FDTD based Analysis of Input Impedance of a Wearable Patch Antenna with Milli Bends

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Abstract

Wearable antennas are prone to bending and crumpling. This work presents the analysis of input impedance of a wearable patch antenna with milli bends using Finite Difference Time Domain (FDTD) method. FDTD method using stair case scheme is used to model milli bends at different places along the length of a wearable patch antenna and the effect of milli bends on input impedance of the wearable patch antenna is presented developing a FDTD code for it. It is shown that presence of milli bends in a wearable patch antenna significantly changed the input impedance of the antenna under consideration. It is observed that milli bends closer to the feeding strip line provided better input impedance matching. Results concluded that change in input impedance leads to change in resonant frequency and reflection coefficient of the antenna. General Terms: RF and microwave communication, Antenna design and analysis.

Keywords: FDTD Method, Input Impedance, Milli Bends, Wearable Patch Antenna

1. Introduction

A bend of the size of milli meter is considered as milli bend. Any wearable patch antenna undergone a milli bend can be accurately modelled using finite difference time domain method. The bending of ground plane, substrate and patch can be accurately modelled using stair case scheme in finite difference time domain method. In most cases, the curved bending using a bending diameter for the whole of the wearable patch antenna was considered for the analysis of bending effects. Also, the crumpling can severely degrade the performance of a wearable antenna. The solution of three dimensional scattering problems can be provided by finite difference time domain method. The time domain and frequency domain characteristics of patch antennas have been calculated using FDTD method. A Perfectly Matched Layer (PML) can be used for the truncation of the problem space. Bending along the dimension which determines antenna’s resonant frequency has the most dominant effect on the antenna performance. In this paper, the input impedance parameter of a wearable antenna with milli bends at different places along antenna length have been calculated and compared using finite difference time domain method.

2. FDTD Method

The FDTD method provides the discrete solution of Maxwell’s equations directly in time domain. The governing Maxwell’s equations may be written as:

\[ \nabla \times H = \varepsilon \frac{\partial E}{\partial t} \] (1)

\[ \nabla \times E = -\mu \frac{\partial H}{\partial t} \] (2)

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 and out of six fields is given as

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\[ E_{z,ij,k}^{n+1} = E_{z,ij,k}^{n} + \frac{\Delta t}{\Delta x} \left( E_{y,ij,k}^{n+1/2} - E_{y,ij,k}^{n+1/2} \right) \]
\[ H_{x,ij,k}^{n+1/2} = H_{x,ij,k}^{n+1/2} + \frac{\Delta t}{\mu \Delta y} \left( E_{z,ij,k}^{n+1} - E_{z,ij,k}^{n} \right) \]

The dimensions of unit cells are \( x \) and \( y \) in and directions.

3. Staircase Modeling of Milli Bends

3.1 Antenna for Analysis
To illustrate the effects of bending on a wearable patch antenna, the geometry of the wearable patch antenna is similar to that shown in Figure 3 of 7. 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 the same as in 7. The time step used is 0.370 picoseconds. The reference plane is at 45 from the edge of the patch. The problem space size is cells. The excitation of the antenna is realized by a Gaussian pulse. The electric source field and current through the source are computed using equations of 11. In our computational space 14, 15 and 7 layer PML is used in and directions respectively to truncate the problem space.

3.2 Staircase modeling of Milli Bends
The wearable patch antennas are subject to bending. Three cases in which wearable patch antennas have undergone a milli bend are taken for analysis. The bend is considered at the beginning, middle and end of the antenna. The modeling of the three milli bends includes the bending of patch, substrate and ground plane which is shown in Figure 1. Total 62 cells in \( x \) direction, 10 cells in \( y \) direction and 8 cells in \( z \) direction are used to model each bend12. All three bends are modelled in such a way that the antenna after bend passes diagonally through the FDTD cells. Each bend covers 4.798 mm length of patch in \( y \)-\( z \) direction. The rest of the length of the patch of 11.202 mm is modelled using in \( y \) direction. This type of modeling does not require any special change in the FDTD equations. In case of metal patch as well as ground plane, the tangential components of electric field are set to zero.

\[ \theta = \tan^{-1} \frac{\Delta x}{\Delta y} \]

The bending angle in this case is.

3.3 Calculation of Input Impedance
The input impedance of the wearable patch antenna for all the cases of bending and without bending is calculated using

\[ Z_{in} = Z_{0} \frac{1 + S_{11} e^{-i2kL}}{1 - S_{11} e^{-i2kL}} \]

where \( k \) is the wavenumber on the microstrip, \( L \) is the length from the edge of the antenna to the reference plane (45). The characteristic impedance of the microstrip line is assumed to have a constant value of 50\( \Omega \). The wavenumber is computed using following relation

\[ k = 2\pi f \sqrt{\mu \epsilon_{r,0}} \]

Effective permittivity of 1.9 is used to calculate the wavenumber5.
4. Results and Discussion

The signal for excitation of the antenna in simulation is consider for first 350 samples and rest samples of voltage are considered as reflected signal from the wearable patch antenna. The simulation images for all the cases are presented in Figure 2.

In simulation images, component at time step=1500 just below the metal patch is shown. The real and imaginary parts of the input impedance for wearable patch antenna in all cases is computed and presented in Figure 3 and Figure 4.

The calculated reflection coefficient for all cases of bending and without any bend in the antenna is shown in Figure 5.

The result of reflection coefficient calculated using FDTD method for the case of without any bend is in agreement with and validate the FDTD code which is further extended to all cases of bending at different positions of antenna length.

![Figure 2](image.png)

**Figure 2.** Simulation images for component of wearable patch antenna at time step=1500 just below the metal patch (a) Without any bend (b) Bend in the beginning (c) Bend in the middle (d) Bend in the end.

The reflection coefficient and real and imaginary parts of input impedance of first and second resonant frequency for all the cases of bending and without any bend are compared and presented in Table 1.

In case of bend in the beginning, middle and end of the wearable patch antenna, the real parts of input impedance for first resonant frequency are 51.11, 53.73 and 54.96 ohms respectively. Similarly, for bend in the beginning, middle and end of the wearable patch antenna, the imaginary parts of input impedance are -2.37, -9.60 and -14.65 ohms. In case of milli bend in beginning, the reflection coefficient for first resonant frequency is -31.703 dB, which is due to the maximum input impedance matching, i.e. real and imaginary parts of input impedance are 51.11 and -2.37 ohms which justify the change.

![Figure 3](image.png)

**Figure 3.** Real part of the input impedance of the wearable patch antenna for all cases of with and without bending calculated using FDTD method.

![Figure 4](image.png)

**Figure 4.** Imaginary part of the input impedance of the wearable patch antenna for all cases of with and without bending calculated using FDTD method.
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Figure 5. Reflection Coefficient $S_{11}$ for wearable patch antenna calculated using FDTD method compared for all cases of bending and without any bend.

For first resonant frequency, the imaginary parts of input impedance are not close to zero for middle and end cases of milli bends, which justifies the values of reflection coefficient. Similarly, second resonant frequency is same for all cases except bend in the middle. The reflection coefficients for second resonant frequency are almost same for all cases of milli bends. It is because of the approximately same input impedance values as shown in Table 1. It is observed that in all three milli bend cases of wearable patch antenna, the convergence is achieved after 4000 time steps.

Table 1. Comparison of Input Impedance ($Z_{in}$) and Reflection Coefficient ($S_{11}$)

| Milli Bend Position | Resonant Frequency (GHz) | $S_{11}$ (dB) | $Z_{in}$ (Real) in ohms | $Z_{in}$ (Imaginary) in ohms |
|---------------------|--------------------------|---------------|-------------------------|-----------------------------|
| Without any Bend    | 7.471                    | -17.838       | 53.73                   | -15.44                      |
|                     | 17.701                   | -12.364       | 104.24                  | -114.75                     |
| In the Beginning    | 7.586                    | -31.703       | 51.11                   | -2.37                       |
|                     | 17.701                   | -13.655       | 70.70                   | -14.42                      |
| In the Middle       | 7.586                    | -20.092       | 53.73                   | -9.60                       |
|                     | 17.816                   | -11.549       | 79.49                   | -18.07                      |
| In the End          | 7.586                    | -16.627       | 54.96                   | -14.82                      |
|                     | 17.701                   | -13.558       | 70.96                   | -14.65                      |

5. Conclusion

The staircase modeling and simulation of milli bends in a wearable patch antenna using FDTD method is presented in this work. The staircase scheme is used to accurately model milli bends in a wearable patch antenna. It is shown that the presence of milli bends in a wearable patch antenna results in change of the input impedance which further shifts the resonant frequency and reflection coefficient when excited with a resistive voltage source. It is observed that for better input impedance matching, the real and imaginary parts of input impedance must approach 50 and zero ohms respectively. It is concluded that milli bends closer to the feeding strip line provided better input impedance matching. Hence, presence of milli bends in a wearable patch antenna could severely affect the input impedance and antenna performance.

6. References

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