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COMPARISON OF DIFFERENT OPERATIONAL RESONANT FREQUENCIES FOR W.B.A.N. AND ANTENNA DESIGN FOR THE MOST FAVOURABLE FREQUENCY

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Abstract— A WIRELESS BODY AREA NETWORK (WBAN) is a wireless sensor network technology that is confined to body of a person under supervision. There are various different challenges in WBAN designing , amongst which antenna designing and suitable operational resonant frequency selection for transmission are some of the major areas of concern. In this paper, we will discuss about different available frequency options for operation and according to the desired specifications will decide the appropriate resonant frequency for operation, also we will design an antenna for the most suitable operational frequency and will draw conclusion based on different results obtained.
Keywords— Microstrip Patch Antenna, CST Studio Suite

I. INTRODUCTION

Wireless body area network is a type of wireless sensor network technology that has confined limits to the body of a person under observation. Being a major area of interest due to various advantageous applications like continuous and flexible health monitoring of patients and performance analysis of athletes, WBAN is one of the major area under study of the present.

Reviewing the basics of WBAN, the network is a kind of wireless sensor network that consists of different wireless sensors which can be either mounted on or embedded skin deep into the body of person under observation, thus the domain further increases study scope and improvements relating wearable technology advancement.

The sensors are supposed to sense in real time and the processed data can be recorded as well as transmitted on regular intervals thus giving a flexibility to work as well as regular health monitoring at the same time.
The major critical domains under WBAN designing are as follows:

- Design and development of sensors
- Designing of transceiver and antenna designing
- Channel modeling of WBAN
- Interference mitigation
- Development of active protocols for active transmission

II. BASICS OF ANTENNA DESIGN

There are many different antenna designs possible for WBAN such as linear wire antenna, loop antenna, arrays of antenna, broadband dipole antenna, travelling wave antenna, apperture antenna, horn antenna, microstrip antenna, reflector antenna etc. each of these have their own speciality. In WBAN system, the antenna design is constrained by the following parameters:

- Size of antenna
- Power radiated by antenna
- Weight of antenna
- Cost of antenna
- Performance of antenna

The desired antenna must be small in size and must be light weight so that it can be easily mounted on the wearable sensor that the person under observation bears. Also the power radiated by the antenna must be small so that continuous radiation around the body doesnot cause serious damage when the device is continuously used. All these requirements can be easily attained by using a microstrip patch antenna. Although there are small issues like low effeciency and high quality factor associated with this low profile antenna still it proves to be the best for WBAN requirements, also the installation of microstrip patch antenna is very easy.

There are several types of microstrip patch antenna elements that can basically be square, rectangular, elliptical, circular, triangular, disc sector, circular ring and ring sector etc. however, the most suitable and easy to fabricate is the rectangular patch element for microstrip antenna. The analysis of rectangular microstrip patch antenna is quite easy using both cavity model as well as the transmission line model and is the most accurate for thin substrates. Thus rectangular patch antenna is widely used configuration of microstrip patch antenna design.

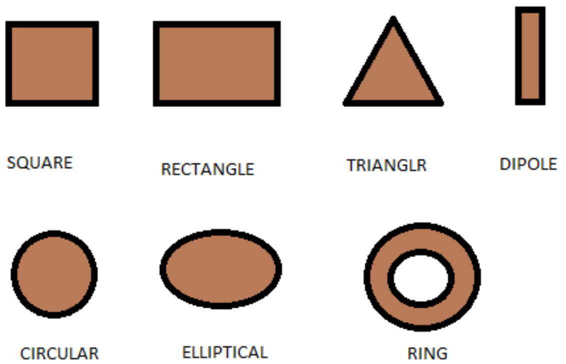


Fig. 1: Shapes of microstrip patch elements

III. CHOICE OF RESONANT OPERATING FREQUENCIES

The choice of resonant frequency of operation for antenna is one of the largest hurdle in antenna designing. As per the requirements , some factors like power radiated, area usage of antenna, feasible installation etc. and certain other parameters also decide the resonant operating frequency.

The general trend is that as the frequency of operation increases, the size of the antenna reduces and the power radiated increases. But for the use of antenna in WBAN, the size must also be small as well as the power radiated by the antenna must also be managed because the antennas are to be mounted over the sensors that the person under observation will be bearing on body. Thus a wise choice of antenna frequency is a must.

There are several frequency ranges possible for ISM band in India which are as listed :

- 26.957MHz – 27.283MHz
- 335.70MHz – 335.84MHz
- 865MHz – 867 MHz
- 2.400GHz – 2.483GHz
- 5.150GHz – 5.350GHz
- 5.825GHz – 5.875GHz

The dimensions of the antenna can be calculated by using the following approximation formulae:

Because of the fact that there is a difference in phase velocities in air and substrate, therefore the dominant mode of operation will be quasi TEM mode. The dielectric constant changes due to fringing effect and wave propagation in line and thus an effective dielectric constant (**ϵ***reff*) must be obtained in order to account for the fringing and the wave propagation in the line. **ϵ***reff* value is smaller than ϵ*r b*ecause the fringing fields around the boundaries of the patch are not confined in the dielectric substrate but are also spread in the air .We can obtain **ϵ***reff* by the formula given below:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\left(\frac{h}{W}\right)\right]^{-1/2}$$

Where, ϵ_{reff}= Effective dielectric constant
ϵ_r= Dielectric constant of substrate
h = Height of dielectric substrate
W = Width of the patch

The length of the patch is extended on each end by a distance Δ*L* due to fringing, which is given by:

$$\Delta L = 0.412h\frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}$$

Hence the effective length is given by:

$$L_{eff} = L + 2\Delta L$$

Also,

$$L_{eff} = \frac{c}{2f_o\sqrt{\epsilon_{reff}}}$$

The operational frequency is given by:

$$f_o = \frac{c}{2\sqrt{\epsilon_{reff}}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{\frac{1}{2}}$$

The width is given by:

$$W = \frac{c}{2f_o\sqrt{\frac{\epsilon_r+1}{2}}}$$

Now, the substrate material and the ground plate and patch materials are to be chosen, we have chosen FR4 substrate for the convenience of the calculations as the corresponding h=1.6mm and the Eeff=4.3."FR" here stands for flame retardant. The antenna is assumed to have a U shaped patch of copper. Ground plate is also made up of copper due to its conducting property.

Using Er= 4.3 and h=1.6mm From the above formulae, we can calculate the dimensions of antenna patch for different frequencies . The following table is obtained using these formulae for different frequencies in ISM band:

FREQUENCY	W(mm)	Eeff	Leff(mm)	ΔL(mm)	L(mm)
335.71MHz	271.94	3.759	211.15	0.766	209.67
865 MHz	105.54	3.842	81.26	0.754	79.78
2.4 GHz	38.41	3.996	31.26	0.741	28.84
5.15GHz	17.724	4.243	12.83	0.721	11.42

Table 1: Dimensions corresponding to different frequencies.

Now, on the basis of the dimensions of the antenna observed, we can rule out all the frequencies less than 2.4 GHz because the size of the antenna is very large thus it is not practically possible to be mounted over the sensors of WBAN. Also the frequencies above 2.4GHz are associated with large power radiation thus they also can not be used as the resonant frequency for our desired system. Although there are some interference issues with 2.4GHz as the WLAN and bluetooth etc also share the same bandwidth but this can be taken care while channel modelling of WBAN. Hence we can easily conclude that the best resonant frequency of operation for WBAN is 2.4GHz.

IV. BASICS OF RECTANGULAR PATCH ANTENNA

For a perfect and lossless transmission of the signal through the antenna, there must be a proper impedance matching between the source , transmission line and the antenna or in other words the source and the antenna must be matched perfectly failing which will result in standing wave formation and thus the signal will be degraded.

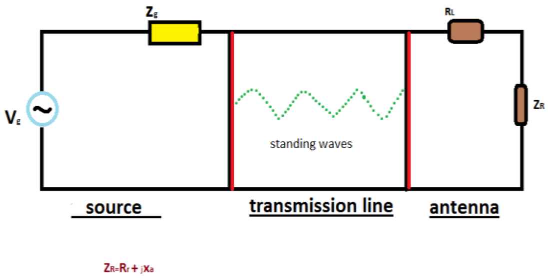


Fig. 2 Standing wave formation due to mismatching

We assume that the transmission line and the source are matched at 50 ohms impedance. Thus using maximum power transfer theorem, the patch must be matched to 50 ohms.
For finding out the impedance at the tip of the rectangular patch microstrip, we use the formulae:

Zth=90 * Er^2/(Er-1) *$(l/w)^2$
And
Zin(x) =Zin(0)$\cos^2$(Πx/ l)
From these equations, we obtain Zth = 303ohms, we have Zth =Zin(0);
So substituting we get, x=10.928mm. This is called the cut depth, denoted by Cd.

Cd denotes that distance from the end edge of microstrip patch where the impedance is equal to 50 ohms, thus the feed is placed at that point on the patch. A slight area upto Cd is removed and the patch is attached to the point where perfect impedance matching takes place.

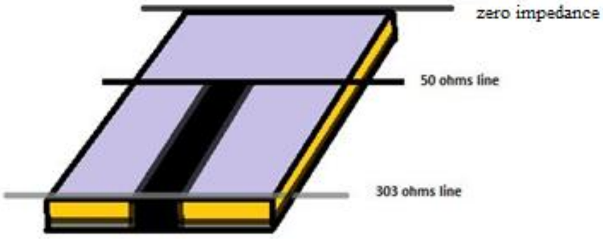


Fig. 3 Portion removed from the microstrip substrate for matching

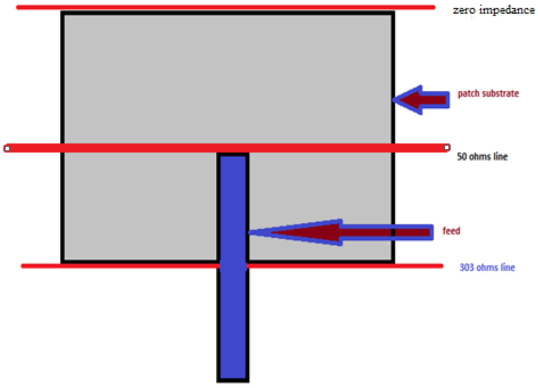


Fig. 4 Feed attached to the 50 ohms impedance matched line

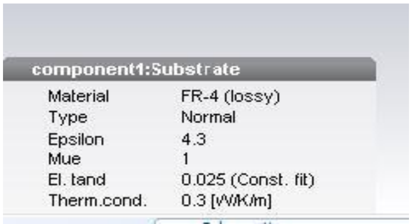
V. RECTANGULAR MICROSTRIP ANTENNA AT 2.4GHZ

As per the dimensions attained using the above all formulae, we design the patch antenna using CST studio suite. The major steps include:

- Choice of substrate material, ground plate and patch
- Declaration of different parameters like length, width, height, cut depth, cut length, thickness, base material etc. and associating them with coordinate axes
- Declaration of boundaries on different parameters
- Analysis of resonant frequency dip
- Observing the power , directivity and gain etc. results for the formulated structure
- Concluding based on the results obtained

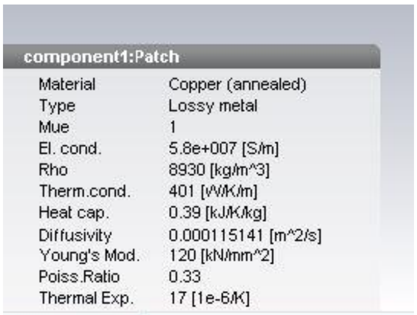
A. Choice of substrate, ground plate and patch

For the designing, as discussed earlier the substrate is FR 4 , the ground plate and patch are of copper material. These materials are selected on the CST suite as shown below:



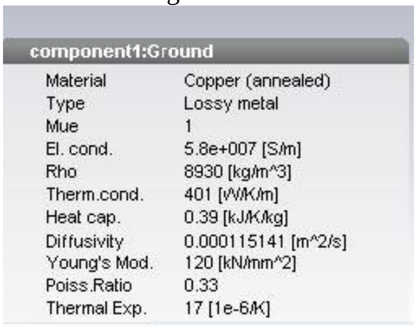
component1:Substrate	
Material	FR-4 (lossy)
Type	Normal
Epsilon	4.3
Mue	1
El. tand	0.025 (Const. fit)
Therm.cond.	0.3 [W/K/m]

Fig. 5 Substrate



component1:Patch	
Material	Copper (annealed)
Type	Lossy metal
Mue	1
El. cond.	5.8e+007 [S/m]
Rho	8930 [kg/m^3]
Therm.cond.	401 [W/K/m]
Heat cap.	0.39 [kJ/K/kg]
Diffusivity	0.000115141 [m^2/s]
Young's Mod.	120 [kN/mm^2]
Poiss.Ratio	0.33
Thermal Exp.	17 [1e-6/K]

Fig. 6 Patch



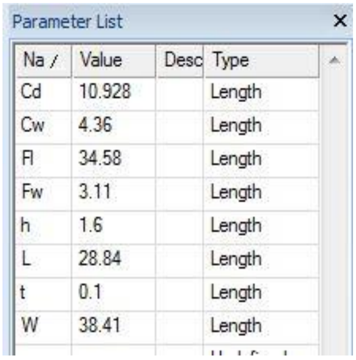
component1:Ground	
Material	Copper (annealed)
Type	Lossy metal
Mue	1
El. cond.	5.8e+007 [S/m]
Rho	8930 [kg/m^3]
Therm.cond.	401 [W/K/m]
Heat cap.	0.39 [kJ/K/kg]
Diffusivity	0.000115141 [m^2/s]
Young's Mod.	120 [kN/mm^2]
Poiss.Ratio	0.33
Thermal Exp.	17 [1e-6/K]

Fig. 7 Ground plate

B. Declaration of different parameters

The next step in antenna design using CST studio suite is declaring the parameters like length, width of substrate, cut depth, cut width due to feed matching, thickness of substrate material etc.

In accordance to the observed values , the parameters are set and values are assigned.



Parameter List

Na /	Value	Desc	Type
Cd	10.928		Length
Cw	4.36		Length
Fl	34.58		Length
Fw	3.11		Length
h	1.6		Length
L	28.84		Length
t	0.1		Length
W	38.41		Length

Fig. 8 Parameters defined

C. Declaring boundaries

Declaration of boundaries on different parameters and associating the substrate with feed is necessary for proper attachment of the feed to the substrate. It is obtained that the minimum substrate width must be not less than 6 times the feed width also the substrate height and feed height are related to each other. The figure below illustrates the relation between the feed parameters and the substrate parameters.

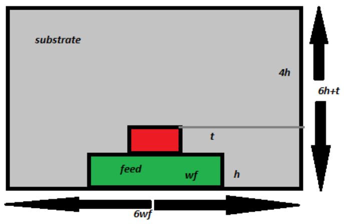


Fig. 9 Relation between feed and substrate

The substrate and patch boundaries are defined in terms of x and y coordinates such as:

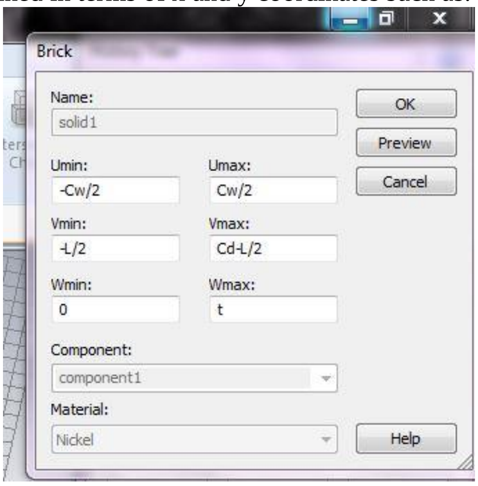


Fig. 10 Patch assign front

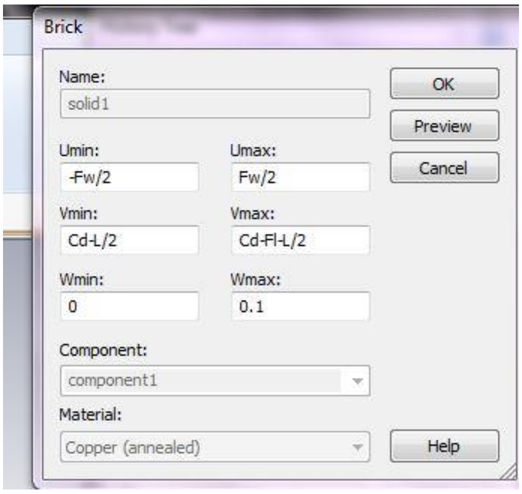


Fig. 11 Patch assign back

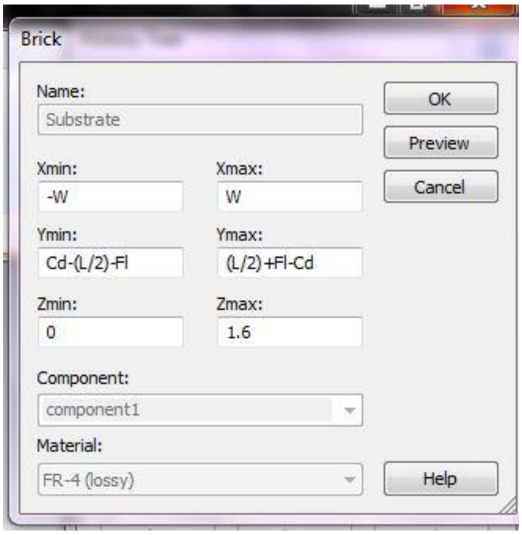


Fig. 12 Substrate assign

D. Assessment of resonant frequency dip

On completion of the designing and associating the parameters with dimensions, we observe the first resonance frequency dip using S parameter for the antenna designed. The following CST studio image corresponds to resonance behaviour and dip at 2.4GHz

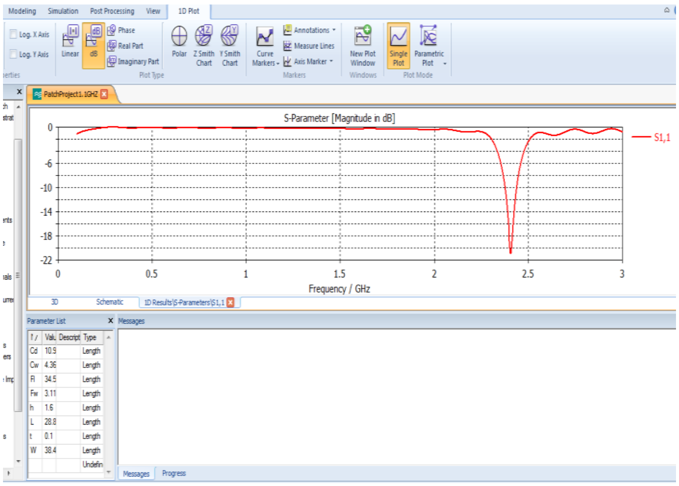


Fig. 12 S-parameter resonant frequency dip at 2.4GHz

The above S1,1 parameter dip at 2.4 GHz confirms that the antenna is correctly designed for resonant frequency of 2.4GHz thus, now we proceed towards the analysis of results corresponding to the design.

The CST STUDIO suite comes with a wide variety of options that can be observed using the software. Following are options that can be obtained:

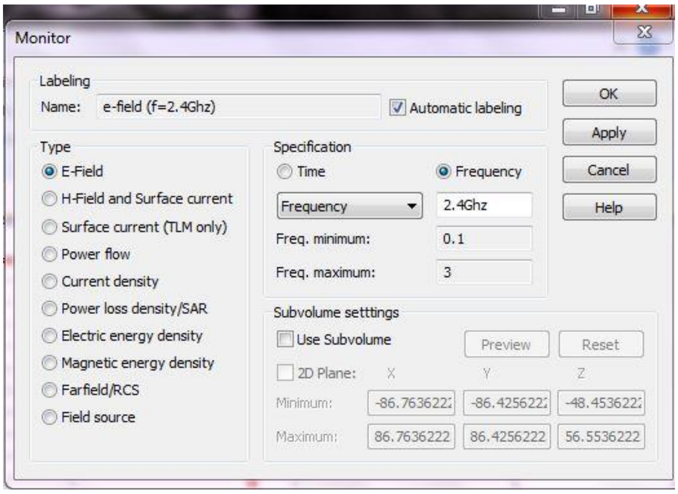


Fig. 13 CST options

VI. RESULTS DRAWN

A. Power

The results corresponding to power radiated , output power from all ports and simulated power are drawn and it is observed that the outgoing power almost vanishes at the resonant frequency corresponding to low losses. The simulated power limitation explains that the power simulated is well within the safe limits, hence 2.4GHz use is proved correct and the last power radiated is also well below the hazardous limits which proves the design a success for WBAN. The following plots prove the above statements:

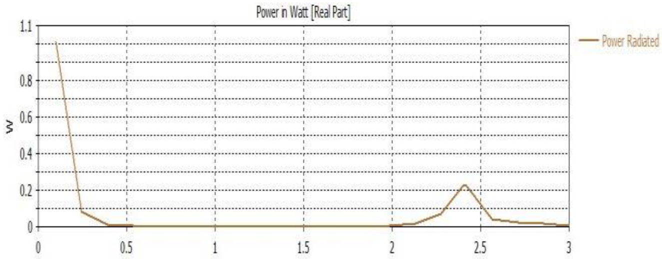


Fig.14 Power radiated

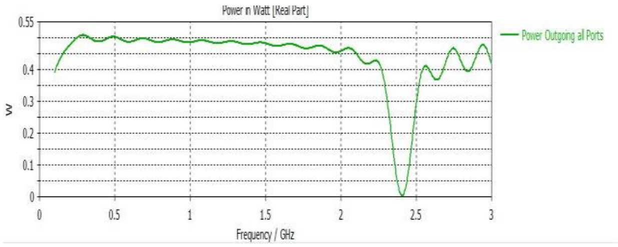


Fig. 15 Power outgoing all ports

B. VSWR

The VSWR plot observed also shows that VSWR is minimum at 2.4GHz as shown :

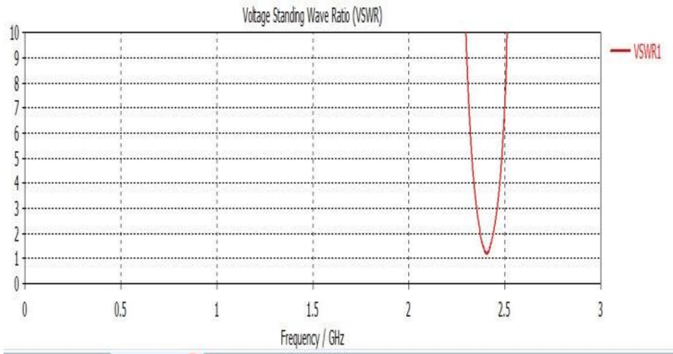


Fig. 16 VSWR

C. Directivity

The following plots show the directivity of this antenna. It is observed that the far-field directivity of the designed antenna is approx 3 times that of an isotropic antenna or 6.98 dBi.

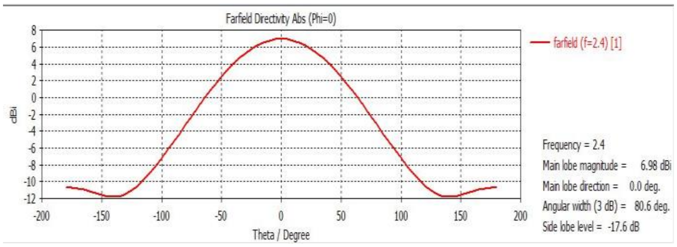


Fig. 17 Far-field directivity

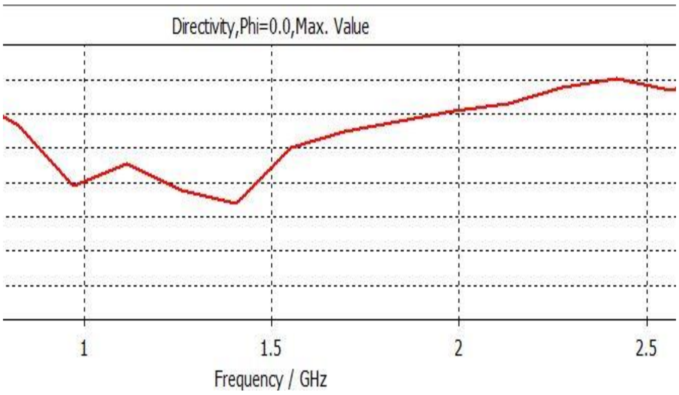


Fig. 18 Maximum directivity frequency plot

VII. CONCLUSION

From the above , we can conclude that the best operational resonant frequency for transmission in WBAN is 2.4GHz and we also realised antenna design using FR4 substrate and copper ground plate. The power ,VSWR and directivity observed are found within the desired limits. Hence this model is appropriate for antenna design for WBAN although there is a wide scope of improvement for this domain in future.

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