भारतीय सूचना प्रौद्योगिकी संस्थान, नागपुर

Indian Institute of Information Technology, Nagpur

Department of Electronics and Communication Engineering

Final Year Project Presentation - 1

Design of Flexible Antenna

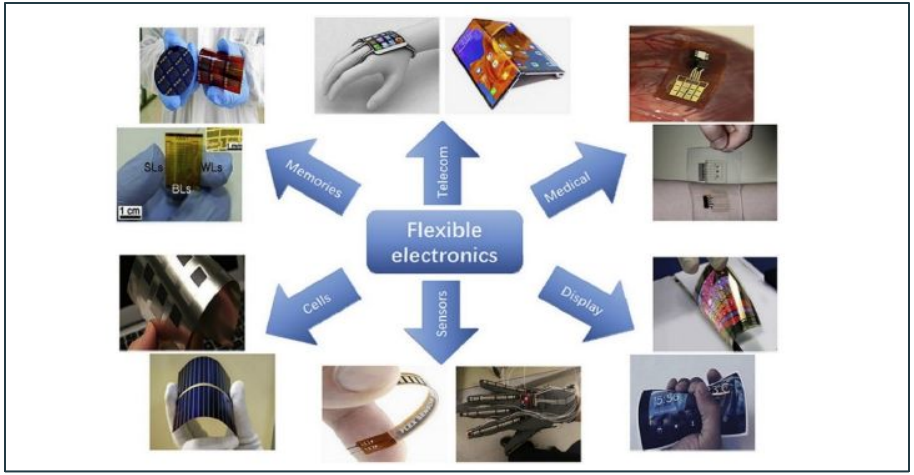
Presented By:
BT19ECE005 Sakshi Pandagale
BT19ECE037 Avish Fakirde
BT19ECE073 Saikumar Mulkalla

Supervisor:
Dr. Paritosh D. Peshwe

Overview

Recent years have seen a steep growth in the field of flexible antenna development due to the increasing demand of

- wearable technology,
- the Internet of Things (IoT) framework,
- point-of-care devices,
- personalised medicine platforms,
- 5G technology,
- wireless sensor networks,
- and communication devices with a smaller form factor, to name a few,



Application areas for flexible electronics [12]

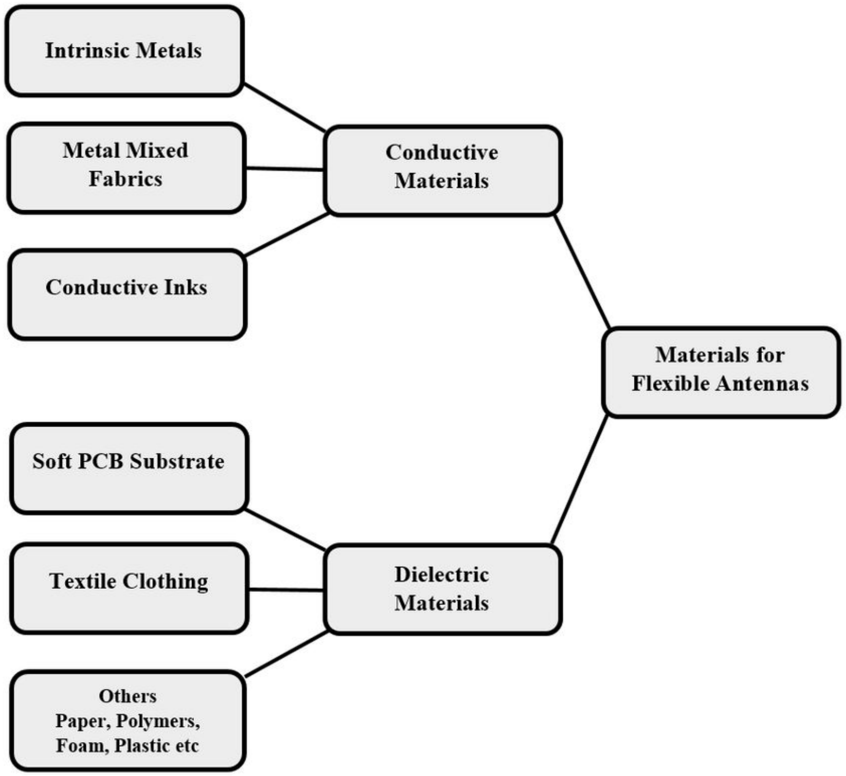
Overview

The choice of our non-rigid antenna is

1. Application specific

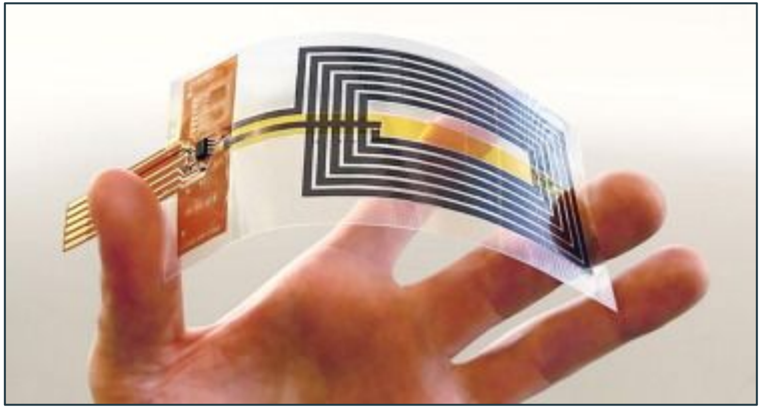
Overview

2. Type of substrate and materials used



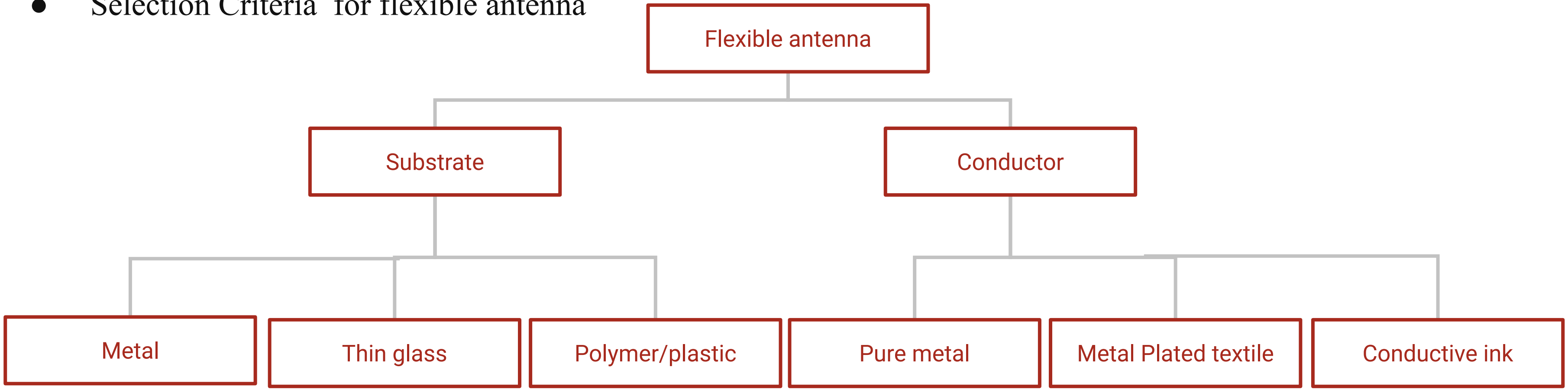
Introduction

- What are Flexible antennas ?
- Where and Why are flexible antennas used?



Material Overview for Flexible Antenna

- Important characteristics of flexible antenna are compactness,flexibility ,durability,efficient ,low weight.
- So materials used for flexible antenna are different from conventional antenna
- Selection Criteria for flexible antenna



Material Overview for Flexible Antennas(Substrate)

- Plastic or polymer materials are the best candidates for flexible antenna applications which include polyethylene terephthalate (PET),polyethylene naphthalate (PEN),polycarbonate (PC) and polyethersulfone (PES), polyimide.
- PET and PEN are preferred in many flexible antenna designs due to excellent electrical, mechanical, and moisture resistant properties.
- PET and PEN substrate have excellent conformality, but low glass transition temperature limits their application for the high-temperature condition.
- The use of polydimethylsiloxane (PDMS) polymer as a substrate has been emerging because of its low Young’s modulus (<3 MPa) suggesting high flexibility/conformality .
- But PDMS has weak metal–polymer adhesion(but certain solutions have been found out).

Material Overview for Flexible Antennas(Substrate)

- Paper substrate has been preferred for flexible antennas due to the cost-effective nature and ease of manufacturing.
- Liquid crystal polymer (LCP) is used for high-frequency flexible antennas due to low dielectric loss, lower moisture absorption, resistant to chemicals, and can withstand temperatures up to 300 ◦C

Substrate	**Dielectric constant**	**Dielectric Loss**	**Thickness (mm)**
LCP	2.9	0.0025	0.1
Cotton/Polyester	1.6	0.02	2.808
Felt	1.3	0.02	1.1
Woolen felt	1.16	0.02	3.5

Material Overview for Flexible Antenna(Substrate)

Substrate	Dielectric constant	Dielectric Loss	Thickness (mm)
PET	3	0.008	0.140
PEN	2.9	0.025	0.125
Polyimide	2.91	0.005	0.2
PDMS	2.65	0.02	-
PDMS with glass Microsphere	1.85	0.014	-
PDMS with Phenolic Microsphere	2.24	0.022	-
PDMS with silicate Microsphere	2.45	0.02	-
Paper (Kodak Photo paper)	2.85	0.05	0.254

Material Overview for Flexible Antenna

Substrate	Advantages	Disadvantages	
Paper	• Low-cost • Biodegradable • Ease of disposal through fiber recycling or incineration	• Limited surface mounting methods • Layer of coating to create an adhesion base • Barrier coating necessary against water and moisture influences	
PET(Polyethylene terephthalate)	• Low-cost Rugged	• Limited surface mounting methods	
Liquid Crystal Polymer(LCP)	• Low relative dielectric constants • Low dissipation factors • Conventional surface mounting methods	• High cost • Highly anisotropic properties • Drying required before processing	

Material Overview for Flexible Antenna

Substrate	Advantages	Disadvantages	
Polyimide	• HIgh Temperature endurance • Rugged • Excellent electrical characteristics • Conventional surface mounting methods	• High cost • Not environmentally friendly	
PLA	• Biodegradable • Available in both flexible and rigid forms	• High material fabrication complicity • Limited surface mounting methods	
Vinyl polymer	• Low cost • biodegradable	•	

Material Overview for Flexible Antenna (Conductive Material)

- Nanoparticle inks (i.e., silver and copper) are often preferred for fabricating flexible antennas due to their high electrical conductivity.
- copper tapes,
- Electro-textile materials Flectron (copper-coated nylon fabric), and nonwoven conductive fabrics (NWCFs) are generally used in flexible antennas.
- silver nanowire embedded silicone , silver loaded fluorine rubber , carbon nanotubes (CNT)-based conductive polymers , liquid metals in the stretchable substrate [40], and use of stretchable fabric itself
- Polymers like polyaniline,polypyrrole

Material Overview for Flexible Antenna (Conductive Material)

Materials Types	Conductive Materials	Conductivity, σ (S/m)
Metal nanoparticles	Ag nanoparticle	2.173 × 107
Metal nanoparticles	Cu nanoparticle	1 × 106
Conductive Polymers	PEDOT	100–1500
Conductive Polymers	Polyaniline (Pani)	5
Conductive Polymers	Polypyrrole (PPy)	40–200
Conductive Polymers with additives	C nanotube	4000–7000
Conductive Polymers with additives	PANI/CCo Composite	7.3 × 103
Conductive Polymers with additives	AgNW/PDMS	8130
Conductive Polymers with additives	Ag flakes + Fluorine Rubber	8.5 × 104

Material Overview for Flexible Antenna (Conductive Material)

Materials Types	Conductive Materials	Conductivity, σ (S/m)
Graphene Based materials	Nanoflakes	6 × 105
Graphene Based materials	Paper	4.2 × 105
Graphene Based materials	Meshed Fabric	2 × 105
Liquid Metal	Eutectic GaIn	3.4 × 106

Ideal Parameters of Flexible Antenna

- The antenna should be operated at Ultra high frequencies of 1.5 - 5 GHz range. But **Federal Communications Commission(FCC)** has opened an unlicensed frequency band around 60GHz, given the smaller wavelength and the higher free space attenuations at such frequencies, it is easier to confine the signal around human body.

- On Body Communication desire wide beam or omnidirectional radiations in the plane parallel to human body surface to provide maximum coverage over the body.

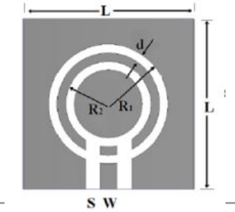
- According to IEEE 95.1 and International Commission on Non-Ionizing Radiation Protection(ICNIRP) the Specific Absorption Rate(SAR) for On Body Antennas is 1.6W/kg for any 1g of tissue and 2W/kg for any 10g of tissue.

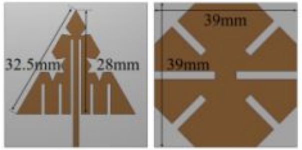
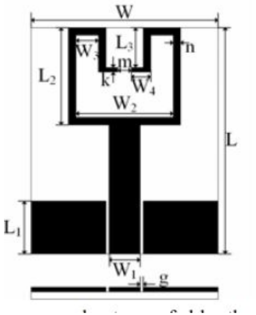
- According to IEEE 802.15.6 Standard the Maximum Data Rate should be in range of 0.0919 - 0.4857 Mbps.

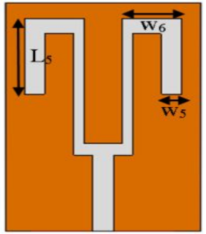
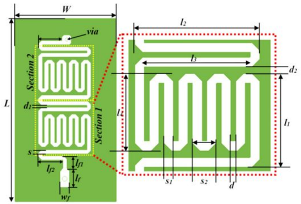
Ideal Parameters of Flexible Antenna for Wireless Body Area Networks

- The Gain for the WBAN antenna can range from 2.24 - 7.53dB however when the antenna come in contact with Human Body this gain value decreases as Human body is a lossy medium, when loss added to the substrate loss no matter what substrate you are using, the body tissue helps in impedance matching, the lossy body is a good absorber so gain decreases.
- The Reflection Coefficient for the Flexible antenna should be below -10dB.
- The VSWR for the most of Antenna Applications should be less than 2.

Literature Review

Sr No.	Title	Designed Antenna	Substrate(s) Used	Antenna Parameters	Comments
1.	[1]Flexible Efficient Quasi-Yagi Printed Uniplanar Antenna	Quasi-Yagi Antenna 	Rogers RT/Duroid 5880 substrate board (t = (0.127 mm, εr = 2.2, μr = 1.0, and tan σ = 0.0009)	R.Freq 1.5 - 1.6 GHz (1.589GHz) E.Size 0.17λ0 x 0.43λ0 Peak Gain 5.76dBi Radiation efficiency 85.33%	The Antenna is Compact and Efficient Directive Radiator but the frequency band used is not an ISM frequency band.The substrate is not ideal for flexible antenna.
2.	[2]A Compact Wideband Flexible Implantable Slot Antenna Design With Enhanced Gain	Slot Antenna 	Kapton polyimide substrate (εr = 2.91 & tan σ = 0.005). Rogers 6010 (εr = 10.2 & tan σ = 0.0023).	R.Freq 2 - 3GHz (2.45GHz) E.Size 0.082λ0 × 0.082λ0 × 0.00327 λ0 Peak Gain -9.0dBi	Antenna designed on an ideal flexible substrate but the gain and SAR of the antenna can be improved.

3.	[3]A Compact, Low-Profile Fractal Antenna for Wearable On-Body WBAN Applications	Triangular Patch Antenna with Koch fractal design 	Roger RT/duroid 5880 substrate (t = 0.508mm, εr = 2.2 & tan σ = 0.0009)	R.Freq 2.36 - 2.55 GHz (2.45GHz) E.Size 0.318λo x 0.318λo x 0.004λo Peak Gain 2.06dBi Radiation Efficiency 75%	The Antenna is designed with good SAR but the gain of the Antenna can be improved.
4.	[4]Investigation of SAR Reduction Using Flexible Antenna with Metamaterial Structure in Wireless Body Area Network	Microstrip Patch Antenna 	Polyimide substrate (t = 50 µm, εr = 3.5 & tan σ = 0.027)	R.Freq 2.4 - 3 GHz (2.45GHz) & 5.5 - 6 GHz (5.8GHz) Peak Gain 9.3dBi (2.45GHz) & 5.37dBi(5.8GHz) Radiation efficiency 48.4%(2.45GHz) & 35.7%(5.8GHz)	The Antenna is designed on a good Flexible Substrate and with ideal gain.But the Radiation Efficiency of Antenna can be improved.

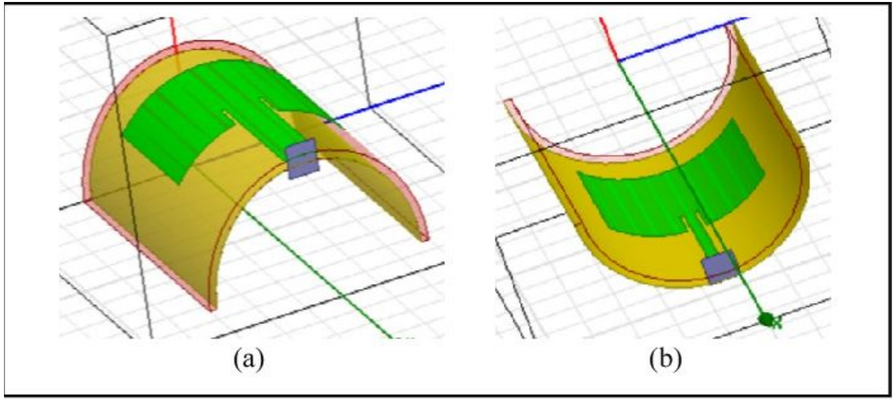
5.	[5]Fully Fabric High Impedance Surface-Enabled Antenna for Wearable Medical Applications	Microstrip Patch Antenna with U-Shaped bent design 	jeans substrate (εr = 1.7 mm & t = 0.7 mm)	R.Freq 1.38 - 2.73 GHz (2.45GHz) E.Size .37λo×0.37λo×0.02 λo Peak Gain 7.47dBi Radiation Efficiency 71.8% SAR 0.0257 W/kg	The Antenna designed as good SAR and gain but the Antenna designed on semi-flexible substrate that cannot stand for several degrees of bending.
6.	[6]Flexible Meander-Line Antenna Array for Wearable Electromagnetic Head Imaging	Meander-Line Antenna 	room-temperature-vulcanizing (RTV) silicone substrate (t = 4mm)	R.Freq 0.45-3.6 GHz (2.7GHz) E.Size 0.036 λo×0.067λo×0.006λo SAR < 0.2 W/kg	The Antenna designed achieved good SAR but the paper does not describe the gain and structure of antenna is also complex.

7.	[7]Flexible-Screen-Printed Antenna with Enhanced Bandwidth by Employing Defected Ground Structure	antenna is CPW and composed of two inverted L-shape elements, a matching stub, and a defected ground structure	substrate used is flexible Kapton material with a thickness of 125 µm, a relative permittivity of εr=3.5 and a loss tangent of tan δ=0.007	R.freq - 1.77-6.95 GHz Peak Gain- 2.6dBi	DGS can increase the bandwidth from 30% to 119%. As a result, the antenna achieves a bandwidth of 1.77-6.95 GHz
8.	[8]Folding-Dependent vs. Folding-Independent Flexible Antennas on E-Textiles	Monopole antenna and rectangular patch	cotton fabric is chosen as the substrate material (εr = 1.6, tanδ = 0.04)	R.Freq - 2 - 3 GHz Peak gain - 3.2dBi	foldable monopole shows ~44.5% increase in resonance frequency when its vertical length dropped by half. rectangular foldable patch was shown to exhibit a minimal ~3.5% increase in resonance frequency when its length or width dropped by half.

Software Tools Available for Designing

High Frequency Structure Simulator (HFSS) software

- Ansys HFSS is a 3D electromagnetic (EM) simulation software for designing and simulating high-frequency electronic products such as antennas, antenna arrays, RF or microwave components, high-speed interconnects, filters, connectors, IC packages and printed circuit boards.

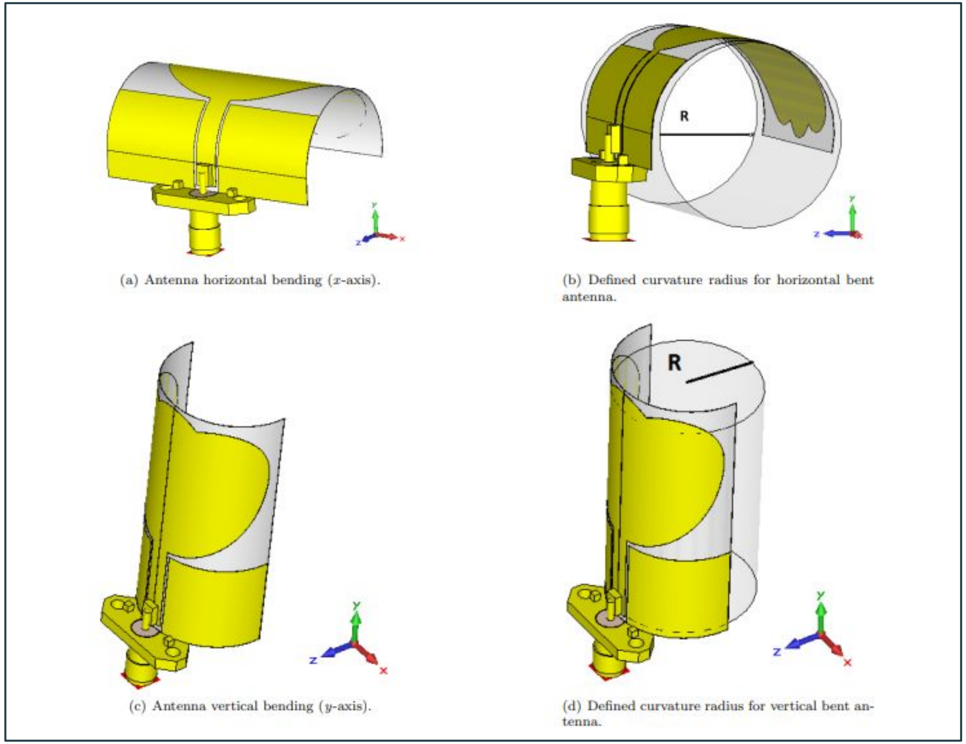


Flexible MPA model in ANSYS HFSS (a) flexed down, and (b) flexed upwards[13]

Software Tools Available for Designing

Computer Simulation Technology (CST) software

- CST Studio Suite® is a high-performance 3D EM analysis software package for designing, analyzing and optimizing electromagnetic (EM) components and systems. Electromagnetic field solvers for applications across the EM spectrum are contained within a single user interface in CST Studio Suite.



Antenna bending made possible with CST software [11]

Software Tools Available for Designing Flexible antennas

Computer Simulation Technology (CST) software

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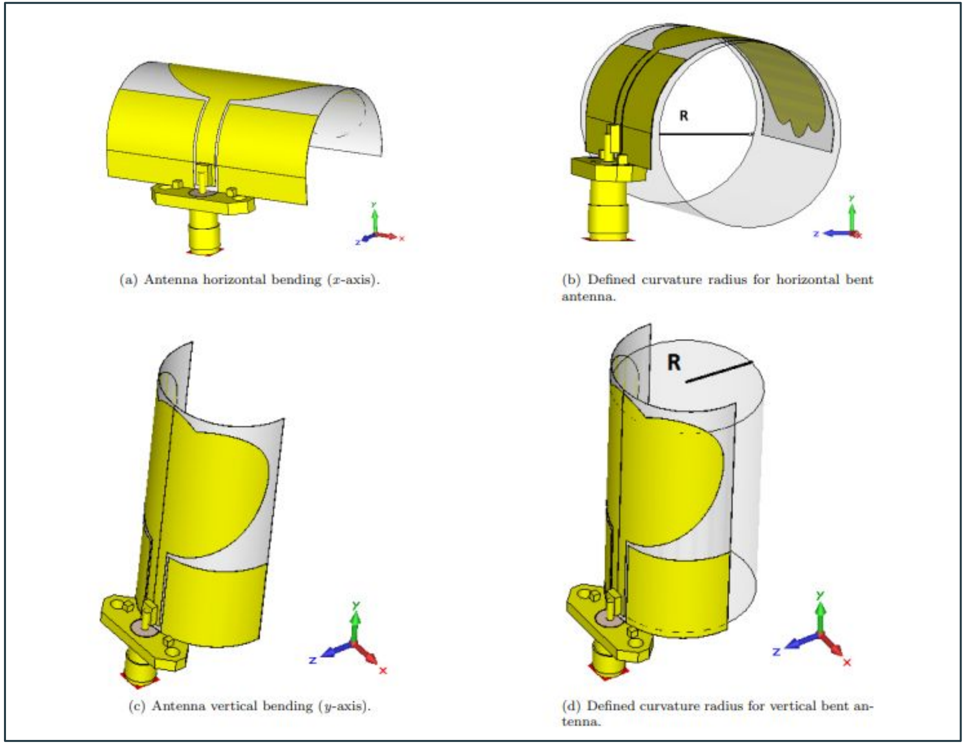

Antenna bending made possible with CST software [11]

Comparison between HFSS and CST software

HFSS	CST
3D EM Simulator	3D EM Simulator
Finite Element Method (FEM)	Finite Integration Technique (FIT)
Passive circuit simulation	Passive and active circuit simulation
HFSS FEM is much better than CST Frequency Domain	Time domain of HFSS is not as good as CST

Conclusion

The Research for the flexible antenna is booming these days and the antenna have the alot of parameters that can be improved. After going through Journal paper we concluded that the flexible antenna can be designed for the specific application and the research scope is available for the improvement of gain of antenna by various gain enhancement methods.

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5. A. Y. I. Ashyap et al., "Fully Fabric High Impedance Surface-Enabled Antenna for Wearable Medical Applications," in IEEE Access, vol. 9, pp. 6948-6960, 2021, doi: 10.1109/ACCESS.2021.3049491.
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Thank
You

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Final Year Project Presentation - 2

Design of Flexible Antenna for Wireless Body Area Networks

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Supervisor:

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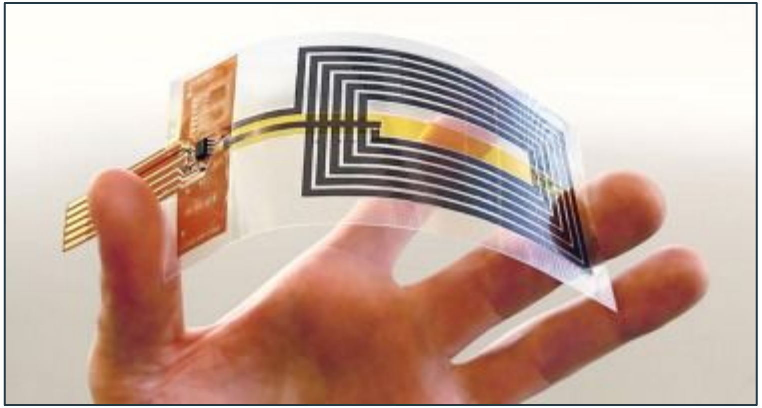
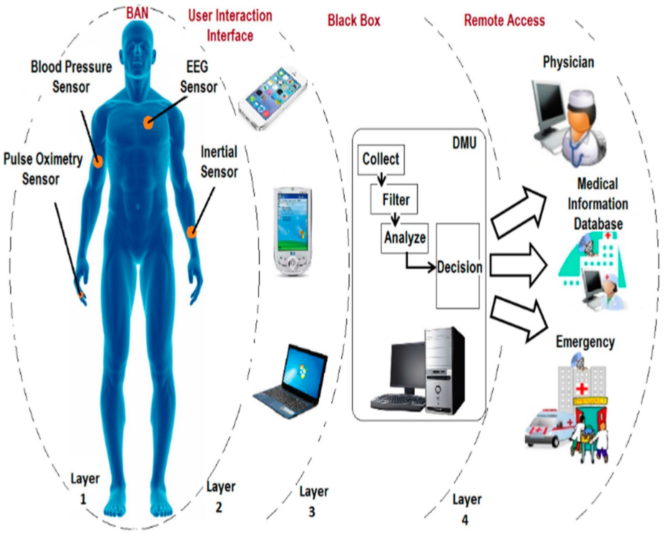
Introduction

- What are Flexible antennas ?
- Where and Why are flexible antennas used?



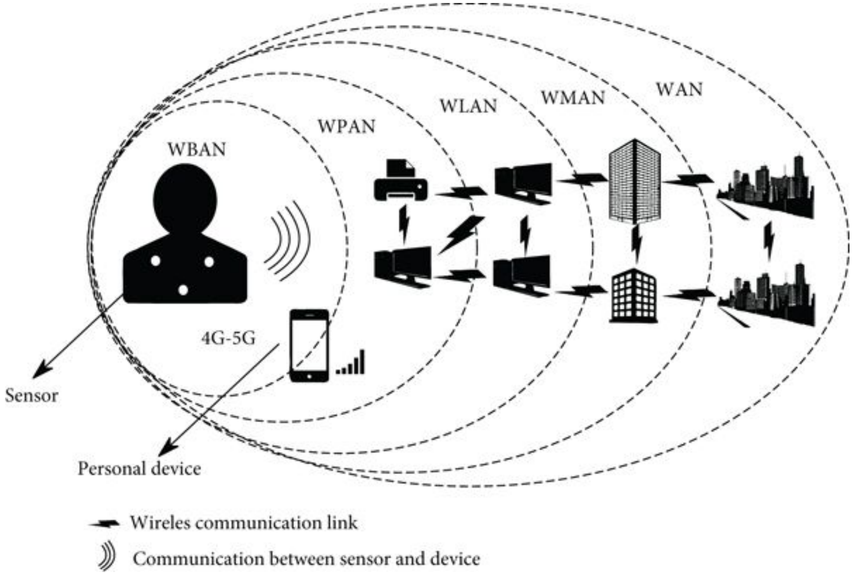
Wireless Body Area Networks(WBAN)

- In today’s world, wireless communication has a major application in sharing of information anywhere and at anytime.
- WBAN(Wireless Body Area Network) allows the user to move another without having the restriction of a cable for sharir information.
- On-body communication occurs between wearable devices whic consist of sensor nodes. The **ISM** (*Industrial Scientific and Medical*) band and **UWB** (Ultra-wideband) communication can be used only for on-body communication.
- WBAN is legal, affordable, and user-friendly. It is an emerging technology and is expected to have a big impact on the society.
- The aim of WBANs is to simplify and improve speed, accuracy, and reliability of communication of sensors/actuators within, on, and in the immediate proximity of a human body.



Requirements of WBAN

- ➢ Low power consumption
- ➢ Interoperability
- ➢ Self-healing
- ➢ Security
- ➢ Low latency



Applications of WBAN

1. Medical Applications:
   - Remote healthcare monitoring
   - Telemedicine
2. Non-medical Applications:
   - Sports
   - Military
   - Lifestyle and entertainment

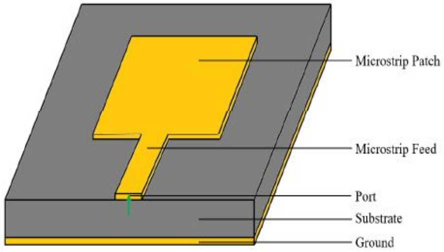
Patch Antenna

- In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required.

- These antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust .

- It is mounted on a small, rectangular, flat surface and consists of two metallic plates placed upon each other. One plate is larger than the other, which is called ground plane and has a dielectric layer in the middle.

- An array of microstrip antennas can be used to form a pattern that is difficult to synthesize using a single element.



Work Done Till Now

Designed Patch Antenna with parameters

Substrate Material : Paper

Parameters for designing

⇒ Patch

Width(W) = 48.58263 mm

Length(L) = 39.5 mm

Thickness(t) = 0.035 mm

⇒ Feed Line

Width(Wf) = 4.7788049746335 mm

Length(Lf) = 22.393485804682 mm

Thickness(tf) = t = 0.035 mm

Electrical Length of Feed = 90 Degree

Impedance(Zo) = 50 ohm

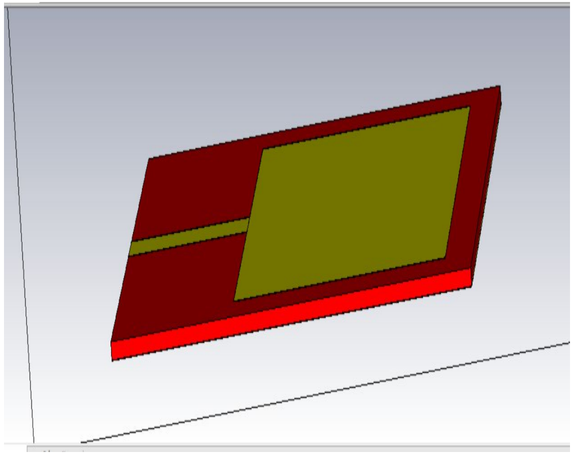
⇒ Substrate : Paper

Width(Ws) = W+6h mm

Length(Ls) = L+6h+18 mm

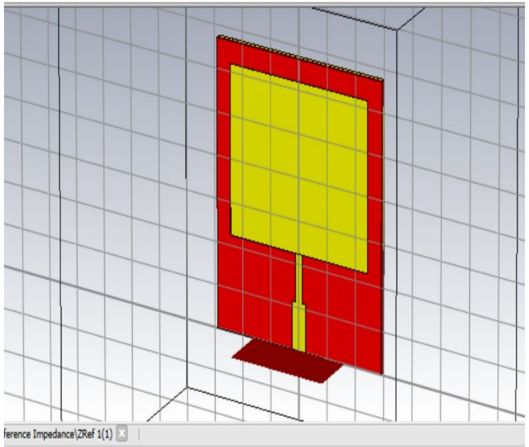
Thickness(h) =1.6 mm

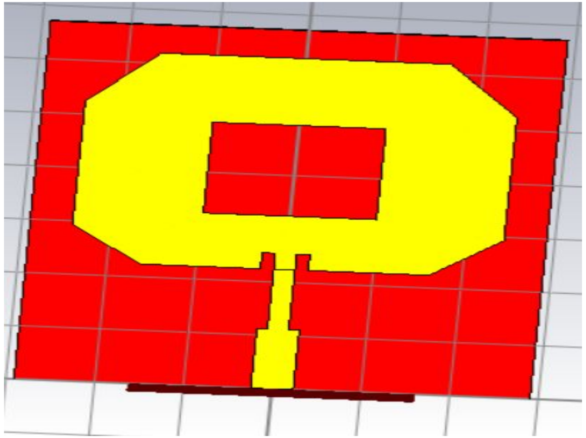
Dielectric Constant(ε_r) = 2.31

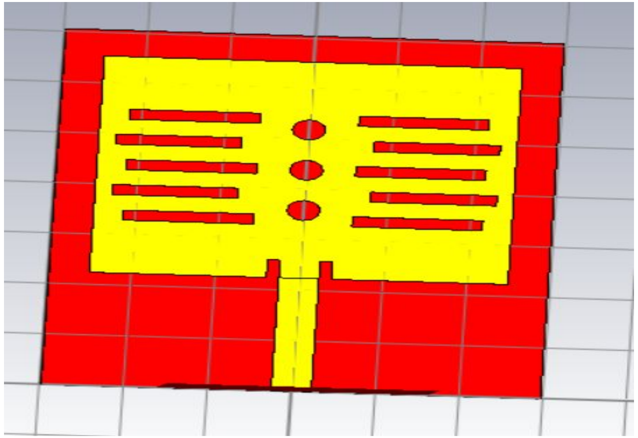


Achieved,
S11 = -4.1026dB
Gain = 6.49dBi

To improve S11 and Gain the design of antenna was altered,





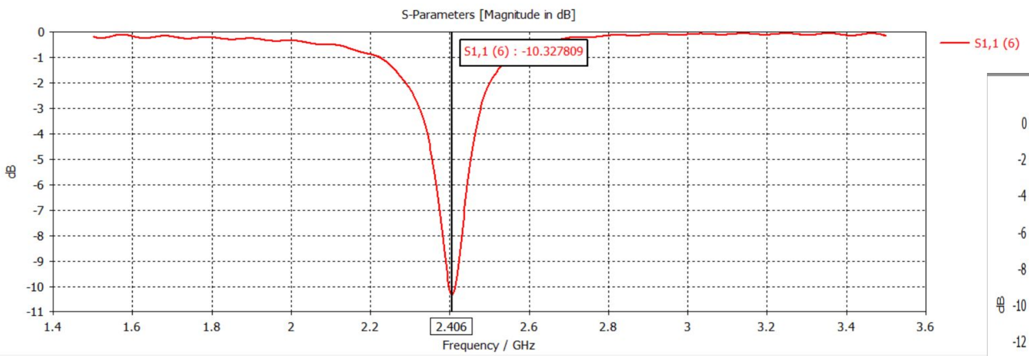


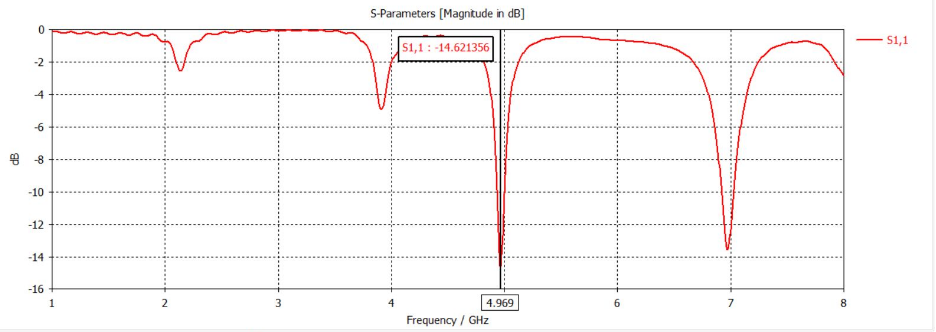
Changed Parameters:
→Shape of the feed
→Wf=3mm, Lf=18mm
Achieved
S11 = -10.263
Gain = 6.68

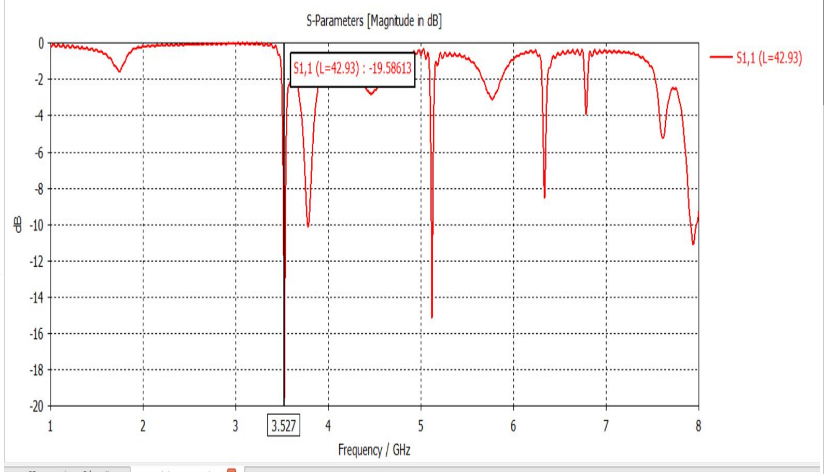
Changed Parameters:
→Rectangular Slot was Introduced and Edges was trunked.
Achieved
S11 = -14.621(4.96GHz)
Gain = 5.22

Changed Parameters:
→Rectangular and Circular slots are Introduced.
Achieved
S11 = -19.5861(3.5GHz)
Gain = 3.2

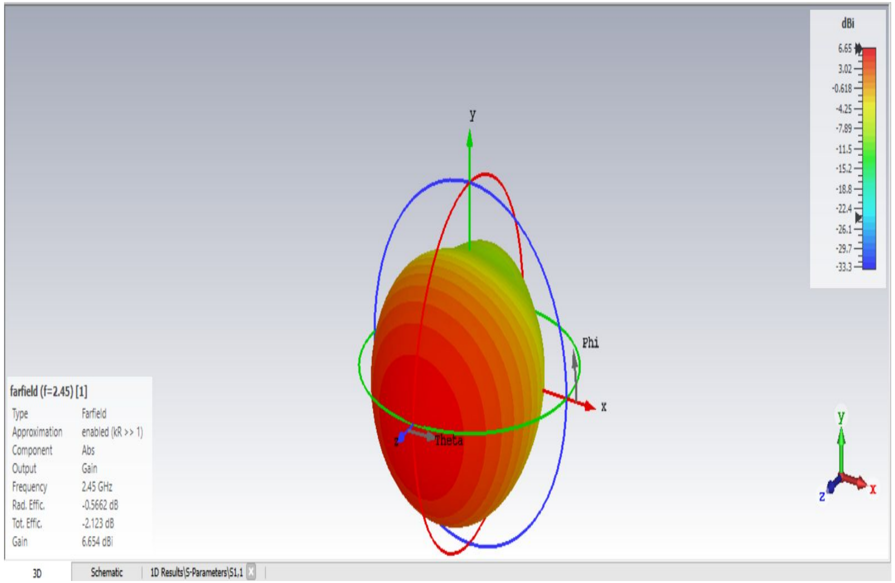
Results(S11)

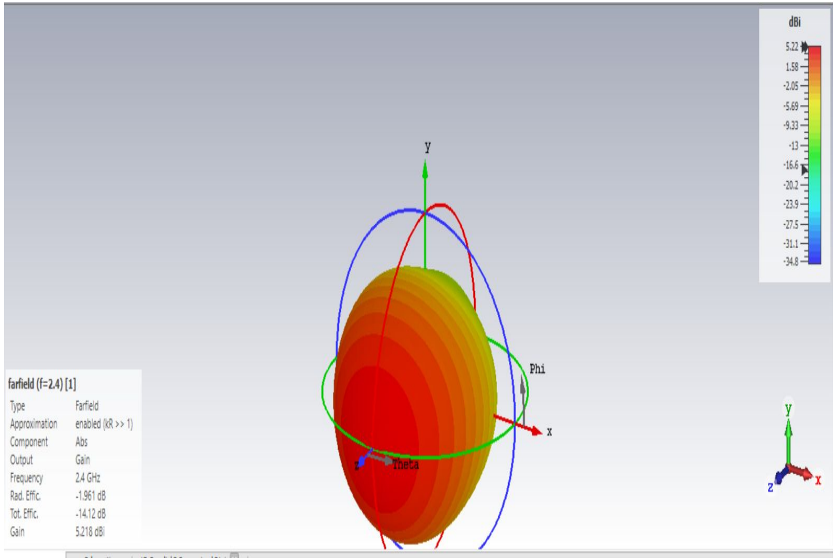

S-Parameters [Magnitude in dB]
S1,1 (6)
S1,1 (6) : -10.327809
dB
2.406
Frequency / GHz


S-Parameters [Magnitude in dB]
S1,1
S1,1 : -14.621356
dB
4.969
Frequency / GHz


S-Parameters [Magnitude in dB]
S1,1 (L=42.93)
S1,1 (L=42.93) : -19.58613
dB
3.527
Frequency / GHz

Results(Gain)





Future Work

- To compare the paper and cloth substrate design
- To get more accurate results at ISM band frequency(2.45GHz).
- To Optimize the design of the antenna
- To Track the SAR value for the designed antenna and optimize it.

References

- A. S. M. Alqadami, A. E. Stancombe, K. S. Bialkowski and A. Abbosh, "Flexible Meander-Line Antenna Array for Wearable Electromagnetic Head Imaging," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 7, pp. 4206-4211, July 2021, doi: 10.1109/TAP.2020.3037742.
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- V. Mishra and A. Kiourti, "Wearable Planar Magnetoinductive Waveguide: A Low-Loss Approach to WBANs," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 11, pp. 7278-7289, Nov. 2021, doi: 10.1109/TAP.2021.3070681.
- https://www.slideshare.net/RiazAhmedLiyakath/flexible-antennas
- https://techsparks.co.in/thesis-in-wireless-body-area-network/#:~:text=Requirements%20of%20WBAN&text=These%20are%3A,is%20required%20in%20this%20case.
- G. -P. Gao, C. Yang, B. Hu, R. -F. Zhang and S. -F. Wang, "A Wearable PIFA With an All-Textile Metasurface for 5 GHz WBAN Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 2, pp. 288-292, Feb. 2019, doi: 10.1109/LAWP.2018.2889117.

Suggestion are Welcome

-Thank You

भारतीय सूचना प्रौद्योगिकी संस्थान, नागपुर

Indian Institute of Information Technology, Nagpur

Department of Electronics and Communication Engineering

Final Year Project Presentation - 2 Representation

Design of Flexible Antenna for Wireless Body Area Networks

Presented By:

BT19ECE005 Sakshi Pandagale

BT19ECE037 Avish Fakirde

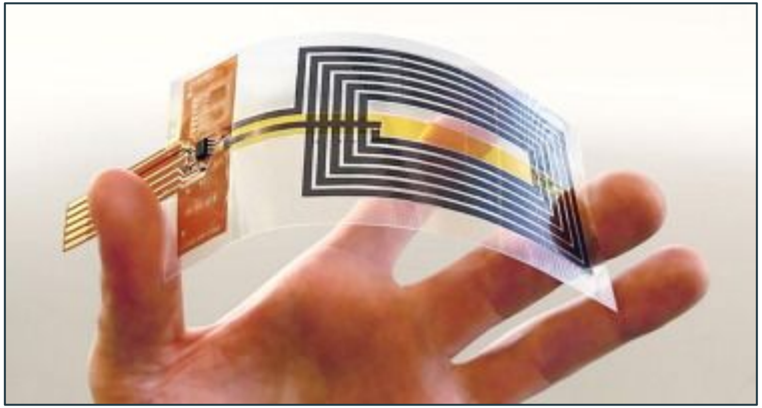
BT19ECE073 Saikumar Mulkalla

Supervisor:

Dr. Paritosh D. Peshwe

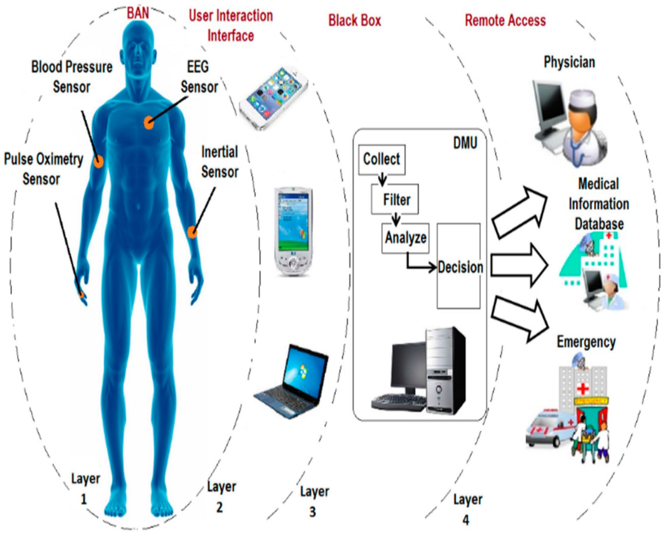
Introduction

- What are Flexible antennas ?
- Where and Why are flexible antennas used?



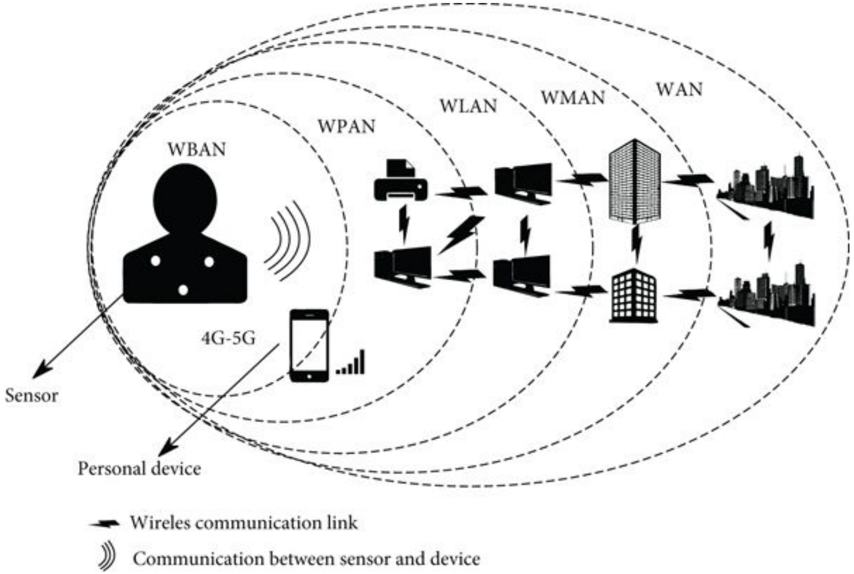
Wireless Body Area Networks(WBAN)

- In today's world, wireless communication has a major application in sharing of information anywhere and at anytime.
- WBAN(Wireless Body Area Network) allows the user to move another without having the restriction of a cable for sharii information.
- On-body communication occurs between wearable devices whic consist of sensor nodes. The **ISM** (*Industrial Scientific and Medical*) band and **UWB** (Ultra-wideband) communication can be used only for on-body communication.
- WBAN is legal, affordable, and user-friendly. It is an emerging technology and is expected to have a big impact on the society.
- The aim of WBANs is to simplify and improve speed, accuracy, and reliability of communication of sensors/actuators within, on, and in the immediate proximity of a human body.



Requirements of WBAN

- ➢ Low power consumption
- ➢ Interoperability
- ➢ Self-healing
- ➢ Security
- ➢ Low latency



Applications of WBAN

1. Medical Applications:
   - Remote healthcare monitoring
   - Telemedicine
2. Non-medical Applications:
   - Sports
   - Military
   - Lifestyle and entertainment

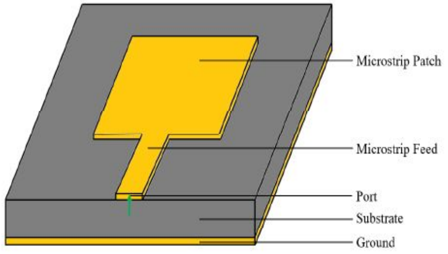
Patch Antenna

- In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required.

- These antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust .

- It is mounted on a small, rectangular, flat surface and consists of two metallic plates placed upon each other. One plate is larger than the other, which is called ground plane and has a dielectric layer in the middle.

- An array of microstrip antennas can be used to form a pattern that is difficult to synthesize using a single element.



Work Done Till Now

Designed Patch Antenna with parameters

Substrate Material : Jeans

Parameters for designing

⇒ Patch

Width(W) = 51.92 mm

Length(L) = 45.27 mm

Thickness(t) = 0.035 mm

⇒ Feed Line

Width(Wf) = 3.514 mm

Length(Lf) = 24.387 mm

Thickness(Hf) = t = 0.035 mm

Electrical Length of Feed = 90 Degree

Impedance(Zo) = 50 ohm

⇒ Substrate : Jeans

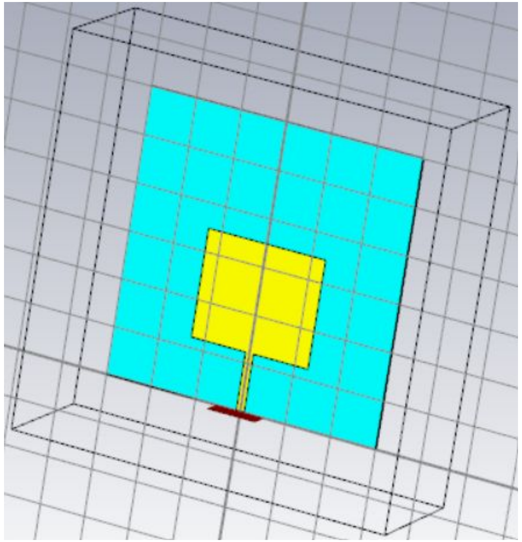
Width(Ws) = 120 mm

Length(Ls) = 120 mm

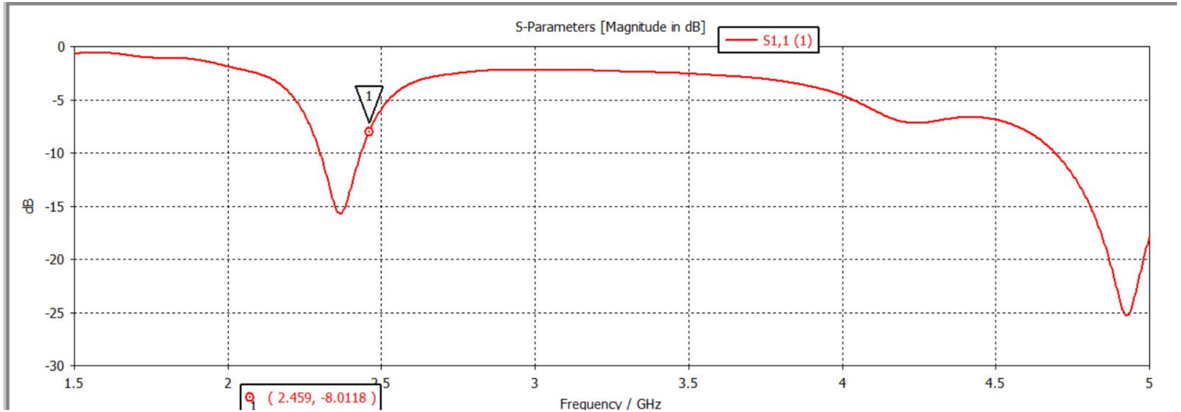
Thickness(h) =1 mm

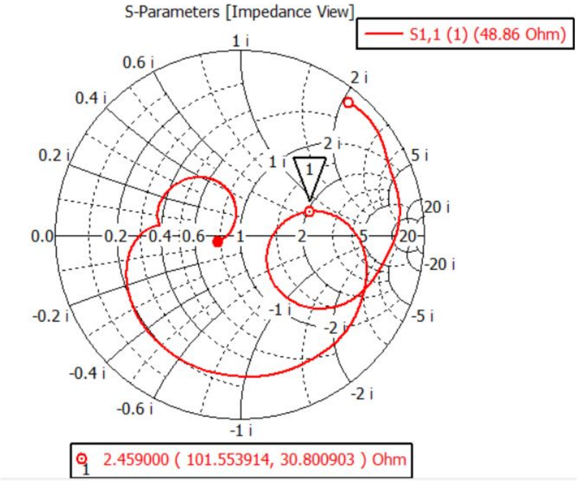
Dielectric Constant(ε_r) = 1.78

Loss Tangent = 0.085

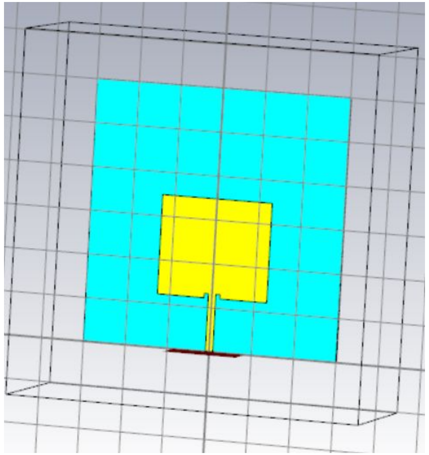


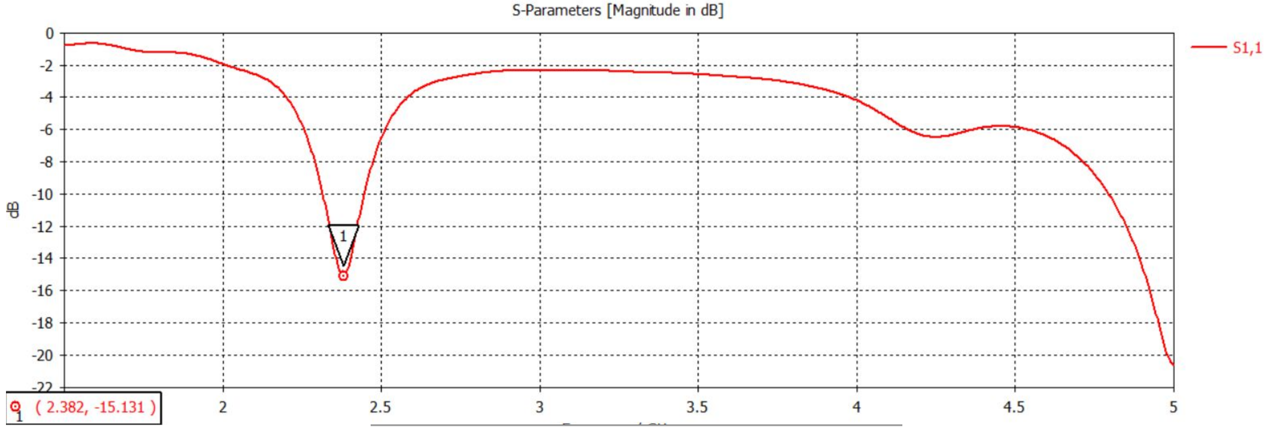
Achieved,
S11 = -8.011.dB
Gain = -1.015dBi

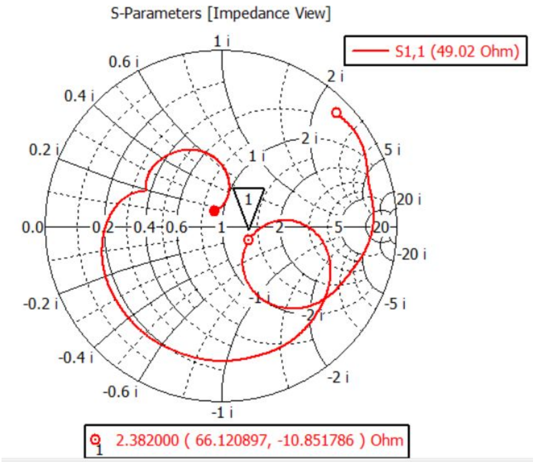

S-Parameters [Magnitude in dB]
S1,1 (1)
dB
0
-5
-10
-15
-20
-25
-30
1.5
2
2.5
3
3.5
4
4.5
5
Frequency / GHz
1
(2.459, -8.0118)


S-Parameters [Impedance View]
S1,1 (1) (48.86 Ohm)
2.459000 (101.553914, 30.800903) Ohm

To improve S11 and Gain the design of antenna was altered,

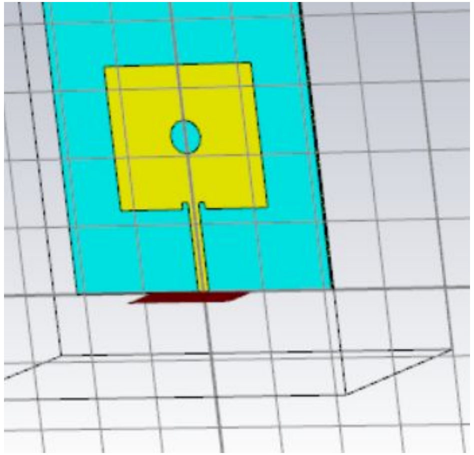


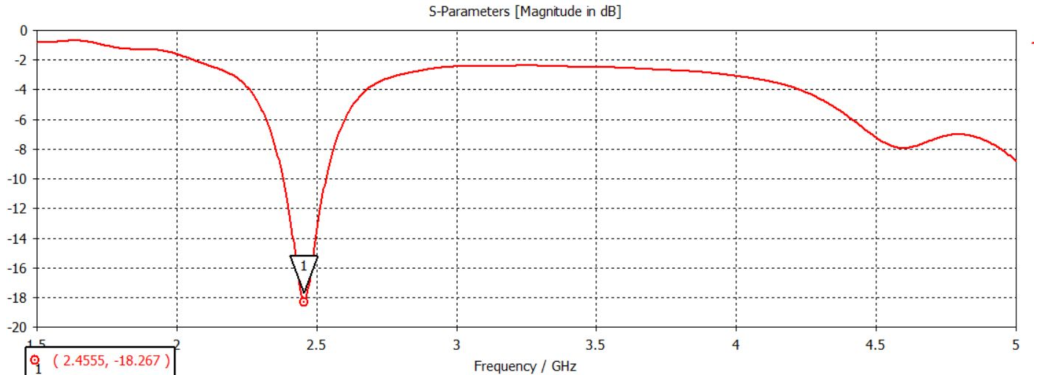


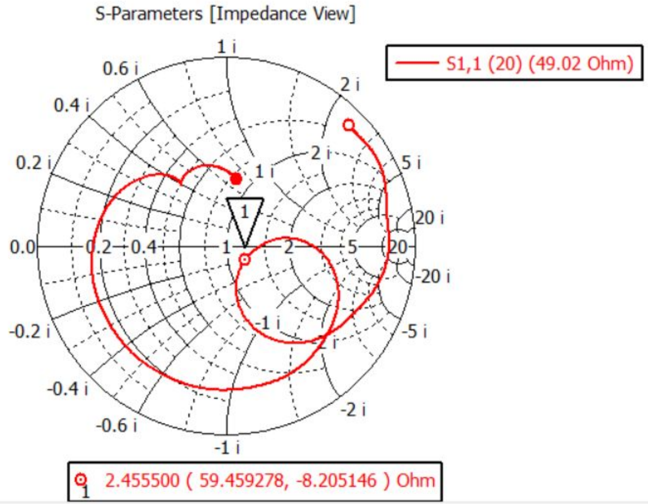


Changed Parameters:
→2 rectangular added
→W1=2mm, L2=2mm
Achieved
S11 = -15.131dB
Gain = -1.157dBi

To improve S11 and Gain the design of antenna was altered,

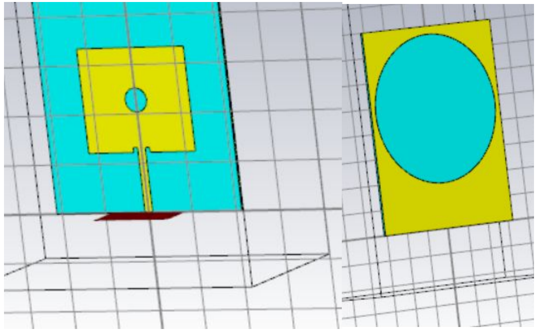


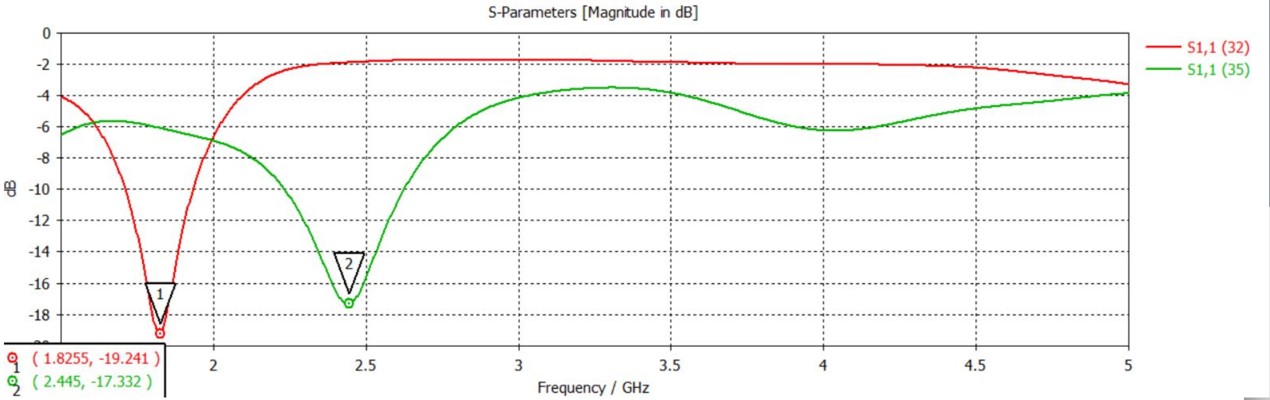


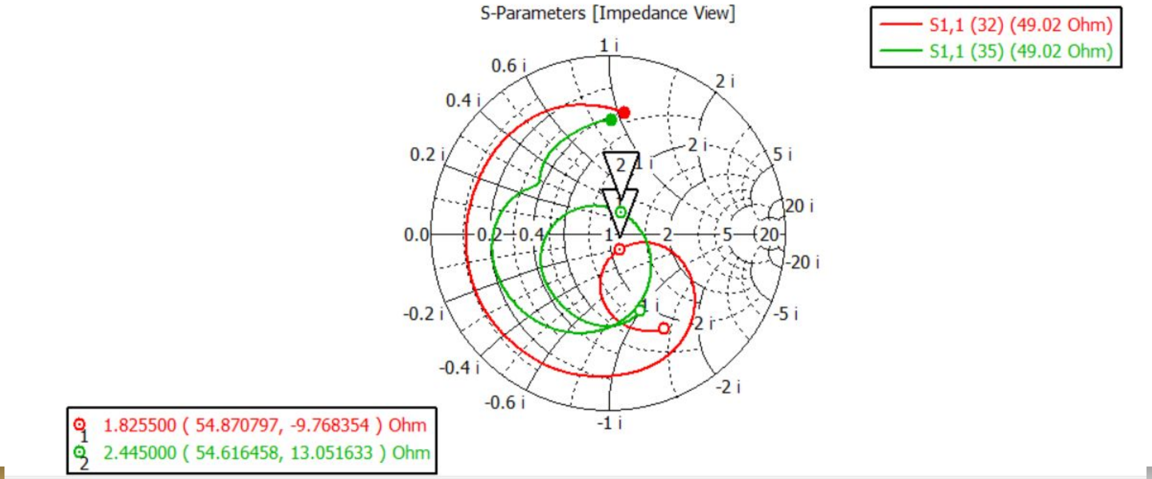


Changed Parameters:
→Circular slot added in the center of patch
→R1= 5mm
Achieved
S11 = -18.26dB
Gain = -2dBi

To improve S11 and Gain the design of antenna was altered,







Changed Parameters:

→Circular slot added in ground

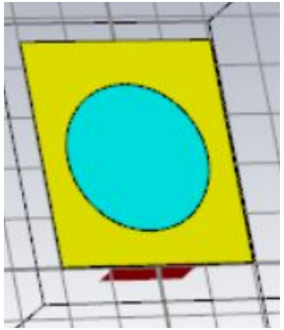
→R1= 29.5mm

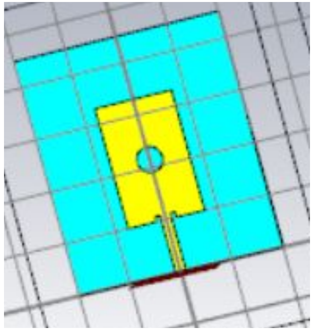
Achieved

S11 = -18.26dB

Gain = 2.89dBi

Final Antenna Design,





Changed Parameters:
→2 rectangular added(2mm x 2mm)
→Circular slot added in the center of patch (R1= 5mm)
→Circular slot added in ground
(RB1= 29.5mm)

Designed Patch Antenna with parameters

Substrate Material : Jeans

Parameters for designing

⇒ Patch

Width(W) = 30 mm

Length(L) = 46 mm

Thickness(t) = 0.035 mm

⇒ Feed Line

Width(Wf) = 4 mm

Length(Lf) = 20 mm

Thickness(Hf) = t = 0.035 mm

Electrical Length of Feed = 74.02 Degree

Impedance(Zo) = 45.2 ohm

⇒ Substrate : Jeans

Width(Ws) = 80mm

Length(Ls) = 90 mm

Thickness(h) =1 mm

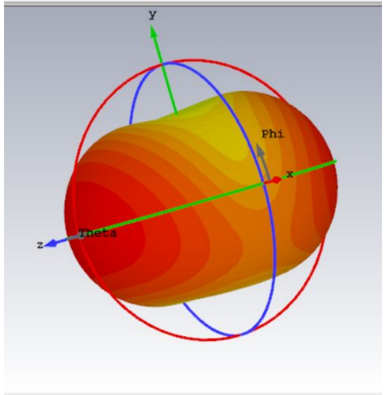
Dielectric Constant(ε_r) = 1.78

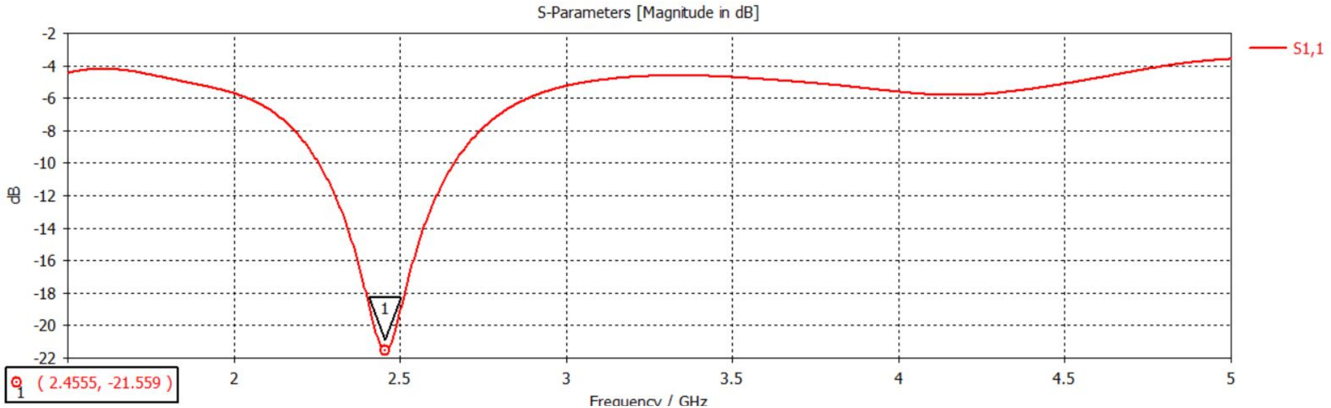
Loss Tangent = 0.085

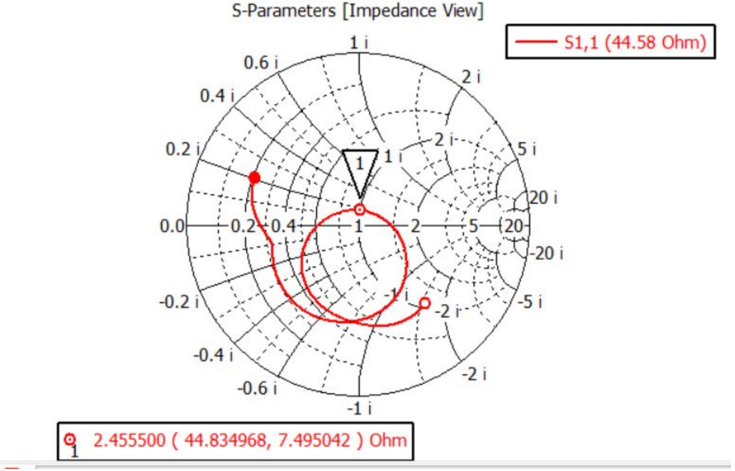
Achieved,

S11 = -21.559.dB

Gain = 3.5825dBi







farfield (f=2.45) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.45 GHz
Rad. Effic.	-0.8236 dB
Tot. Effic.	-0.8544 dB
Gain	3.582 dBi

Patch Antenna - Comparison

Papers	Publication Name (Where it was published) (Journal or conference)	Frequency of Operation (GHz)	Resonance frequency (GHz)	Substrate used	Substrate Dimension (Ws x Ls x h)	Ground Dimension (Wg x Lg x t)	Patch Dimension (WxLxt)	Feed Dimension (Wf x Lf x t)	Gain(dBi)	S11(dB)
[1]Link	Journal IEEE Transactions on Antennas and Propagation	1.5 - 1.6	1.5835	Rogers RT/Duroid 5880	84x33.85x0.127	84x33.85	84x33.85	Coaxial Feed	5.76	-22.72
[2]Link	Journal IEEE Transactions on Antennas and Propagation	1 - 5	2.45	Kapton polyimide	10 x 10 x 0.4	10 x 10 x 0.4	10 x 10 x 0.4	CPW Feed	-9	<-20
[3]Link	Journal IEEE Antennas and Wireless Propagation Letters	2.36 - 2.55	2.45	Rogers RT/Duroid 5880	39 x 39 x 0.508	39 x 39	39 x 39	Microstrip Feed	2.06	<-30
[4]Link	Journal IEEE Transactions on Antennas and Propagation	2.4 - 3	2.45	Polyimide substrate	25 x 30 x 0.05	25 x 30	25 x 30	CPW Feed	9.3	-25
[5]Link	Journal IEEE Access	1.38 - 2.73	2.45	jeans substrate	20 x 30 x 0.7	20 x 30	18 x 18	2.146 x 6	7.47	<-15
[6]Link	Journal IEEE Transactions on Antennas and Propagation	0.45 - 3.6	2.7	(RTV) silicone substrate	24 x 45 x 4	24 x 45 x 0.025	13 x 35.4 x 0.025	3 x 3 x 0.025	-	<-10
[7]Link	Journal IEEE Antennas and Wireless Propagation Letters	1.77 - 6.95	2.6	Kapton polyimide	55 x 40 x 0.125	55 x 40	26 x 30.5	6 x 19	2.6	<-30
[8]Link	Conference 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting	2 - 3	2.4	cotton fabric	55.8 x 47.4 x 2	55.8 x 47.4	-	-	3.2	<-20
Avish Design	-	1.5 - 5	2.45	jeans substrate	80 x 90 x 1	80 x 90x 0.035	30 x 46 x 0.035	4 x 20 x 0.035	3.582	-21.559

Future Work

- To get more accurate results at ISM band frequency(2.45GHz).

- To Optimize the design of the antenna

- To Track the SAR value for the designed antenna and optimize it.///%%%//

References

- A. S. M. Alqadami, A. E. Stancombe, K. S. Bialkowski and A. Abbosh, "Flexible Meander-Line Antenna Array for Wearable Electromagnetic Head Imaging," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 7, pp. 4206-4211, July 2021, doi: 10.1109/TAP.2020.3037742.
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- https://www.radartutorial.eu/06.antennas/Microstrip%20Antenna.en.html
- D. Jiang, G. Zhang, O. W. Samuel, F. Liu and H. Xiao, "Dual-Factor WBAN Enhanced Authentication System Based on Iris and ECG Descriptors," in IEEE Sensors Journal, vol. 22, no. 19, pp. 19000-19009, 1 Oct.1, 2022, doi: 10.1109/JSEN.2022.3198645.

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- https://techsparks.co.in/thesis-in-wireless-body-area-network/#:~:text=Requirements%20of%20WBAN&text=These%20are%3A,is%20required%20in%20this%20case.
- G. -P. Gao, C. Yang, B. Hu, R. -F. Zhang and S. -F. Wang, "A Wearable PIFA With an All-Textile Metasurface for 5 GHz WBAN Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 2, pp. 288-292, Feb. 2019, doi: 10.1109/LAWP.2018.2889117.

Suggestion are Welcome

-Thank You

भारतीय सूचना प्रौद्योगिकी संस्थान, नागपुर

Indian Institute of Information Technology, Nagpur

Department of Electronics and Communication Engineering

Final Year Project Presentation - 3

Design of Flexible Antenna for Wireless Body Area Networks

Presented By:
BT19ECE005 Sakshi Pandagale
BT19ECE037 Avish Fakirde
BT19ECE073 Saikumar Mulkalla

Supervisor:
Dr. Paritosh D. Peshwe

Why WBAN?

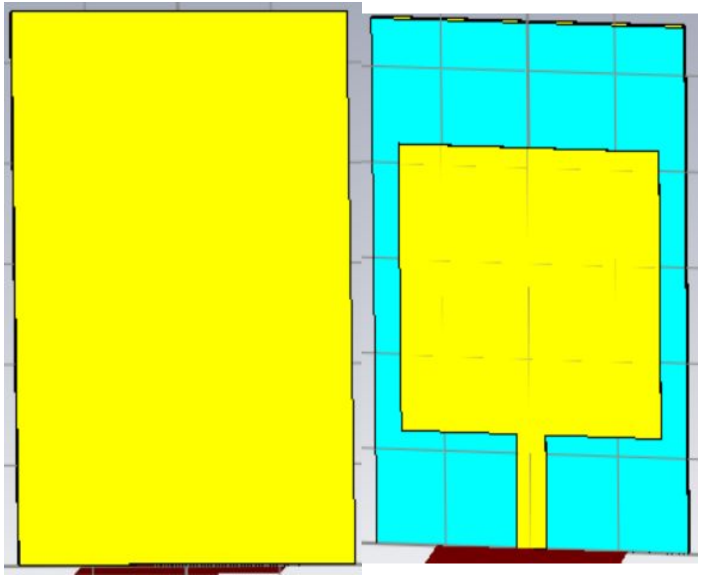
- Personal Health Monitoring
- Early Detection of Health Issues
- Remote Patient Monitoring
- Sports and Fitness

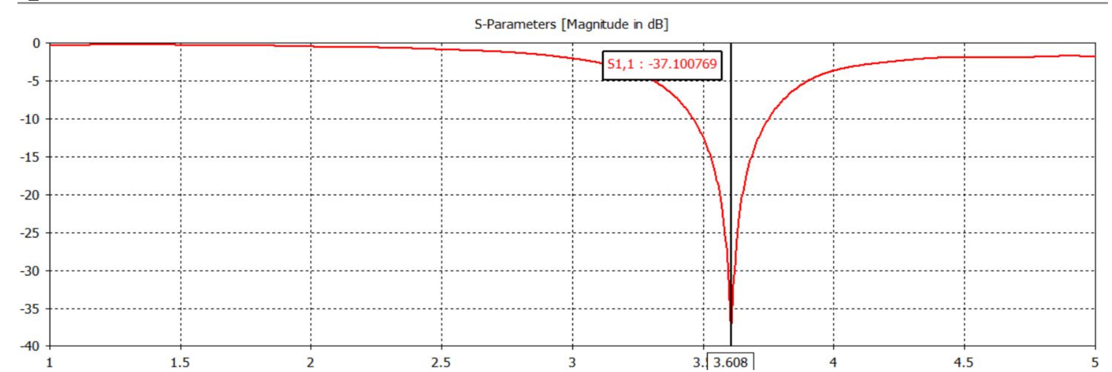
- Wearable Devices
- Low-Power Consumption
- Enhanced Privacy and Security

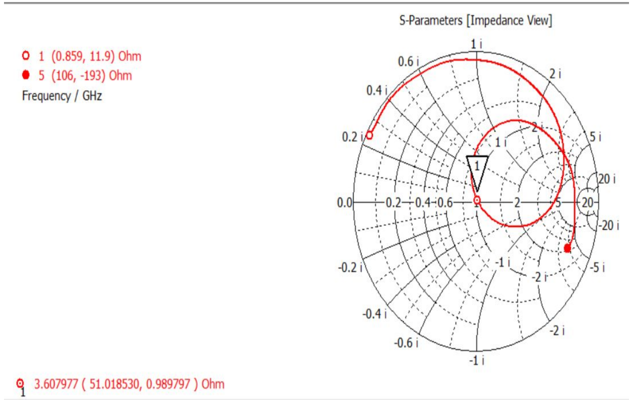
Design_1

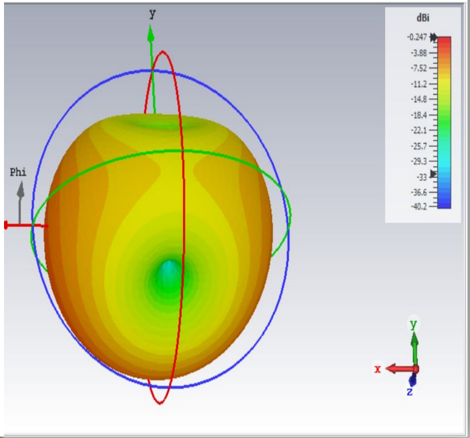
The iteration of the antenna design is depicted

- Iteration1

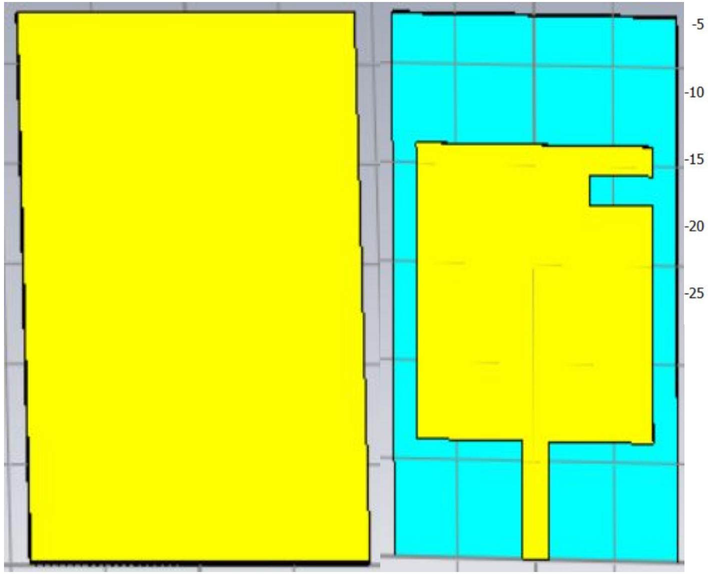


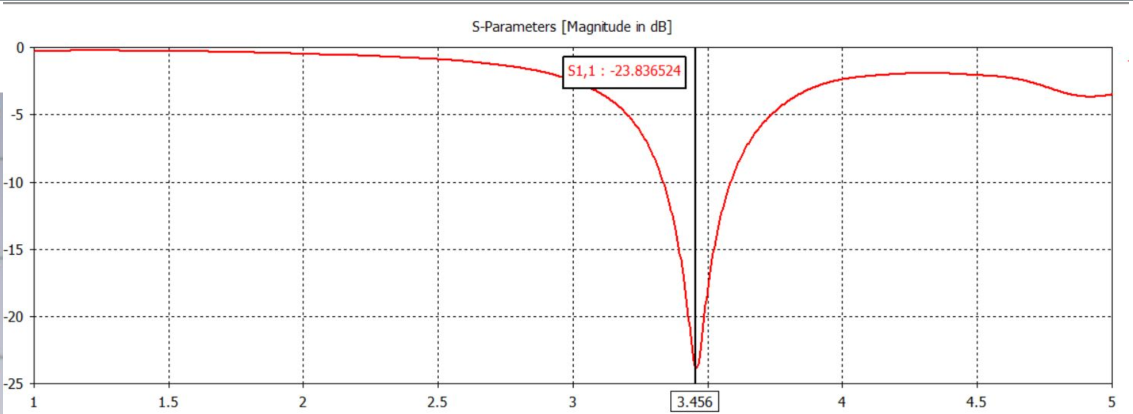


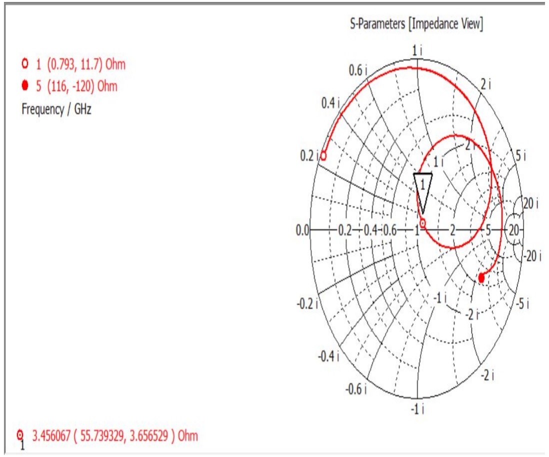


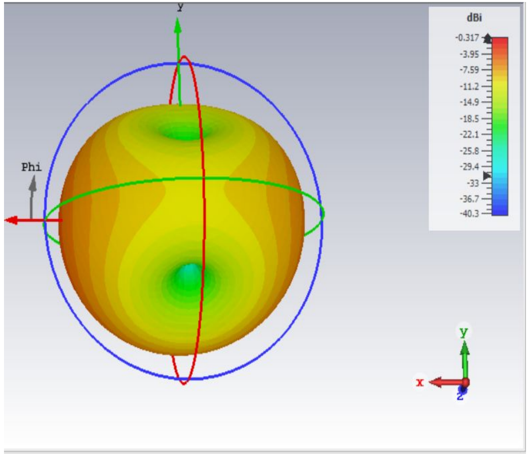


- Iteration2

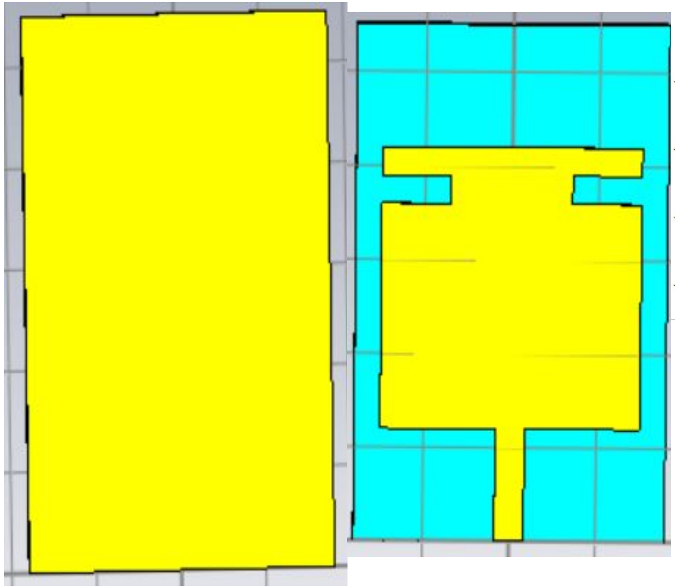


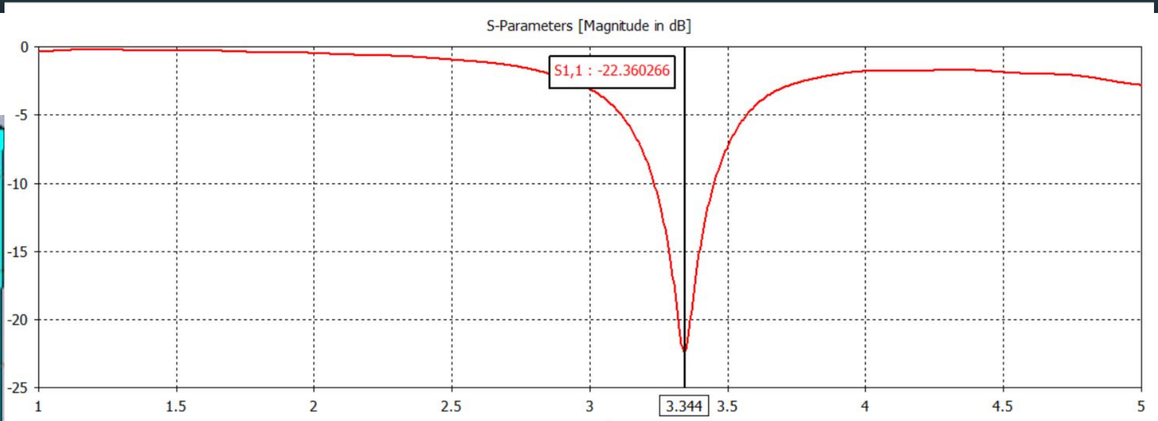

S-Parameters [Magnitude in dB]
S1,1 : -23.836524
0
-5
-10
-15
-20
-25
1
1.5
2
2.5
3
3.456
4
4.5
5


S-Parameters [Impedance View]
1 (0.793, 11.7) Ohm
5 (116, -120) Ohm
Frequency / GHz
3.456067 (55.739329, 3.656529) Ohm

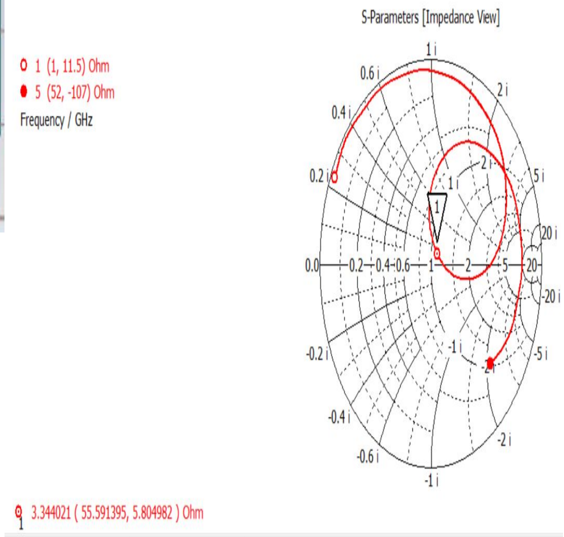

dBi
-0.317
-3.95
-7.59
-11.2
-14.9
-18.5
-22.1
-25.8
-29.4
-33
-36.7
-40.3
Phi

- Iteration3

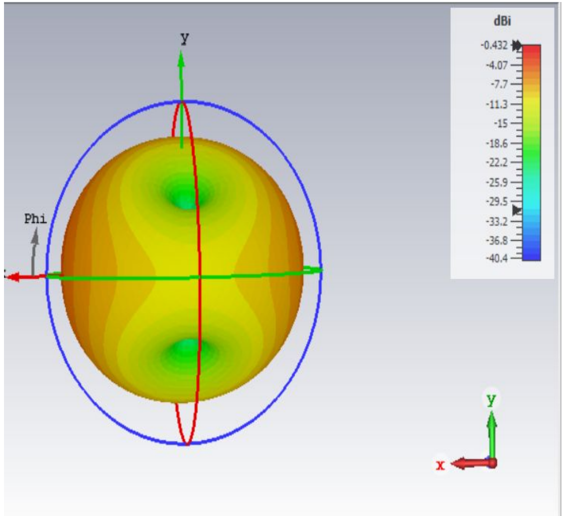




S-Parameters [Magnitude in dB]
S1,1 : -22.360266
0
-5
-10
-15
-20
-25
1
1.5
2
2.5
3
3.344
3.5
4
4.5
5

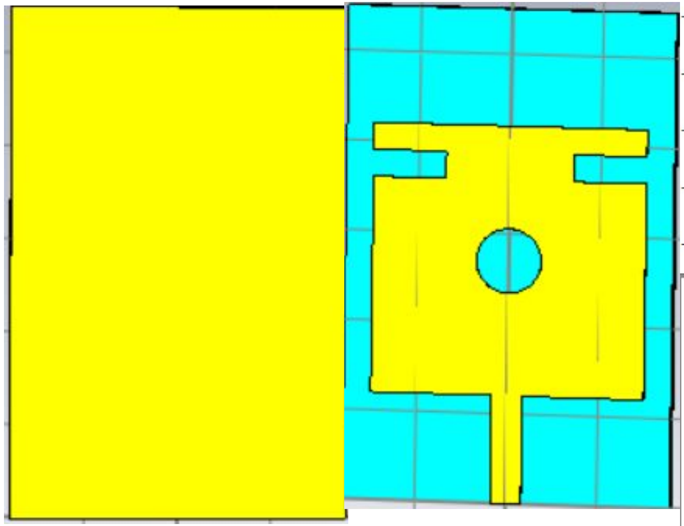


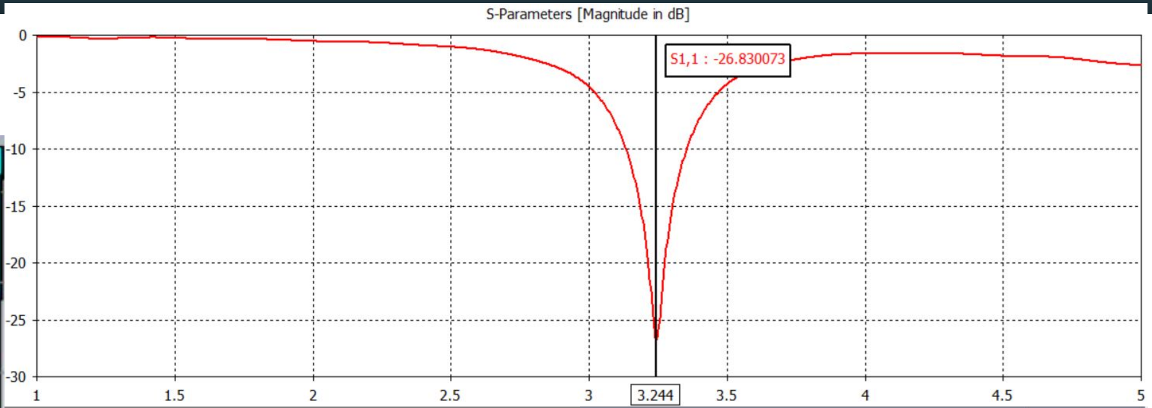
S-Parameters [Impedance View]
1 (1, 11.5) Ohm
5 (52, -107) Ohm
Frequency / GHz
3.344021 (55.591395, 5.804982) Ohm



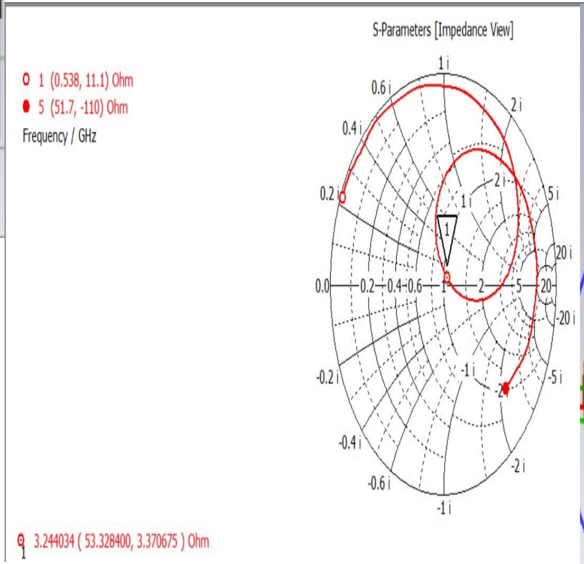
dBi
-0.432
-4.07
-7.7
-11.3
-15
-18.6
-22.2
-25.9
-29.5
-33.2
-36.8
-40.4
y
Phi
x

- Iteration4

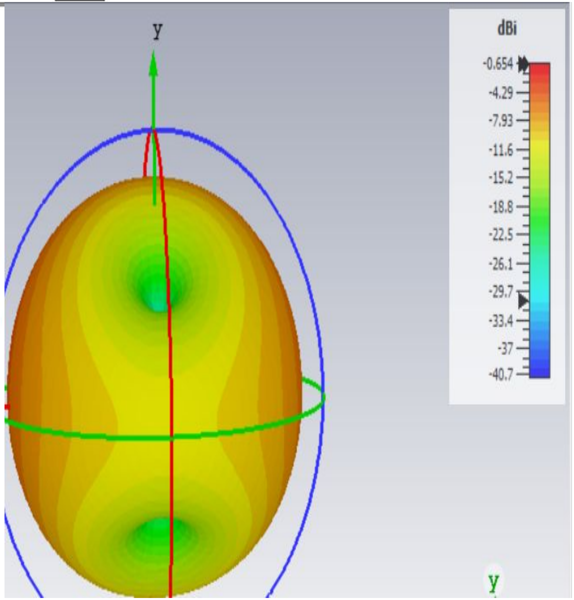




S-Parameters [Magnitude in dB]
S1,1 : -26.830073
0
-5
-10
-15
-20
-25
-30
1
1.5
2
2.5
3
3.244
3.5
4
4.5
5

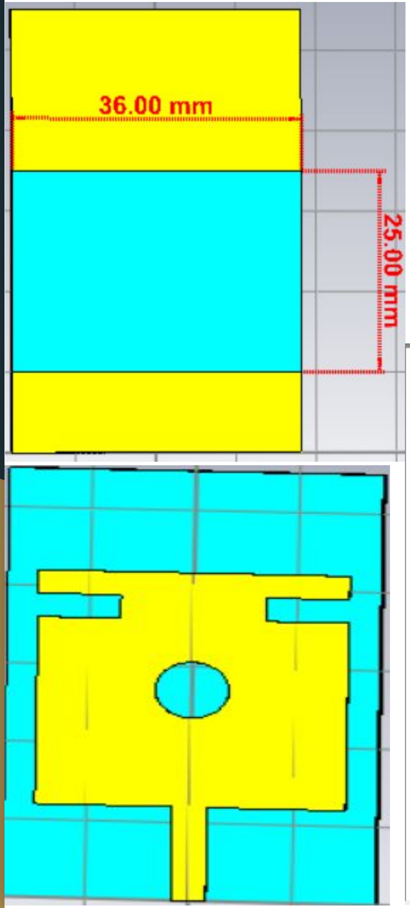


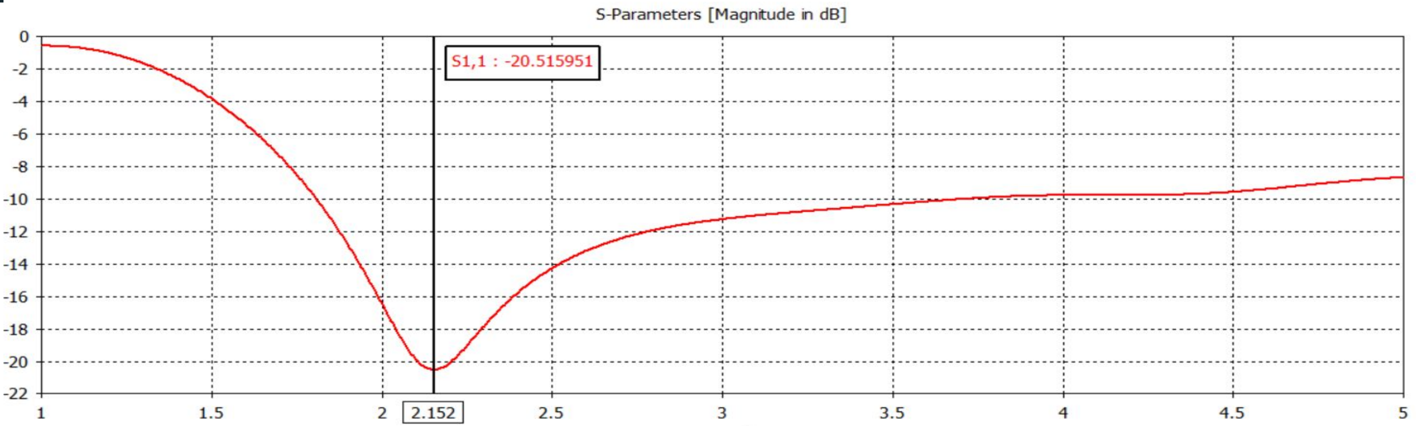
S-Parameters [Impedance View]
1 (0.538, 11.1) Ohm
5 (51.7, -110) Ohm
Frequency / GHz
3.244034 (53.328400, 3.370675) Ohm

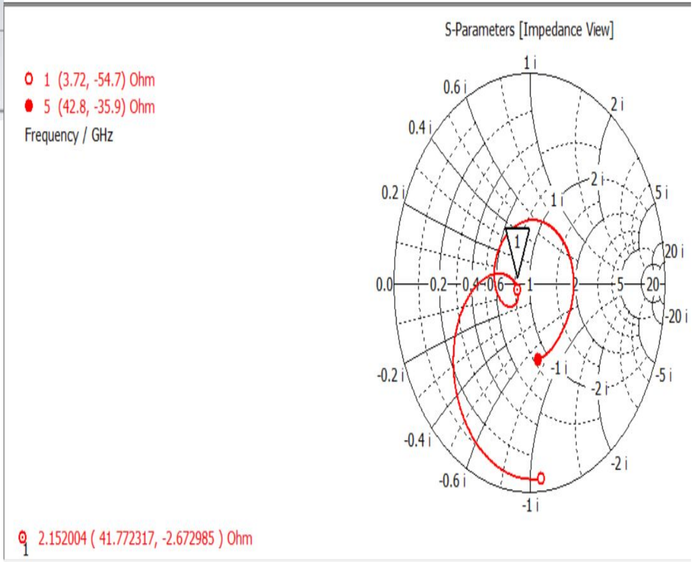


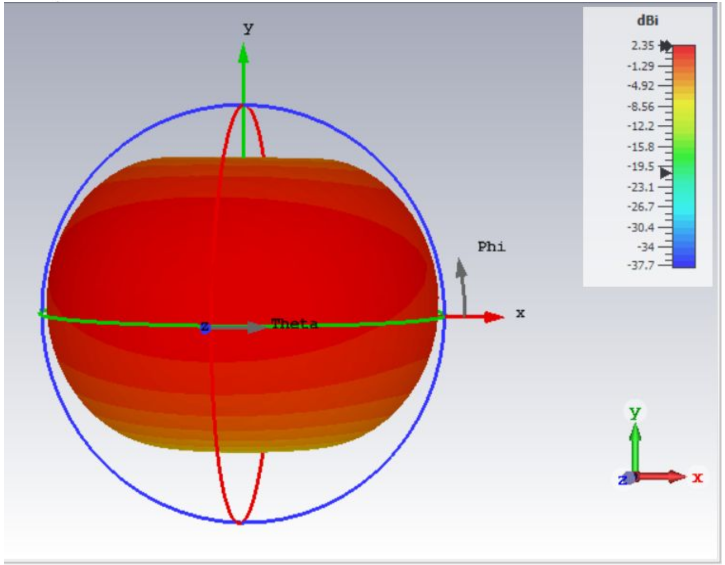
y
dBi
-0.654
-4.29
-7.93
-11.6
-15.2
-18.8
-22.5
-26.1
-29.7
-33.4
-37
-40.7

- Iteration5

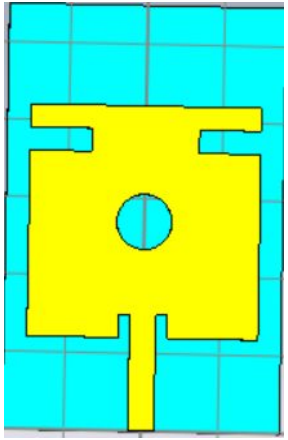

36.00 mm
25.00 mm

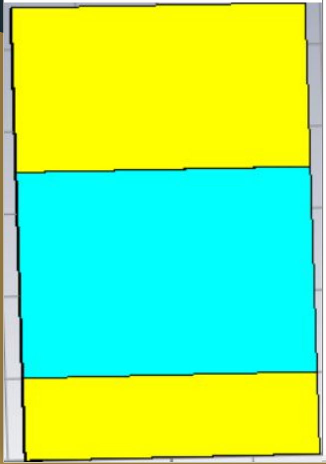

S-Parameters [Magnitude in dB]
S1,1 : -20.515951
2.152

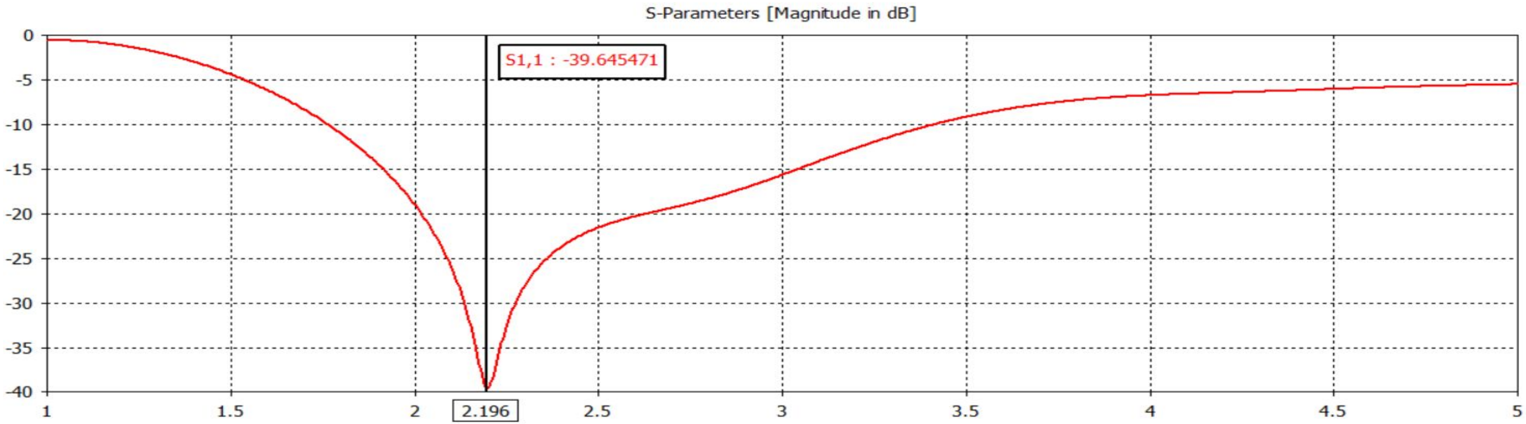

S-Parameters [Impedance View]
1 (3.72, -54.7) Ohm
5 (42.8, -35.9) Ohm
Frequency / GHz
2.152004 (41.772317, -2.672985) Ohm

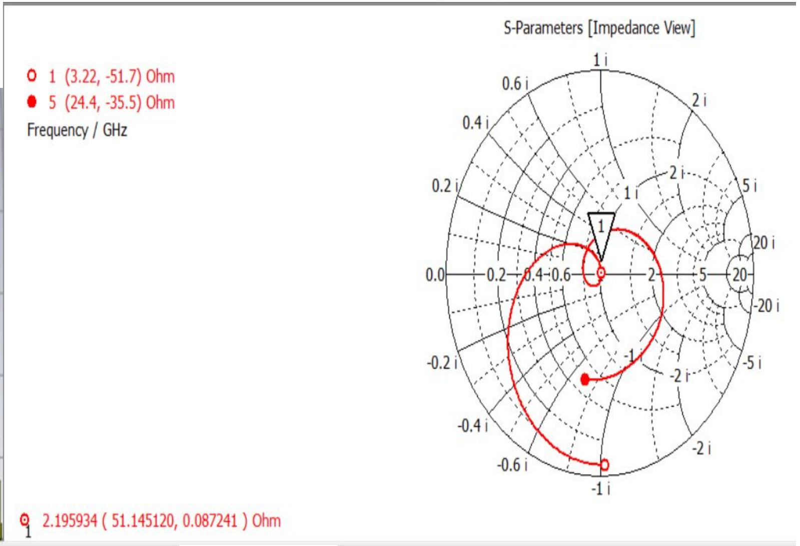

dBi
2.35
-1.29
-4.92
-8.56
-12.2
-15.8
-19.5
-23.1
-26.7
-30.4
-34
-37.7
Phi
Theta

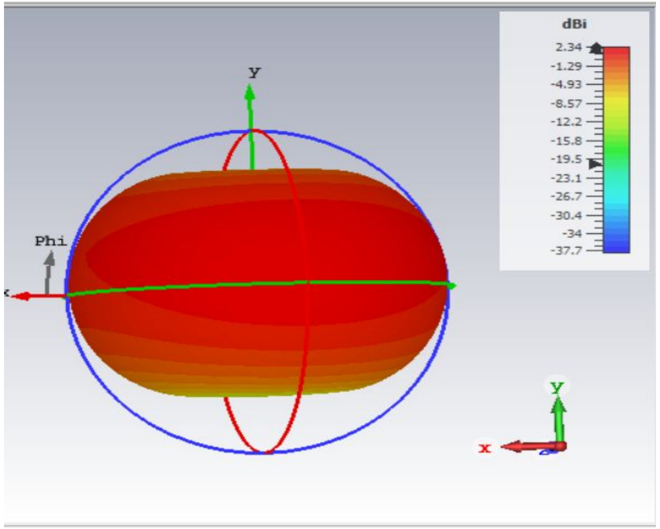
- Iteration6



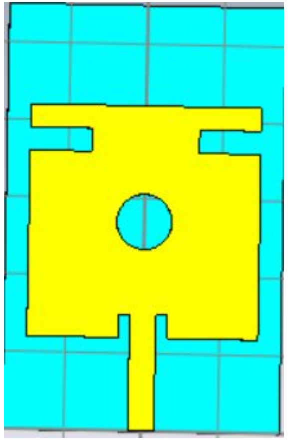


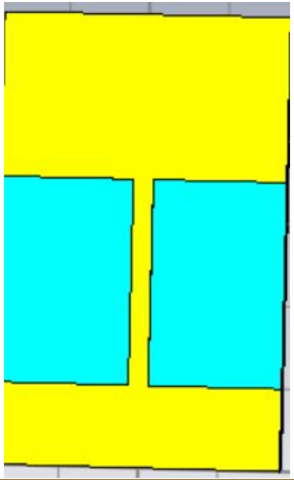

S-Parameters [Magnitude in dB]
S1,1 : -39.645471
0
-5
-10
-15
-20
-25
-30
-35
-40
1
1.5
2
2.196
2.5
3
3.5
4
4.5
5

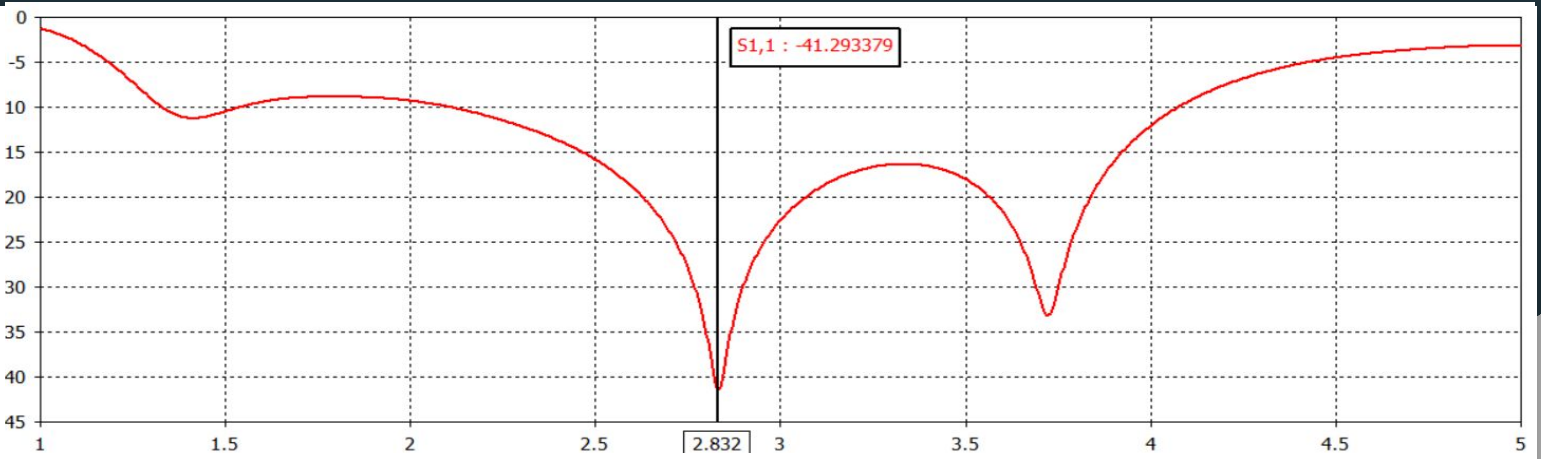

S-Parameters [Impedance View]
1 (3.22, -51.7) Ohm
5 (24.4, -35.5) Ohm
Frequency / GHz
2.195934 (51.145120, 0.087241) Ohm


dBi
2.34
-1.29
-4.93
-8.57
-12.2
-15.8
-19.5
-23.1
-26.7
-30.4
-34
-37.7
Y
Phi
x

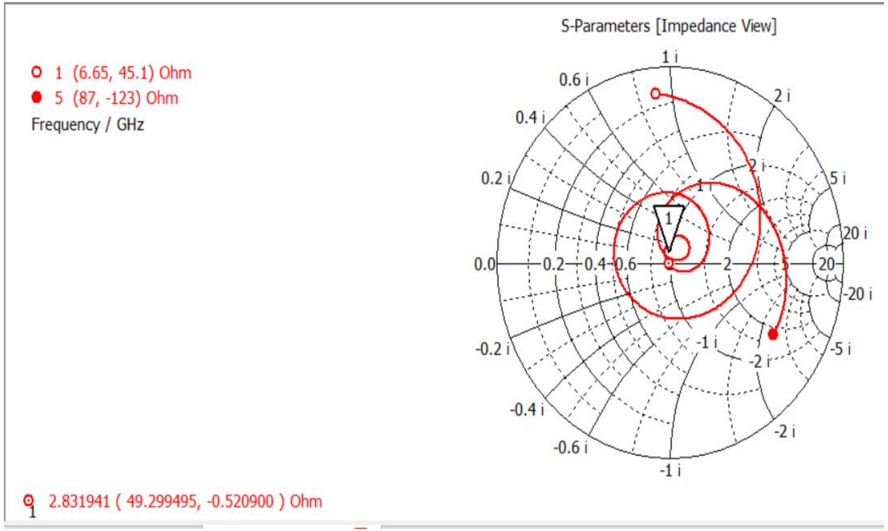
- Iteration7



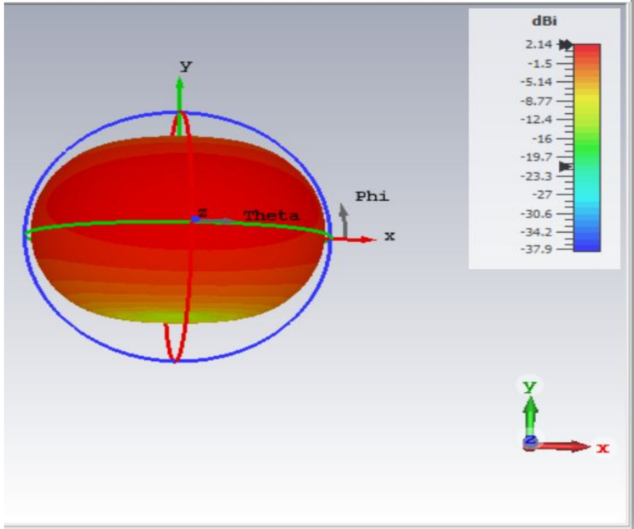




S1,1 : -41.293379
0
-5
10
15
20
25
30
35
40
45
1
1.5
2
2.5
2.832
3
3.5
4
4.5
5

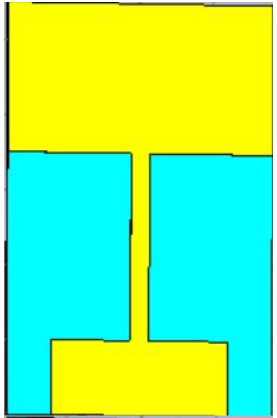


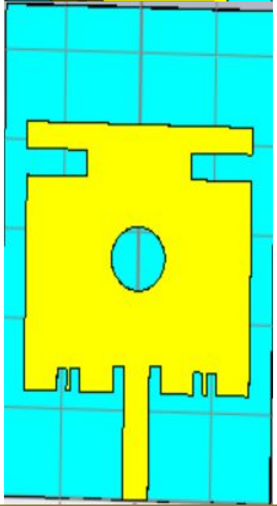
S-Parameters [Impedance View]
1 (6.65, 45.1) Ohm
5 (87, -123) Ohm
Frequency / GHz
2.831941 (49.299495, -0.520900) Ohm

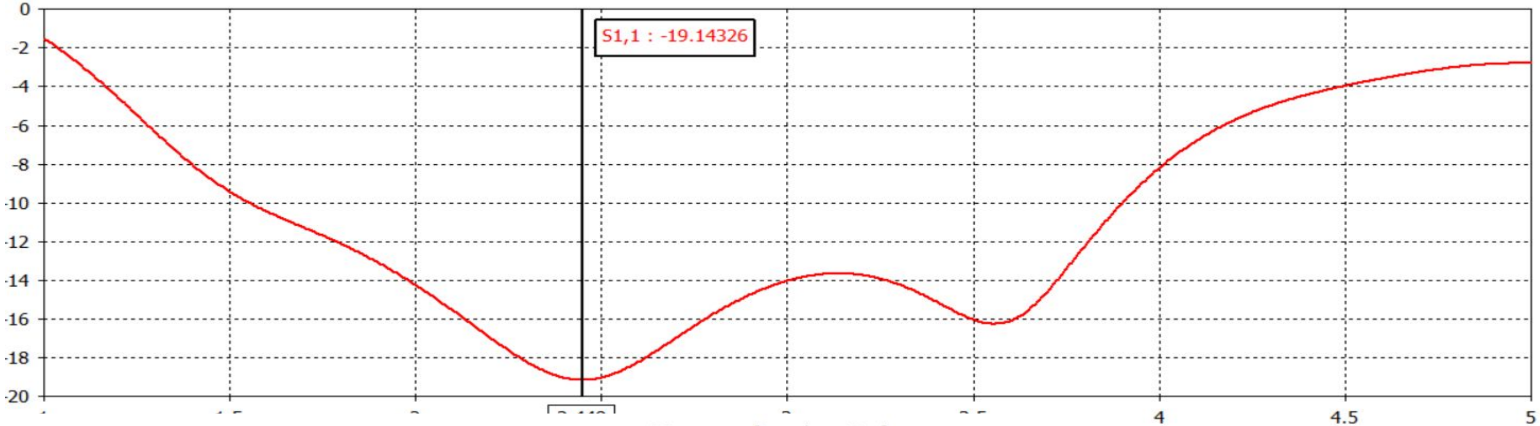


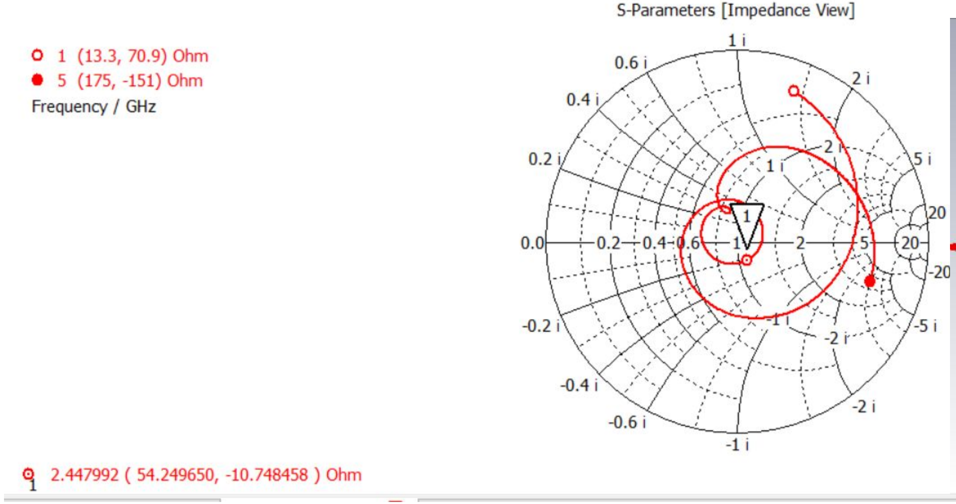
dBi
2.14
-1.5
-5.14
-8.77
-12.4
-16
-19.7
-23.3
-27
-30.6
-34.2
-37.9
Y
Phi
Theta
x

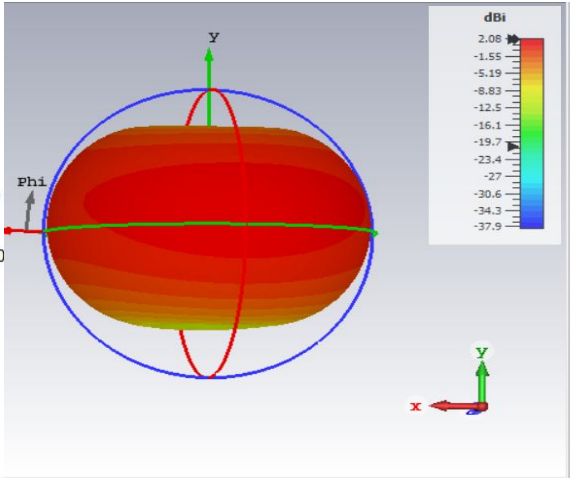
- Final Iteration



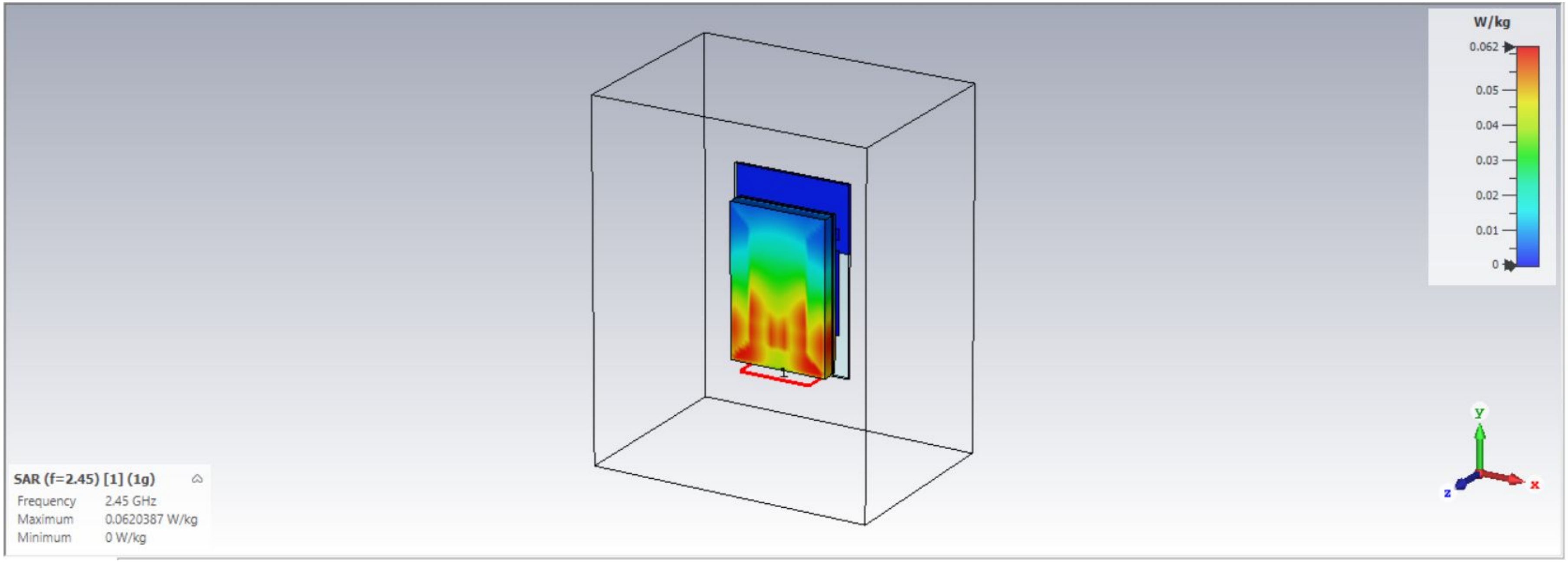




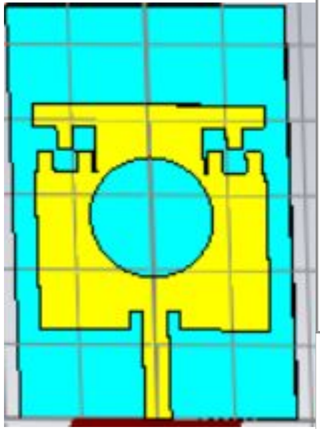


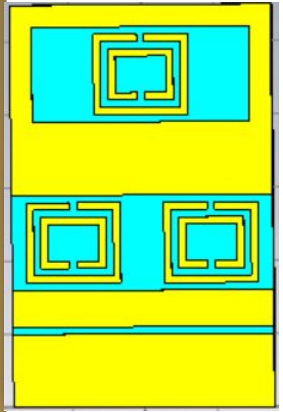


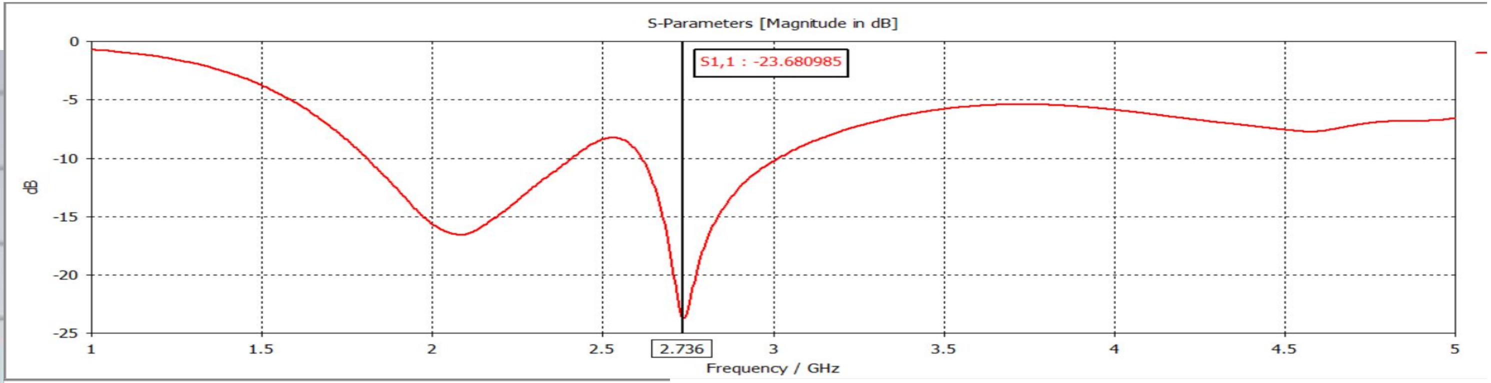
The SAR for the above antenna measured over a phantom model of Skin-Fat-Muscle of 1mm, 0.5mm and 4mm thickness respectively is 0.062W/Kg for 1g of Tissue, Which is less than the limits kept by IEEE and FCC.

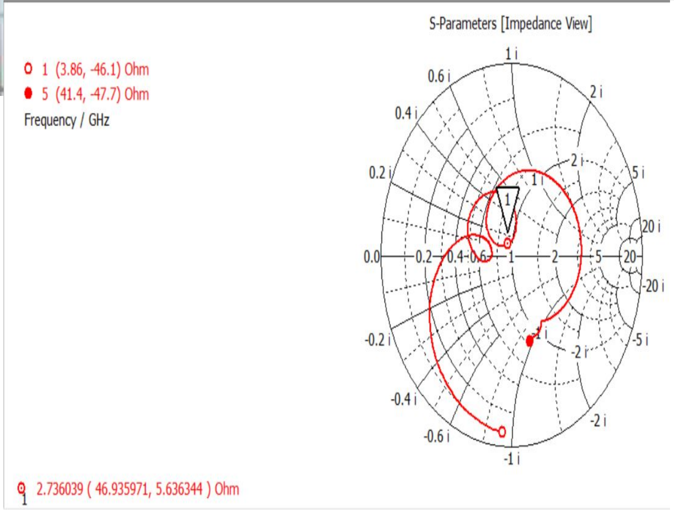


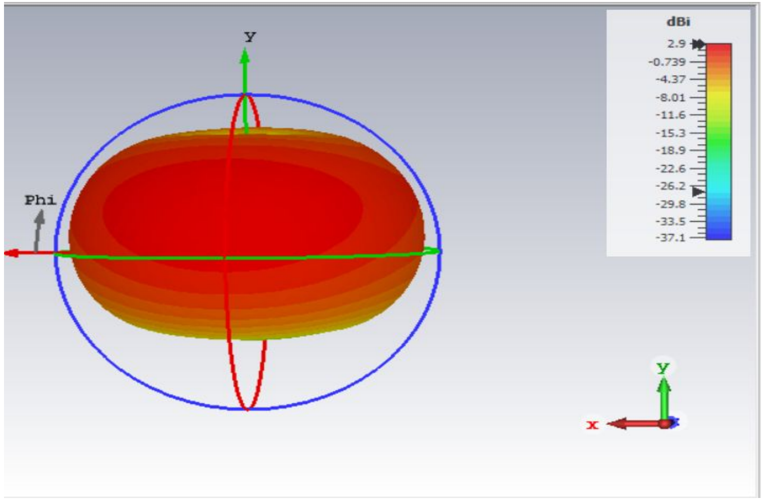
The above design was further modified to increase the gain by adding Split Rings in Ground Plane,





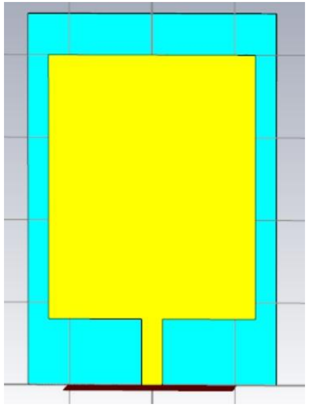


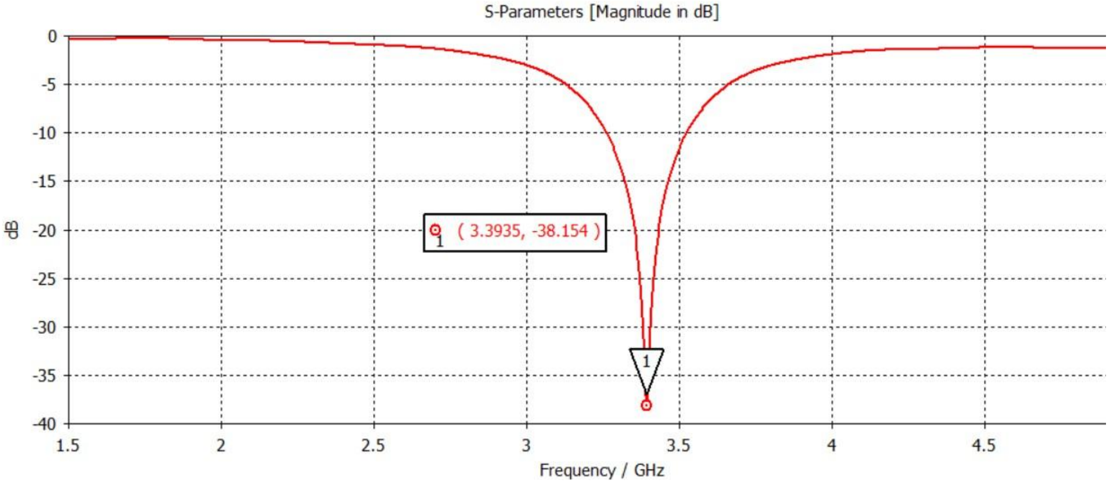


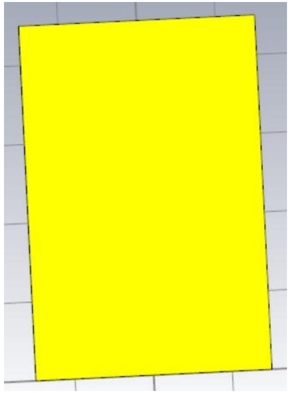


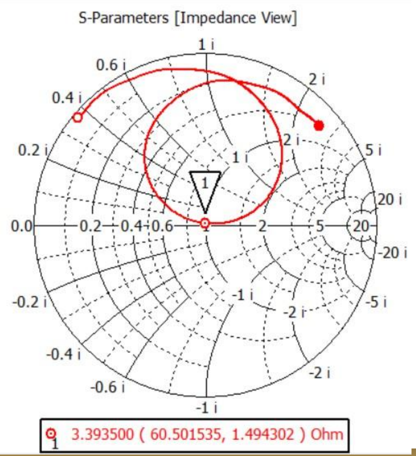
Design_2

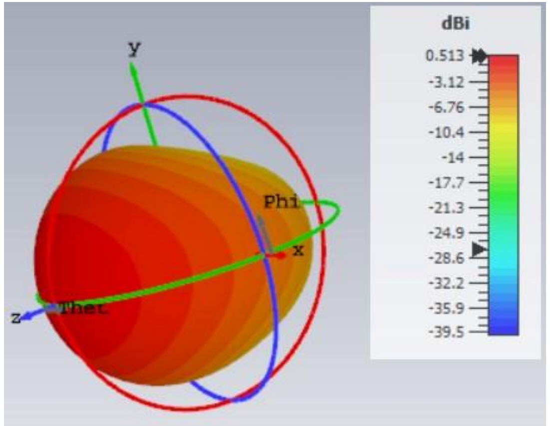
- Iteration1



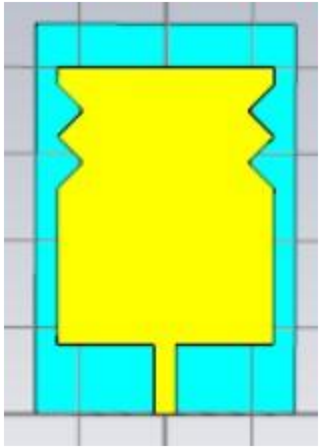


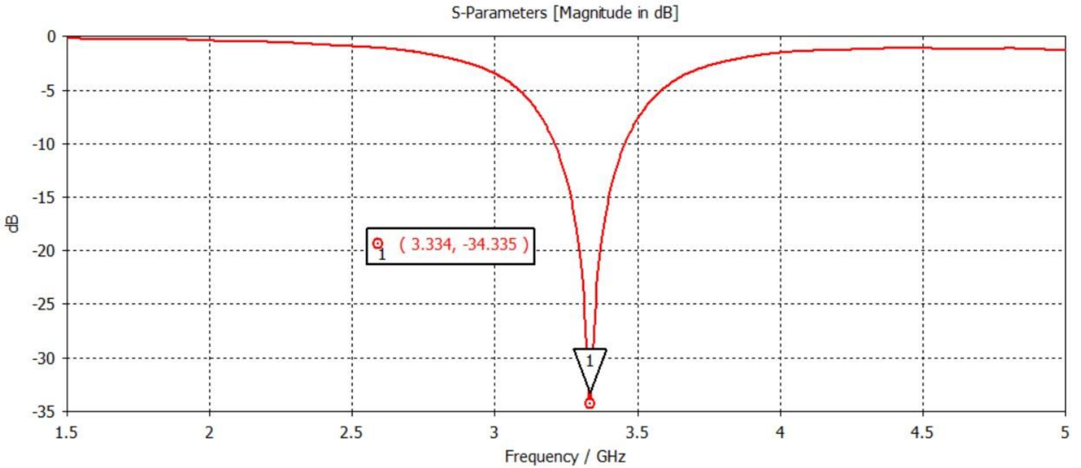


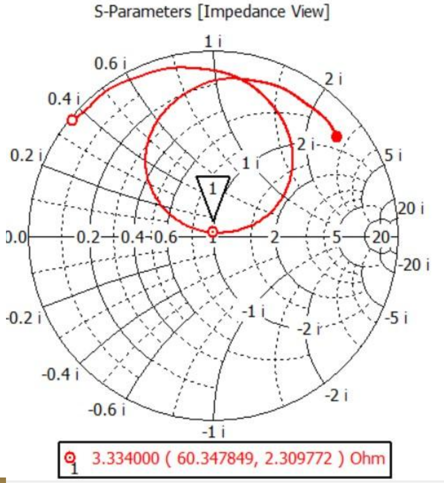


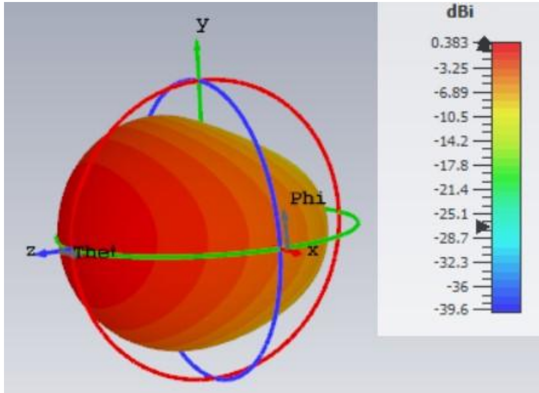


- Iteration 2

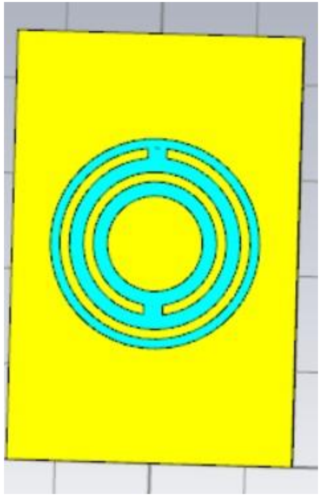


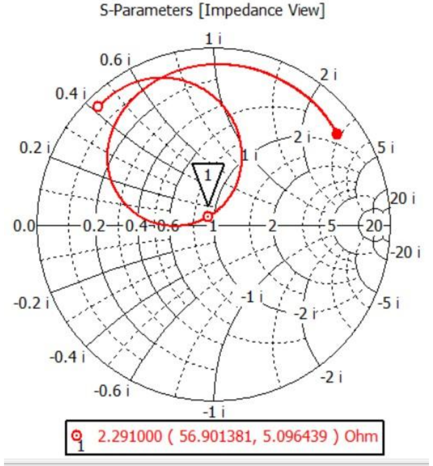

S-Parameters [Magnitude in dB]
(3.334, -34.335)
dB
Frequency / GHz

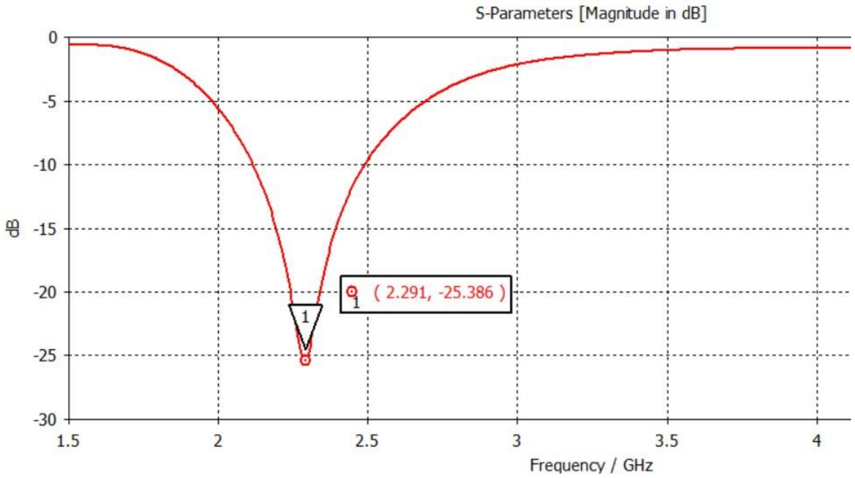

S-Parameters [Impedance View]
3.334000 (60.347849, 2.309772) Ohm

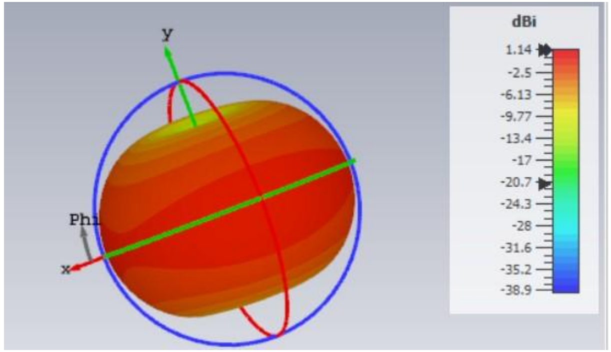

dBi
0.383
-3.25
-6.89
-10.5
-14.2
-17.8
-21.4
-25.1
-28.7
-32.3
-36
-39.6

- Iteration 3

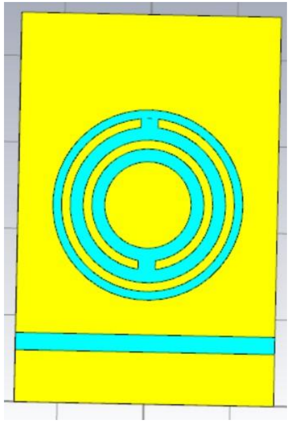


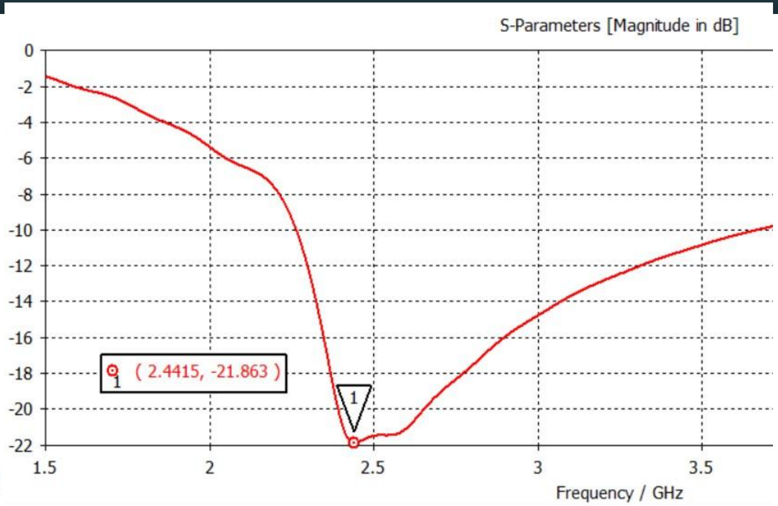

S-Parameters [Impedance View]
2.291000 (56.901381, 5.096439) Ohm

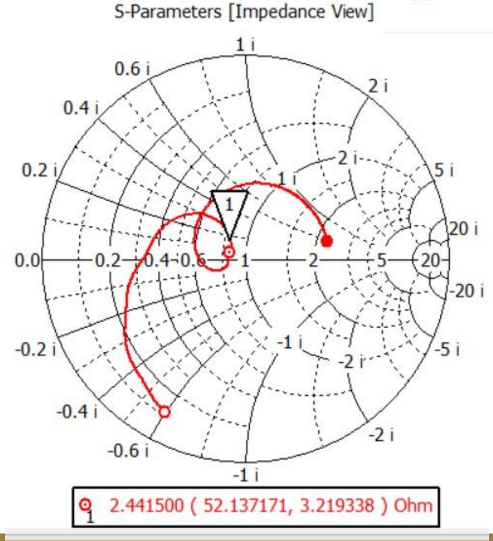

S-Parameters [Magnitude in dB]
dB
Frequency / GHz
(2.291, -25.386)

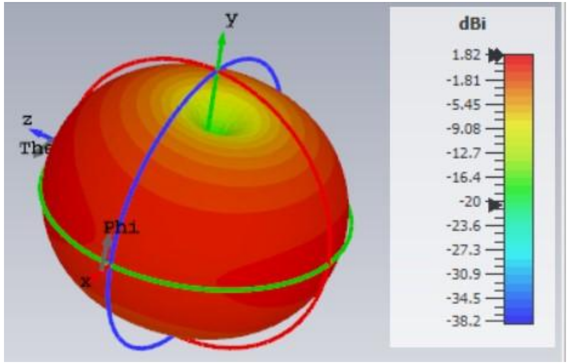

dBi
1.14
-2.5
-6.13
-9.77
-13.4
-17
-20.7
-24.3
-28
-31.6
-35.2
-38.9

- Iteration 4

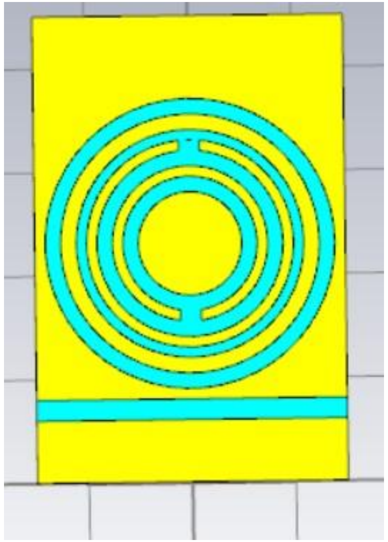


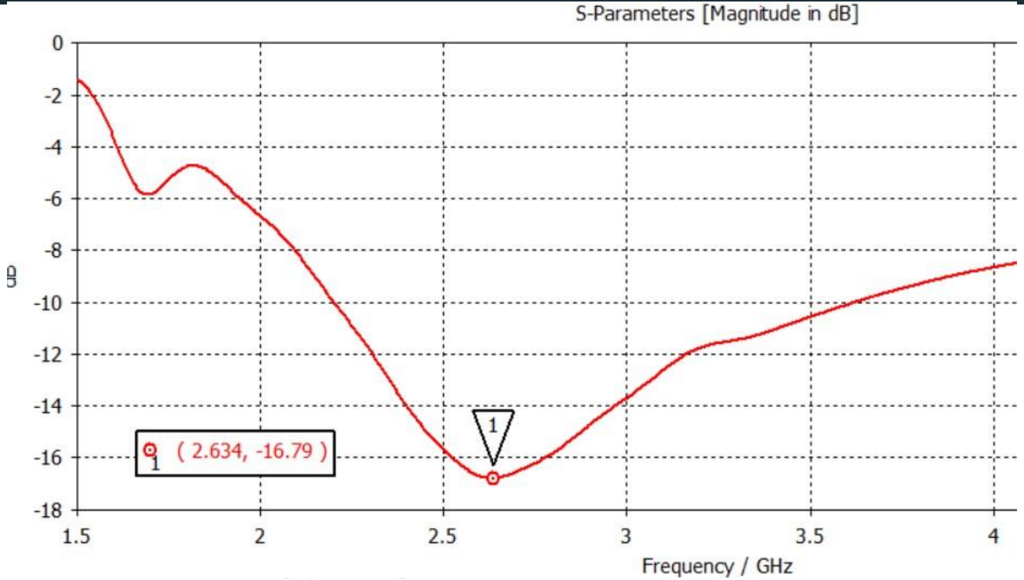

S-Parameters [Magnitude in dB]
(2.4415, -21.863)
Frequency / GHz

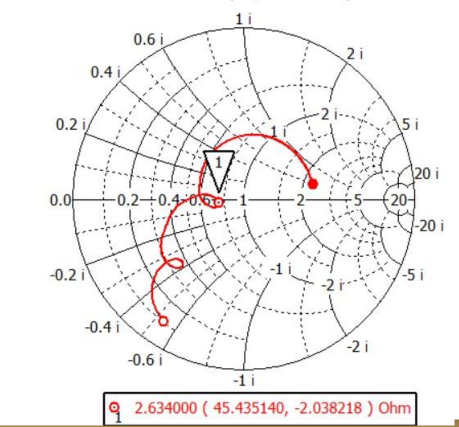

S-Parameters [Impedance View]
2.441500 (52.137171, 3.219338) Ohm

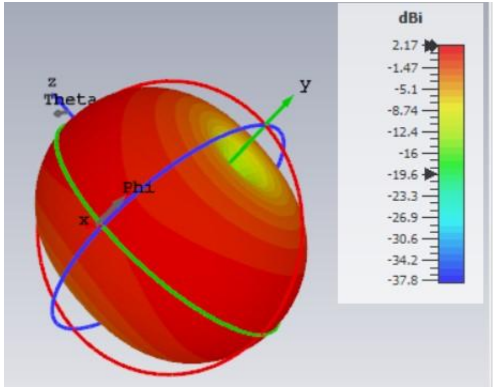

dBi
1.82
-1.81
-5.45
-9.08
-12.7
-16.4
-20
-23.6
-27.3
-30.9
-34.5
-38.2

- Iteration 5

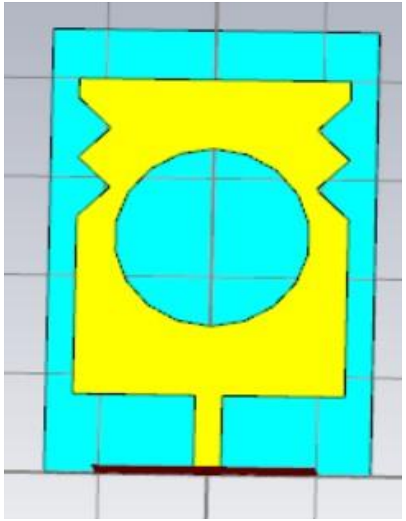


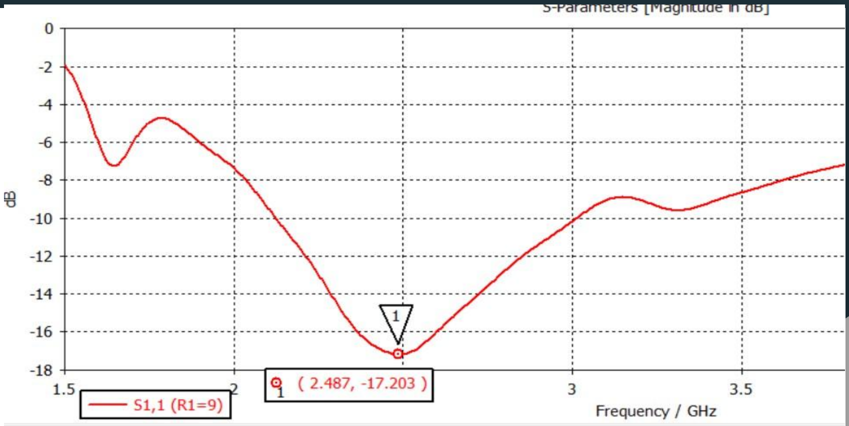

S-Parameters [Magnitude in dB]
dB
Frequency / GHz
(2.634, -16.79)

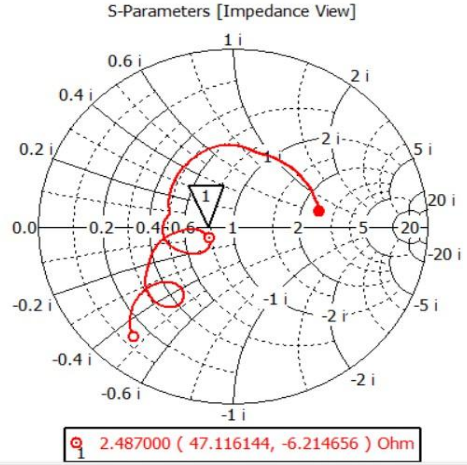

2.634000 (45.435140, -2.038218) Ohm

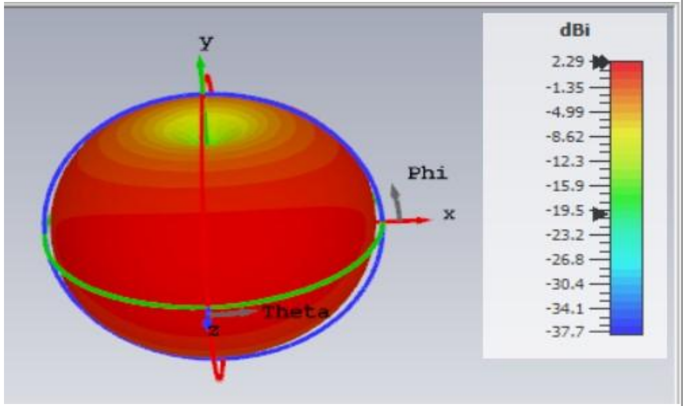

dBi
2.17
-1.47
-5.1
-8.74
-12.4
-16
-19.6
-23.3
-26.9
-30.6
-34.2
-37.8

● Iteration 6

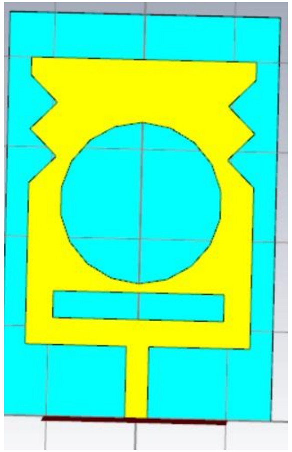


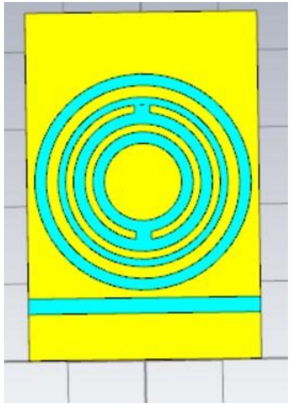

S-Parameters [Magnitude in dB]
dB
Frequency / GHz
S1,1 (R1=9)
(2.487, -17.203)

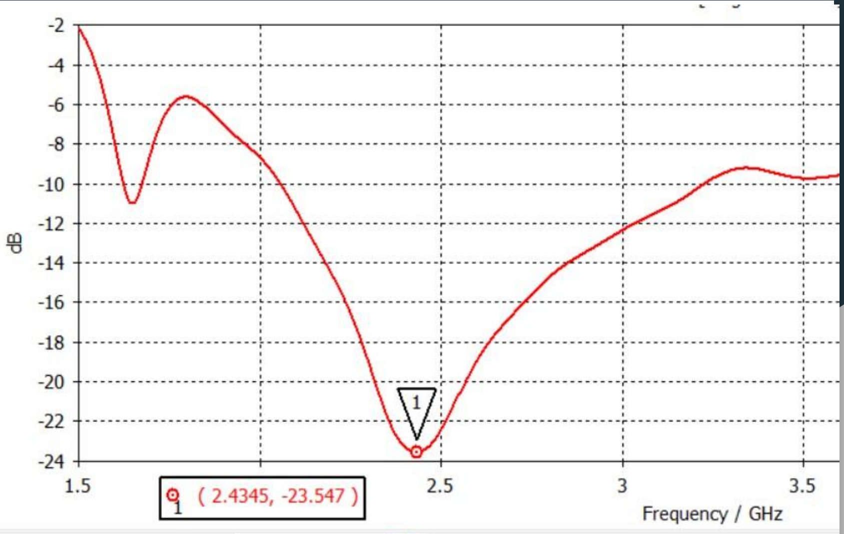

S-Parameters [Impedance View]
2.487000 (47.116144, -6.214656) Ohm

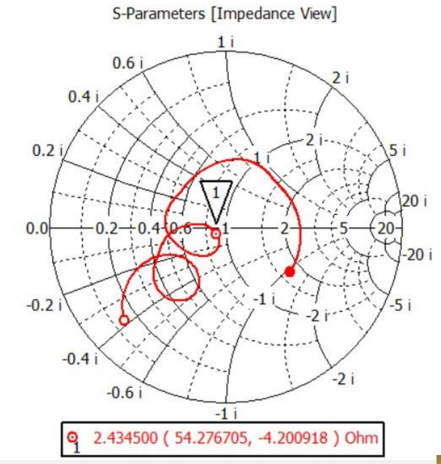

dBi
2.29
-1.35
-4.99
-8.62
-12.3
-15.9
-19.5
-23.2
-26.8
-30.4
-34.1
-37.7
y
Phi
x
Theta
z

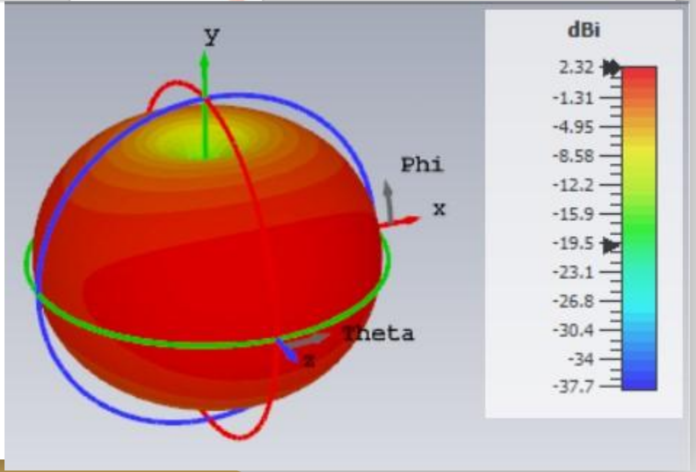
- Final Iteration -Iteration 7



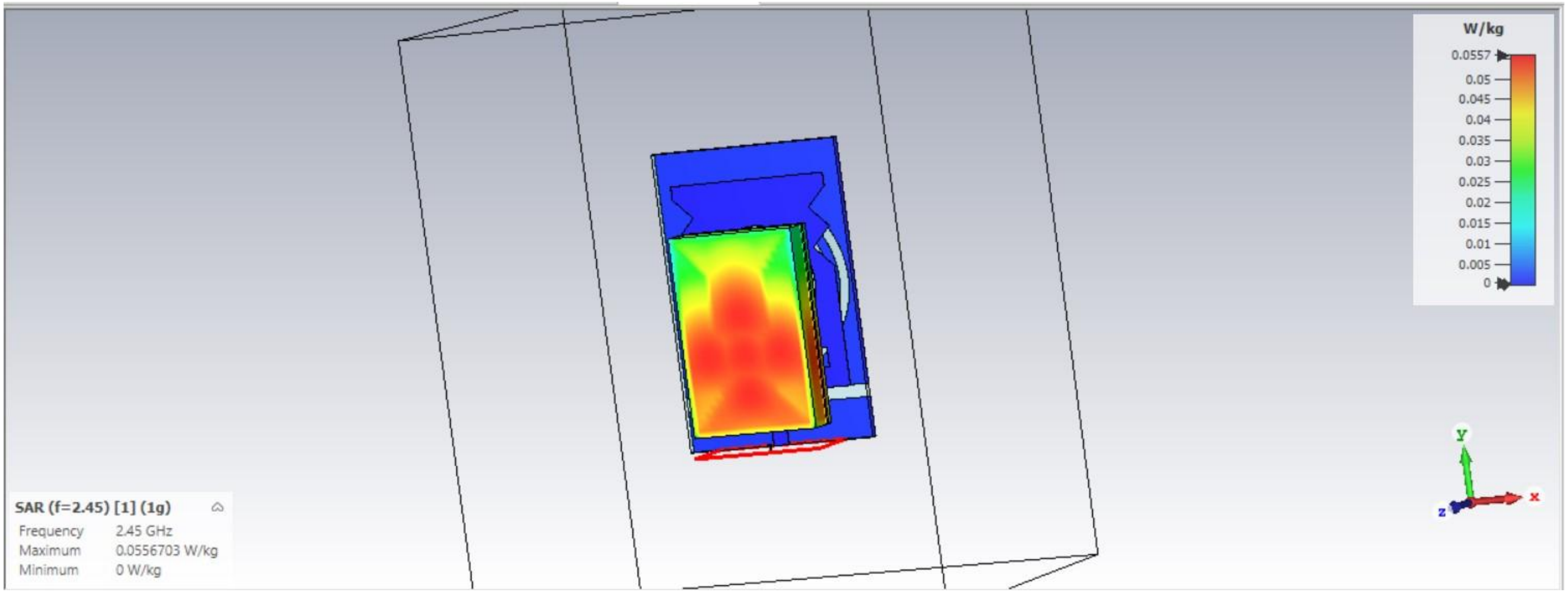






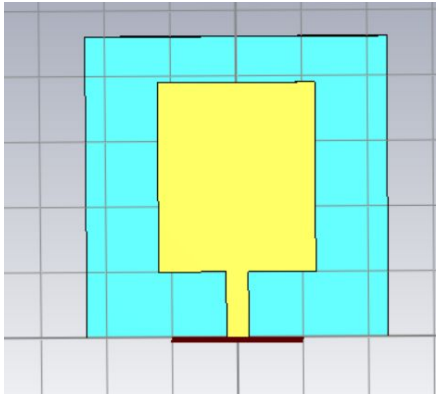


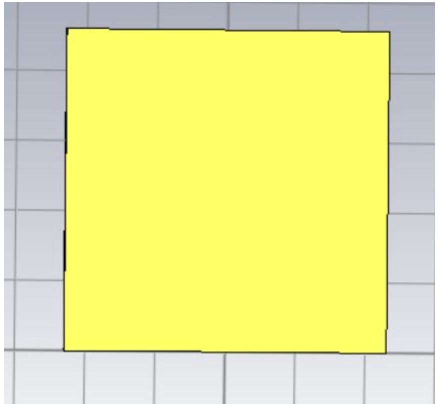
The SAR for the above antenna measured over a phantom model of Skin-Fat-Muscle of 1mm, 0.5mm and 4mm thickness respectively is 0.0556W/Kg for 1g of Tissue, Which is less than the limits kept by IEEE and FCC.

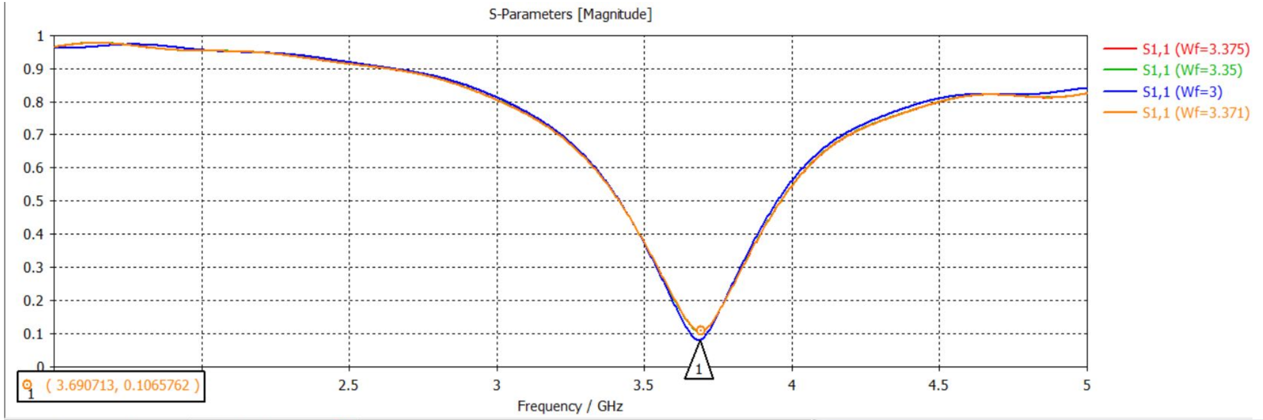


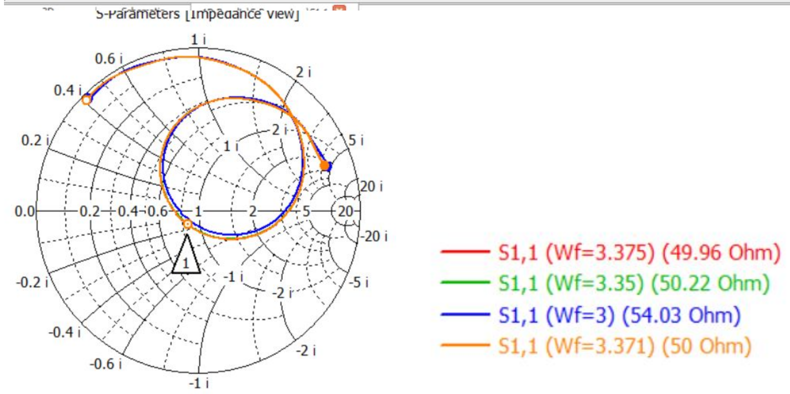
Design 3 Iteration -1

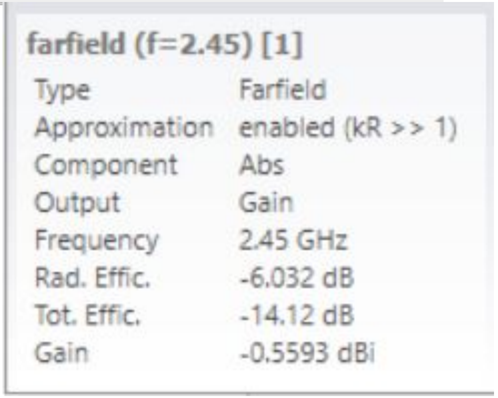
initial dimensions - Lp - 29; Wp - 24; Hf = 0.035; feedline - > 2.5 x 10







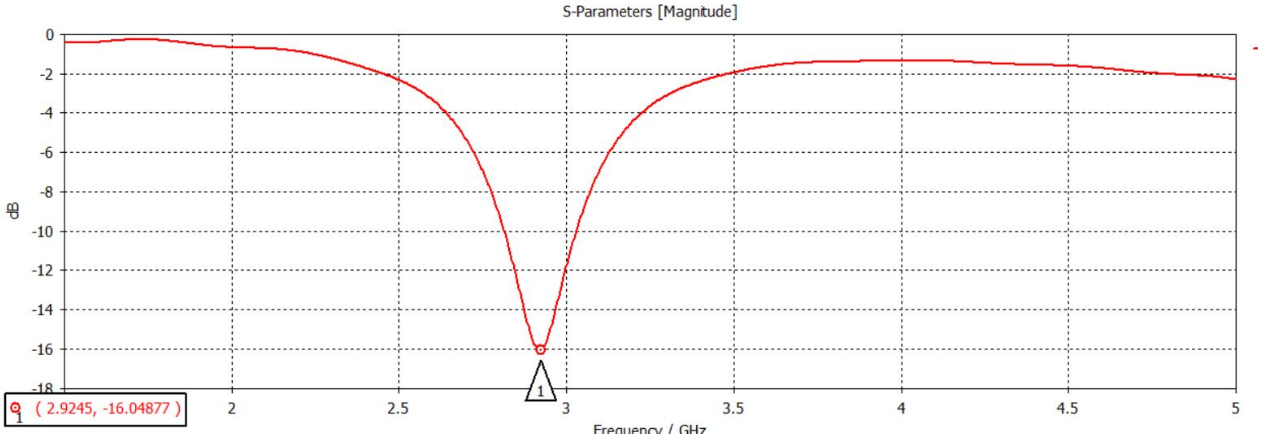




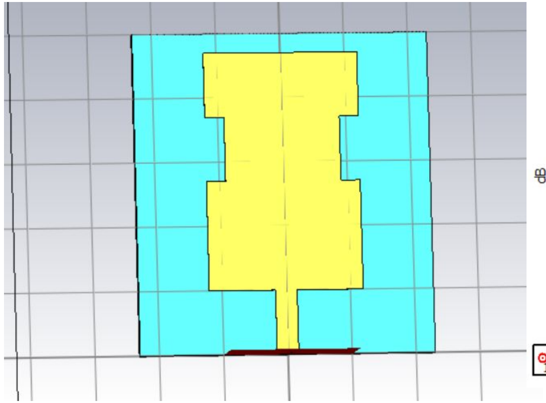
farfield (f=2.45) [1]

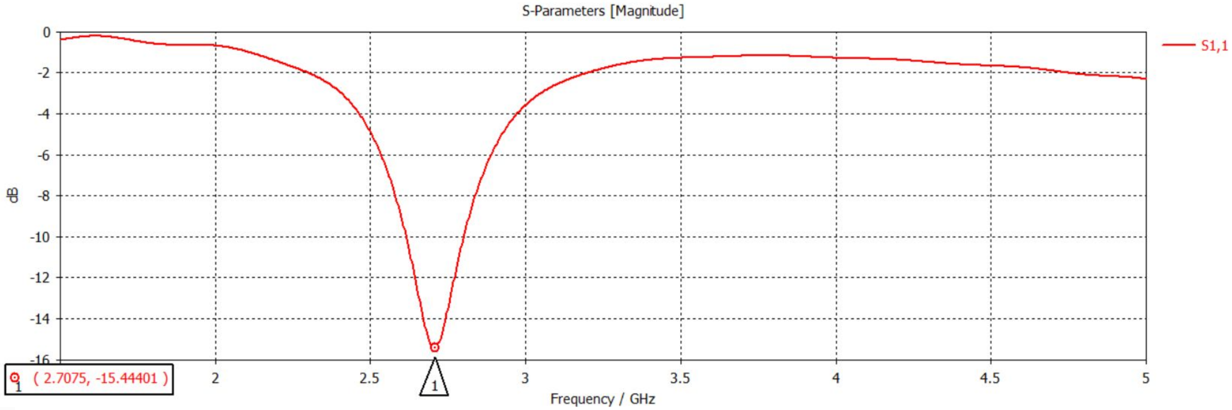
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.45 GHz
Rad. Effic.	-6.032 dB
Tot. Effic.	-14.12 dB
Gain	-0.5593 dBi

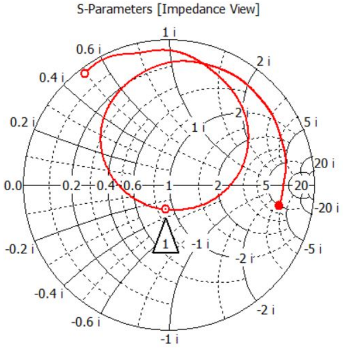
After Lp -> 29->37



Iteration - 2 - adding slots



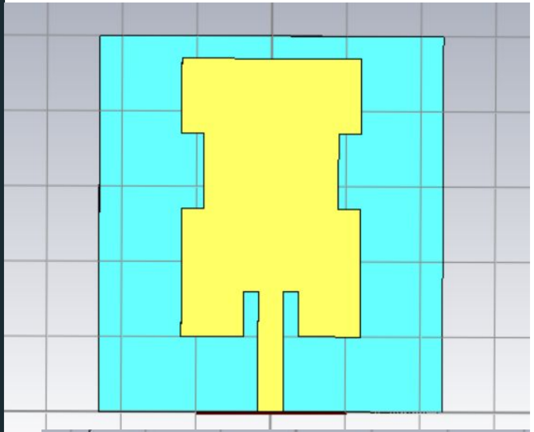


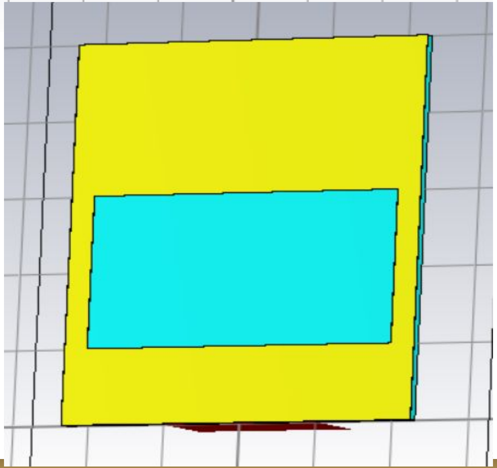


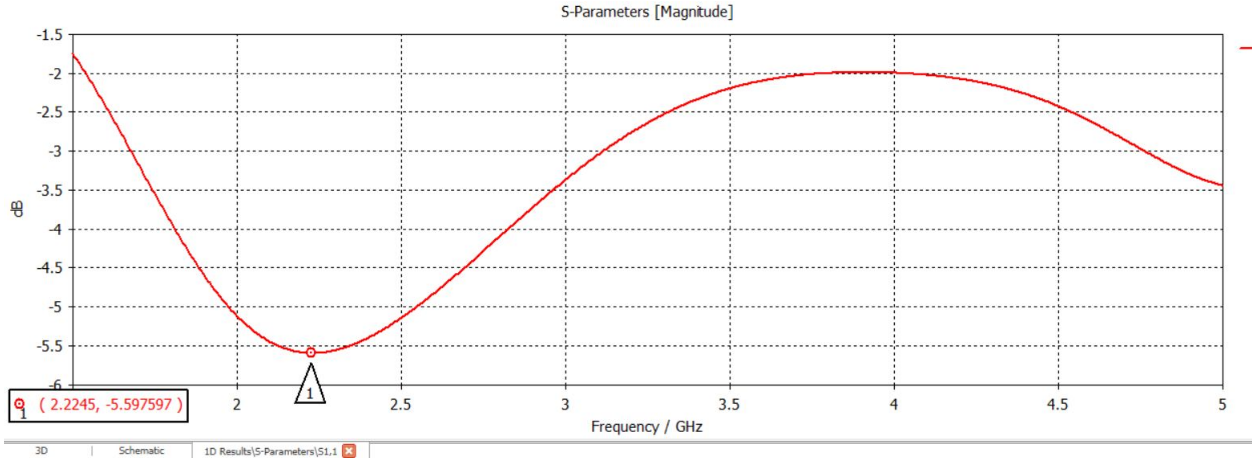
farfield (f=2.45) [1]

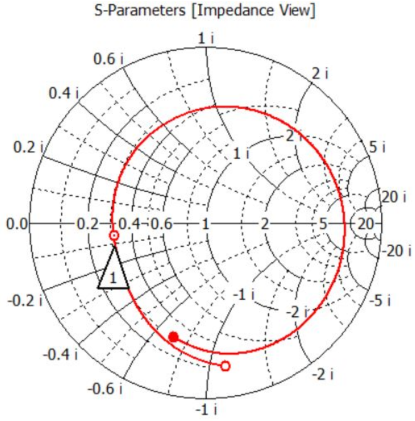
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.45 GHz
Rad. Effic.	-8.203 dB
Tot. Effic.	-10.61 dB
Gain	-2.056 dBi

Iteration-3

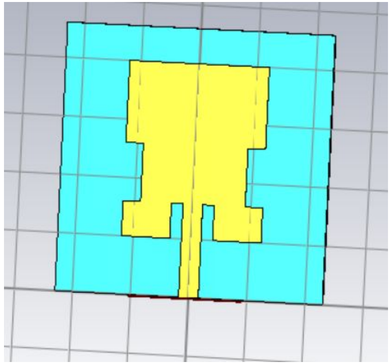


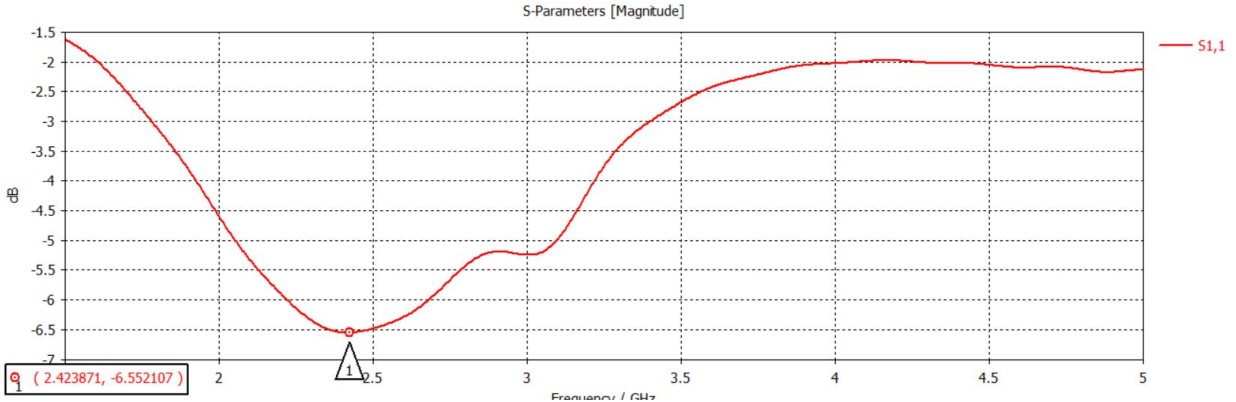


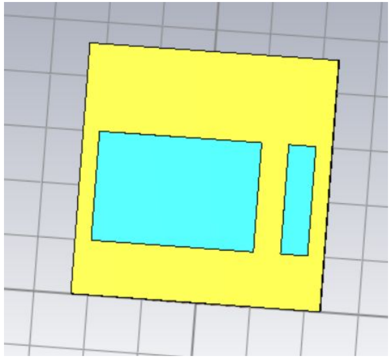

S-Parameters [Magnitude]
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
dB
(2.2245, -5.597597)
1
2
2.5
3
3.5
4
4.5
5
Frequency / GHz
3D
Schematic
1D Results\S-Parameters\S1,1

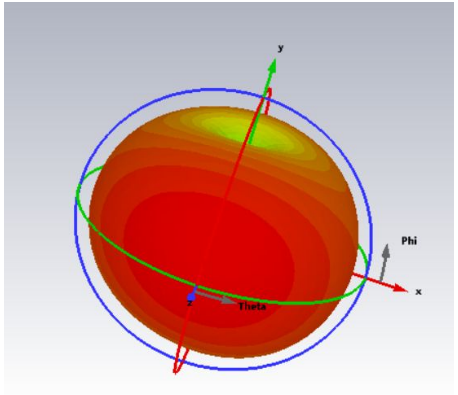

S-Parameters [Impedance View]
1 i
0.6 i
2 i
0.4 i
0.2 i
5 i
20 i
0.0
0.2
0.4
0.6
1
2
5
20
-20 i
-0.2 i
-5 i
-0.4 i
-0.6 i
-2 i
-1 i
1

Iteration - 4





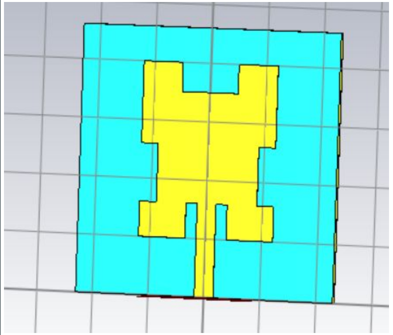


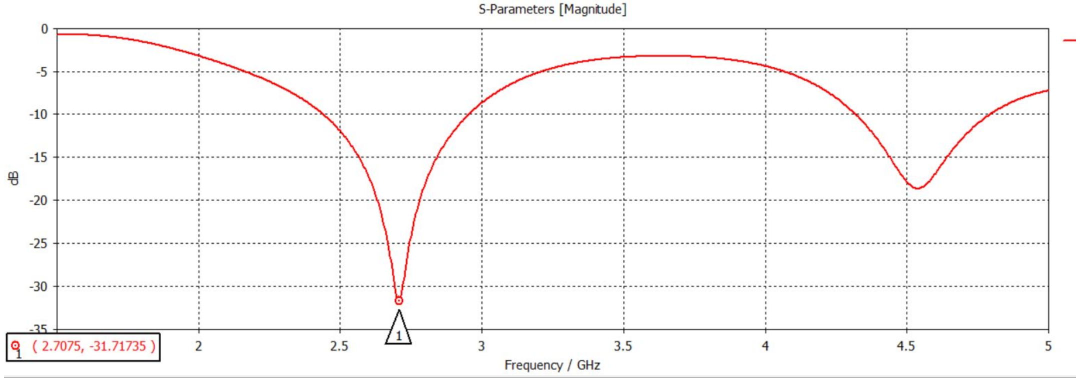


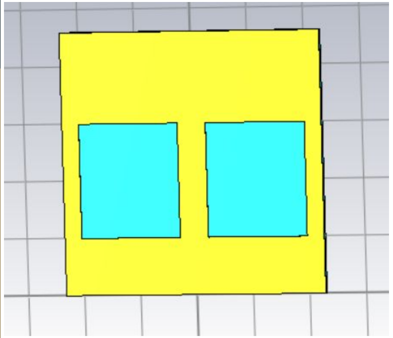
farfield (f=2.45) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.45 GHz
Rad. Effic.	-1.858 dB
Tot. Effic.	-2.948 dB
Gain	1.829 dBi

Iteration 5

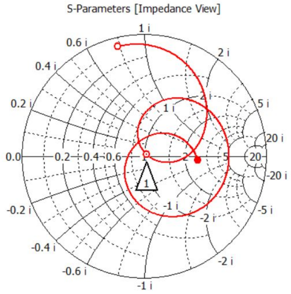


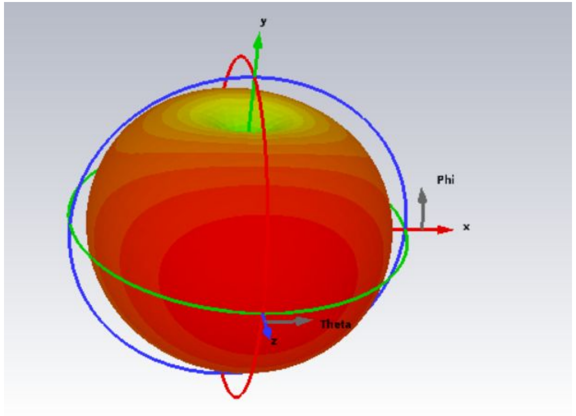




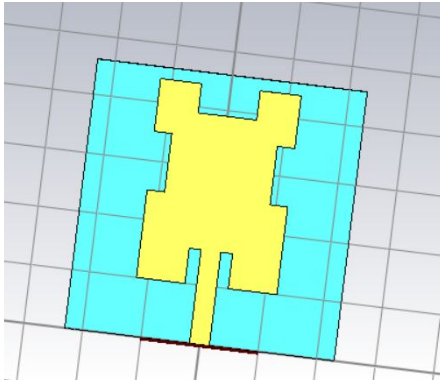
farfield (f=2.45) [1]

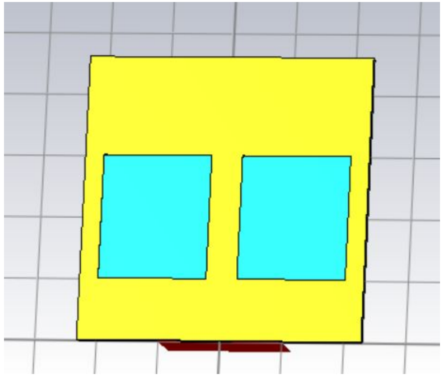
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.45 GHz
Rad. Effic.	-1.754 dB
Tot. Effic.	-2.180 dB
Gain	2.356 dBi

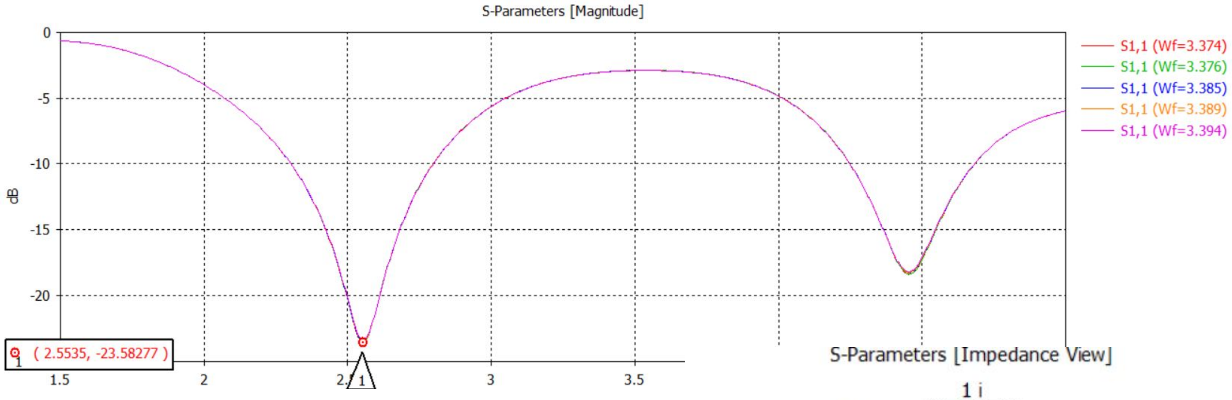




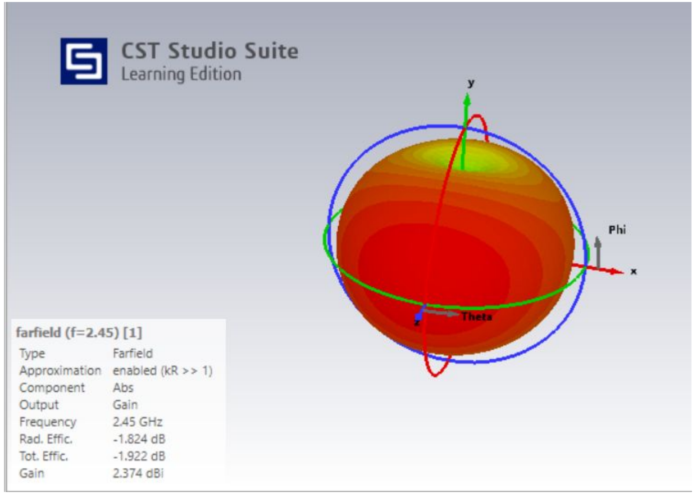
Iteration 6



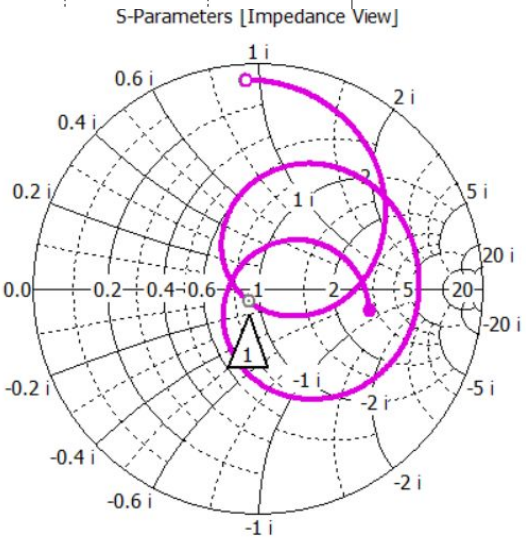




S-Parameters [Magnitude]
0
-5
-10
-15
-20
dB
1.5
2
2.5
3
3.5
1
(2.5535, -23.58277)
S1,1 (Wf=3.374)
S1,1 (Wf=3.376)
S1,1 (Wf=3.385)
S1,1 (Wf=3.389)
S1,1 (Wf=3.394)

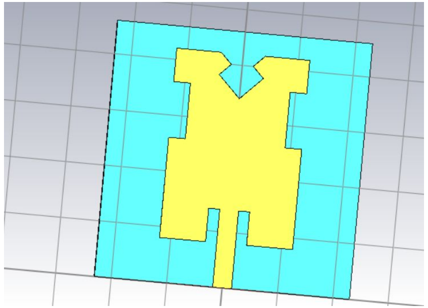


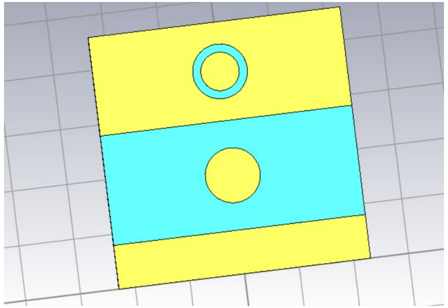
CST Studio Suite
Learning Edition
y
x
z
Phi
Theta
farfield (f=2.45) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 2.45 GHz
Rad. Effic. -1.824 dB
Tot. Effic. -1.922 dB
Gain 2.374 dBi

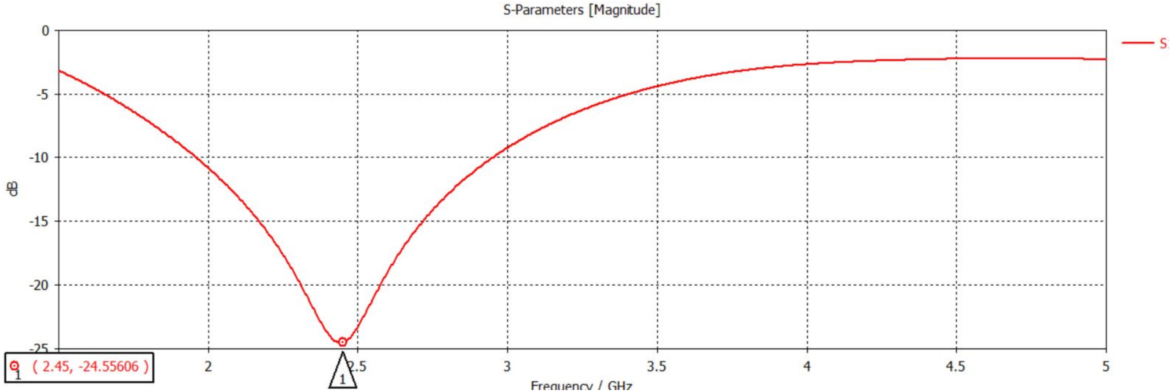


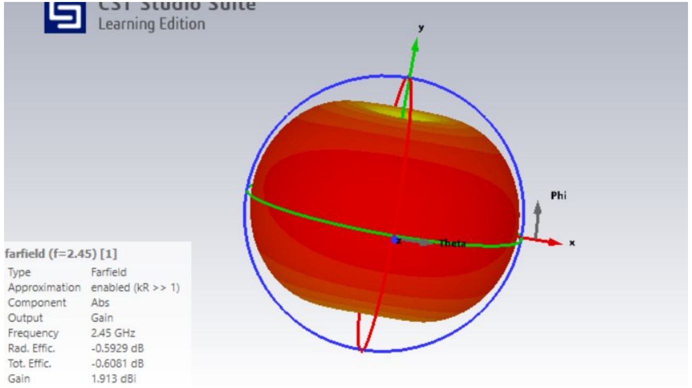
S-Parameters [Impedance View]
1 i
0.6 i
2 i
0.4 i
0.2 i
5 i
20 i
0.0
0.2
0.4
0.6
1
2
5
20
-20 i
-0.2 i
-5 i
-0.4 i
-2 i
-0.6 i
-1 i

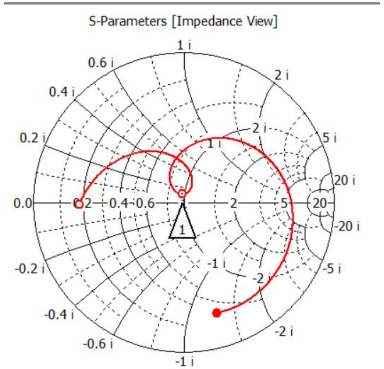
Iteration 7



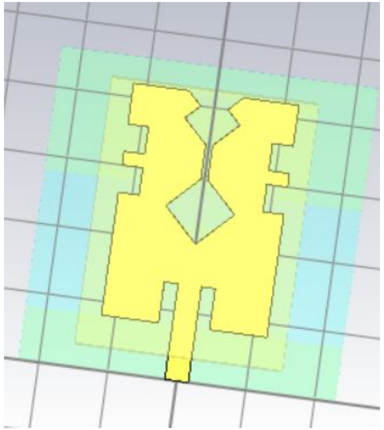


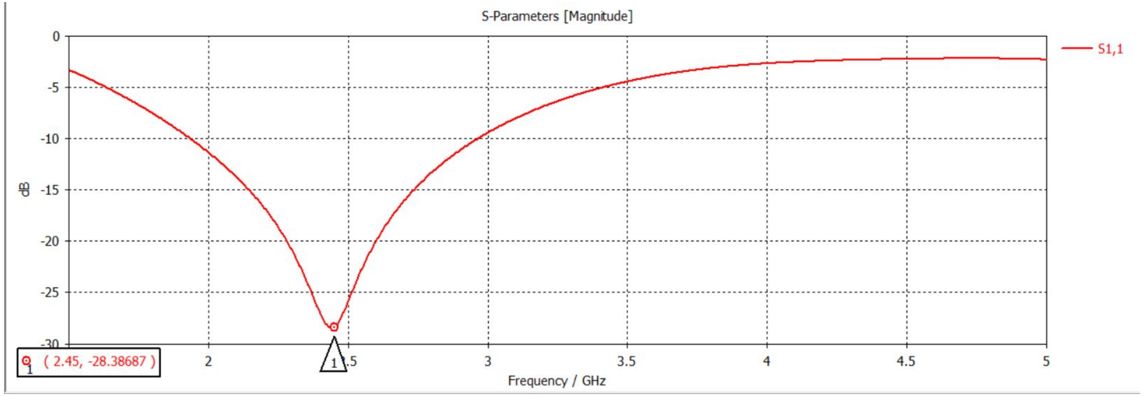

S-Parameters [Magnitude]
0
-5
-10
-15
-20
-25
dB
(2.45, -24.55606)
2
2.5
3
3.5
4
4.5
5
Frequency / GHz
1

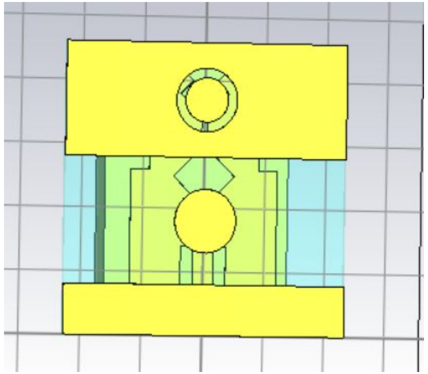

CST Studio Suite
Learning Edition
y
Phi
x
Theta
farfield (f=2.45) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 2.45 GHz
Rad. Effic. -0.5929 dB
Tot. Effic. -0.6081 dB
Gain 1.913 dBi

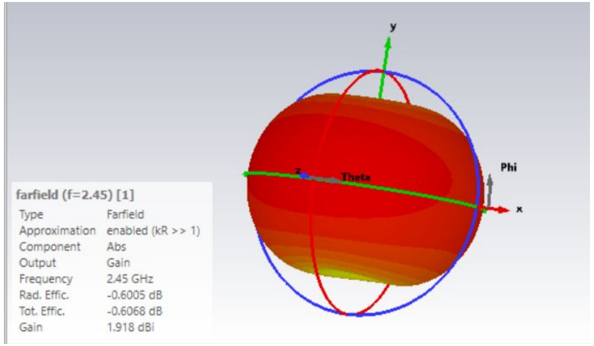

S-Parameters [Impedance View]
1 i
0.6 i
2 i
0.4 i
5 i
0.2 i
20 i
0.0
0.2
0.4
0.6
2
5
20
-20 i
-0.2 i
-5 i
-0.4 i
-2 i
-0.6 i
-1 i

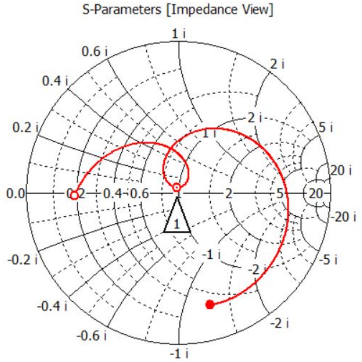
Final Iteration





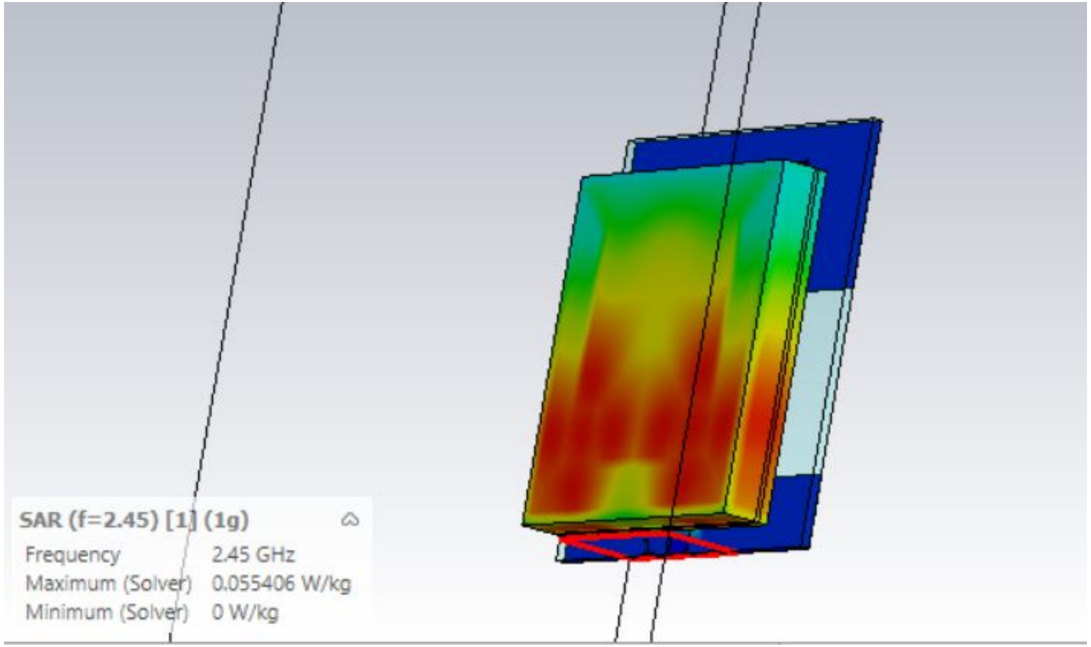






SAR Calculation

The SAR for the above antenna measured over a phantom model of Skin-Fat-Muscle of 1mm, 0.5mm and 4mm thickness respectively is 0.05546W/Kg for 1g of Tissue, Which is less than the limits kept by IEEE and FCC.



Future Work

- To get more significant gain.
- To Fabricate antenna and study the fabricated antenna and compare the simulated and measured result.

References

- A. S. M. Alqadami, A. E. Stancombe, K. S. Bialkowski and A. Abbosh, "Flexible Meander-Line Antenna Array for Wearable Electromagnetic Head Imaging," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 7, pp. 4206-4211, July 2021, doi: 10.1109/TAP.2020.3037742.
- https://core.ac.uk/download/41813223.pdf
- https://www.geeksforgeeks.org/wireless-body-area-network/
- https://www.radartutorial.eu/06.antennas/Microstrip%20Antenna.en.html
- D. Jiang, G. Zhang, O. W. Samuel, F. Liu and H. Xiao, "Dual-Factor WBAN Enhanced Authentication System Based on Iris and ECG Descriptors," in IEEE Sensors Journal, vol. 22, no. 19, pp. 19000-19009, 1 Oct.1, 2022, doi: 10.1109/JSEN.2022.3198645.

- V. Mishra and A. Kiourti, "Wearable Planar Magnetoinductive Waveguide: A Low-Loss Approach to WBANs," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 11, pp. 7278-7289, Nov. 2021, doi: 10.1109/TAP.2021.3070681.
- https://www.slideshare.net/RiazAhmedLiyakath/flexible-antennas
- https://techsparks.co.in/thesis-in-wireless-body-area-network/#:~:text=Requirements%20of%20WBAN&text=These%20are%3A,is%20required%20in%20this%20case.
- G. -P. Gao, C. Yang, B. Hu, R. -F. Zhang and S. -F. Wang, "A Wearable PIFA With an All-Textile Metasurface for 5 GHz WBAN Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 2, pp. 288-292, Feb. 2019, doi: 10.1109/LAWP.2018.2889117.

Suggestion are Welcome

-Thank You

Indian Institute of Information Technology, Nagpur

Department of Electronics and Communication Engineering

Final Year Project Presentation - 4

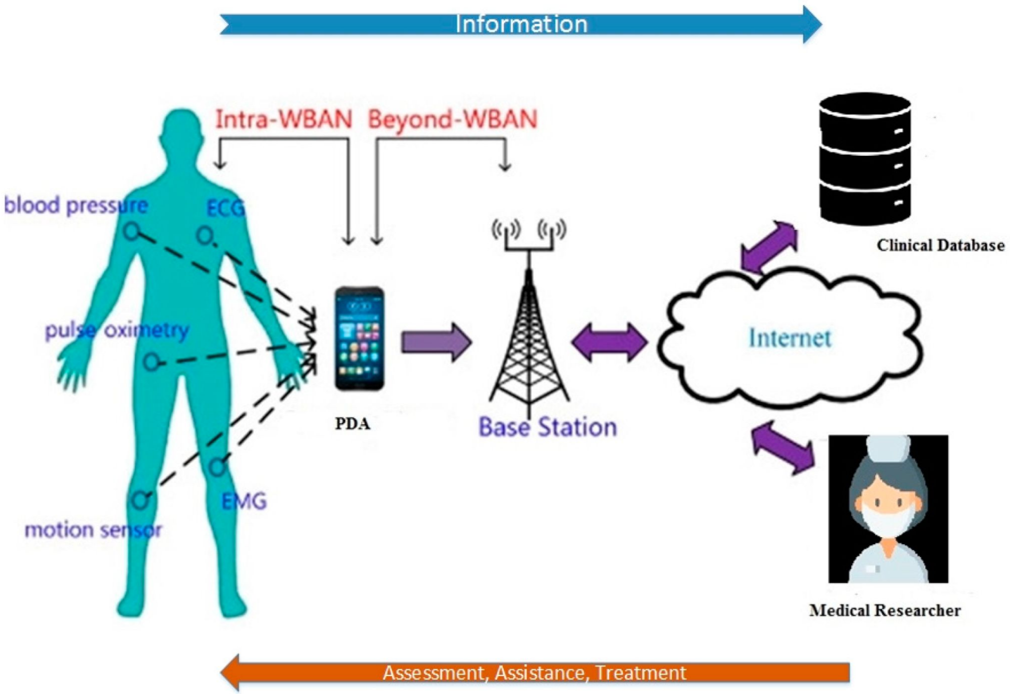
Flexible Microstrip Patch Antenna Design on Jeans Substrate Radiating at 2.45 GHz for WBAN Application

Presented By:
BT19ECE005 Sakshi Pandagale
BT19ECE037 Avish Fakirde
BT19ECE073 Saikumar Mulkalla

Supervisor:
Dr. Paritosh D. Peshwe

Overview of Project

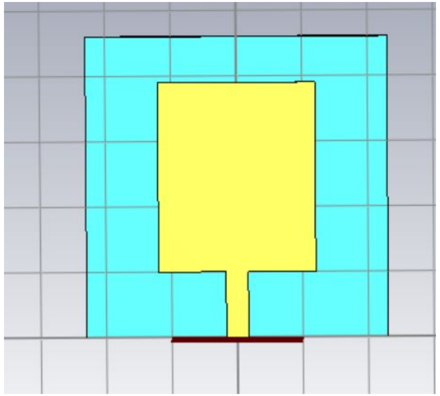
- Why Research on WBAN?
- What is WBAN?
- Flexible Antennas for WBAN
- Why jeans substrate?

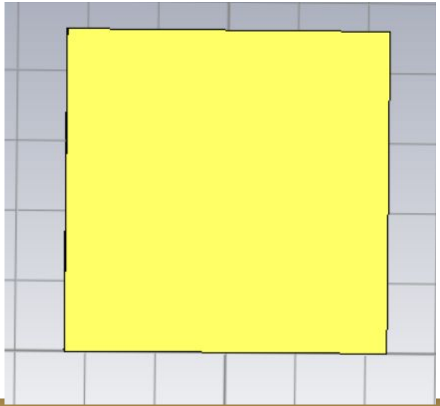


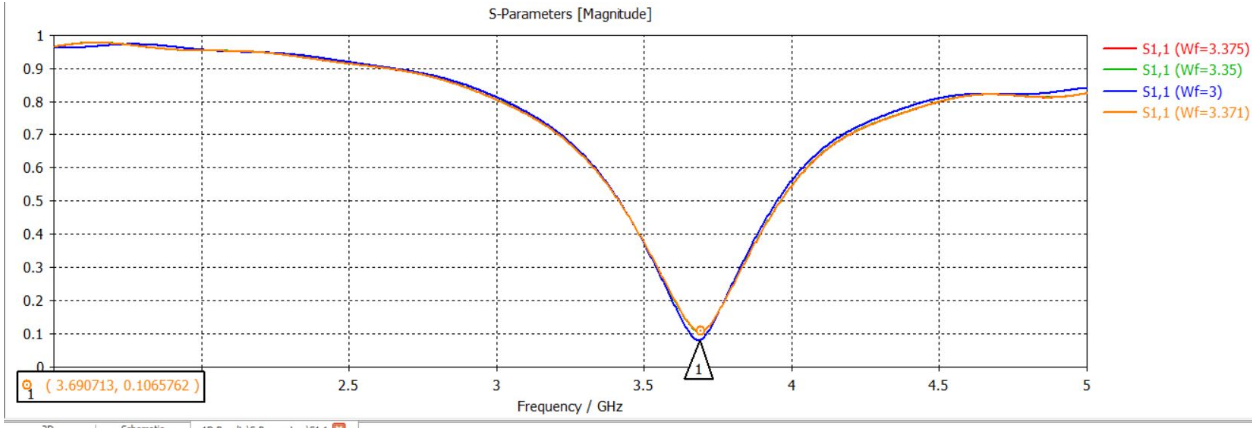
- In this Project, we propose three different microstrip patch antenna.
- Jeans material
- A 50Ω transmission line backed with a defected ground structure (DGS) was employed to excite the radiating element.
- The final design of the antenna is a modified form of the conventional patch antenna. The ground plane was modified, and slots were etched to make the antenna resonant at the desired frequency and to obtain significant gain.

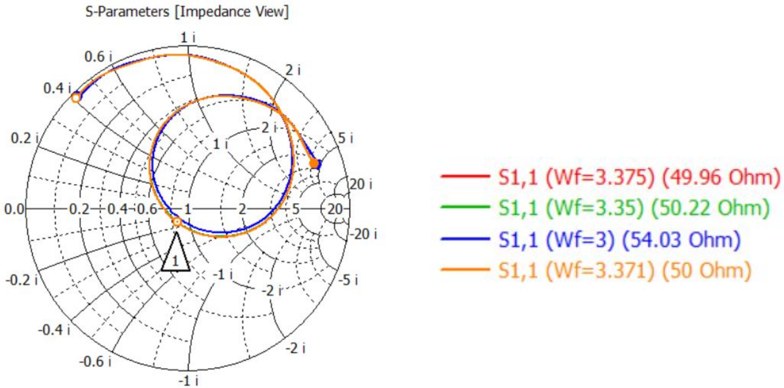
Antenna Design 1

- ## Iteration 0





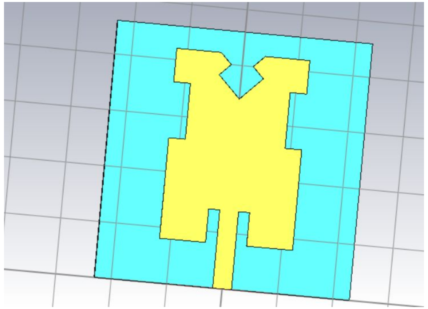


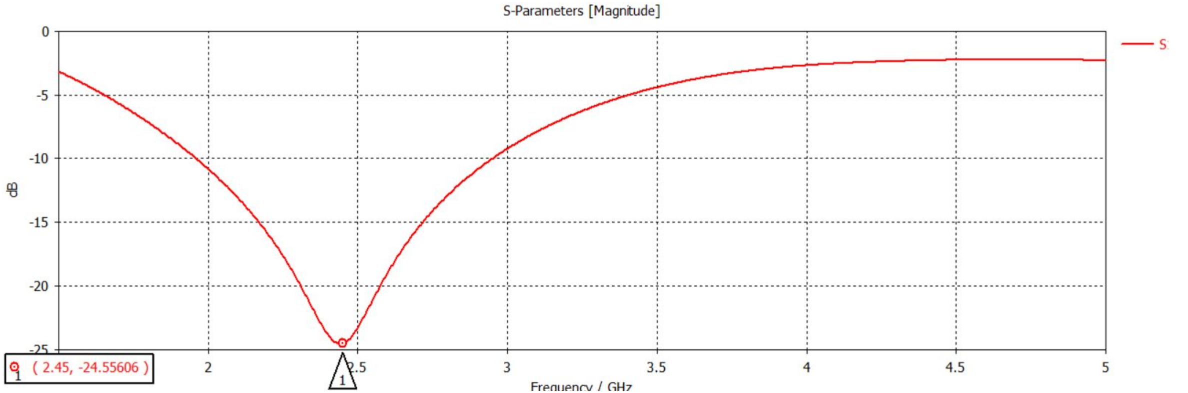


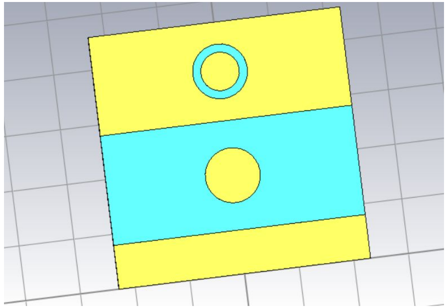
farfield (f=2.45) [1]

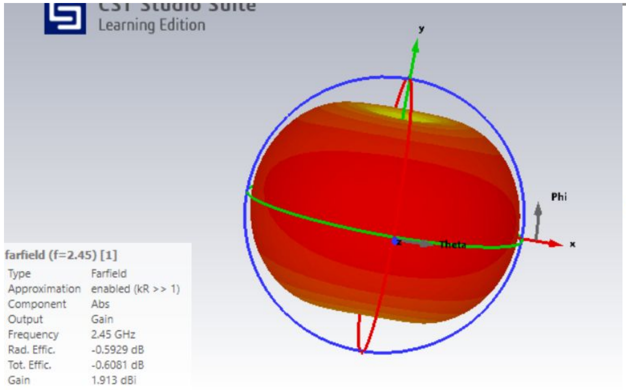
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.45 GHz
Rad. Effic.	-6.032 dB
Tot. Effic.	-14.12 dB
Gain	-0.5593 dBi

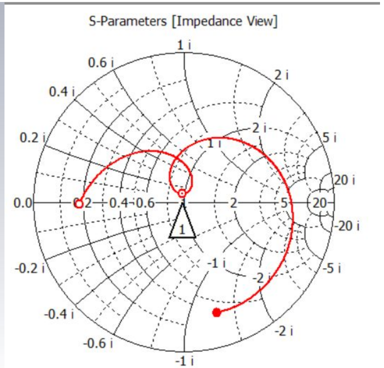
● Iteration 1







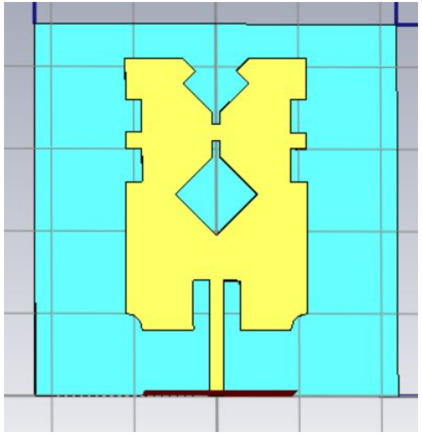


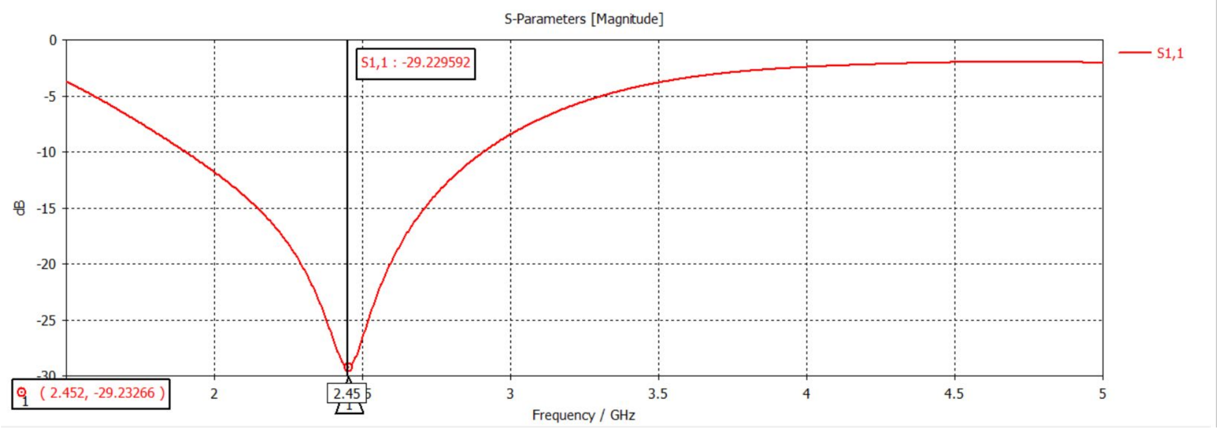


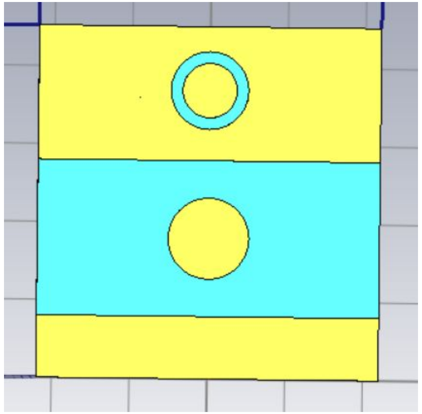
S11 = -24.556
At 2.45 GHz

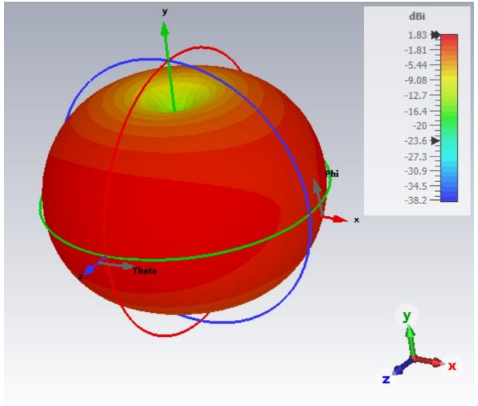
Gain = 1.913 dBi

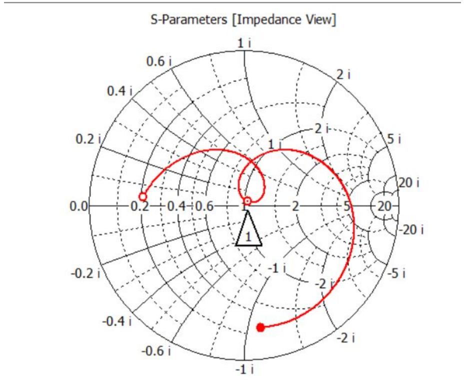
- # The Final Iteration







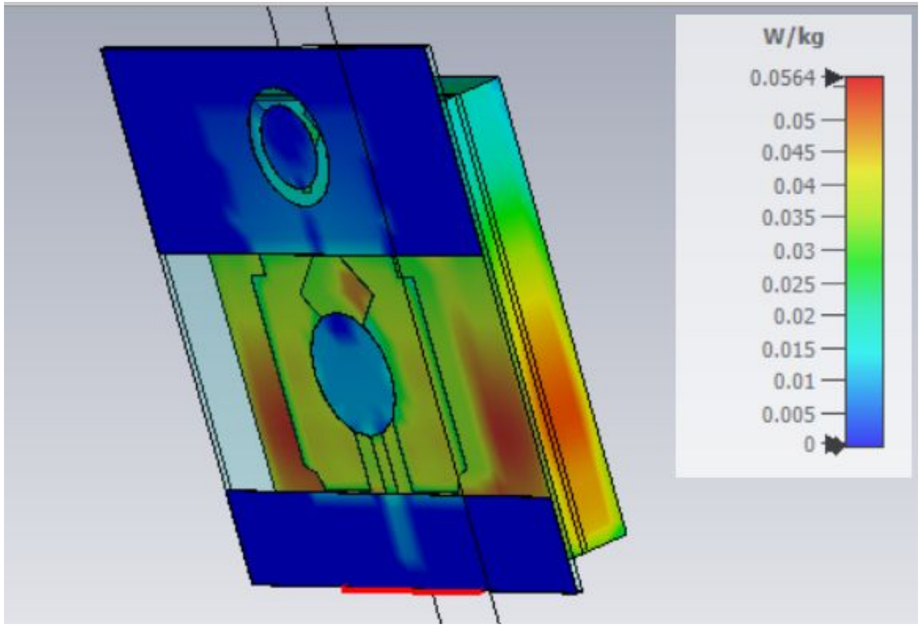




S11 = -29.229
At 2.45 GHz

Gain = 1.85 dBi

The SAR for the above antenna measured over a phantom model of Skin-Fat-Muscle of 1mm, 0.5mm and 4mm thickness respectively is 0.05642W/Kg for 1g of Tissue, Which is less than the limits kept by IEEE and FCC.



Merits of Antenna Design 1

- Overall dimension of antenna is 44 x 45.2 x 0.6 mm^3.
- S11 = -29.225dB
- Bandwidth = 1.014 GHz (1.895 GHz - 2.909 GHz) and Fractional Bandwidth = 35.44%.
- Gain = 1.828dBi and Radiation Efficiency = 86.27%
- The SAR of the is well within the limits kept by the FCC and IEEE.
- To access antennas' flexibility, bending analysis was performed under two bending conditions; vertical and horizontal with different radii of curvatures. Under all Under all bending conditions, the antenna was well-matched at the targeted ISM (2.45) band and exhibits good gain. This study concludes that the proposed antenna is flexible.

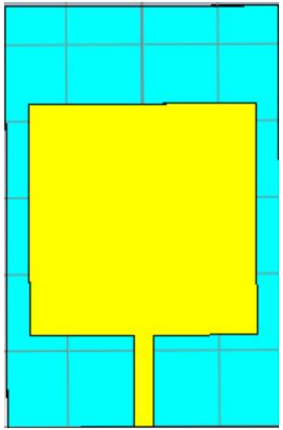
Improvements can be made to Antenna Design 1

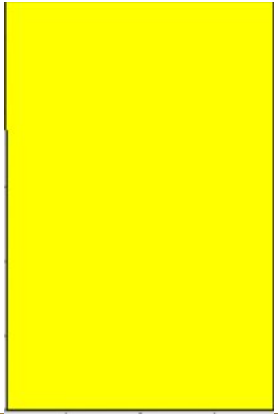
- The size of the antenna is compact, however the dimensions can be reduced further.
- The Gain, while being positive, can also be increased with further work.
- The radiation efficiency of this antenna can also be improved.

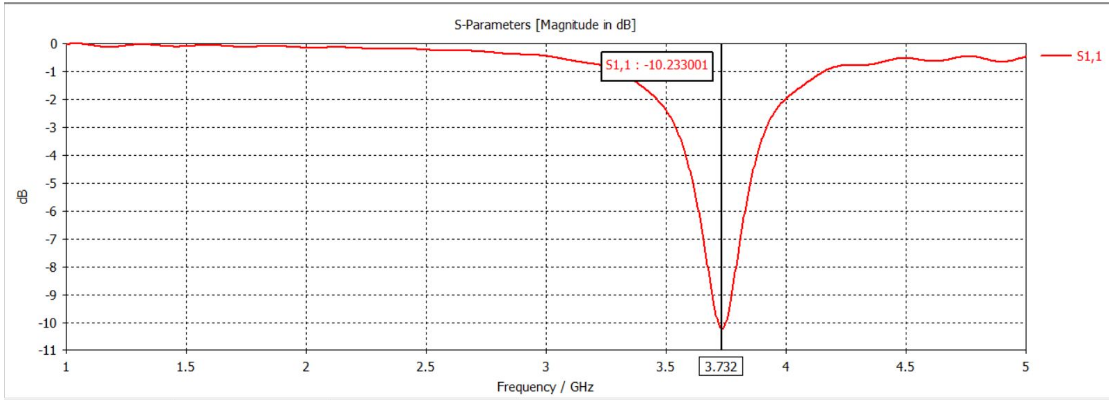
➢ This scope made us design another antenna design that has improved Gain and a smaller Antenna width.

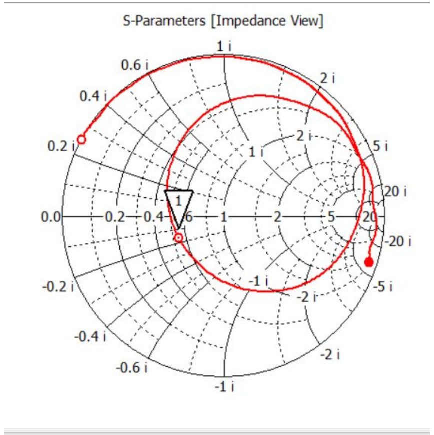
Antenna Design 2

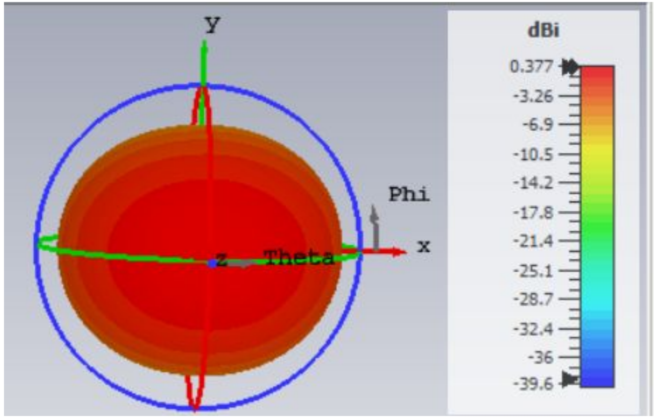
- **Iteration 0**







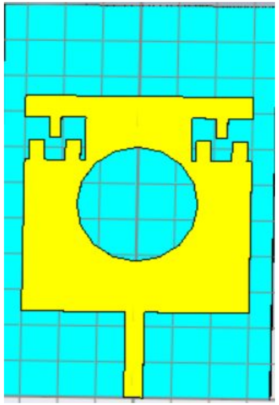


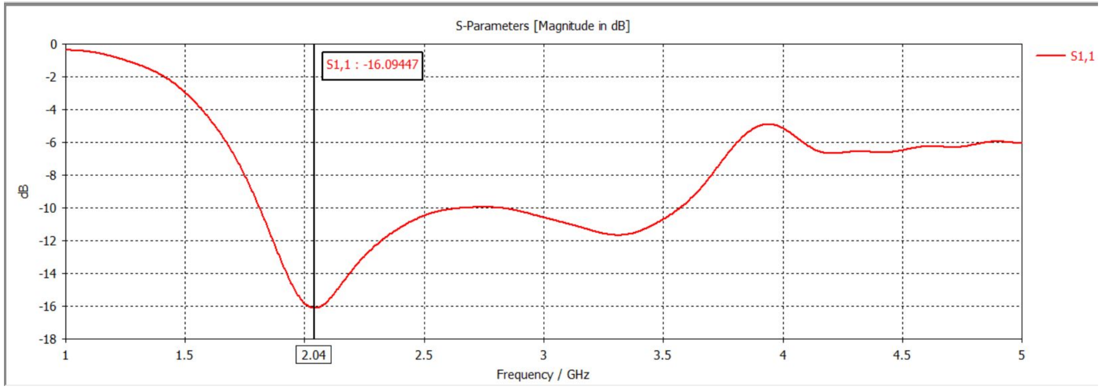


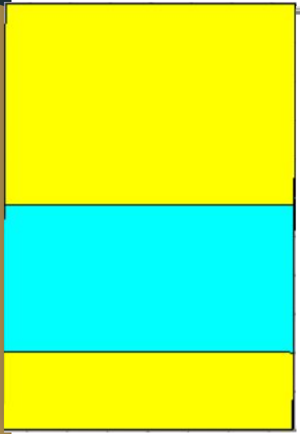
- S11 = -10.233dB ; 3.732 GHz
- Gain = 0.377

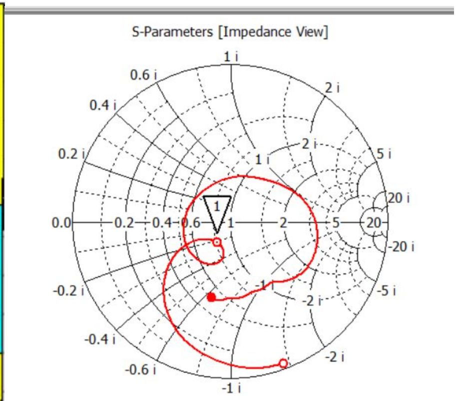
Antenna Design 2

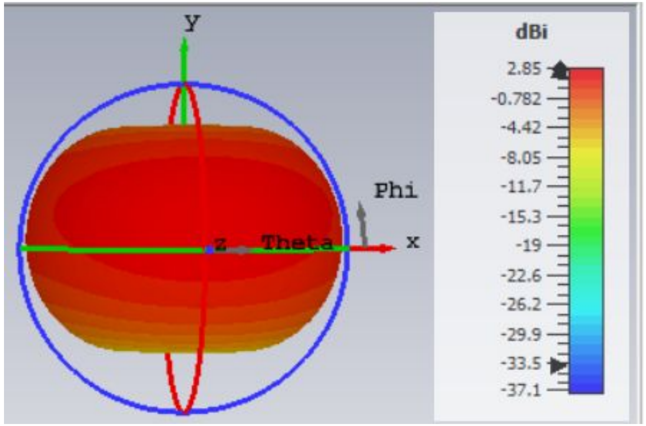
- **Iteration 1**







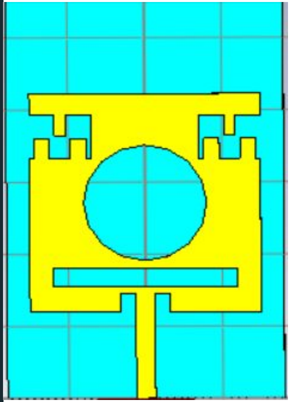


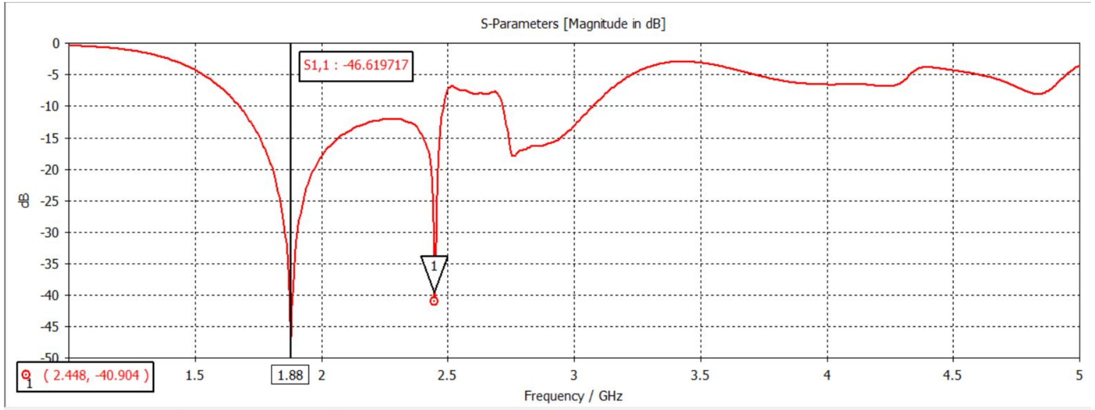


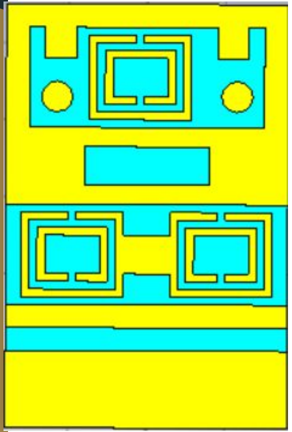
- S11 = -16.09dB ; 2.04 GHz
- Gain = 2.85dBi

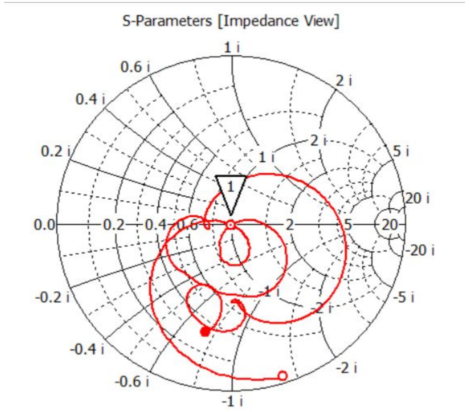
Antenna Design 2

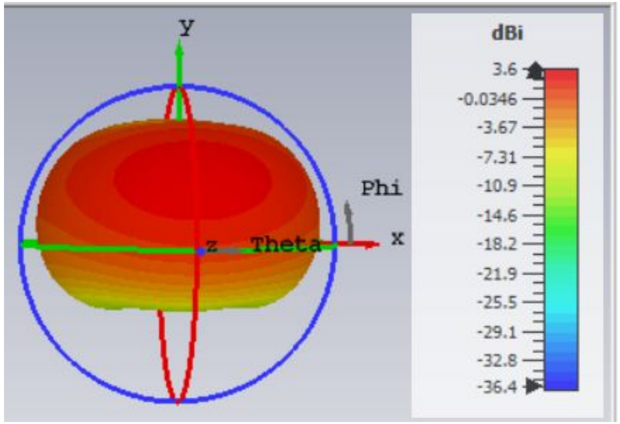
- **Final Iteration**





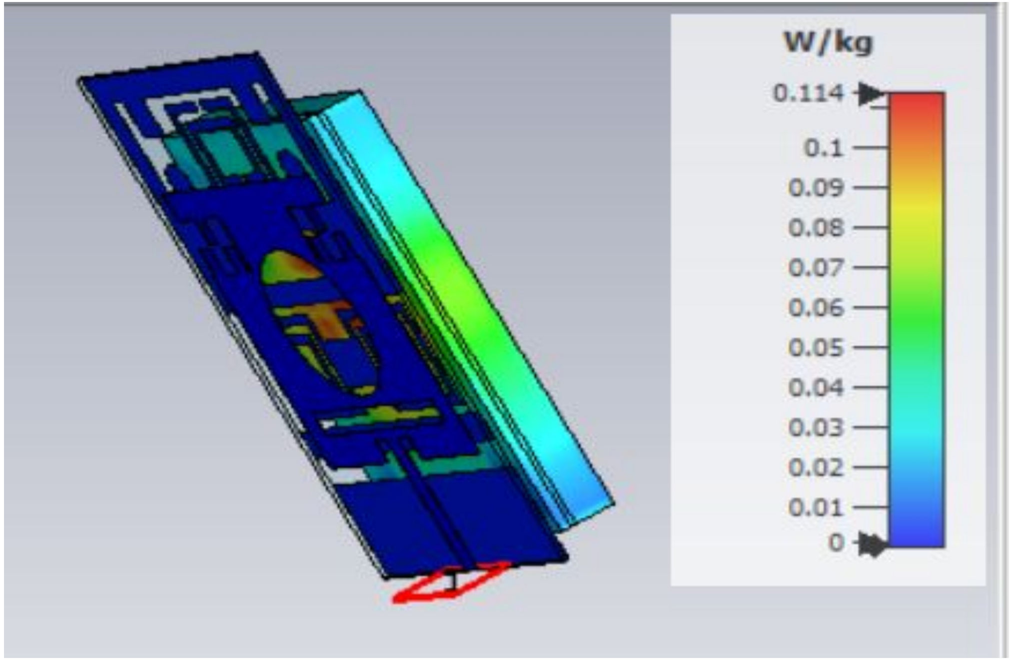






- S11 = -41dB ; 2.45 GHz
- Gain = 3.6dBi

The SAR for the above antenna measured over a phantom model of Skin-Fat-Muscle of 1mm, 0.5mm and 4mm thickness respectively is 0.114W/Kg for 1g of Tissue, which is less than the limits kept by IEEE and FCC.



Merits of Antenna Design 2

- Overall dimension of antenna is 36 mm x 55 mm x 0.6 mm.
- S11 = -41 dB
- Bandwidth = 0.8 GHz (1.68 GHz - 2.48 GHz) and Fractional Bandwidth = 38.5%.
- Gain = 3.6dBi and Radiation Efficiency = 77.7%
- The SAR of the is well within the limits kept by the FCC and IEEE.
- To access antenna's flexibility, bending analysis was performed under two bending conditions; vertical and horizontal with different radii of curvatures. Under all Under all bending conditions, the antenna was well-matched at the targeted ISM (2.45) band and exhibits good gain. This study concludes that the proposed antenna is flexible.

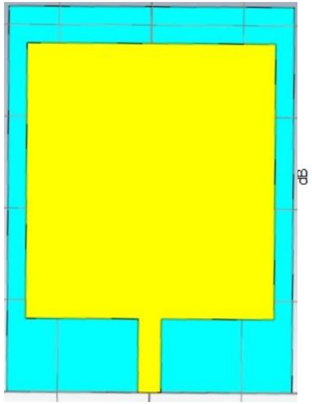
Improvements can be made for Antenna Design 2

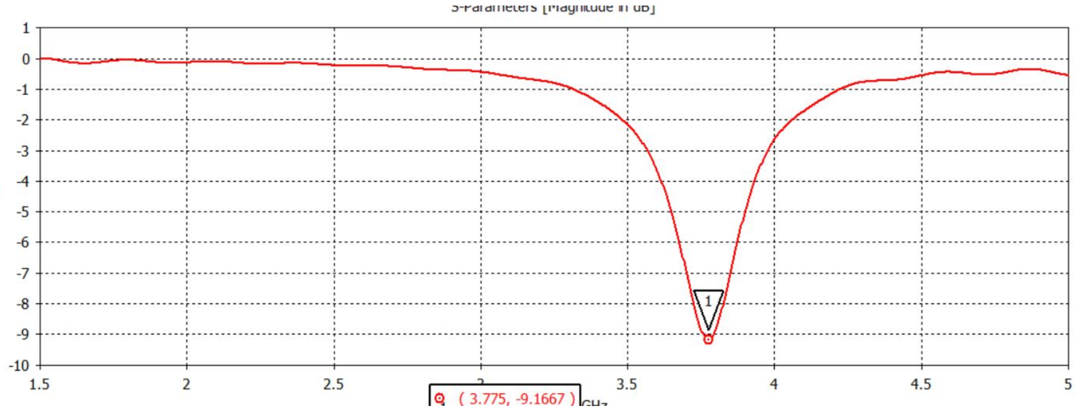
- The size of the antenna is compact, but it can be further made small.
- The radiation efficiency of Antenna can be improved.

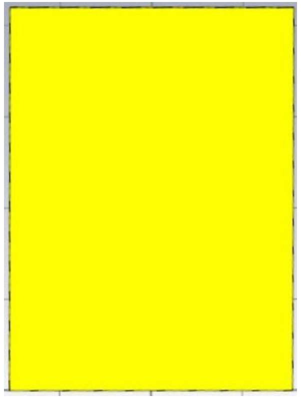
➢ This scope made us design another antenna design that has improved Radiation efficiency and compact size.

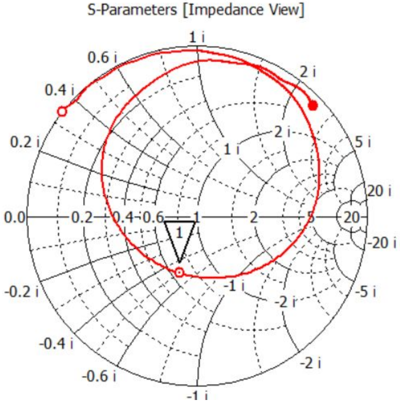
Antenna Design 3

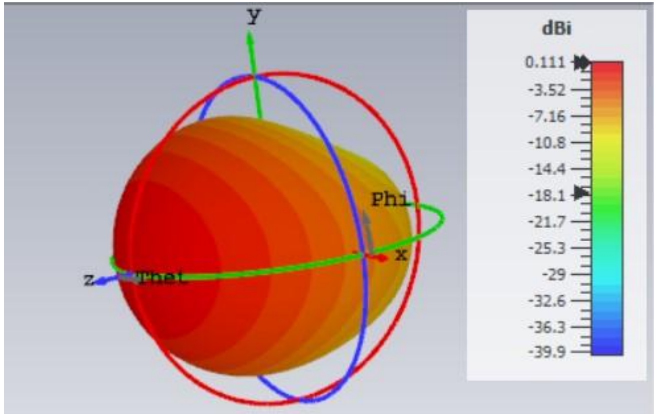
- **Iteration 0**







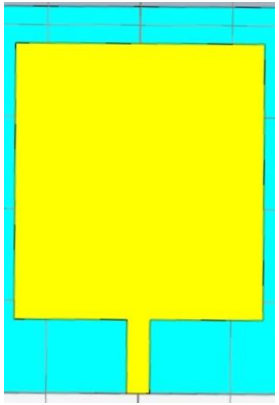


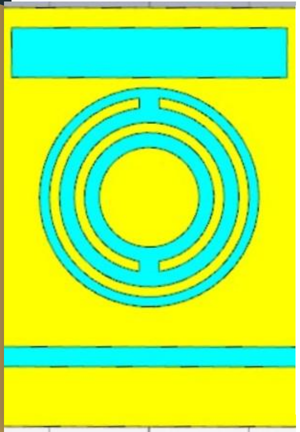


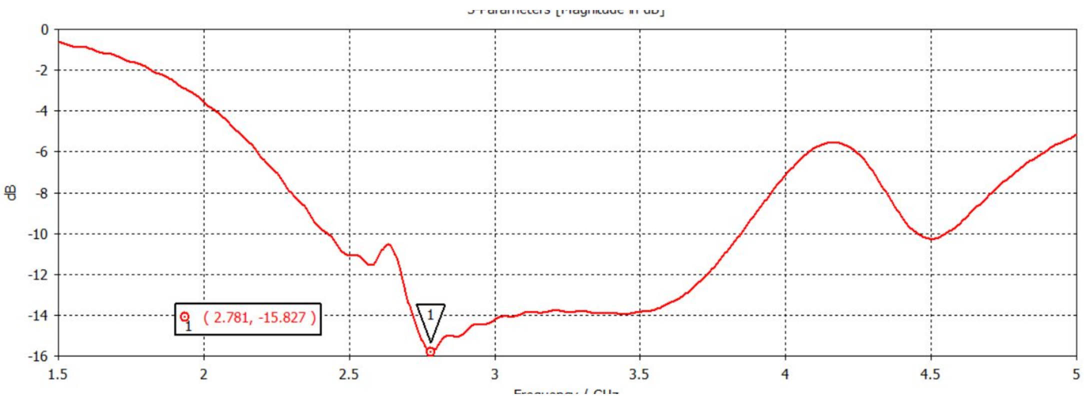
- S11 = -9.166dB ; 3.775 GHz
- Gain = 0.111dBi

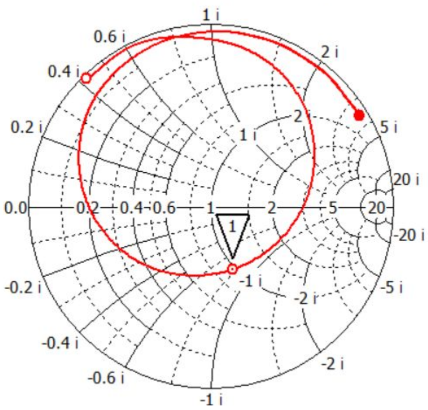
Antenna Design 3

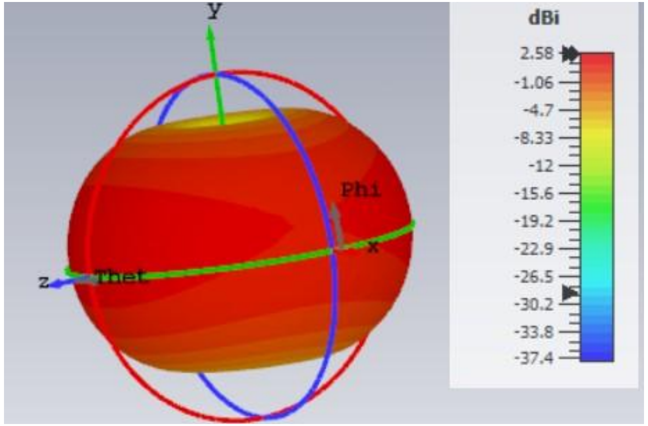
- **Iteration 1**







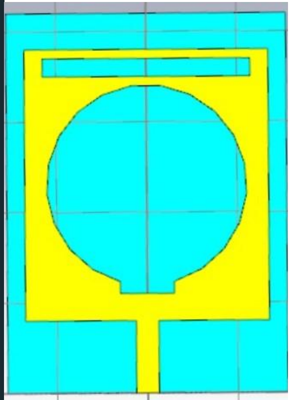


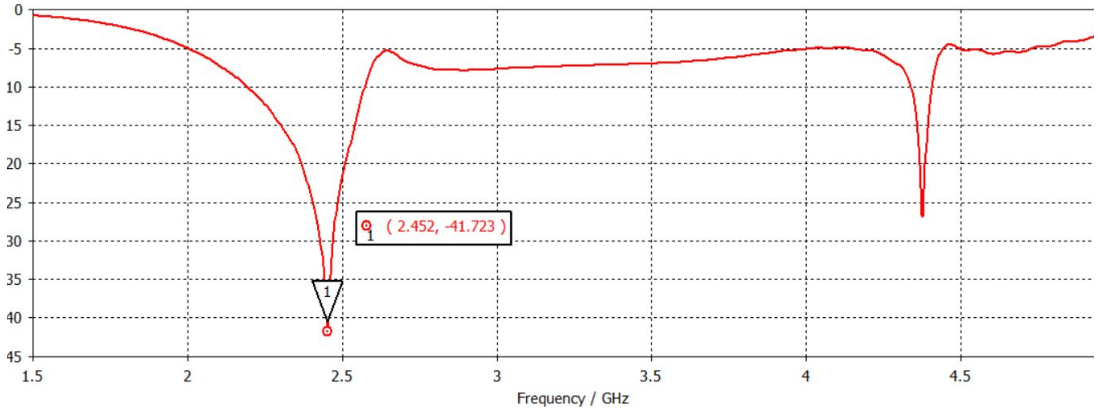


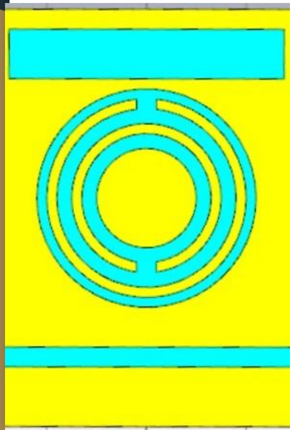
- S11 = -8.8095dB ; 2.455 GHz
- Gain = 2.58dBi

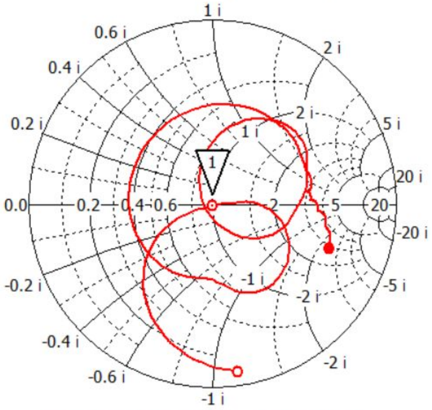
Antenna Design 3

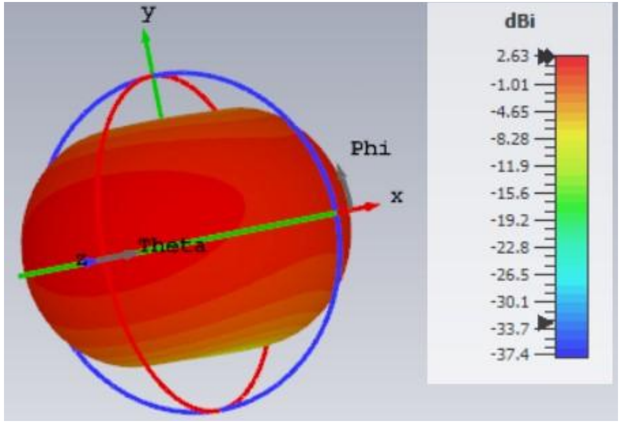
- **Final Iteration**





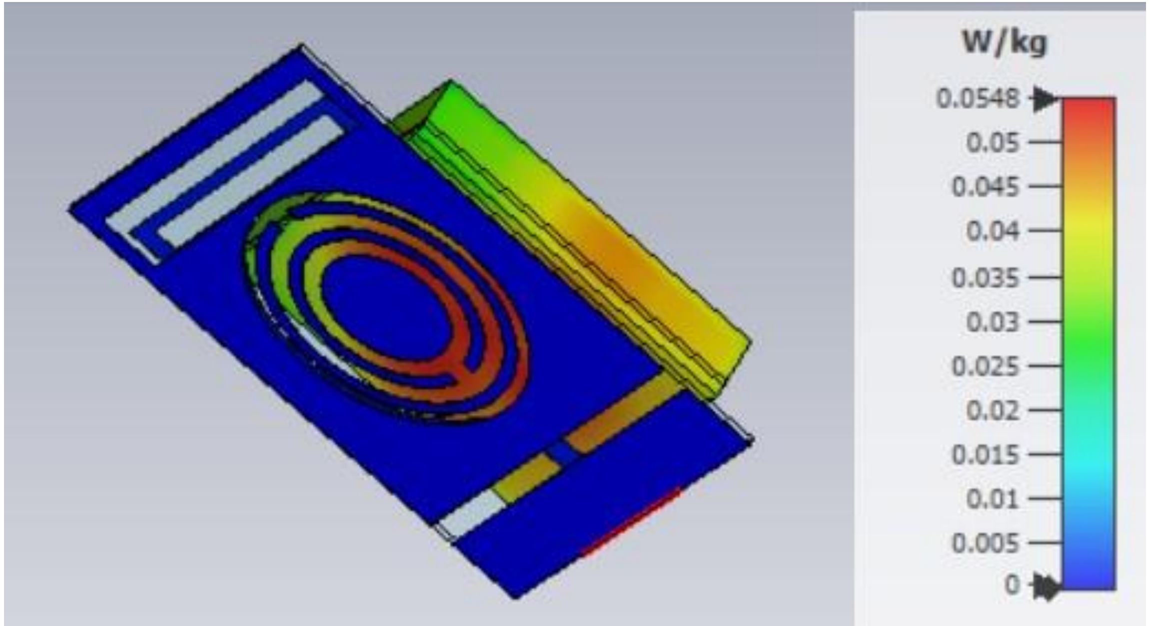




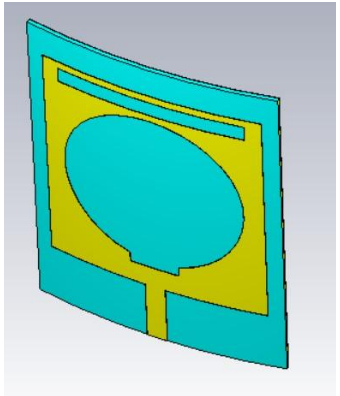


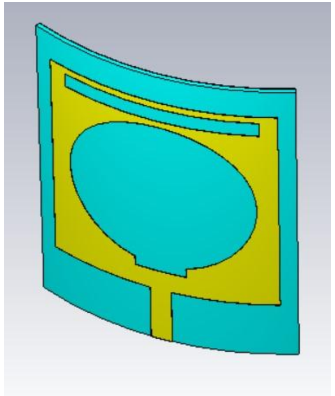
- S11 = -41dB ; 2.45 GHz
- Gain = 2.63dBi

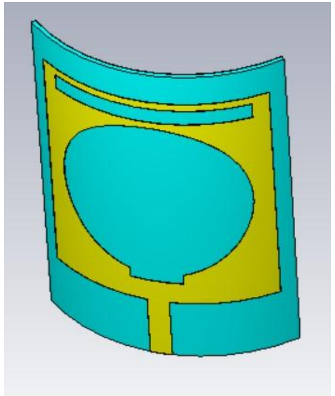
The SAR for the above antenna measured over a phantom model of Skin-Fat-Muscle of 1mm, 0.5mm and 4mm thickness respectively is 0.0548W/Kg for 1g of Tissue, which is less than the limits kept by IEEE and FCC.

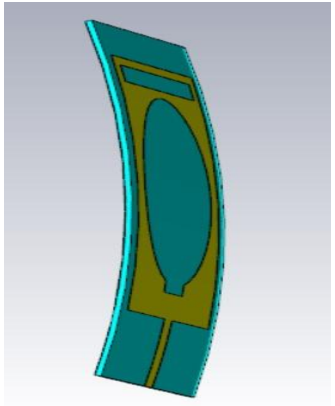


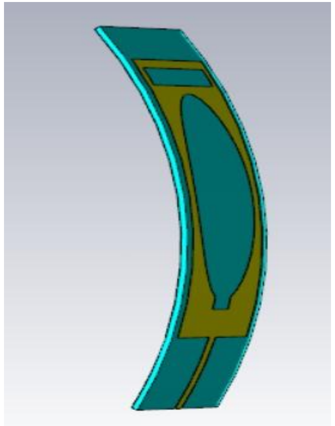
Bending Analysis

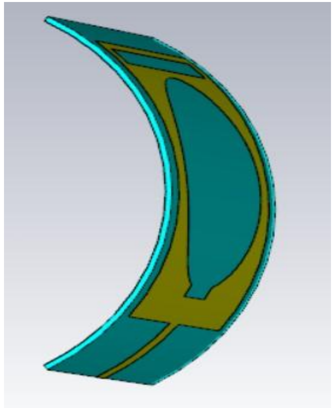










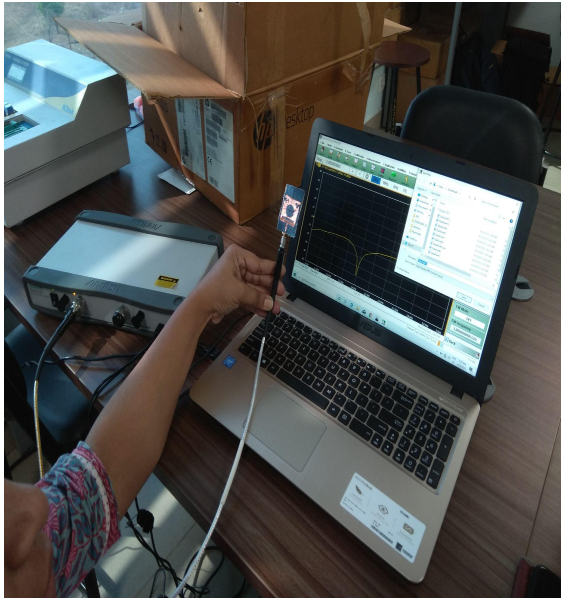


Merits of Antenna Design 3

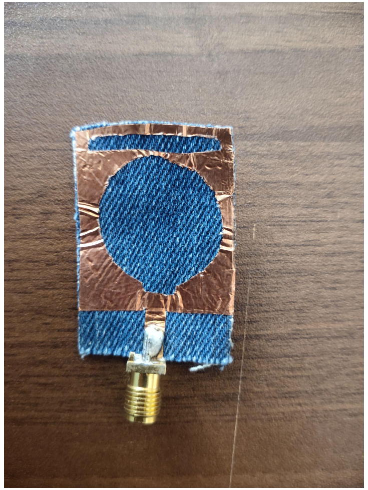
- Overall dimension of antenna is 31 mm x 42 mm x 0.6 mm.
- S11 = -41.72 dB
- Bandwidth = 0.379 GHz (2.192 GHz - 2.571 GHz) and Fractional Bandwidth = 38.5%.
- Gain = 2.62dBi and Radiation Efficiency = 90.86%
- The SAR of the is well within the limits kept by the FCC and IEEE.
- To access antenna's flexibility, bending analysis was performed under two bending conditions; vertical and horizontal with different radii of curvatures. Under all Under all bending conditions, the antenna was well-matched at the targeted ISM (2.45) band and exhibits good gain. This study concludes that the proposed antenna is flexible.

Fabrication and Testing of Proposed Antenna Designs

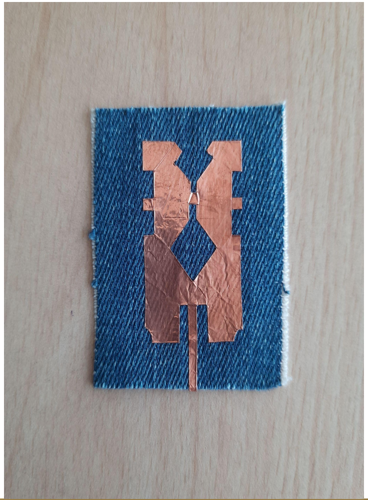
The antenna designs were fabricated and tested using Vector Network Analyzer. The measured and simulated results demonstrate a remarkable level of agreement with each other. Any variations between these values can be attributed to minor fabrication and soldering errors.



Fabricated Antenna Design 2 and Testing it by VNA.



Fabricated Antenna Design 3 and Testing it by VNA.



Fabricated Antenna Design 1

Comparison of proposed antennas with other wearable antennas

Ref.	Dimensions (mm^2)	Frequency (GHz)	S11 (dB)	Gain (dBi)
[1]	70 x 70 x 2.26	2.36 - 2.40	-30	1.38
[2]	85.5 x 85.5 x 5.62	1.4 - 2.4	-16	1.94
[3]	72.54 x 72.54 x 1.67	2.4 - 2.5	-18, -23	1.92, 2.27
[4]	40 x 40 x 1.6	1.7 - 3.94	-30.1	1.96-2.36
[5]	39 x 39 x 0.508	2.36 - 2.55	< -30	2.06
[6]	70 x 50 x 0.66	1.198 - 4.055	-26	2.9
Design 1	44 x 45.2 x 0.6	1.895 - 2.909	-29.22	1.83
Design 2	36 x 55 x0.6	1.68 - 2.48	-41	3.6
Design 3	31 x 42 x 0.6	2.19 - 2.57	-41.72	2.62

Conclusion

- We have developed highly flexible fabric antennas that are compact and low-profile, making them ideal for use in Wireless Body Area Networks.
- All the proposed antennas resonate at 2.45 GHz with an exceptional reflection coefficient, gain, and radiation efficiency.
- Notably, the proposed antenna designs demonstrate exceptional performance when subjected to bending along both the x and y axes.
- Additionally, these antennas comply with the strict SAR guidelines outlined by both the IEEE and FCC regulatory bodies.
- Three antenna designs have been proposed that are suitable for WBAN, based on the bandwidth, radiation efficiency, and gain requirements. Any one of these designs can be chosen accordingly.

List of Publications

- Antenna Design 2 have been submitted for SCI Wireless Networks Journal.
- Antenna Design 3 have been submitted for SCI Wireless Personal Communications Journal.

References

[1] H. Yang and X. Liu, "Wearable Dual-Band and Dual-Polarized Textile Antenna for On- and Off-Body Communications," in IEEE Antennas and Wireless Propagation Letters, vol. 19, no. 12, pp. 2324-2328, Dec. 2020.

[2] R. Joshi et al., "Dual-Band, Dual-Sense Textile Antenna With AMC Backing for Localization Using GPS and WBAN/WLAN," in IEEE Access, vol. 8, pp. 89468-89478, 2020.

[3] Mustafa, A.B., Rajendran, T. An Effective Design of Wearable Antenna with Double Flexible Substrates and Defected Ground Structure for Healthcare Monitoring System. J Med Syst 43, 186 (2019).

[4] A. Iqbal, A. Smida, A. J. Alazemi, M. I. Waly, N. Khaddaj Mallat and S. Kim, "Wideband Circularly Polarized MIMO Antenna for High Data Wearable Biotelemetric Devices," in IEEE Access, vol. 8, pp. 17935-17944, 2020.

[5] A. Arif, M. Zubair, M. Ali, M. U. Khan and M. Q. Mehmood, "A Compact, Low-Profile Fractal Antenna for Wearable On-Body WBAN Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 5, pp. 981-985, May 2019.

[6] X. Lin, Y. Chen, Z. Gong, B. -C. Seet, L. Huang and Y. Lu, "Ultrawideband Textile Antenna for Wearable Microwave Medical Imaging Applications," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 6, pp. 4238-4249, June 2020.

[7] S. Alharbi and A. Kiourti, "Folding-Dependent vs. Folding-Independent Flexible Antennas on E-Textiles," 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Atlanta, GA, USA, 2019, pp. 755-756.

[8] V. Mishra and A. Kiourti, "Wearable Planar Magnetoinductive Waveguide: A Low-Loss Approach to WBANs," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 11, pp. 7278-7289, Nov. 2021.
[9] https://www.slideshare.net/RiazAhmedLiyakath/flexible-antennas
[10] https://techsparks.co.in/thesis-in-wireless-body-area-network/#:~:text=Requirements%20of%20WBAN&text=These%20are%3A,is%20required%20in%20this%20case.
[11] G. -P. Gao, C. Yang, B. Hu, R. -F. Zhang and S. -F. Wang, "A Wearable PIFA With an All-Textile Metasurface for 5 GHz WBAN Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 2, pp. 288-292, Feb. 2019.

Thank You