrete approximation of Maxwell's curl equations is obtained by using the central difference approximations for both temporal and spatial derivatives. The discrete finite difference approximation of H_x and E_z out of six fields is given as

$$H_x\big|_{i,j,k}^{n+1/2} = H_x\big|_{i,j,k}^{n-1/2} + \frac{\Delta t}{\mu \Delta z}\left(E_y\big|_{i,j,k}^{n} - E_y\big|_{i,j,k-1}^{n}\right) - \frac{\Delta t}{\mu \Delta y}\left(E_z\big|_{i,j,k}^{n} - E_z\big|_{i,j-1,k}^{n}\right) \qquad (3)$$

$$E_z\big|_{i,j,k}^{n+1} = E_z\big|_{i,j,k}^{n} + \frac{\Delta t}{\varepsilon \Delta x}\left(H_y\big|_{i+1,j,k}^{n+1/2} - H_y\big|_{i,j,k}^{n+1/2}\right) - \frac{\Delta t}{\varepsilon \Delta y}\left(H_x\big|_{i,j+1,k}^{n+1/2} - H_x\big|_{i,j,k}^{n+1/2}\right) \qquad (4)$$

To ensure the stability of the time stepping algorithm, Δt is chosen to satisfy the criteria $v_{max}\,\Delta t \leq \left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2}\right)^{-1/2}$ where v_{max} is the maximum velocity of light within the problem space.

Modeling of Milli Bends in Wearable Patch Antenna

The modeling of each bend is done using staircase modeling in FDTD method. The geometry of the wearable patch antenna used for the analysis is similar to that shown in Fig. 3 of [5]. The only difference is that the substrate is considered to be a cloth based flexible substrate subject to bending which is required in a wearable patch antenna. The thickness of the dielectric substrate is 0.794 mm with relative permittivity 2.2 over a ground plane. The cell sizes used are $\Delta x = 0.389\,mm$, $\Delta y = 0.4\,mm$ and $\Delta z = 0.265\,mm$, the same as in [5]. The problem space size is $62 \times 120 \times 20$ cells. The time step used is 0.370 picoseconds. The reference plane is at $45\Delta y$ from the edge of the patch. The excitation of the antenna is realized by a Gaussian pulse

$$V_s(t) = e^{\frac{-(t-t_0)^2}{T^2}} \qquad (6)$$

The electric source filed [10] is given by

$$E_s|^n_{i_s,j_s,k_s} = \frac{V_s(n\Delta t)}{\Delta z} + \frac{I_s^{n-1/2}R_s}{\Delta z} \qquad (7)$$

where R_s is the source resistance and I_s is the current through the source. In this analysis PML is used in x, y and z directions respectively to truncate the problem space.

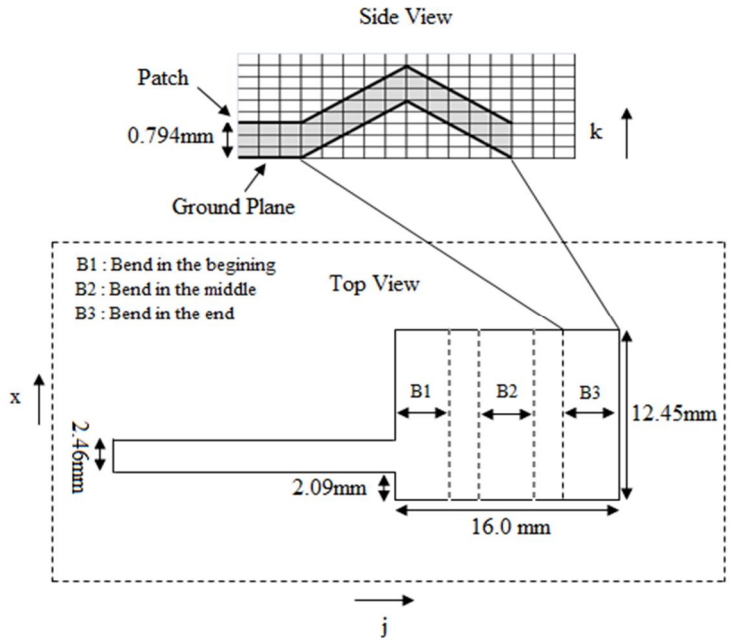

Figure1. Modeling of three milli bends in the beginning, middle and end of the wearable patch antenna using FDTD Method

Fig. 1 presents the modeling of the three milli bends which includes the bending of patch, substrate and ground plane. Total 62 cells in x direction, 10 cells in y direction and 8 cells in z direction are used to model each bend. The bending angle of 33.524° is considered for all cases of milli bends.

Simulation and Results

The excitation and reflected signals for wearable patch antenna with a milli bend at different places along antenna length are compared and presented in Fig 2. The calculated reflection coefficient for all cases of bending and without any bend in the antenna is shown in Fig. 3. The result of reflection coefficient calculated using FDTD method for the case of without any bend is in agreement with [5] and validate the FDTD code which is further extended to all cases of bending at different positions of antenna length.

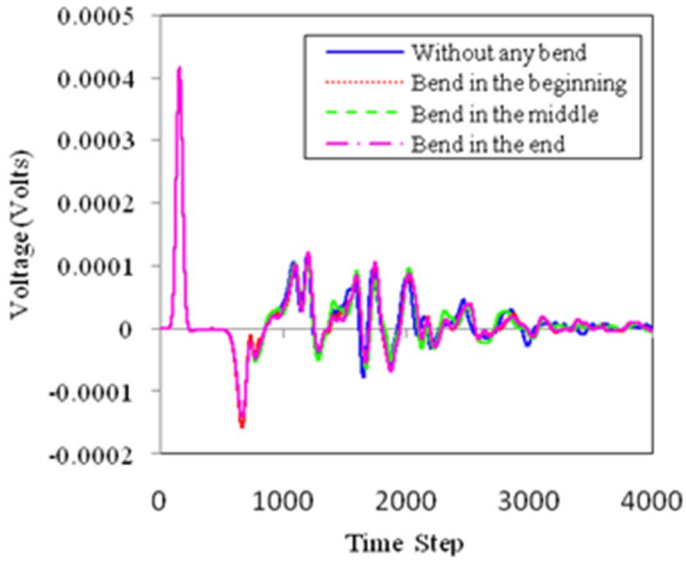

Figure 2. Excitation and reflected signals with a milli bend and without any bend observed at $45\Delta y$ from the edge of the patch

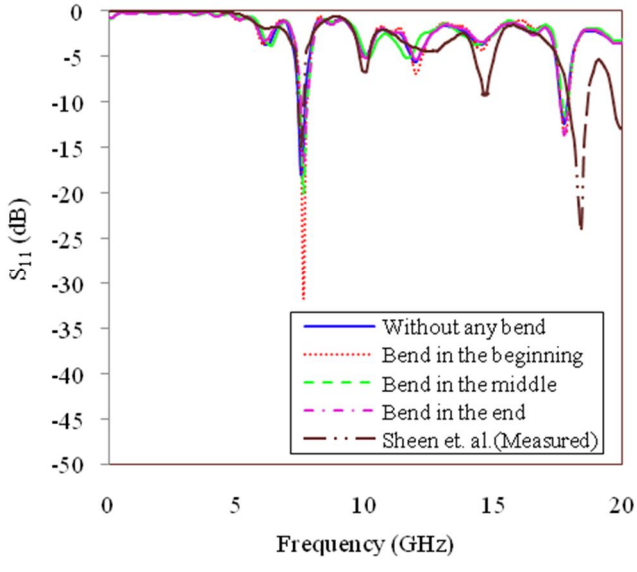

Figure3. Reflection Coefficient S_{11} computed using FDTD method and compared for all cases of milli bends

The reflection coefficient for all the cases of bending and without any bend are compared and presented in Table 1.

Table 1. Comparison of Reflection Coefficient (S_{11})

Position of Milli Bend	**Resonant Frequency (GHz)**	**S_{11}(dB)**
Without any Bend	7.471	-17.838
	17.701	-12.364
In the Beginning	7.586	-31.703
	17.701	-13.655
In the Middle	7.586	-20.092
	17.816	-11.549
In the End	7.586	-16.627
	17.701	-13.558

In case of bend in the beginning, middle and end of the wearable patch antenna, the first resonant frequency significantly shifts from 7.471 GHz to 7.586 GHz. The reflection coefficient for bend in the beginning significantly changes to -31.703 dB and real and imaginary parts of input impedance for this case are 51.11 and -2.37 ohms which justify the change. Similarly, second resonant frequency is same for all cases except bend in the middle. The convergence is achieved after 4000 time steps for all the three cases of bending.

Conclusion

The staircase modeling and simulation of milli bends in a wearable patch antenna using FDTD method is presented in this work. Staircase scheme provided simple and accurate modelling of the milli bends in wearable antenna. It is shown that the presence of milli bends in a wearable patch antenna results in shifting of the resonant frequency and change in the reflection coefficient when excited with a resistive voltage source. The presence of milli bends directly affects the input impedance of the antenna which further changes the value of reflection coefficient. Hence, milli bends in a wearable patch antenna could significantly change the reflection coefficient and severely affect the antenna performance.

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