Design and Implementation of an 2.4 GHz Microstrip Patch Antenna

Introduction:

The design and fabrication of a 2.4GHz microstrip patch antenna was one of the significant projects undertaken during my training period at ACCIMT. Microstrip patch antennas have gained considerable attention in modern wireless communication systems due to their low profile, lightweight nature, ease of integration, and cost-effectiveness. These antennas are extensively used in various applications including Wi-Fi devices and wireless routers (2.4GHz ISM band), IoT (Internet of Things) devices, Military radar systems and Medical devices.

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Challenge:

The challenge of this project lay in designing and implementing a functional patch antenna without access to specialized fabrication equipment. Working as a team of two, we approached this through careful theoretical calculations, simulation using electromagnetic software, and innovative fabrication techniques using readily available materials. Despite the limitations in resources, we successfully designed, fabricated, and tested a working prototype that achieved satisfactory performance at the target frequency of 2.4GHz.

This project provided valuable hands-on experience in Practical application of microwave engineering principles, understanding of antenna parameters and their optimization, Implementation of cost-effective fabrication techniques, Testing and measurement using Vector Network Analyzer (VNA), Problem-solving in resource-constrained environments and Team collaboration and project management. We have published all the design files including the Footprints and results in a GitHub Repo: https://github.com/Git-Kavinda/2.4GHZ_Patch_Antenna_Design.

Theory:

Main Reference: (Balanis, 2005)

- uStrip antennas consists of a very thin ($t << \lambda0$, where $\lambda0$ is the free-space wavelength) metallic strip (patch) placed a small fraction of a wavelength ($h << \lambda0$, usually $0.003\lambda0 \leq h \leq 0.05\lambda0$) above a ground plane.
- For a rectangular patch, the length L of the element is usually $\lambda0/3 < L < \lambda0/2$,
- The strip (patch) and the ground plane are separated by a dielectric sheet (referred to as the substrate)
- Dielectric constants are usually in the range of $2.2 \leq Ir \leq 12$.
- The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size.

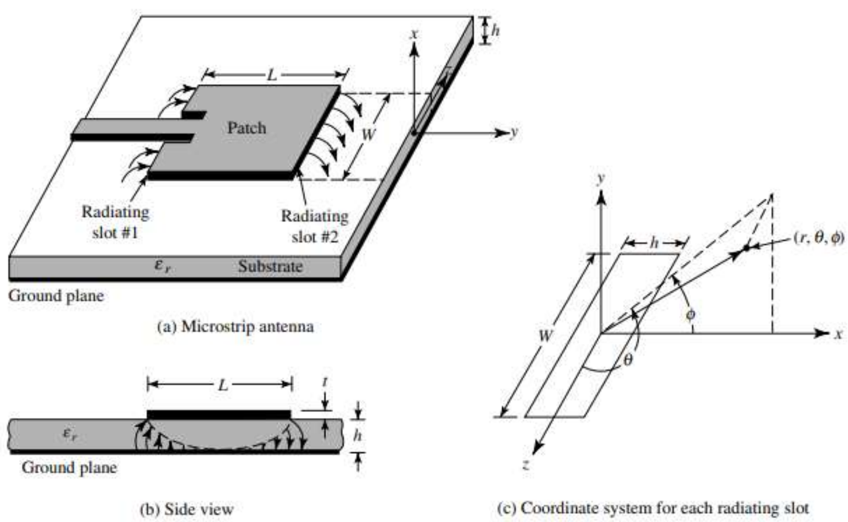


*Figure **Error! No text of specified style in document.**-1: Microstrip antenna and coordinate system. ref:(Balanis, 2005)*

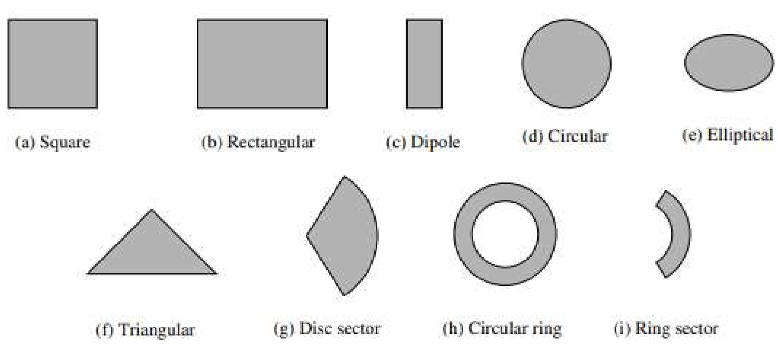


*Figure **Error! No text of specified style in document.**-2: Some shapes of microstrip patch elements.*

- microstrip antennas are also referred to as patch antennas.
- Microstrip dipoles are attractive because they inherently possess a large bandwidth and occupy less space, which makes them attractive for arrays.

Feeding Methods:

- The four most popular are the microstrip line, coaxial probe, aperture coupling, and proximity coupling. In this project, we mainly focused on microstrip line and coaxial probe.
- microstrip line - The microstrip feed line is also a conducting strip, usually of much smaller width compared to the patch. The microstrip-line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However as the substrate thickness increases, surface waves and spurious feed radiation increase, which for practical designs limit the bandwidth (typically 2–5%).
- Coaxial-line feeds - e inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane, are also widely used. The coaxial probe feed is also easy to fabricate and match, and it has low spurious radiation. However, it also has narrow bandwidth and it is more difficult to model, especially for thick substrates ($h > 0.02\lambda 0$).

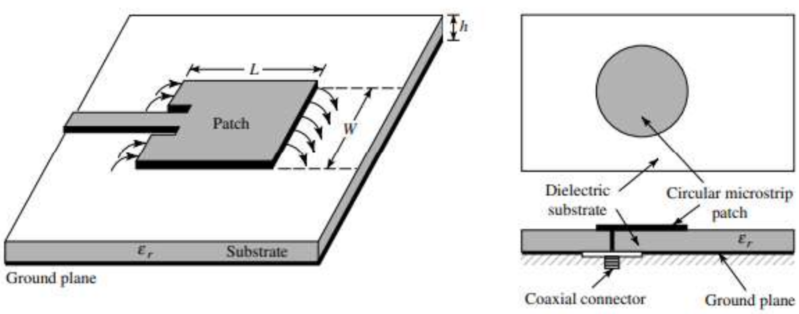


*Figure **Error! No text of specified style in document.**-3: Feeding Methods of Patch antennas, Microstrip Line (Left), Coaxial connector(Right)*

Equations For Rectangular Patch Antennas:

1. Fringing Effects

Because the dimensions of the patch are finite along the length and width, the fields at the edges of the patch undergo fringing. For the principal E-plane (xy-plane) fringing is a function of the ratio of the length of the patch L to the height h of the substrate (L/h) and the dielectric constant of the substrate. Since for microstrip antennas L/ h >> 1, fringing is reduced; however, it must be taken into account because it influences the resonant frequency of the antenna. The same applies for the width.

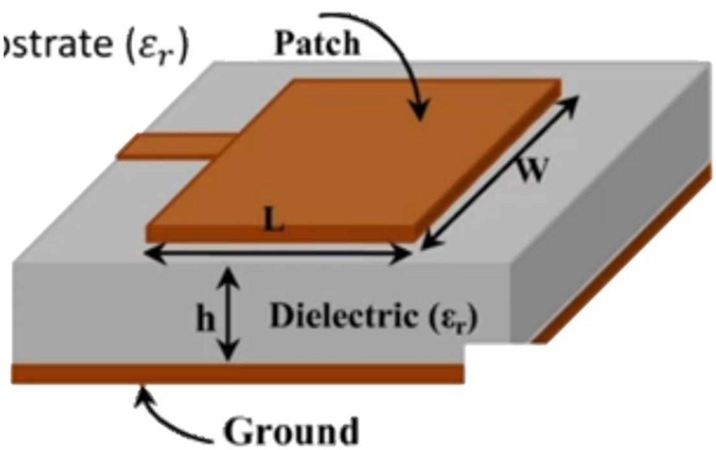
Effective dielectric constant - Some of the waves travel in the substrate and some in air. Effective dielectric constant account for fringing and the wave propagation in the line.

$$\underline{W/h > 1}$$

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

Design and Simulation:

Main References : (*(1) How to Solve Design Equation of Rectangular Microstrip Patch Antenna - YouTube*, n.d.) and (Balanis, 2005)



Step 01. For an efficient radiator, a practical width that leads to good radiation efficiencies is,

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r + 1}} = \frac{\upsilon_0}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}}$$

where υ0 is the free-space velocity of light.

$$W = \frac{v_0}{2f_0}\sqrt{\frac{2}{(\epsilon_r + 1)}}$$

$$W = \frac{3 * 10^8}{2 * 2.4 * \frac{10^9\sqrt{4.3 + 1}}{2}}$$

$$W = 0.0383m = 38\ mm$$

Step 02. Calculate of ϵ_{eff}

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

$$\epsilon_{eff} = 3.99 = 4$$

Step 03: Calculate the Effective Length

$$l_{eff} = \frac{v_0}{2f_0\sqrt{\epsilon_{eff}}}$$

$$l_{eff} = 31.25\ mm$$

Step 04 : Calculate the length extension Δl

$$\Delta l = 0.412h\left[\frac{\left(\epsilon_{eff} + 0.3\right)\left(\frac{w}{h} + 0.265\right)}{\left(\epsilon_{eff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)}\right]$$

$$\Delta l = 0.741\ mm$$

Step 05: Calculates the actual length

$$L = l_{eff} - 2\Delta l$$

$$L = 29.7$$

Step 06: Finding the substrate dimensions

$$L_s = 6h + L = 39.3\ mm$$

$$W_s = 6h + W = 47.6\ mm$$

Step 07 : calculates the inset length

$$y_0 = \frac{29.7}{2} = 14.8\ mm$$

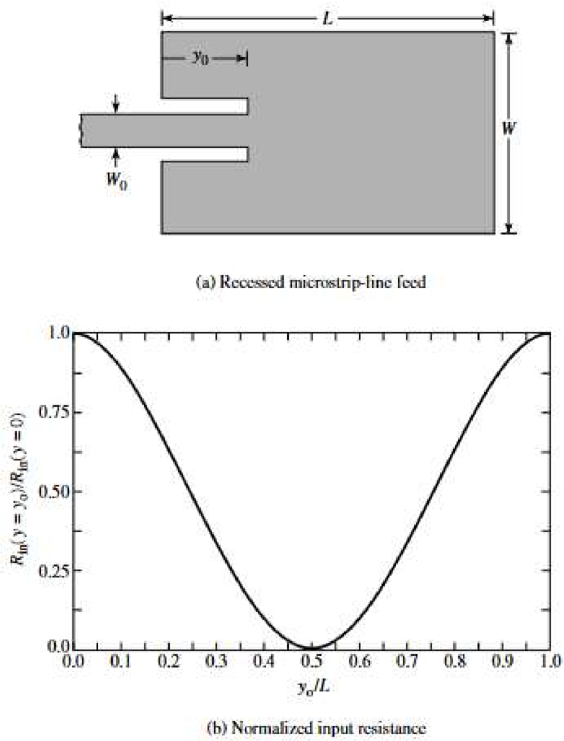


Figure ***Error! No text of specified style in document.****-4: Recessed microstrip-line feed and variation of normalized input resistance.*

The Calculations are verified using this online tool: https://www.emtalk.com/mpacalc.php?er=4.3&h=1.6&h_units_list=hmm&fr=2.4&Operation=Synthesize&La=30.861282783623&L_units_list=Lmm&Wa=39.528470752105&W_units_list=Wmm&Rin=225

Simulations:

Used CST Studio Suite for Modelling, Simulating and verifying the design before fabricating.

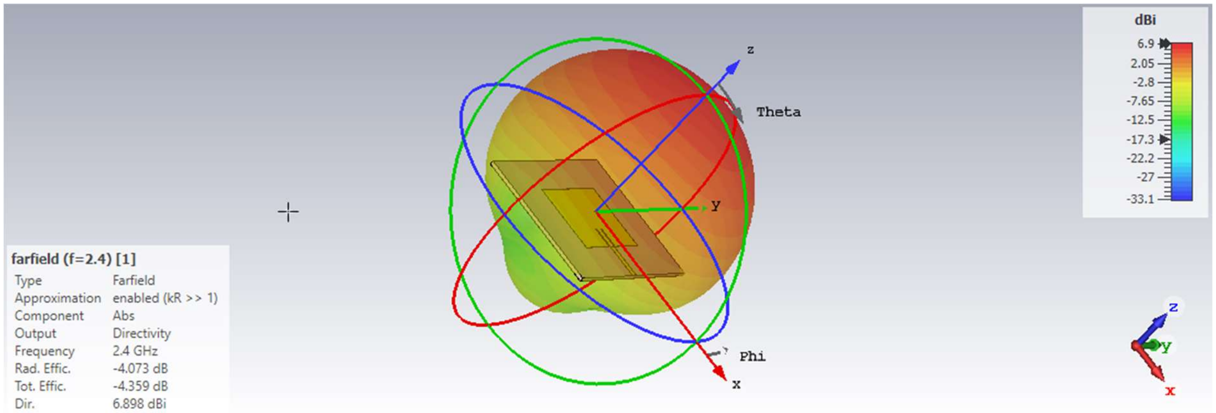


*Figure **Error! No text of specified style in document.**-5: Designed Antenna Modelling using CST Studio and visualizing the Far filed properties*

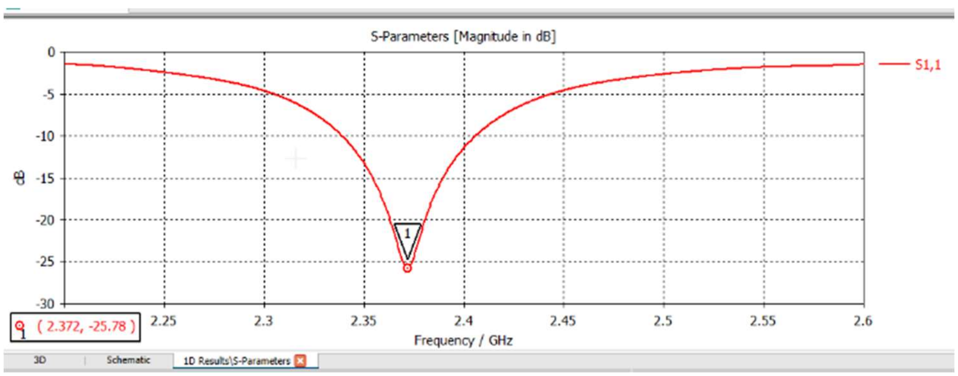


*Figure **Error! No text of specified style in document.**-6: Simulated Reflection Coefficient (S11)*

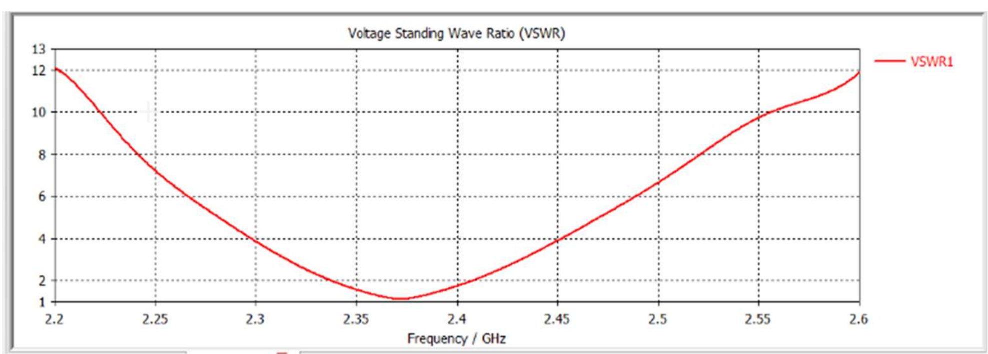


*Figure **Error! No text of specified style in document.**-7: Simulated VSWR*

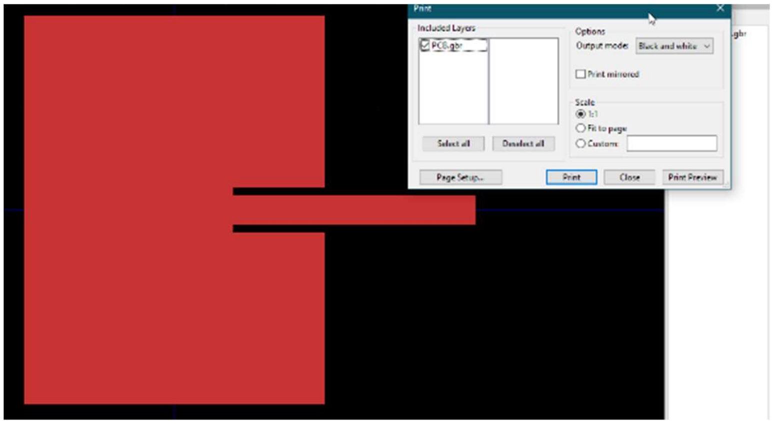


*Figure **Error! No text of specified style in document.**-8: Exported Graber File (Footprint)*

Fabrication Procedure:

Step 01: Mark the antenna graph on the FR-4 substrate PCB. Used art paper to get print out and heat it using a iron. For increase the accuracy, redraw the layout using a permanent marker.

*Figure **Error! No text of specified style in document.**-9: Toner transfer of the PCB layout on FR-4 PCB*

Step 02: Removing unwanted copper using etching. Used Ferric chloride for this purpose.

*Figure **Error! No text of specified style in document.**-10: Etching antenna design on PCB*

Step 03 : Attaching the 50 ohm SMA Connector

*Figure **Error! No text of specified style in document.**-11: Attaching the 50 ohm SMA Connector*

Testing and Results:

The fabricated antenna was tested using Filed fox RF analyzer.

Figure ***Error! No text of specified style in document.****-12: Testing setup using Filed fox RF analyzer*

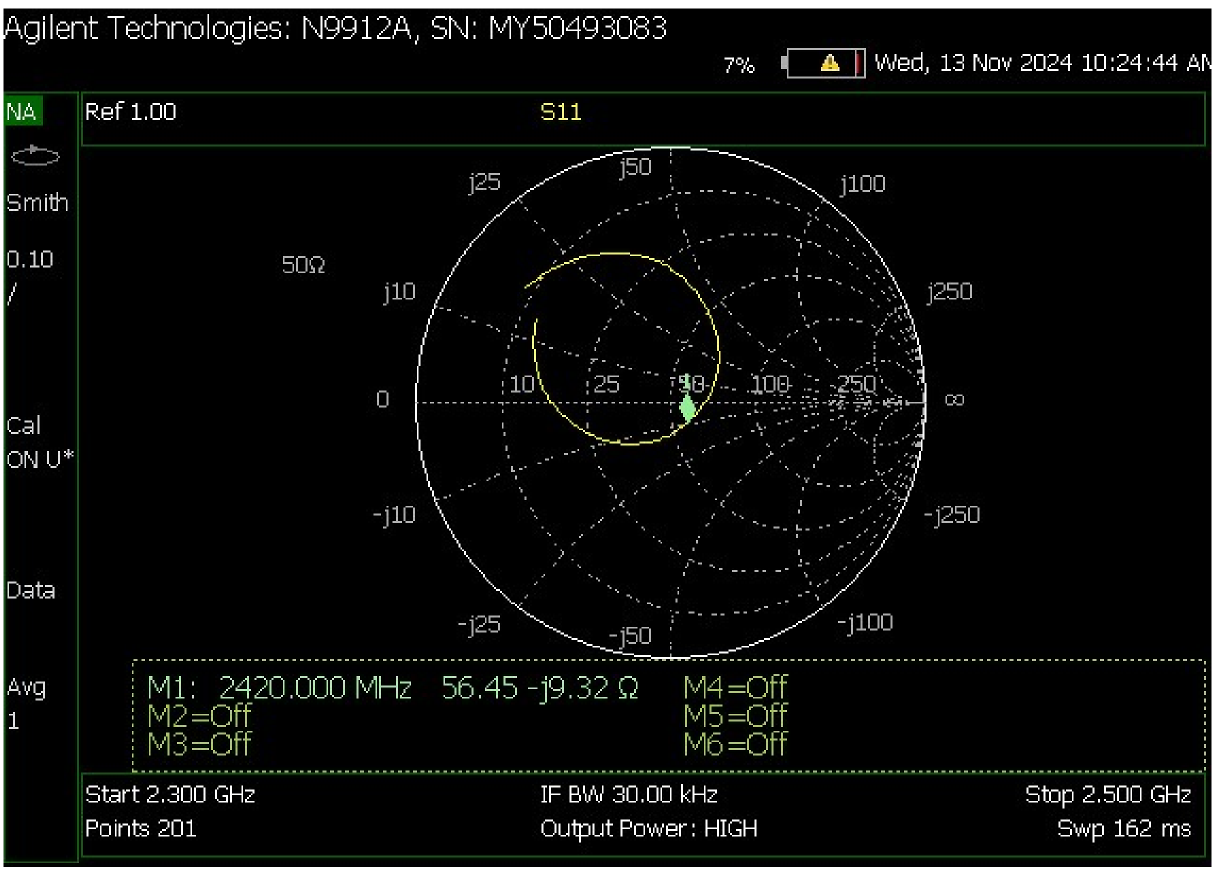


Figure ***Error! No text of specified style in document.****-13: Smith Chart of Fabricated antenna*

Shows the impedance matching characteristics of the antenna at 2.42 GHz. The measurement point (56.45 - j9.32 Ω) indicates that the antenna's impedance is reasonably close to the desired 50Ω, though not perfectly matched.

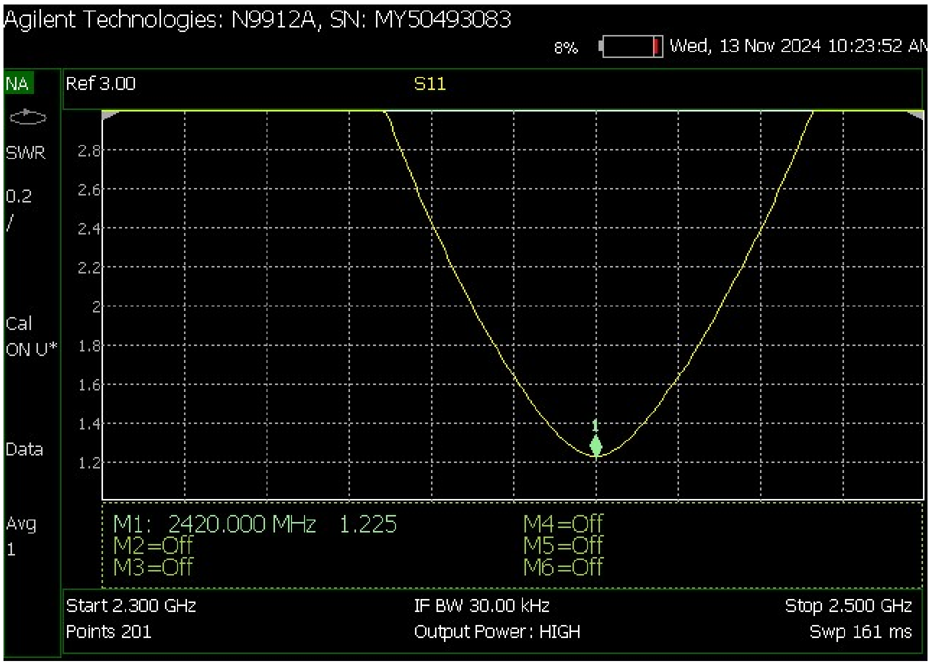


*Figure **Error! No text of specified style in document.**-14:S11 of Fabricated antenna*

Displays the Voltage Standing Wave Ratio across the frequency range of 2.3-2.5 GHz. At 2.42 GHz, the VSWR is 1.225, which is quite good as it's well below the typically acceptable value of 2.0, indicating good impedance matching and efficient power transfer.

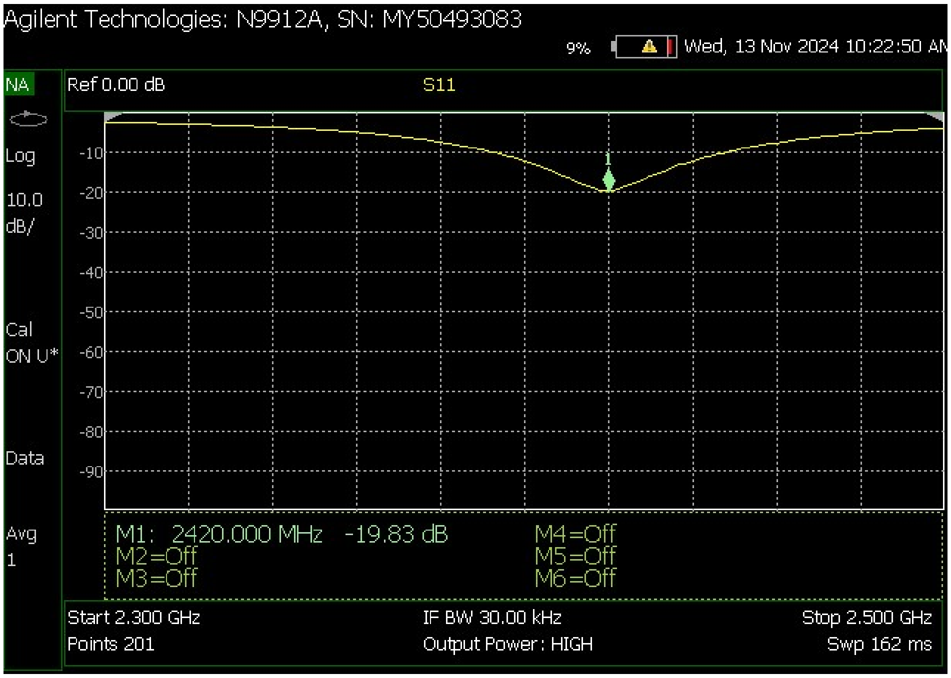


Figure ***Error! No text of specified style in document.****-15: Log graph of fabricated antenna*

Shows the S11 parameter (return loss) in dB across the same frequency range. At 2.42 GHz, the return loss is -19.83 dB, which is better than the generally acceptable level of -10 dB, indicating that only a small portion of the input power is being reflected back and most of the power is being radiated by the antenna.