# Probe-Fed Rectangular Patch Antenna


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***Abstract*—This paper presents a probe-fed rectangular patch antenna whose bandwidth of 70 MHz and center frequency of 2.446 GHz which yields the IEEE 802.11b Standards' requirements. The design procedure of the analytic and numeric approach is carried out by the insight of the previous implementations in the literature and by the means of the simulation tool of Ansys High Frequency Structure Simulator (HFSS). The designed antenna consists of a rectangular patch with a rectangular ground plane and probe-feeding. The antenna structure is placed on an FR-4 substrate whose relative permittivity is 4.4 and thickness is 1.6mm.**



***Index Terms*—rectangular patch antenna, IEEE 802.11b standards, return loss, radiation pattern, polarization**


## I. Introduction

Patch antennas are cheap and simple to manufacture using printed circuit technology, low profile, conformable to planar and non-planar surfaces, mechanically robust on mounted rigid surfaces. Also, they are very flexible in terms of polarization, resonant frequency, impedance, and pattern when specific patch shapes and modes are chosen accordingly. In fact, via changing the load between patch and ground plane, the desired impedance, polarization, resonant frequency and pattern can be obtained [1]. In the project, a rectangular shape of a patch antenna and probe feed are considered. The proposed antenna is designed to conform to the specifications of the IEEE 802.11b standards [2].

The standards in wireless network communications were first developed in 1997 by IEEE under the name of IEEE 802.11 [3]. The implementations and specifications in communication over wireless local area networks (WLAN) are represented by the IEEE 802.11 standards. The implemented standard in the project is IEEE 802.11b which utilizes one of the Industrial, Scientific, and Medical (ISM) bands of 2.4-2.5 GHz spectrum. The 2.4 GHz band is divided into 14 channels with a bandwidth of 22 MHz and 5MHz spacing [2]. So, its maximum raw data rate is 11 Mbit/s. The frequency ranges of the channels are shown in the Fig. 1.

In the project, 2.437 GHz, the center frequency of the channel 6, is selected as the resonance frequency of the patch antenna and the required bandwidth of the antenna is at least 25MHz. So, the antenna should cover at least the frequency region of [2.425 2.450] GHz range.

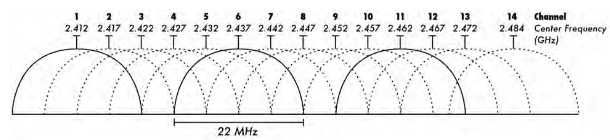


Fig. 1. The channels in the IEEE 802.11b standard [4]

In the literature, there are many implementations of the rectangular patch antenna which works at the resonance frequency of 2.4GHz. The antenna presented in the paper [5] is a rectangular patch antenna working at the frequency of 2.4GHz that is developed using a new bio composite substrate of Bambusa Vulgaris and High Density Polyethylene. The antenna proposed in the paper [6] presents a broadband microstrip patch antenna with the substrate of styrofoam, which works at the frequency of 2.4 GHz. The antenna proposed in the paper [7] is also a rectangular patch antenna with the substrate of Duroid5880 which is designed for WLAN applications.

## II. Analytic Design

The rectangular patch antenna is designed according to the design procedure of the Balanis' Antenna Theory Analysis and Design textbook [1]. Firstly, the values of the dielectric constant of the substrate ($\epsilon_r$), the resonant frequency ($f_r$), and the height of the substrate $h$ should be specified. In the project, an FR-4 substrate is selected to be placed, and the IEEE 802.11b standard is chosen to be implemented with the channel 6, therefore, the specified information in the design procedure is given as follows:

$$\epsilon_r = 4.4 \qquad f_r = 2.4GHz \qquad h = 1.6mm$$

As a first step, the width ($W$) of the patch is calculated as follows:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} = 3.8cm$$

In order to compute the length ($L$) of the patch, the effective dielectric constant should be determined:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W}}} = 4.086$$

After obtaining the effective dielectric constant, the extended incremental length ($\Delta L$) of the patch is calculated as follows:

$$\Delta L = h(0.412)\frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} = 0.739mm$$

Finally, the length ($L$) is determined as follows:

$$L = \frac{\lambda_0}{2\sqrt{\epsilon_{reff}}} - 2\Delta L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L = 2.944cm$$

After calculating the dimensions of the patch, the next step is to determine the feed location of the patch in order to match the antenna to $50\Omega$. The approximate expression for the input impedance ($R_{in}$) for a resonant patch that has a thin substrate ($h \ll \lambda_0$) is given as follows:

$$R_{in} = 90\frac{\epsilon_r^2}{\epsilon_r - 1}\frac{L}{W} = 396.5\Omega$$

Since the input impedance at the radiating edge of the patch is $396.5\Omega$ while the desired input impedance is $50\Omega$, the feed point position ($y$) is calculated as follows:

$$50 = R_{in}cos^2(\frac{\pi}{L}y) \Rightarrow y = 1.13cm$$

$$x = \frac{W}{2} = 1.9cm$$

After deciding all the parameters, the values of the rectangular patch antenna variables are given in the table I.

TABLE I
THE ANALYTIC VALUES FOR RECTANGULAR PATCH ANTENNA

| Variables | Values (cm) |
|---|---|
| Patch width (W) | 3.8 |
| Patch length (L) | 2.94 |
| Substrate width (h) | 0.16 |
| Feed position (x,y) | (1.9,1.13) |

The simulation platform of HFSS is used to observe the performance of the rectangular patch antenna with the above-mentioned variables. The tool of the ACT extension is considered to design the antenna. The parameters which are not present in the above table yet used in the HFSS model are set to the default values of the ACT extension.

S-parameter sweep is run between $1.2GHz$ and $5GHz$ in order to observe the return loss of the designed antenna. So, the corresponding S11 values are given in the Fig. 2. It can be mentioned that there are other resonance frequencies further from 3.6GHz, which are formed by the different modes of the patch antenna. However, these frequencies are not in the interest of the project.

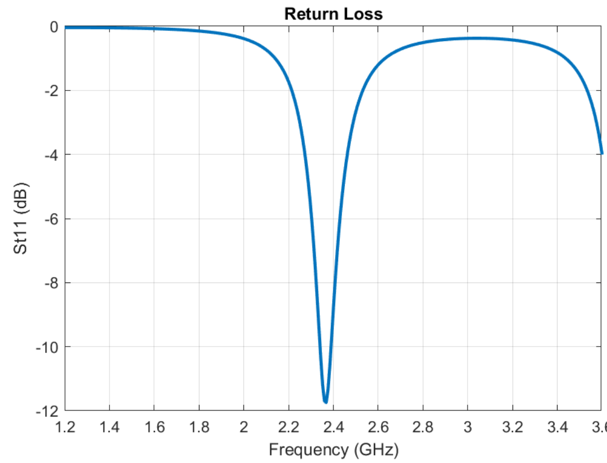


Fig. 2. The S11 values of the analytically designed antenna

It can be observed from the figure that the specified bandwidth is not satisfied by the analytic design. So, the antenna parameters will be optimized in the following section by considering the simulation results in order to conform to the given standard.

## III. Numeric Design

Firstly, the effect of the feed position ($y$) is examined. So, the rectangular patch antenna is simulated with the feed positions from 0.6 cm to 1 cm by increments of 0.1cm. The obtained S11 values are given in the Fig. 3.

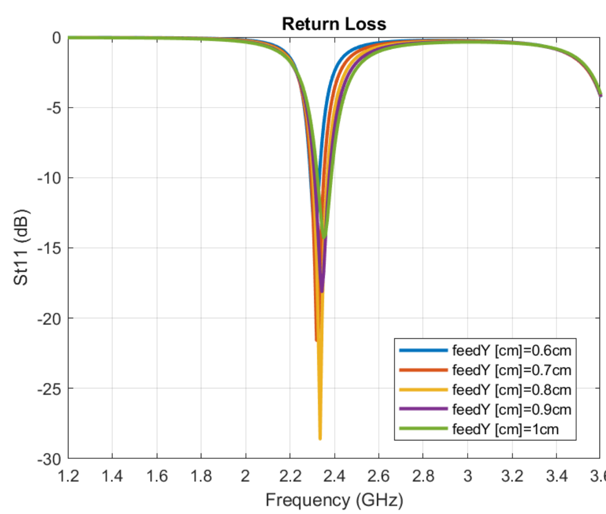


Fig. 3. The S11 values of the antenna with different feed positions

It can be seen from the figure that the performance of the antenna increases beginning from 0.6cm until 0.8cm then decreases as increasing the feed location further. Therefore, the feed location (y) is selected as 0.8 cm. The S11 values are improved by setting it to 0.8 cm; however, the center frequency is altered. So, in order to shift the resonance frequency to 2.4 GHz, the patch dimensions should be changed.

Another parameter that is examined to match the antenna to $50\Omega$ and to obtain the center frequency of 2.4 GHz is the length of the patch (L). So, the rectangular patch antenna is simulated with lengths from 2.7 cm to 3.1 cm by increments of 0.1cm. The obtained S11 values are given in the Fig. 4.

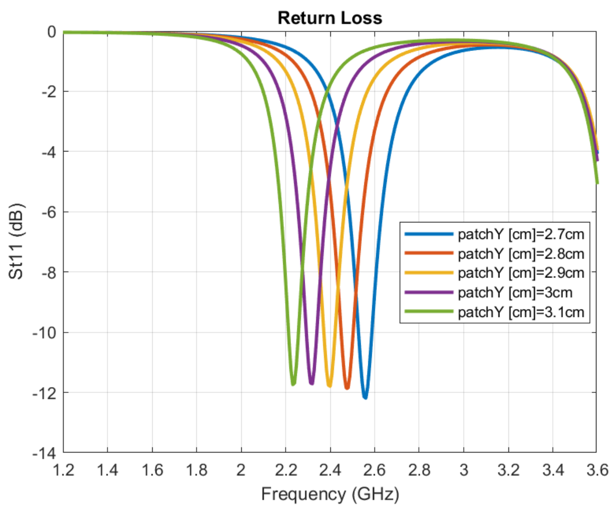


Fig. 4. The S11 values of the antenna with different lengths

Since setting the feed position to 0.8cm shift the center frequency to left, the length of the patch is selected as the value which gives the center frequency just bigger 2.4 GHz. So, it is chosen as 2.8 cm.

The final values of the rectangular patch antenna's parameters and the remaining default values are given in the table II.

TABLE II
THE NUMERIC VALUES OBTAINED FROM SIMULATIONS FOR RECTANGULAR PATCH ANTENNA

| Variables | Values (cm) |
|---|---|
| Patch width (W) | 3.8 |
| Patch length (L) | 2.8 |
| Subsrate dimensions | (6.7, 5.4) |
| Substrate width (h) | 0.16 |
| Feed position (x,y) | (1.9,0.8) |
| Coaxial radius (ri, ro) | (0.104, 0.354) |
| Feed length | 2.08 |

The designed antenna with the above parameters is shown in the Fig. 5.

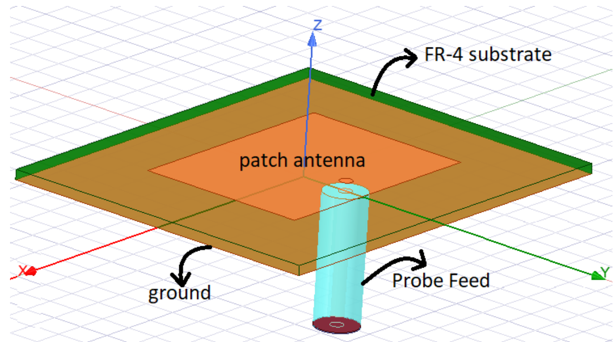


Fig. 5. The designed antenna

## IV. RESULTS

The probe feed rectangular patch antenna that works at the center frequency of 2.446 GHz with the S11 values of -25.96 dB and whose maximum gain is 4.0 dBi is designed by using the parameter values in the table II.

### A. Return Loss

The return loss of the designed antenna is shown in the Fig. 6.

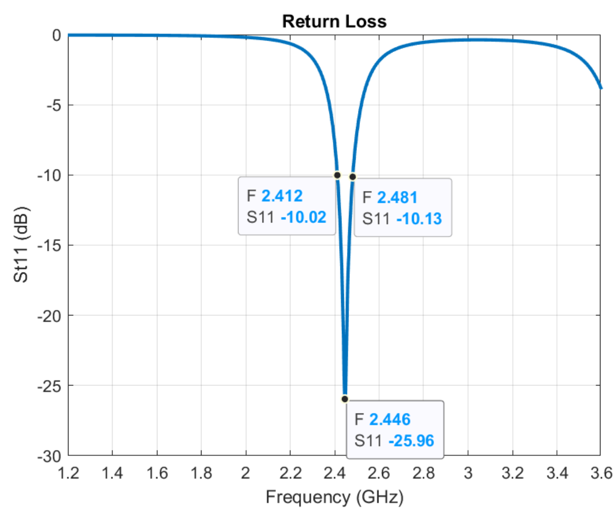


Fig. 6. The S11 values of the designed antenna

It can be observed from the figure that the center frequency of the antenna is 2.446 GHz and its bandwidth for 10 dB return loss is 70 MHz. As mentioned in the introduction section, the antenna covers the selected channel 6 ([2.425 2.450] GHz range) of the IEEE 802.11b standard. Namely, it satisfies both the center frequency and bandwidth requirement.

### B. Radiation Pattern

The 3D radiation pattern of the designed antenna is shown in the Fig. 7.

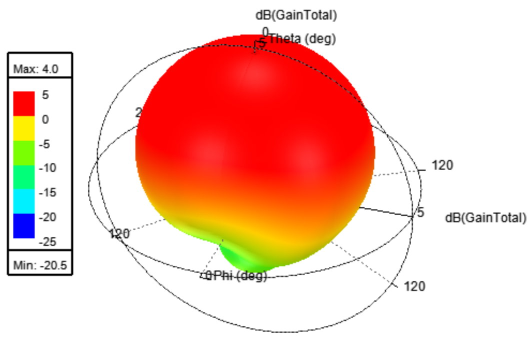


Fig. 7. The 3D radiation pattern of the designed antenna

The designed antenna has a maximum gain of 4 dBi.

### C. Polarization

In order to observe the polarization type of the designed antenna, its axial ratio versus theta graphs at the frequency of 2.4 GHz is shown in the Fig. 8.

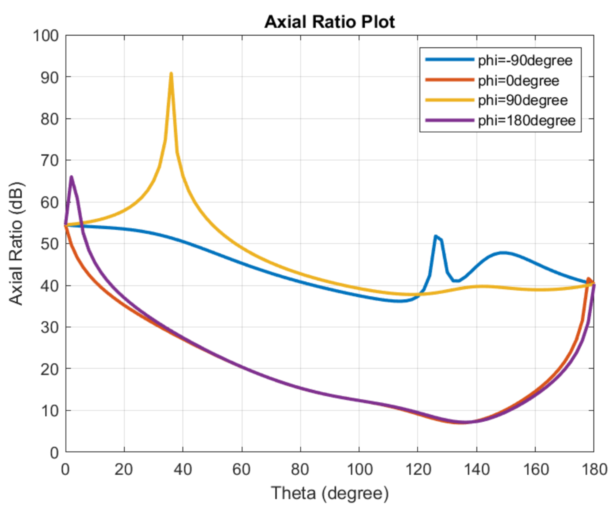


Fig. 8. The axial ratio of the designed antenna

It can be seen from the figure that the axial ratio always bigger than 10 dB, so it can be said that the antenna polarization is linear. In fact, if it would be a circular type polarization, then the axial ratio should be 0 dB since the minor axis values and major axis values should be equal. Actually, in theory, the axial ratio should be infinity in the linear polarization; however, in the real cases, this cannot be obtained.

## V. Conclusion

The designed probe feed rectangular patch antenna operates at the center frequency of 2.446 GHz and the bandwidth frequencies 2.412 GHz and 2.481 GHz which covers the channel 6 ([2.425 2.450] GHz range) of IEEE 802.11b standard. At the center frequency, the antenna has 4 dBi of gain and -25.96 dB of S11 values.

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