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Effect of Substrate Height Variation on the Performance of a Microstrip Antenna

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Abstract:

The need for broadband antennas has grown considerably in recent years, with high-frequency and high-speed data networking becoming increasingly prevalent. This article examines the factors that influence the bandwidth of a microstrip antenna. The extension of the antenna is determined by two key parameters: the thickness of the dielectric substrate and the type of substrate material. This research evaluates the performance characteristics of a rectangular patch microstrip antenna with different substrate thicknesses. The changes in resonant frequency, bandwidth, and return loss characteristics are influenced by varying one parameter while keeping the other constant. The rectangular patch microstrip antenna, designed for a microstrip feed line operating at 9 GHz, was developed using two substrate heights of 1.6 mm and 1.8 mm with a microstrip line feed. The design was implemented using CST Microwave Studio simulation software, resulting in directivity values of 6.94 dBi for the 1.6 mm substrate and 7.12 dBi for the 1.8 mm substrate thickness.

Keywords: Rectangular patch, substrate height, FR-4 (lossy), performance, CST

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كلية التقنية الكهربائية والإلكترونية – بنغازي – ليبيا

الملخص

ازدادت الحاجة إلى هوائيات النطاق العريض بشكل ملحوظ في السنوات الأخيرة، مع تزايد انتشار شبكات البيانات عالية التردد والسرعة. تتناول هذه المقالة العوامل المؤثرة على عرض نطاق هوائي الميكروستريب. يتحدد ابعاد الهوائي بمعاملين رئيسيين: سُمك الركيزة العازلة ونوع مادة الركيزة. يُقيّم هذا البحث خصائص أداء هوائي ميكروستريب مستطيل الشكل ذي رقعة مع سماكات مختلفة للركيزة. تتأثر تغيرات تردد الرنين وعرض النطاق وخصائص فقدان العودة بتغيير أحد المعاملين مع تثبيت الآخر. تم تطوير هوائي الميكروستريب المستطيل الشكل، المصمم لخط تغذية ميكروستريب يعمل بتردد 9 جيجاهرتز. باستخدام ارتفاعين للركيزة: 1.6 مم و1.8 مم مع خط تغذية ميكروسترب. تم تنفيذ التصميم باستخدام برنامج محاكاة CST Microwave Studio، مما اسفر عن قيم توجيهيه بلغت 6.94 ديسبل للركيزة ذات سمك 1.6مم و7.12 ديسبل للركيزة ذات سمك 1.8مم.

الكلمات المفتاحية: رقعة مستطيلة، ارتفاع الركيزة، FR-4 (مُفَقِّد)، الأداء، CST

1-Introduction:

Telecommunications is expanding rapidly, with ongoing efforts to enhance performance, reliability, and efficiency while minimizing cost. Antennas play a vital role in this field, serving as the key elements that transmit and receive electromagnetic waves in free space. To meet the diverse needs of modern communication systems, researchers have developed many antenna types that vary in structure, geometry, and transmission characteristics. [1] [2].

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Among the many antenna types, the microstrip patch antenna (MPA) is widely used. It consists of a conductive patch of planar or non-planar shape placed on one side of a dielectric substrate with a ground plane on the opposite side. The most common patch shapes are rectangular and circular. Rectangular patches are favored for their simple design and easy analysis, while rectangular patches provide the benefit of symmetric radiation patterns. In this study, we used a CST Studio Suite to build a rectangular microstrip patch antenna operating at 9 GHz using substrate FR-4 at two different heights, and we compared their performance.

2-Literature review:

Microstrip patch antennas (MPAs) are widely used in modern wireless communication systems because they are low-profile, lightweight, inexpensive, and easy to fabricate and integrate with other circuits. These advantages make them suitable for applications such as DBS systems, mobile communication, GPS, and radar. However, MPAs also suffer from drawbacks, including narrow impedance bandwidth, low gain, and reduced efficiency limitations largely caused by impedance mismatch in the feeding network. To overcome these challenges, researchers have explored improvements through modifications of key design parameters, especially the substrate.

The effects of patch dimensions and feed-point location was studied in [3], the finding was that the **patch length** primarily controls the resonant frequency: increasing the length lowers the frequency and improves return loss, while decreasing it raises the frequency and increases efficiency. The **patch width** mainly influences bandwidth and gain, with wider patches offering higher gain, better efficiency, and a reduced resonant frequency. Their results also showed that proper **feed-point placement** is essential for impedance matching, with optimal performance observed around 7.5 mm from the patch center. Adding an air gap as an extra dielectric layer was also shown to enhance gain and efficiency [3].
While in [4], the study focused on substrate thickness and patch width. They found that increasing the **substrate height** improves bandwidth and return loss up to an optimal limit; beyond that point, higher-order modes appear and degrade performance. Increasing the **patch width** similarly broadens bandwidth and increases radiation efficiency, with the best results when the width is about 1.5 times

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the patch length. These findings indicate that both substrate height and patch width must be optimized to balance gain, bandwidth, and impedance matching [4]

Complementary results were reported by Choudhury [5], who examined the effects of **dielectric constant (εr)** and substrate thickness. Higher dielectric constants reduce the resonant frequency but also narrow the bandwidth, creating a trade-off between compact size and wideband capability. Substrates with lower εr values (e.g., Rogers TMM3, εr = 3.27) offer wider bandwidth and higher efficiency than high-εr materials like Rogers TMM6 (εr = 6.0). Increasing substrate height further lowers the operating frequency due to stronger fringing fields, but excessive height causes surface-wave losses that reduce efficiency [5]

3- Structure of a microstrip antenna:

A microstrip antenna typically features a single-layer configuration that includes a metallic patch or multiple patches located on one side of a thin, non-conductive substrate, with a metallic ground plane positioned on the opposite side of the substrate panel. There are various types of substrates that can be utilized in the construction of microstrip patch antennas, with their dielectric constants usually falling between 2.2 and 12. For optimal antenna performance, thicker substrates with dielectric constants toward the lower end of this range are favoured because they enhance efficiency, increase bandwidth, and allow fields to radiate more freely into space, though this comes with the trade-off of larger element sizes. It is a widely used printed resonant antenna suitable for narrow-band microwave wireless communications. Figure 1 shows a basic structure of a rectangular microstrip patch antenna.[1].

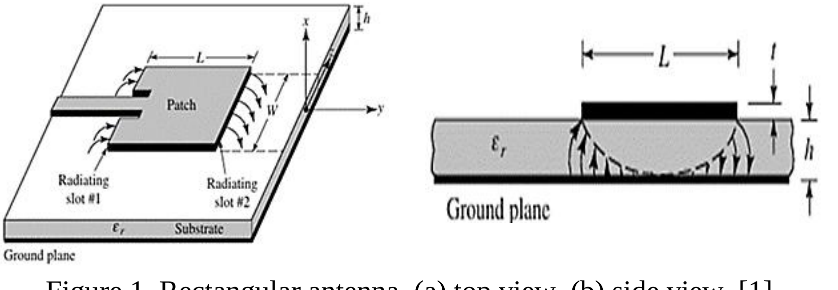

Figure 1. Rectangular antenna, (a) top view, (b) side view. [1]

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4- Antenna design:

A rectangular microstrip patch antenna is constructed using substrate heights of 1.6mm and 1.8mm with dielectric constants of the substrates (Ɛr = 4.3) and an operating frequency of 9 GHz. Below are the steps and a practical sequence of steps used to compute the patch dimensions

Step1: Determining the width of the patch: the width W is calculated by [1]:

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Where: c is the speed of light in free space = (3x108m/s)

Step2: Calculation of effective Dielectric Constant ε_{eff} :

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{\frac{-1}{2}} \qquad (2)$$

Where: h is the height of the microstrip patch antenna, and W is the width of the microstrip patch antenna.

Step3: When w is found, the extension of the length ΔL can be determined by the equation as:

$$L = 0.412h\frac{\left(\varepsilon_{reff}+0.3\right|\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \qquad (3)$$

Step4: The actual length patch can be determined by using following equation:

$$L = L_{eff} - 2L \qquad (4)$$

Where: L_{eff} is the effective length which is:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \qquad (5)$$

Step5: determine the ground plane dimensions length (L_g) and width (W_g):

$$L_g = 6h + LW_g = 6h + W \qquad (6)$$

5- Simulation and Result:

With CST Studio Suite 2019 software, the simulation results illustrate how variations in substrate height influence key antenna characteristics, including return loss (S11), VSWR, gain, directivity, radiation pattern, and efficiency. These parameters are used to assess and compare the performance of the proposed rectangular

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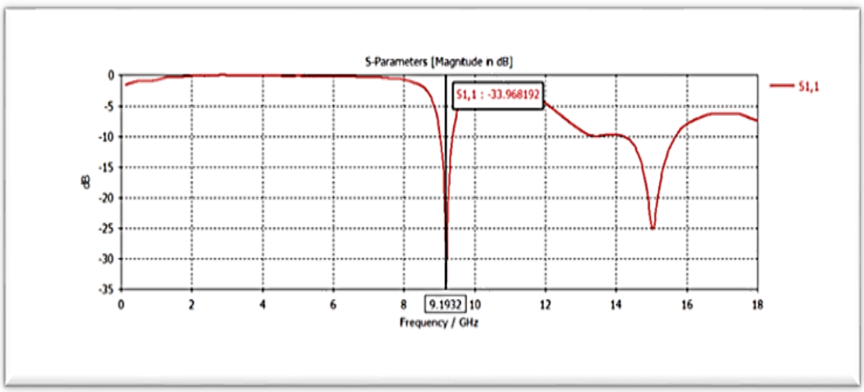
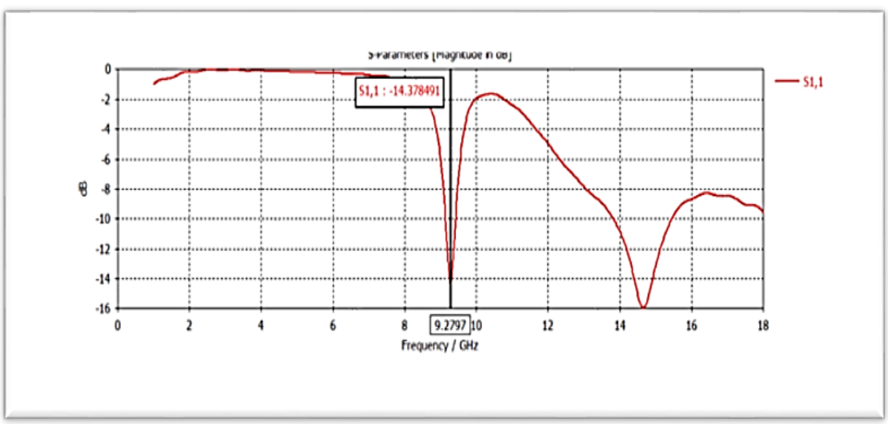
microstrip patch antenna design. A summary and discussion of the simulated results for the different substrate heights are presented below to evaluate the overall impact on antenna behavior.

5.1 Return Loss (S11):

Figure 2 shows the return loss (S11) characteristics of the designed rectangular patch antenna. As observed from the plots, the antenna resonates at the target frequency of 9 GHz for both substrate heights. The measured return loss is −33.9 dB or the 1.6 mm substrate and −14.38 dB for the 1.8 mm substrate.



(a)



(b)

Figure 2. Return loss (S11) vs frequency plot for the designed rectangular patch antenna with substrate height (a) h=1.6mm, (b) h=1.8 mm

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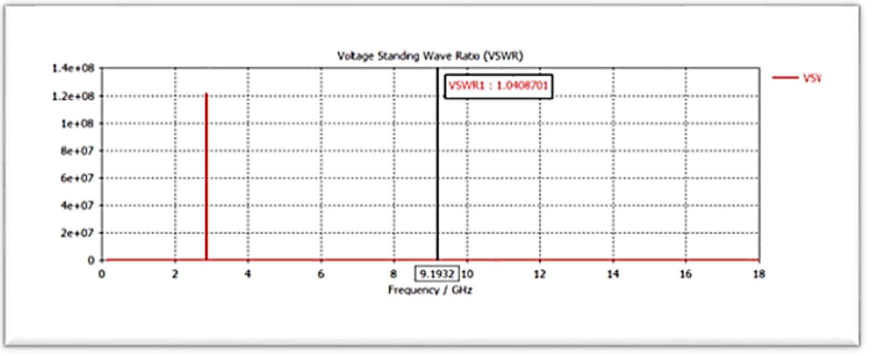
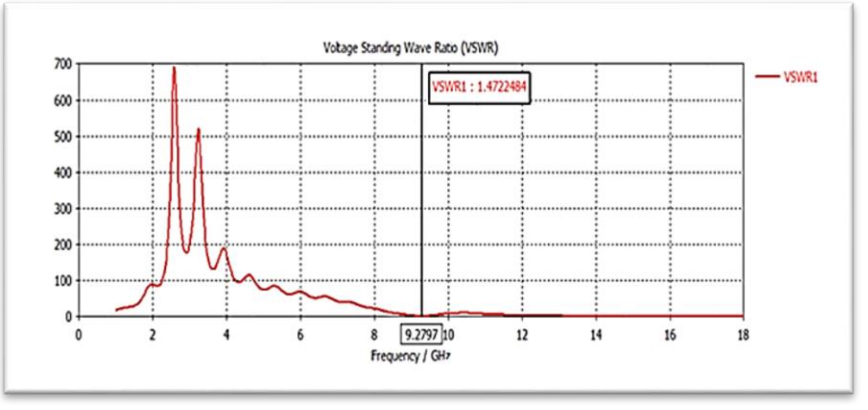
5.2. Voltage Standing Wave Ratio (VSWR):

From Figure 3, the designed patch antenna exhibits a VSWR of 1.04 for the 1.6 mm substrate and 1.47 for the 1.8 mm substrate at the resonant frequency of 9 GHz. Both values indicate good impedance matching, as they fall well below the commonly accepted limit of 2 for a properly matched antenna.



(a)



(b)

Figure 3.VSWR vs frequency plot for the designed rectangular patch antenna with substrate height (a) h=1.6mm, (b) h=1.8 mm

5.3Gain and Directivity:

The 3D polar plot of the simulated antenna design is shown in figure 4.

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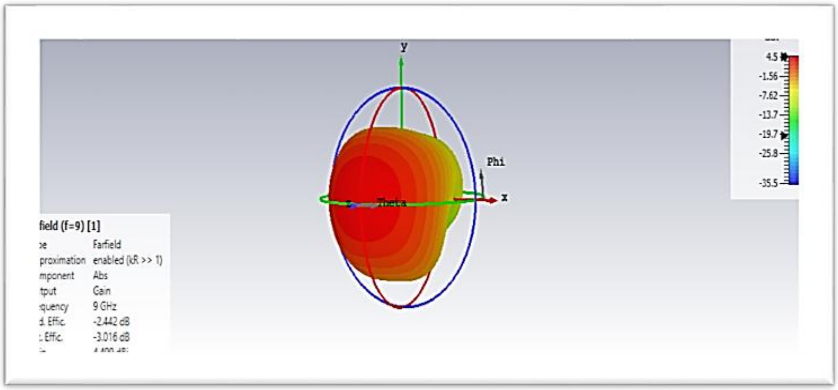
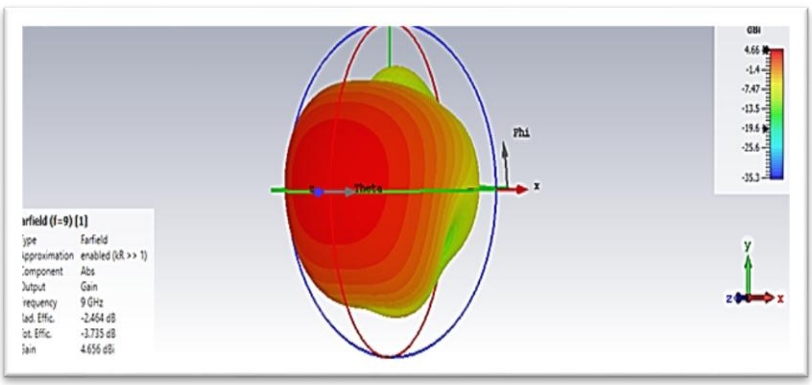


(a)



(b)

Figure 4. 3D plot of the gain of the simulated patch antenna with substrate height: (a) h=1.6mm, (b) h=1.8 mm.

From the 3D polar plot shown in figure 4(a, b), the gain of the designed rectangular patch antenna is 4.49dBi for (h=1.6) and 4.65dBi for (h=1.8), at the resonant frequency of 9 GHz.

5-4-Radiation Pattern:

The measured far-field radiation patterns of the designed rectangular patch antennas are shown in Figure 5(a–d). Figures 5(a) and 5(c) represent the E-plane plane), while Figures 5(b) and 5(d) show the H-plane. The half-power beamwidth (-3 dB) is 73.6° in the E-plane and 88.1° in the H-plane at 1.6 mm substrate, while for the 1.8 mm substrate, it increases to 91.6° in the E-plane and 114.9° in the H-plane.

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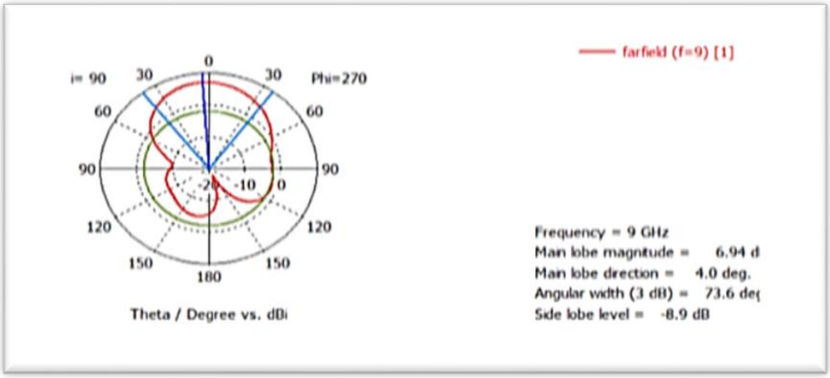
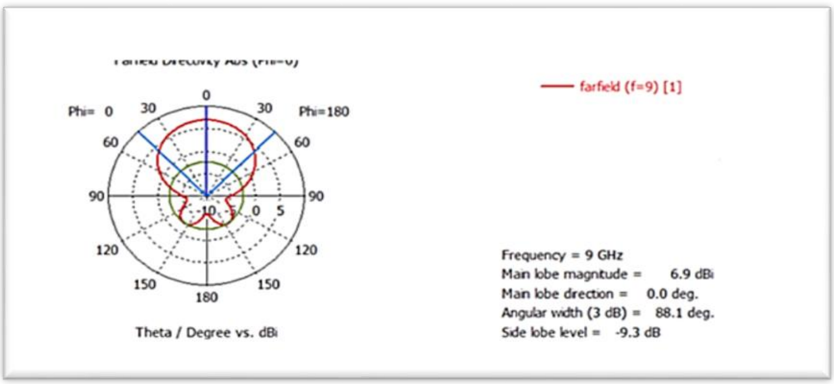


(a)



(b)

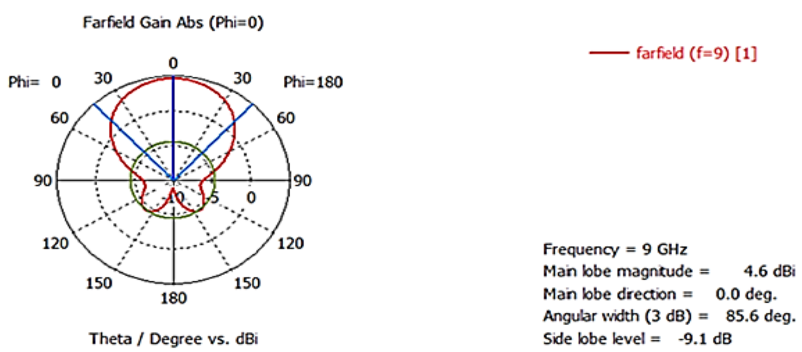


Figure 5. Radiation pattern of the designed rectangular patch antenna
(a) :(h=1.6mm) in (E-plane), (b) :(h=1.6mm) in (H-plane)
(c) :(h=1.8mm) in (E-plane), (d) :(h=1.8mm) in (H-plane)

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Table 1 summarizes the simulation results of the designed rectangular patch antenna. It presents key performance parameters, including resonant frequency, return loss (S11), VSWR, gain, and directivity, highlighting the antenna's overall characteristics.

Table 1: Summary of simulated results of rectangular patch antenna

Height	1.6mm	1.8mm
ε_r	4.3	4.3
Frequency(GHZ)	9	9
S11(dB)	-33.9	-14.38
VSWR	1.04	1.47
Directivity (dBi)	6.94	7.12
Gain (dBi)	4.49	4.65

In comparison with our design and the results of previous studies, we found that our design (S11) performed better, exhibiting a higher frequency. We compared the results at a column height of 1.6 mm, which significantly improves impedance matching, achieving a return loss of −33.9 dB as seen in figure 2-a. The remaining parameters, such as VSWR, gain, and Directivity were not calculated in any of the studies. We obtained VSWR 1.04, gain4.49dBi, and directivity 6.94dBi, as illustrated in Figures 3-a and 4-a, and did not find similar results at a height of 1.8 mm.

Table 2 the performance parameters for our designed and previous studies.

Parameters	Our design	Rf[3]	Rf[4]	Rf[5]
Frequency (GHz)	9	2.48	7	6
Height (mm)	1.6	1.59	1.6	1.6
S11(dB)	-33.9	-10	-49	-45

5- Conclusion:

Rectangular micro-band antennas can be successfully constructed with varying substrate heights at 9 GHz frequency and FR-4 substrate With CST Studio Suite. Observations show that the antenna bandwidth increases with increasing substrate height Table1 shows a comparison of different substrate heights. As we

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increase the height of the substrate, the antenna bandwidth increases. Table 2 shows a comparison of our design with the results of previous studies where we found that S11 was better for our design at the high frequency at height 1.6 mm.

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