Progress In Electromagnetics Research C, Vol. 120, 27–44, 2022

Design of Tri-Band Textile Fractal Antenna Using Three Different Substrate Materials for Wi-Fi Applications

Asit Kittur* and Loganathan Balaji

Abstract—The purpose of this study is to embed an antenna on very thin textile materials. A rectangular Fractal Antenna is chosen for this application. This antenna radiates for three different frequencies viz. 2.4 GHz, 4.2 GHz, and 5.9 GHz. The substrate materials used for the three antennas are Poly Viscous, Poly Cotton, and Linen which are easily available. Instead of using traditional method applying copper plate or copper layer on substrate material, a simple process of pasting carbon conductive ink on substrate materials is used. On each textile antenna above mentioned frequencies are radiated. Performance parameters of all three antennas are simulated and matched with practical results. The optimum antenna having the best result is used for Wi-Fi applications.

1. INTRODUCTION

Wireless communication took tremendous gain in world wars. Today wireless communication is exploited in clinical practice, space science, etc.

Antenna remains a basic building block for wireless technology from last 30 years. For transmitting and receiving electromagnetic signals in wireless communication, antennas are extensively used. Now antenna quality depends upon how well it can receive the electromagnetic waves. Comparatively large aperture antenna detects better signals than smaller aperture. But larger aperture antenna has disadvantage of having complex and bulky engineering. The way to overcome this challenge is to implement low profile antenna.

Since 1970 wearable technology has increased its application. Many wearable antennas have been used for the collection of data in the medical field or communicating data with other devices. It may be convenient to integrate wearable directly into clothing instead of attaching them on the body [1–4].

To reduce the cost related to health-care, telemedicine is one of the best options used for elderly people [5]. The combination of information technology and wearable sensors can assist elderly people to live in their home rather than living in expensive hospitals. The sensors are placed on the body of the patient for transmitting signals wirelessly for remote monitor to observe human physiological signals [6–8]. Zig-bee & GSM technologies are used for transmission and reception of signals.

Dual-band textile printed slot antenna with partial ground plane on jeans substrate is used for Wi-MAX (3.25 GHz–3.85 GHz), WLAN (5.15 GHz–5.35 GHz), and X-Band (8 GHz–12 GHz). The ultra-wideband (UWB) uses very low energy for short range. It can also have better battery life. In this application, the antenna is used as a Logo [9].

Textile antenna with dual-band Patch-Loop structure is developed to obtain two wide operating bands. Neoprene fabric having permittivity 1.5 is used as a substrate, and the antenna achieves a gain of 4.21 dBi at 2.58 GHz with a bandwidth of 15.9 GHz. For a gain of 6.45 dBi at 5.34 GHz frequency, the antenna achieves a bandwidth of 11.4 GHz. Here the patch is designed to resonate at 5.4 GHz, and a slot is designed for 2.5 GHz [10].

Received 4 February 2022, Accepted 14 April 2022, Scheduled 5 May 2022
* Corresponding author: Asit Kittur (asit.kittur@gmail.com).
The authors are with Veltech Rangarajan Dr. Sakunthala R & D Institute of Science & Technology, Chennai, India.

A U-shaped antenna is used which can give dual-band or triple-band operations. It is used for Wireless Body Area Network for healthcare and medical purpose. The antenna can also be utilized for Off Body and ISM applications. Felt material is used as a substrate [11].

The antenna is proposed on the bottom, which is located on top of the textile substrate and conductive textile ground that are incorporated in clothing [12]. The radiation pattern is obtained for monopole type in 2.4 GHz and broadside in 5.4 GHz.

A multi-band wearable small size antenna with co-planar coupling and ground plane for 4G mobile communication is used. It operates in 2.4 GHz to 2.8 GHz and 5.1 GHz to 5.9 GHz frequencies. A plastic with dielectric constant of 1 is used as a substrate. Co-planar coupling of radiation patch and ground plane is used [13].

A co-planar waveguide feed slot antenna is used. The thickness of 0.8 mm is used for 2.4 GHz/5.8 GHz dual band WLAN with FR4 used as a substrate [14].

A compact two elements UWB wearable MIMO antenna is presented. It uses high power isolation. The antenna covers the frequency range of 2.74 GHz to 12.33 GHz [15].

The used antenna is concentrated on Specific Absorption Rate (SAR) by Artificial Magnetic Conductor (AMC) for frequency 2.4 GHz to 2.49 GHz [16]. The antenna radiates for seven frequencies having thickness of the substrate 0.4 mm and permittivity of 4.3 [17]. For this, a metallic ground backed surface is used. When the thickness is increased, the antenna shows triple-band behavior with different slots to obtain different frequencies.

Plenty of electromagnetic waves in free space carry lot of energy where energy harvesting antennas are used. The wearable antenna used can transfer RF energy from ambient sources to direct current by soft and portable textile antenna. GSM, 3G, and Wi-Fi triple band antenna is designed. The rectifier converts RF to DC conversions. Nonconductive material such as polyamide, silk, or fleece is used for a hook-shaped antenna [18].

Three different textile materials are used as substrates to measure bow-tie antenna performances. The material which sustains its performance is chosen as a suitable substrate. Wearable antenna design is usually attached to user body or carried in pocket. Three materials Cotton-Crepe, Semi-transparent film, and Skin friendly patch are used as substrates, and their properties are compared [19].

A flexible textile antenna is used for three different materials: FR4, Jeans, and Teflon. The designed monopole textile antenna is compared with conventional monopole antenna. The antenna radiates for 2.4 GHz ISM band and is used for Body Centric Wireless Communication for reduced size in antenna [20].

A micro-strip feed line is given to a rectangular slot patch fabricated on a jeans substrate. The designed antenna is used for WLAN and C-band applications [21]. Cordura fabric substrate material is used for textile antenna, to give a large bandwidth of 2.4 GHz to 9.6 GHz giving return loss of −29 dB at 8.1 GHz [22].

A fractal Koch antenna is used for multiband radiations. Using VHF band, the size of the antenna is reduced by 32% [23–27].

For GSM and WiMAX applications, a dual band planar antenna with a modified split ring resonator is used [28]. For smart energy meter/WLAN/WiMAX a printed multiband monopole antenna is used [29].

So the objectives of this paper is

- To select an antenna which will radiate for three different frequencies.
- To select a thin material to show that radiation can also be done on such materials.
- To select an affordable and easily available method.

2. PROPOSED WORK

1. A tri-band Fractal antenna is simulated in ANSYS HFSS software for frequencies 2.4 GHz, 4.1 GHz, & 5.9 GHz.
2. The prepared antenna can be used for Zig-Bee or Wi-Fi applications as shown in Figure 1. For the uniqueness of research work, three textile materials named poly viscous, linen, & cotton whose thickness is very small are chosen. The antenna is prepared using graphite conductive ink.

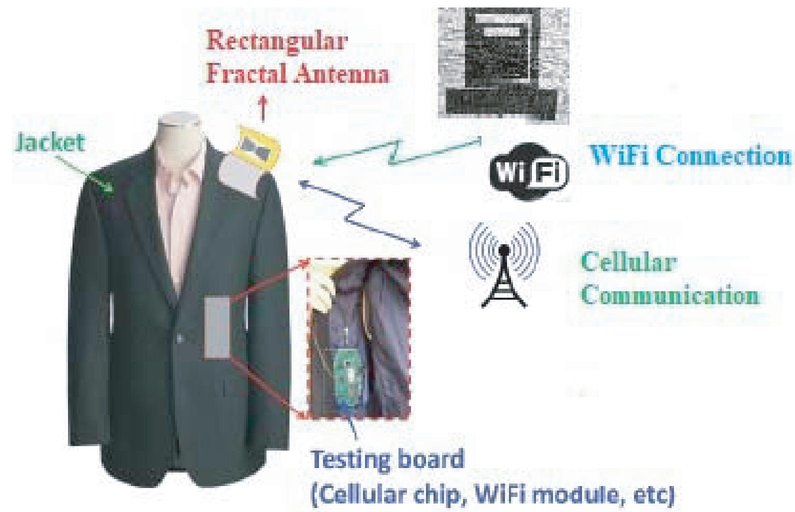


Figure 1. Proposed theory diagram for Wi-Fi application.

3. The performance parameters of all three antennas are tested and compared, and the antenna having good performance is used for Wi-Fi applications.

Looking at the following table mostly for high data rate applications, the frequencies 2.4 GHz, 4.2 GHz, & 5.9 GHz are used.

Table 1. High data rates application and its frequency.

Application	Technology	Frequency
General (Smart Home)	Bluetooth	2.4 GHz
	Zig-bee	2.4 GHz
	Z-Wave	2.4 GHz
	Wi-Fi	2.4 GHz, 3.6 GHz, 4.9 GHz, 5.9 GHz
Medical	MBAN	2.36 GHz to 2.4 GHz
	WBAN	2.4 GHz
Avionics	WAIC	4.2 GHz to 4.4 GHz

3. PROPERTIES OF TEXTILE MATERIAL

The measurement of the thickness of the material and permittivity is a cumbersome task. As shown in Figure 2, the materials are tested in the capacitance & thickness measurement instruments from which its permittivity is calculated, and it is listed in Table 2. This calculated permittivity can be put into the simulation software HFSS.

Table 2. Properties of substrate materials for textile antenna.

Materials	Thickness [mm]	Permittivity $\in_r$
Poly-Viscous	0.025	0.2262
Linen	0.018	0.2164
Poly Cotton	0.018	0.3025

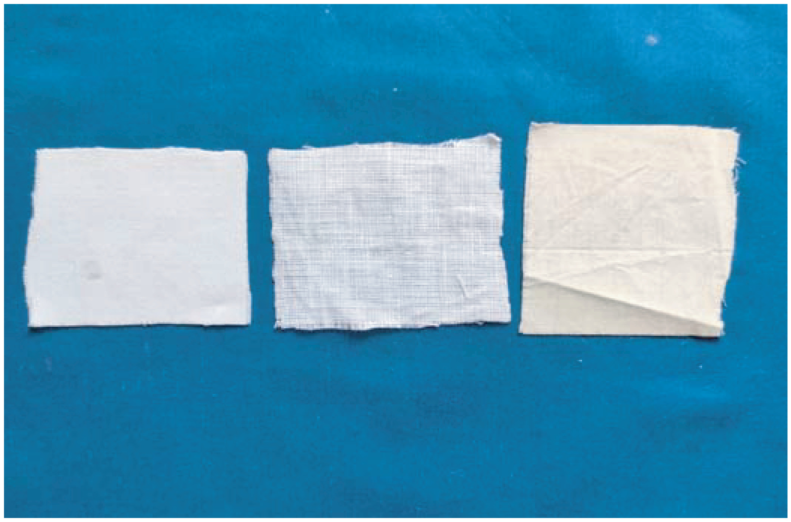


Figure 2. From left side poly viscous, linen, & cotton materials.

4. DESIGN EQUATIONS OF ANTENNA

The design equations for antenna are as follows [30]

$$\text{Width} = \frac{c}{2f_0\sqrt{\frac{\in_R+1}{2}}};$$

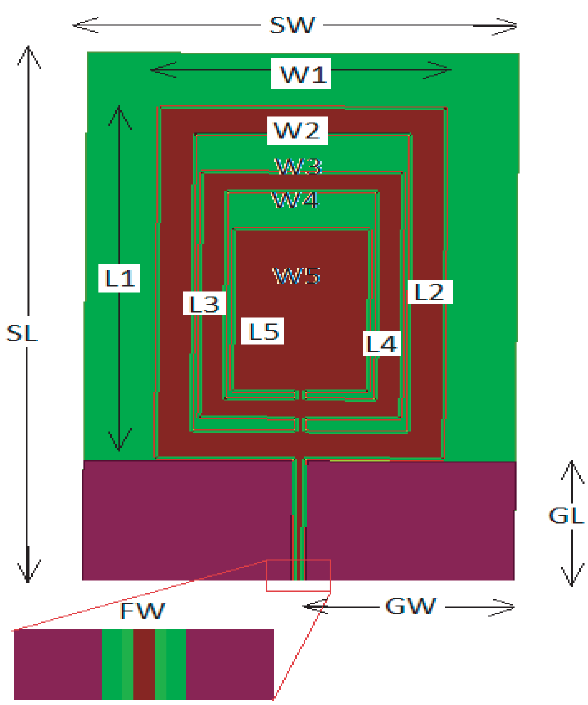


Figure 3. Fractal antenna designed for poly-viscous, linen and cotton.

$$\in_{eff} = \frac{\in_R + 1}{2} + \frac{\in_R - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{w}\right)}}\right]$$

$$\text{Length} = \frac{c}{2f_0\sqrt{\in_{eff}}} - 0.82h\left(\frac{(\in_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\in_{eff} - 0.58)\left(\frac{w}{h} + 0.8\right)}\right)$$

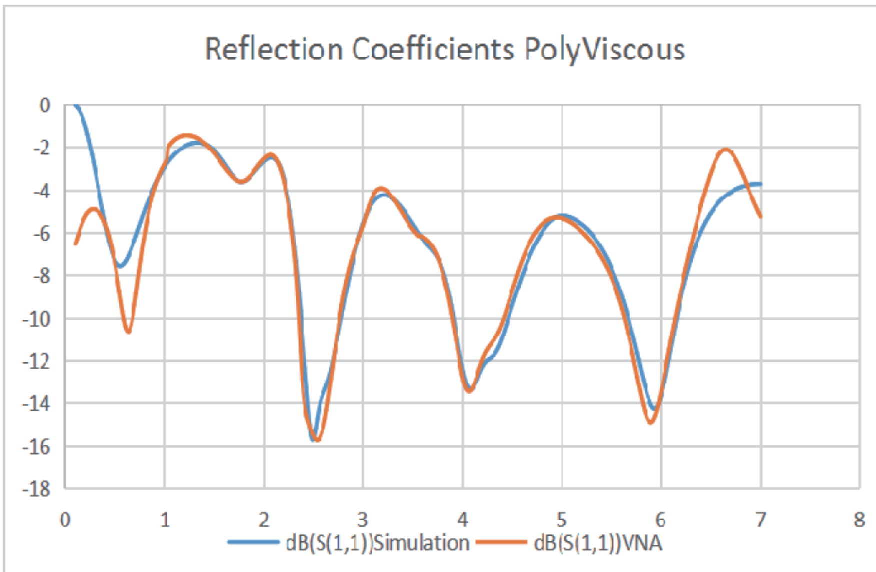


Figure 4. Simulated and VNA tested S_{11} plot of fractal antenna for Poly-Viscous material.

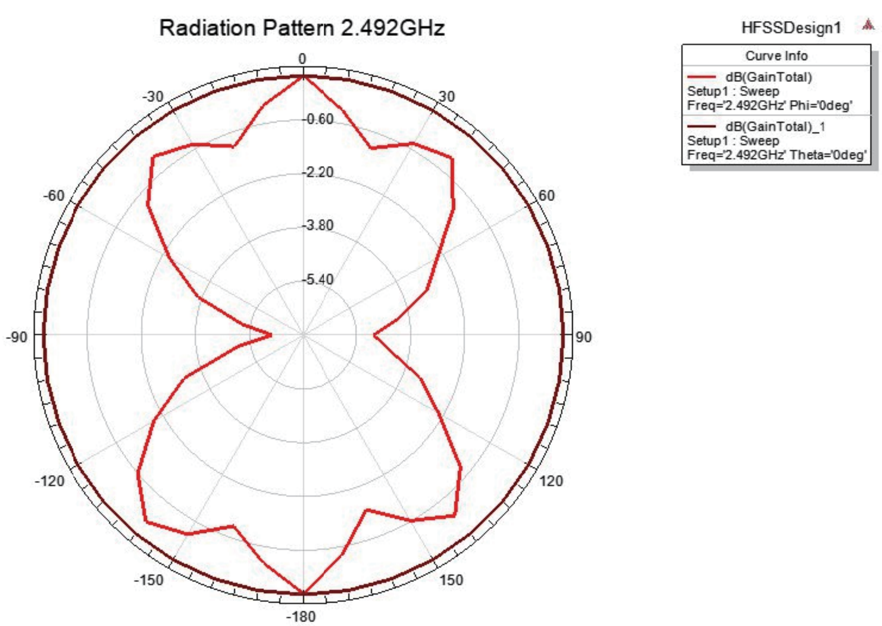


Figure 5. Radiation pattern of fractal antenna for poly-viscous material for frequency 2.4 GHz.

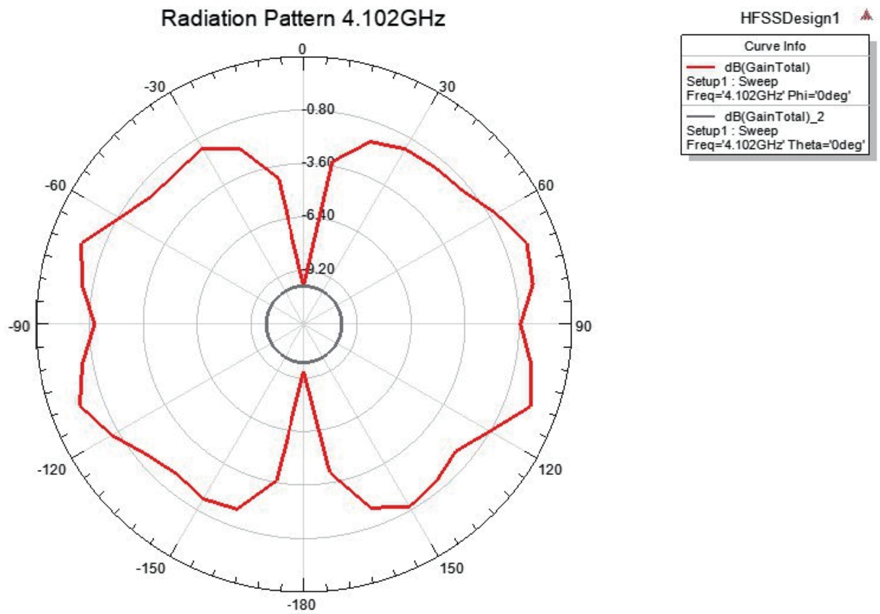


Figure 6. Radiation pattern of fractal antenna for poly-viscous material for frequency 4.1 GHz.

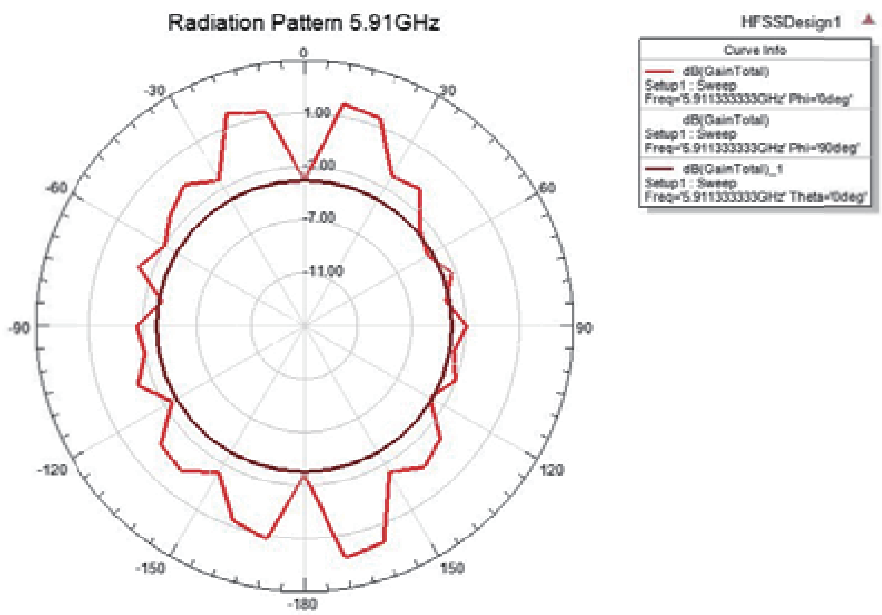


Figure 7. Radiation pattern of fractal antenna for poly-viscous material for frequency 5.9 GHz.

5. FRACTAL ANTENNA DESIGN

5.1. For Poly-Viscous

For basic operation, the antenna is shown in Figure 3, ad when being used for poly viscous, it resonates for three different frequencies. The first antenna is simulated, and practical reflection coefficient plot is shown in Figure 4. The S_{11} results in the two cases are matched.

From radiation pattern of poly viscous material (Figures 5, 6, & 7) even though the thickness is very low, it radiates in both directions uniformly for all three frequencies. The simulated and practical results of VSWR are matched as shown in Figure 8 & Figure 9, respectively. It can also be seen from Figure 4 that both simulated and practical results of reflection coefficient are also matched, and the

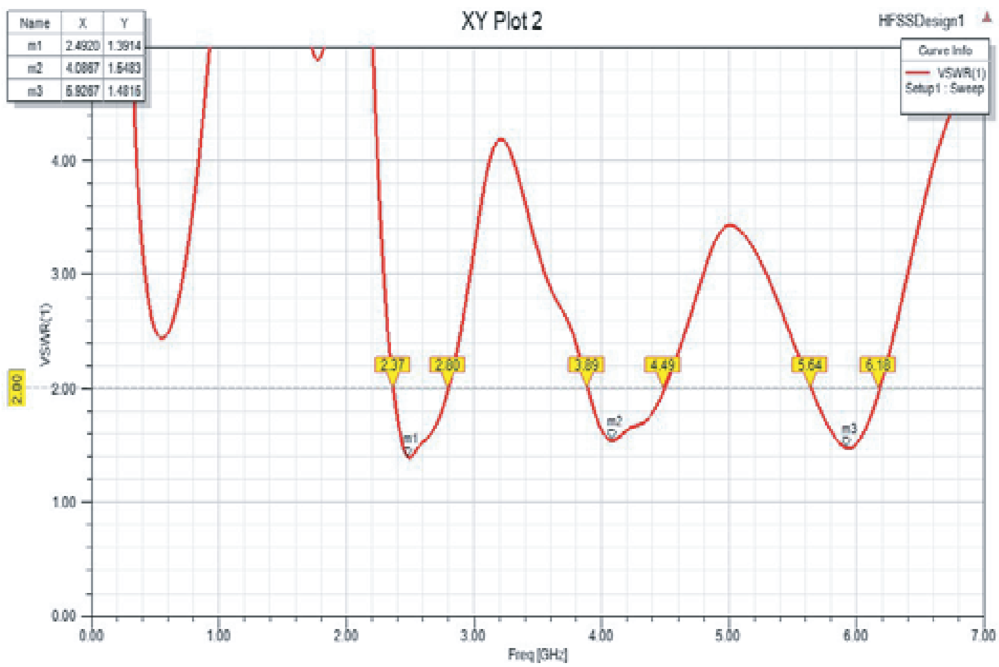


Figure 8. VSWR pattern of fractal antenna for poly-viscous material.

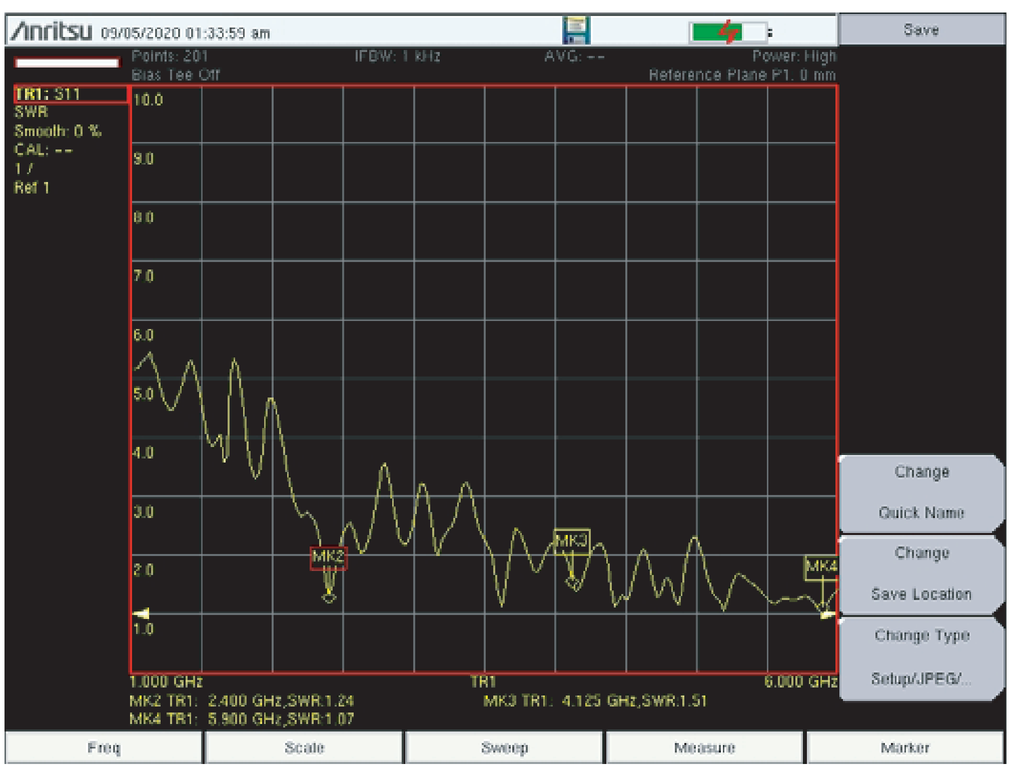


Figure 9. VSWR pattern of fractal antenna for poly-viscous material.

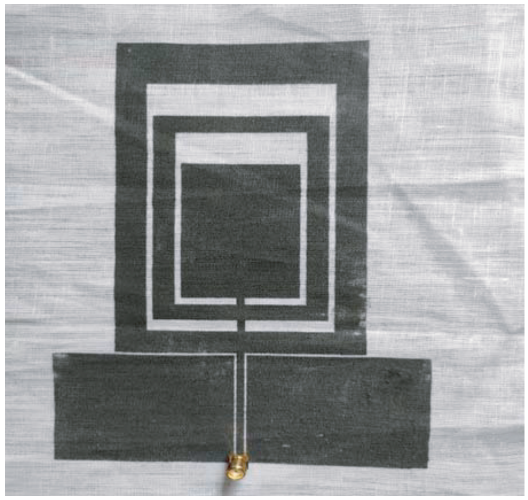


Figure 10. Antenna designed on poly-viscous substrate material.

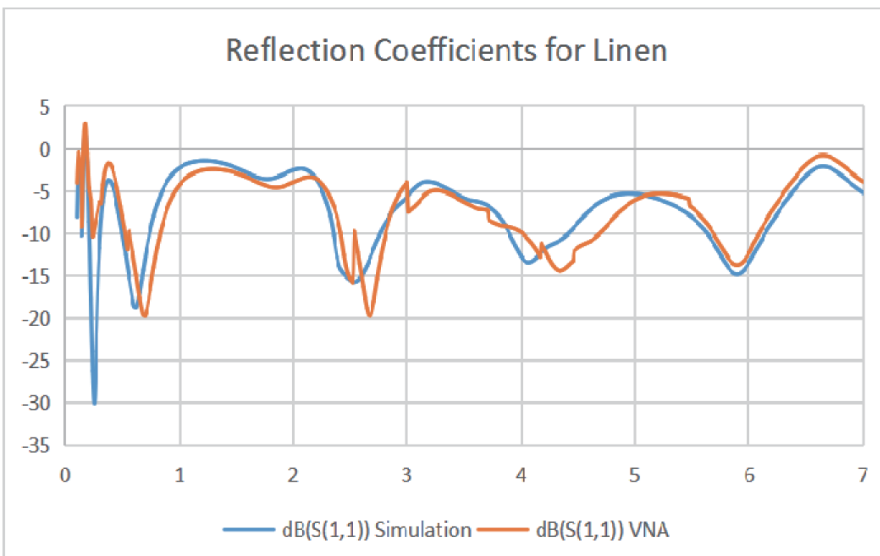


Figure 11. Simulated and VNA tested S_{11} plot of fractal antenna for linen material.

antenna radiates at 2.4 GHz, 4.1 GHz, and 5.9 GHz.

The simulated antenna is converted into coral draw file, and using screen printer it is painted on textile material shown in Figure 10 with graphite conductive ink. The same procedure is done for all three materials. This is the easiest and affordable method to design a textile antenna.

5.2. For Linen

For basic operation of antenna shown in Figure 3, when being used for Linen material, it resonates for three different frequencies. For linen antenna, its reflection coefficient, simulated and tested plots show that it radiates at 2.4 GHz, 4.1 GHz, and 5.9 GHz as shown in Figure 11. As linen and poly viscous materials have almost same properties like thickness and permittivity, the simulated and practical results are also same. The simulated and practical results of return loss and VSWR also match exactly. The radiation patterns for all three frequencies shown in Figures 12, 13, & 14 are uniform. For 5.9 GHz, there are some small lobes but still at acceptable level. The VSWRs of simulated and practical results are also matched as shown in Figure 15 & Figure 16, respectively.

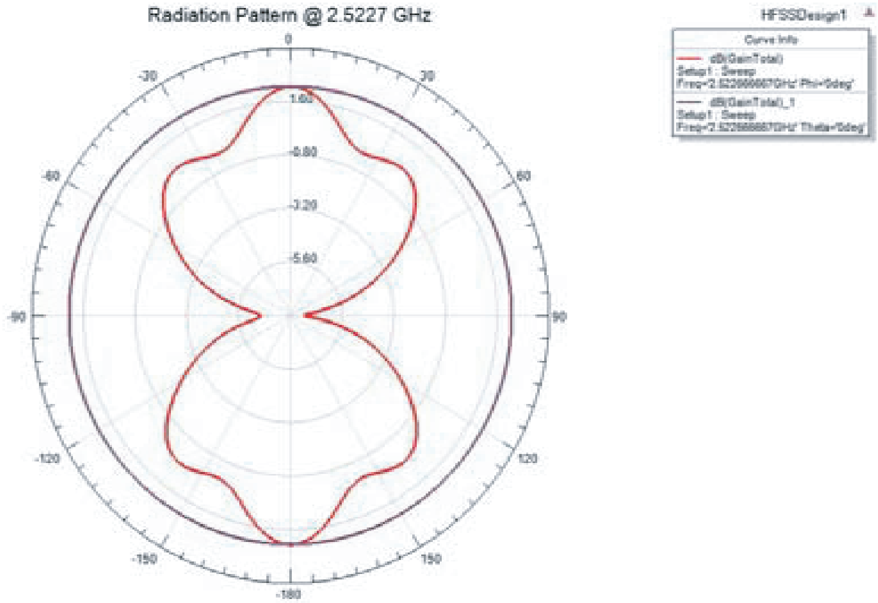


Figure 12. Radiation pattern of fractal antenna for linen material for frequency 2.5 GHz.

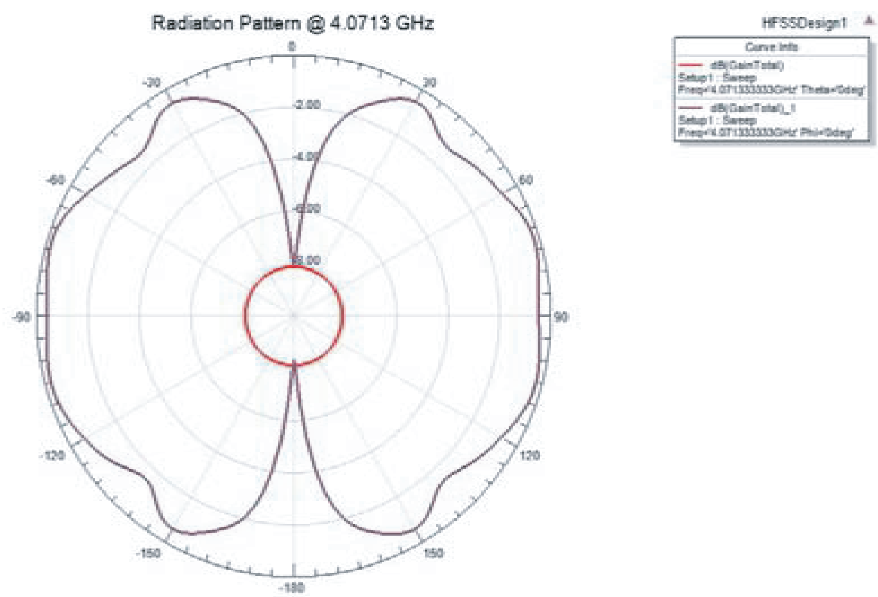


Figure 13. Radiation pattern of fractal antenna for linen material for frequency 4.07 GHz.

5.3. For Poly Cotton

For the antenna shown in Figure 3, when being used for cotton material, there is a marginal increase in frequency. For cotton antenna, its reflection coefficient plot is shown in Figure 17. For cotton material the frequency gets marginally shifted, and it cannot be used for Wi-Fi applications. Even the antenna fails to get proper return loss at 2.4 GHz. The radiation patterns (Figures 18, 19, & 20) are also not uniform and seem random which fails to give proper lobes hence cotton material is not used for Wi-Fi application, and VSWR (Figures 21 & 22) for cotton material is neglected.

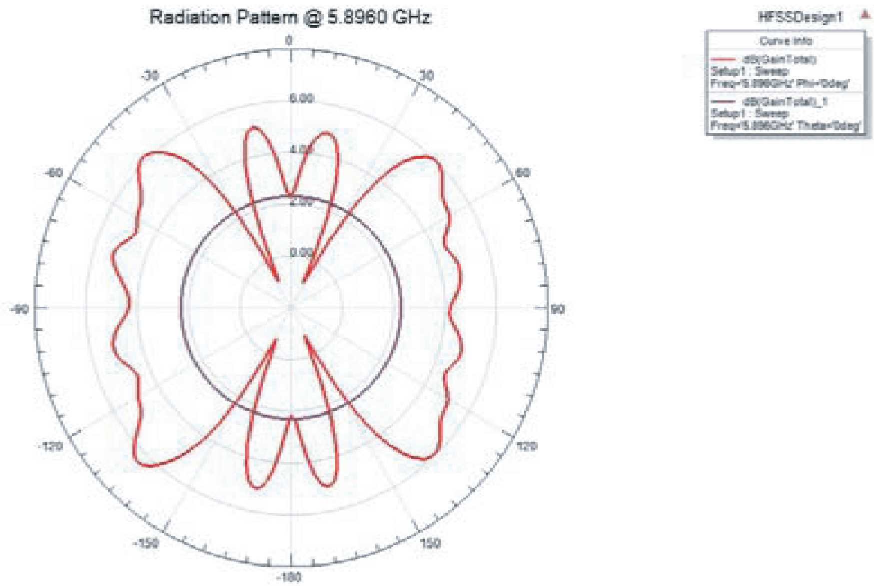


Figure 14. Radiation pattern of fractal antenna for linen material for frequency 5.9 GHz.

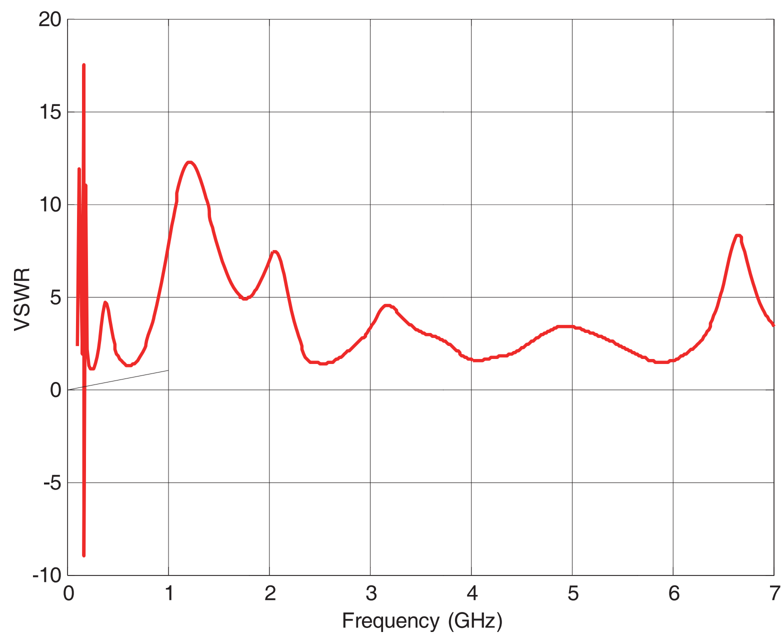


Figure 15. VSWR pattern of fractal antenna for linen material.

6. ANALYSIS AND SYNTHESIS

Performance comparisons of different parameters are mentioned in Table 3. HFSS uses the combination of Method of Moments and Finite Element Method as Electromagnetic Solver Techniques. Four different types of solution modes are available in HFSS which are Modal, Terminal, Transient, & Eigen modes as shown in Figure 23.

This uses the simulation of SMA connector with coaxial cable as waveguide. Radiation boundary is defined as a cube placed symmetrically across the antenna under test. Radiation surface is kept in far field of antenna to measure antenna parameters.

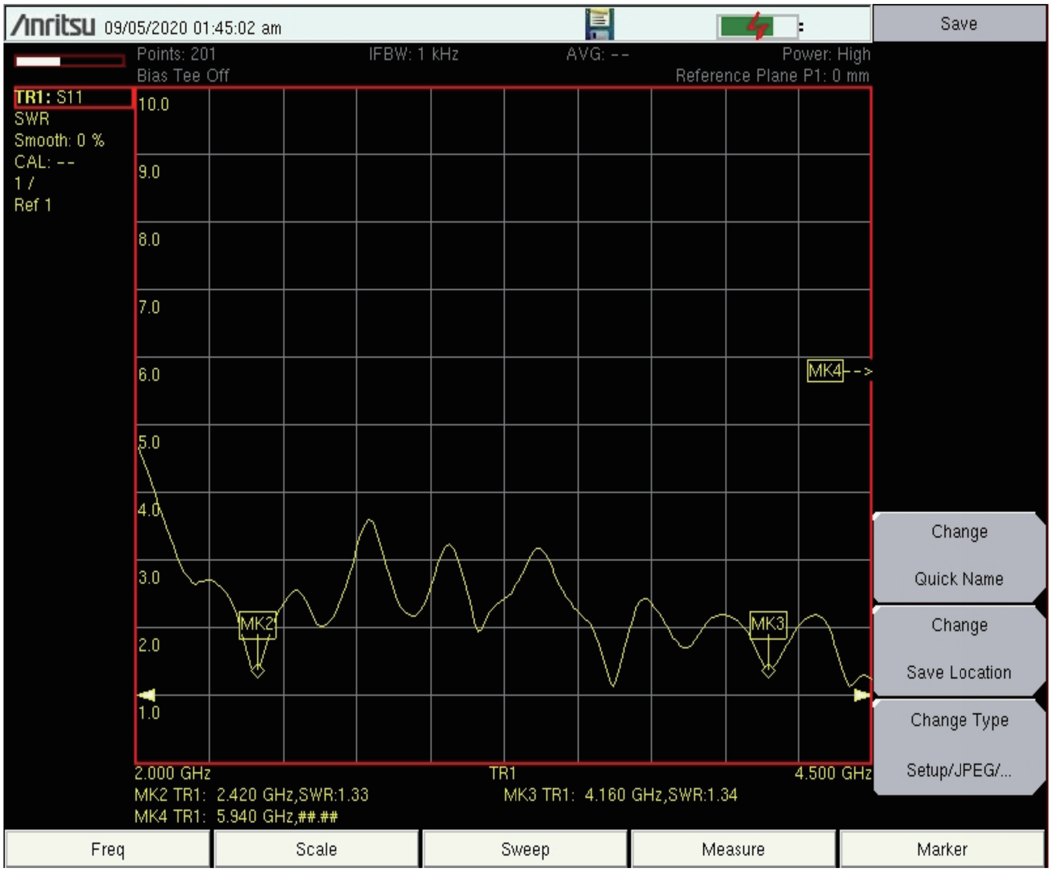


Figure 16. VSWR pattern of fractal antenna for linen material.

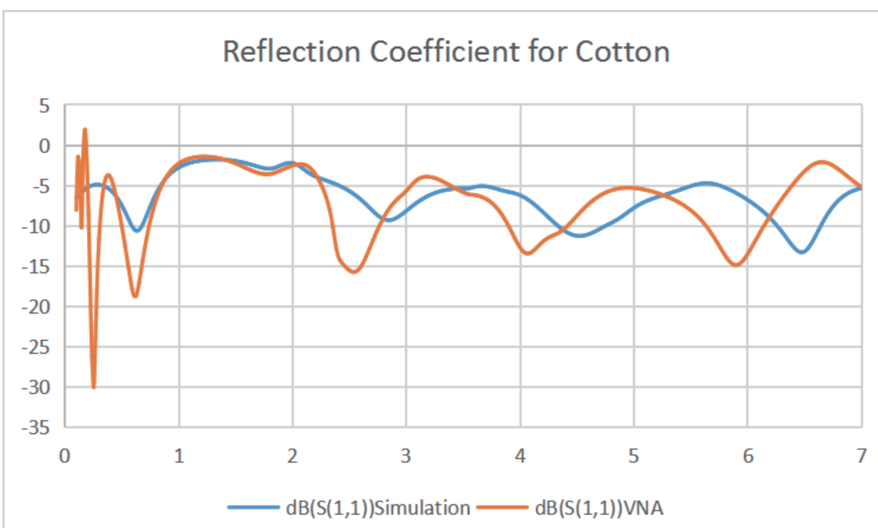


Figure 17. Simulated and VNA tested S_{11} plot of fractal antenna for cotton material.

7. APPLICATIONS

By comparing all three antennas it seems that poly viscous material has better properties and good results. Hence, a Wi-Fi module is connected to it as shown in Figure 24, and by running a small code

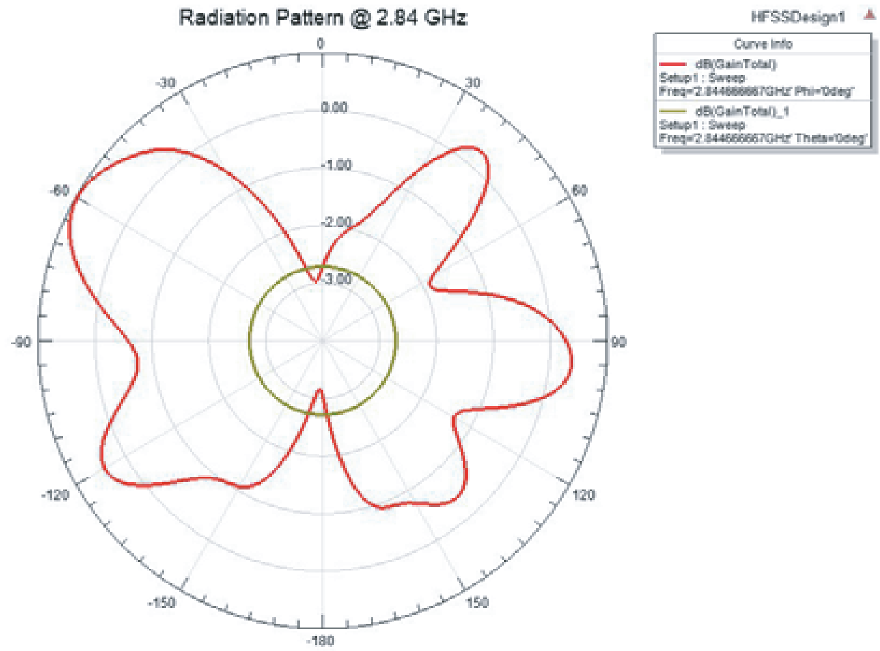


Figure 18. Radiation pattern of fractal antenna for poly-cotton material for frequency 2.8 GHz.

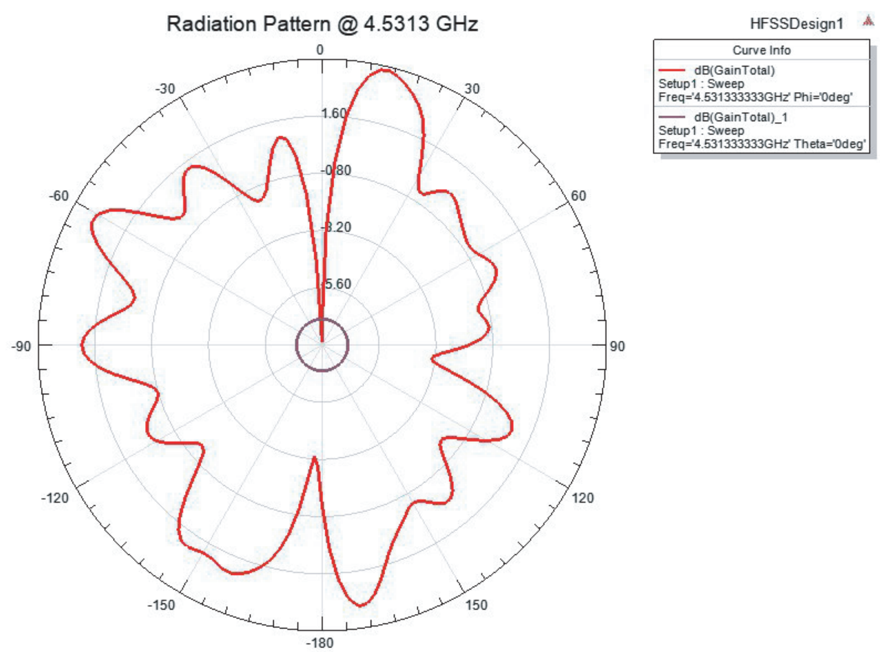


Figure 19. Radiation pattern of fractal antenna for poly-cotton material for frequency 4.5 GHz.

the Wi-Fi is connected to Com Port of Computer. The Wi-Fi is connected at 5.9 GHz frequency showing the IP address of it and signal strength of −73 DBm shown in Figure 25.

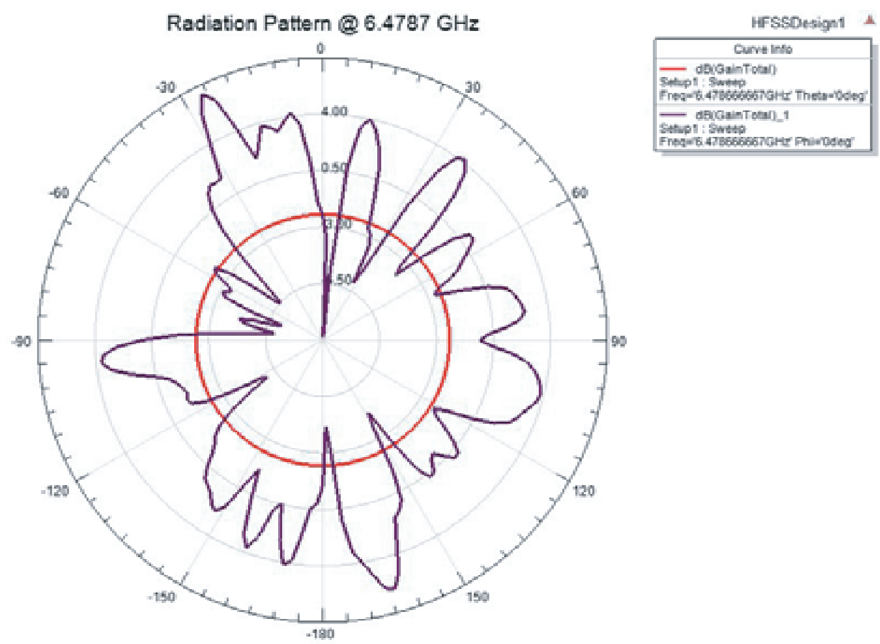


Figure 20. Radiation pattern of fractal antenna for poly-cotton material for frequency 6.45 GHz.

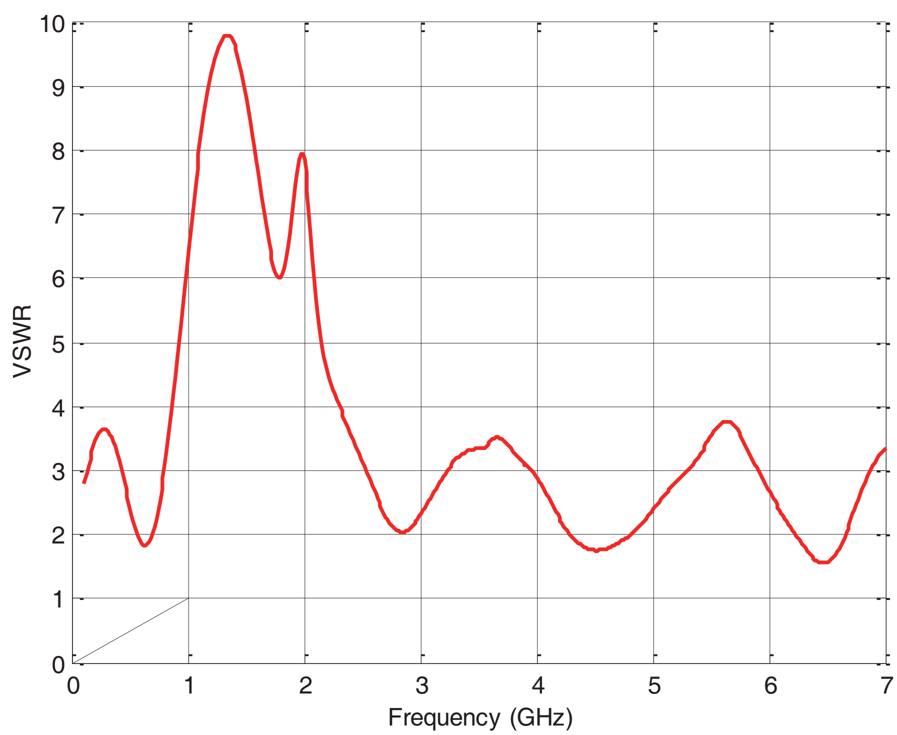


Figure 21. VSWR pattern of fractal antenna for cotton material.

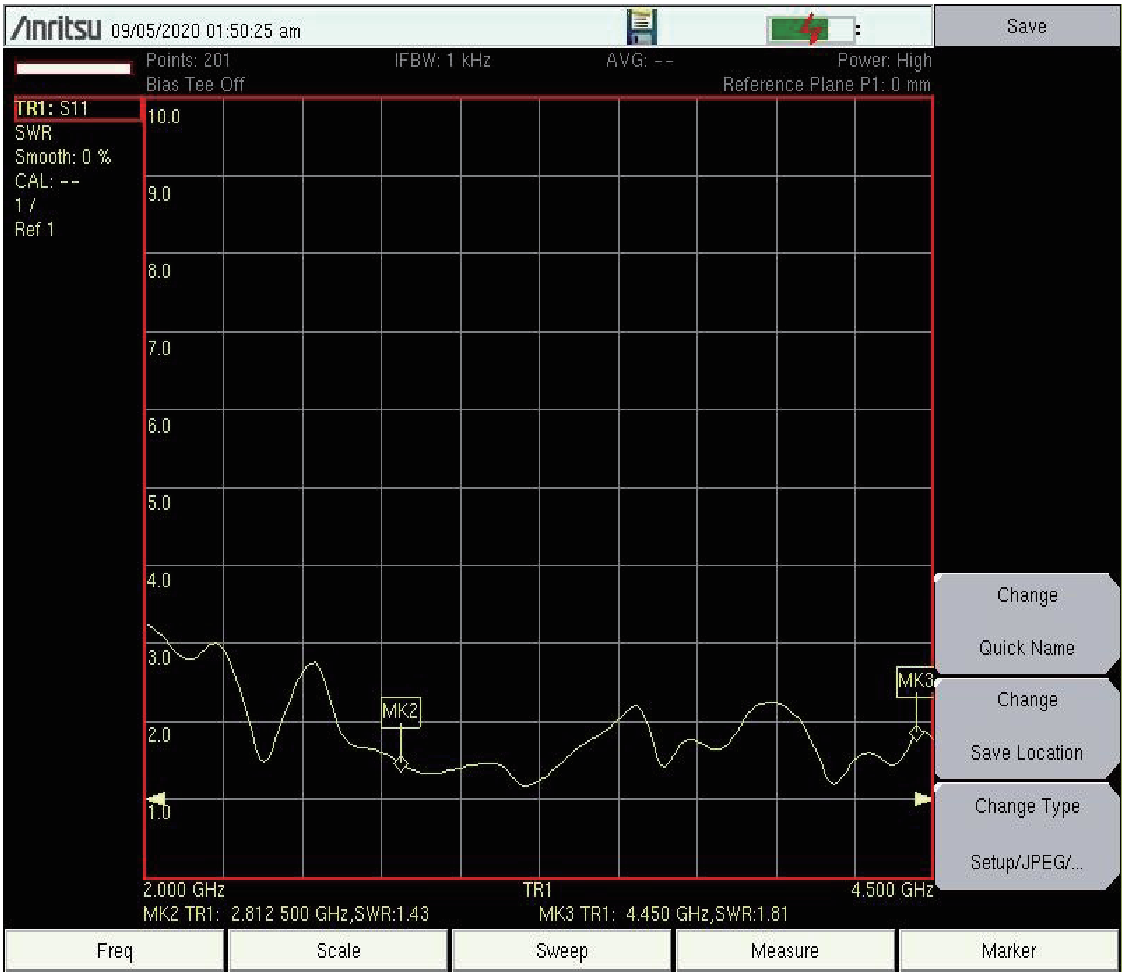
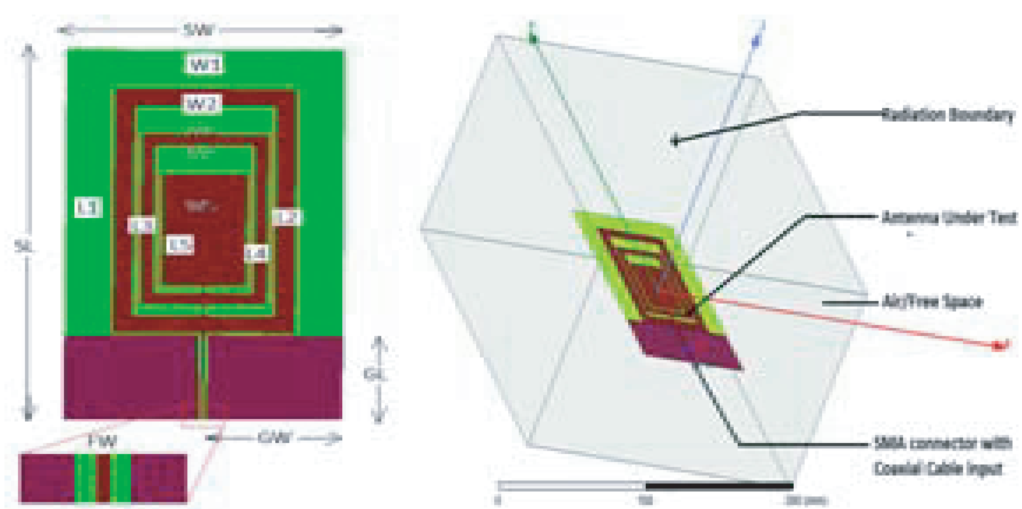
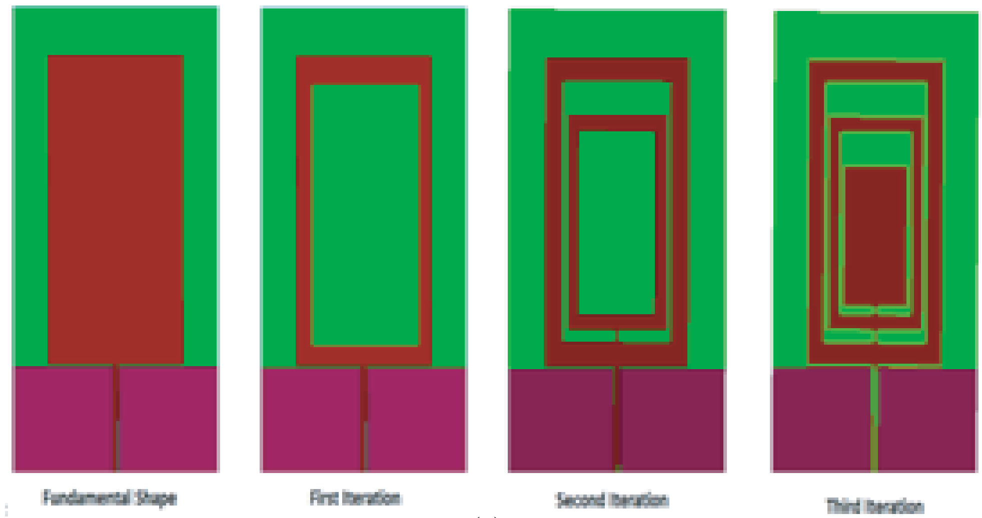


Figure 22. VSWR pattern of fractal antenna for cotton material.



(a) (b)



(c)

Figure 23. (a) Rectangular fractal antenna geometry. (b) Simulation setup. (c) Fractal antenna generation.

Table 3. Performance comparison between the proposed antenna and some existing antennas.

Reference Number	Frequency Used	Antenna Used	Substrate	Application
1	2.45 GHz & 5 GHz	Dual Band Co-Planar Antenna	Zelt	Used for Electromagnetic Band Gap Materials
2	2.4 GHz	Microstrip Antenna	Jeans	RFID Application
3	900 MHz, 2.4 GHz	GSM & WiFi Antenna	Polymer, zylon fibers	GSM & WiFi application for high data rates
4	5.4 GHz	Dual Polarized Antenna	Jeans	For Fire Fighters
6	2.4 GHz	Monopole Antenna	Teflon	Bluetooth Technology
7	2.4 GHz	Microstrip	Jeans	For Cardio Respiratory
8	3.28 GHz–3.85 GHz 5.15 GHz–5.35 GHz, 8 GHz–12 GHz	Dual band slot antenna	Jeans	WiMAX/WLAN Applications
Proposed Antenna	2.4 GHz, 4.2 GHz, 5.9 GHz	Tri-Band Fractal Antenna	Poly Viscous, Linen, Cotton	Wi-Fi/Zig-bee

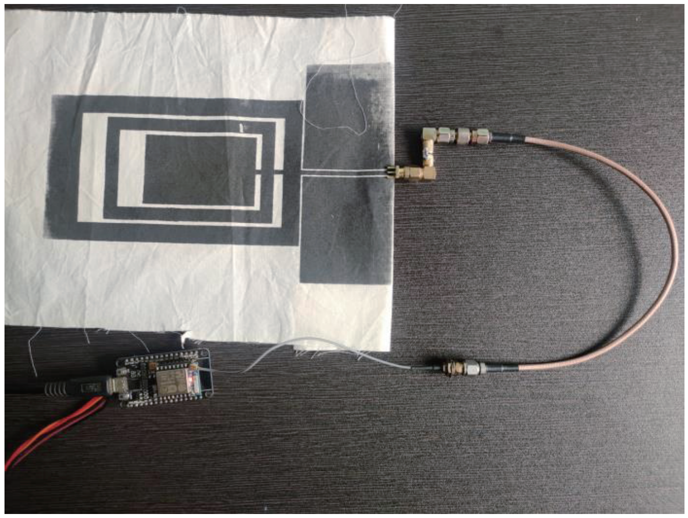


Figure 24. Wi-Fi module is connected to Poly Viscous material antenna.

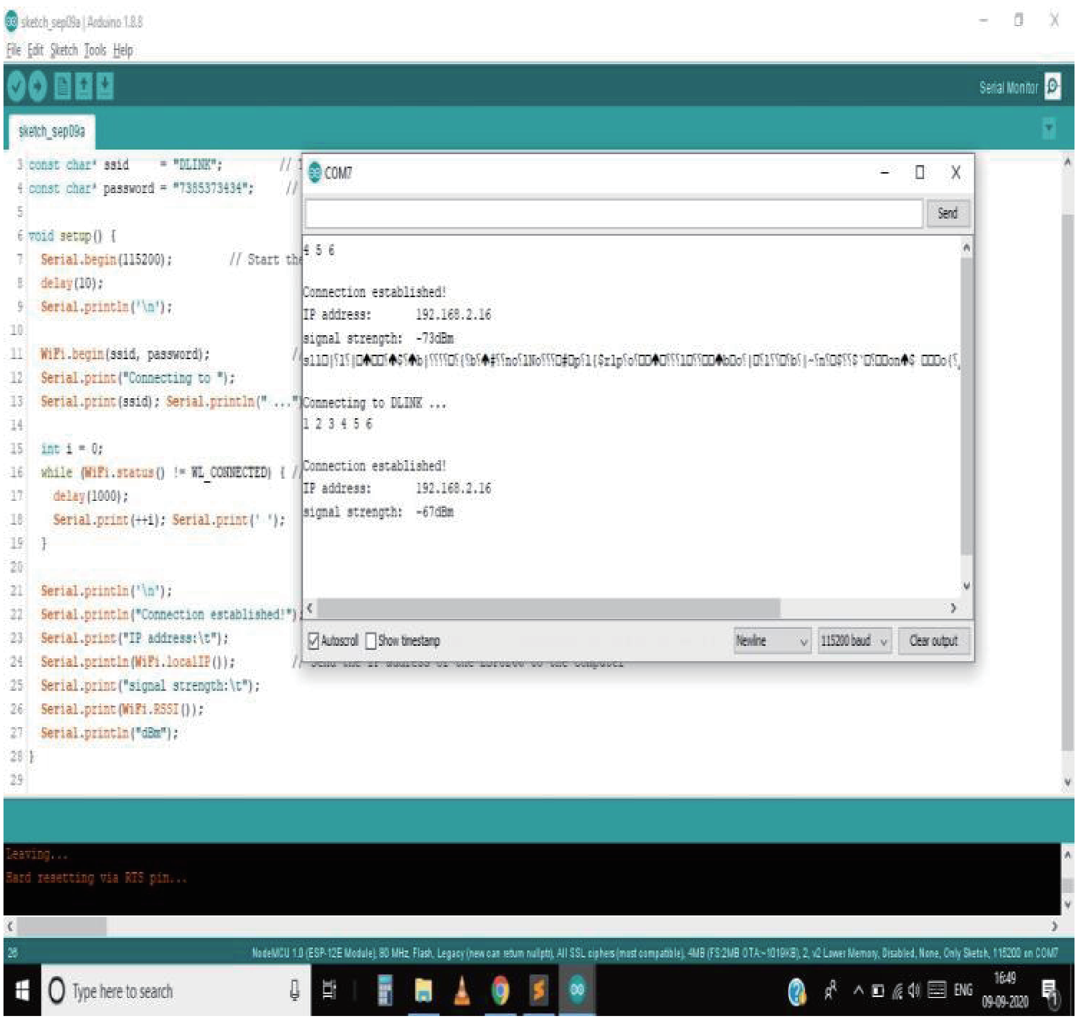


Figure 25. The connection is established between Wi-Fi and antenna.

8. CONCLUSION

The purpose of this activity is to

- Realize the fact that the antenna can radiate on a very thin substrate material.
- Instead of using a costly method of pasting copper material on textile, the simple yet affordable method of graphite (conductive) ink is used.
- By comparing three different frequencies used on three different materials, it is observed that the antenna will give the same performance if materials permittivity remains unchanged.
- However, if there is a small change in permittivity, it will cost a drastic change in the frequency as seen in cotton material.
- The optimum antenna like poly viscous is used for high data rate applications such as Wi-Fi. The antenna also radiates for 2.4 GHz which can be used for Bluetooth or Zig-bee applications.

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