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Design and Analysis of a Microstrip Patch Antenna for GPS Applications

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تصميم وتحليل هوائي رقعة ميكروستريب لتطبيقات GPS

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Abstract:
In this work, we presented microstrip antenna operating at 1.575GHz frequency of (GPS applications). Microstrip patch antennas are widely used in Global Positioning System (GPS) applications due to their compact size, low profile, and ease of integration with RF circuits. This manuscript presents the design, simulation, and performance analysis of a rectangular microstrip patch antenna operating at the GPS L1 frequency (1.575 GHz). The antenna is designed on an FR-4 substrate with a dielectric constant (ε_r) of 4.4 and a thickness of 1.6 mm. Key performance parameters such as return loss, voltage standing wave ratio (VSWR), radiation pattern, and gain are evaluated using electromagnetic simulation software (ANSYS HFSS/CST Microwave Studio). While the antenna simulation was done using advanced design system (ADS-Agilent) software. The proposed antenna demonstrates good impedance matching, directional radiation characteristics, and a gain of approximately 3–5 dBi, making it suitable for GPS applications.

Keywords: Microstrip patch antenna, GPS L1 band, FR-4 substrate, Return loss, Radiation pattern, HFSS/CST.

الملخص
في هذا العمل، قدّمنا هوائيًا ميكروستريبيًا يعمل بتردد 1.575 جيجاهرتز (لتطبيقات نظام تحديد المواقع العالمي). تُستخدم هوائيات الرقعة الميكروستريبية على نطاق واسع في تطبيقات نظام تحديد المواقع العالمي (GPS) نظرًا لحجمها الصغير، وصغر حجمها، وسهولة دمجها مع دوائر الترددات الراديوية. تقدم هذه المخطوطة تصميمًا ومحاكاةً وتحليلًا لأداء هوائي رقعة ميكروستريب مستطيل الشكل يعمل بتردد GPS L1 (1.575 جيجا هرتز). صُمم الهوائي على ركيزة FR-4 بثابت عازل (ε_r) قدره 4.4 وسمك 1.6 مم. تم تقييم معلمات الأداء الرئيسية، مثل خسارة العودة، ونسبة الموجة الدائمة للجهد (VSWR)، ونمط الإشعاع، والكسب، باستخدام برنامج محاكاة كهرومغناطيسي (ANSYS HFSS/CST Microwave Studio). بينما أُجريت محاكاة الهوائي باستخدام برنامج نظام التصميم المتقدم (ADS-Agilent). يُظهر الهوائي المقترح توافقًا جيدًا للممانعة، وخصائص إشعاع اتجاهي، وكسبًا يتراوح بين 3 و5 ديسيبل تقريبًا، مما يجعله مناسبًا لتطبيقات نظام تحديد المواقع العالمي (GPS).

الكلمات المفتاحية: هوائي رقعة شريطي دقيق، نطاقGPS L1، ركيزةFR-4، فقدان الارتداد، نمط الإشعاع، HFSS/CST.

Introduction

For, the many features of the microstrip antenna include versatility, smallest size of antenna, and inexpensive [1]. These advantages make it appropriate for many kinds of applications such as global position system (GPS), Bluetooth, vehicle-based satellite, handheld radios of mobile, and communication equipment [2].

The Global Positioning System (GPS) operates in multiple frequency bands, with the L1 band (1.575 GHz) being the most commonly used for civilian navigation [3]. Microstrip patch antennas are preferred for GPS receivers due to their (Low profile and lightweight structure [1], Ease of fabrication and integration with PCBs, Cost-effectiveness, and good radiation characteristics) [2].
So, the contribution of this article by designing a microstrip antenna at 1.575GHz frequency, it can be utilized in global position system (GPS) application. This work focuses on designing a single-band rectangular microstrip patch antenna optimized for GPS L1 applications.

The remaining sections are organized as follows: Section 2 presents the design of the antenna along with the methodology and mathematical equations. Section 3 presented the proceeding and Results of the Simulation. Eventually, the conclusion and followed by the list of recent cited up-to-date references are closing the article.

Antenna Design and Methodology

For designing this antenna, we will using that basic parameter:

a) The antenna resonant frequency (f_r), that should be selected properly, the GPS applications use 1.575 GHz frequency.
b) The substrate Dielectric constant (ϵ_r), which was 4.4, and $\tan\delta = 0.001$ for our design dielectric material FR4 [3].
c) The dielectric substrate Height (h), it was 1.58 mm.
d) Input impedance ($Zant$) must be matched to 50 Ω and VSWR typically 1.5 [4].

Therefore, the fundamental parameters for the design are tabulated in Table 1.

Table 1: Design Specifications

Parameters	Values (units)
Frequency of operation (f_0)	1.575 GHz (GPS L1)
Substrate material	FR-4 (ε_r = 4.4, tan δ = 0.02)
Substrate thickness (h)	1.6 mm
Feeding technique	Coaxial probe feed
Patch shape	Rectangular
tangent loss $\tan\delta$	0.001
$Zant$	50Ω

Via assisting the software of advanced design system (ADS), to calculate the dimensions of the rectangular microstrip antenna [5]. By using Equation (1), to find out the microstrip antenna width [6]:

$$w = \frac{C}{2f_r\sqrt{\frac{(\epsilon_r+1)}{2}}} \quad (1)$$

w is the patch width.
C is the velocity light in the free space.
ϵ_r is the substrate dielectric constant.
f_r is the operating frequency.
By using Equation (2), to determine the effective dielectric constant:

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

Whereas:
ϵ_{reff} is effective dielectric constant.
h is the dielectric substrate height.
By applying Equation (3), to come out the length extension Δl [7]:

$$\Delta l = 0.412h\frac{(\epsilon_{reff+0.3})(\frac{W}{h}+0.264)}{(\epsilon_{reff-0.258})(\frac{W}{h}+0.8)} \quad (3)$$

By applying Equation (4), to come out the actual length:

$$L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta l \quad (4)$$

Regarding the feed point on the patch, it should be situated at the point where the impedance input is 50 Ω at a resonant frequency [8]. Therefore, a trial-and-error way is applying to obtain the location of feed point [9].

The proceeding and Results of the Simulation

Via The ADS software, that used to model and simulate microstrip antenna depending on the moments method. The calculated dimensions first used as input to the ADS software to begin the antenna simulation.
In order to get optimized values and best results at the resonant frequency (f_r), return loss (S_{11}) and the bandwidth (BW). we have tuned the dimensions of the antenna. Whereon the patch width is along the Y axis, and the patch length is along the X axis.

Figure (1), and Table (1) indicates to, the microstrip dimensions antenna operates at 1.575 GHz. The parameters and dimensions antenna are tabled in Table (2).

Table 2: Antenna Dimension at 1.575GHz**.**

Parameter	**Width mm**	**Length mm**	ϵ_{reff}	ΔL **mm**
Value	57.96	45.14	4.18	0.7330

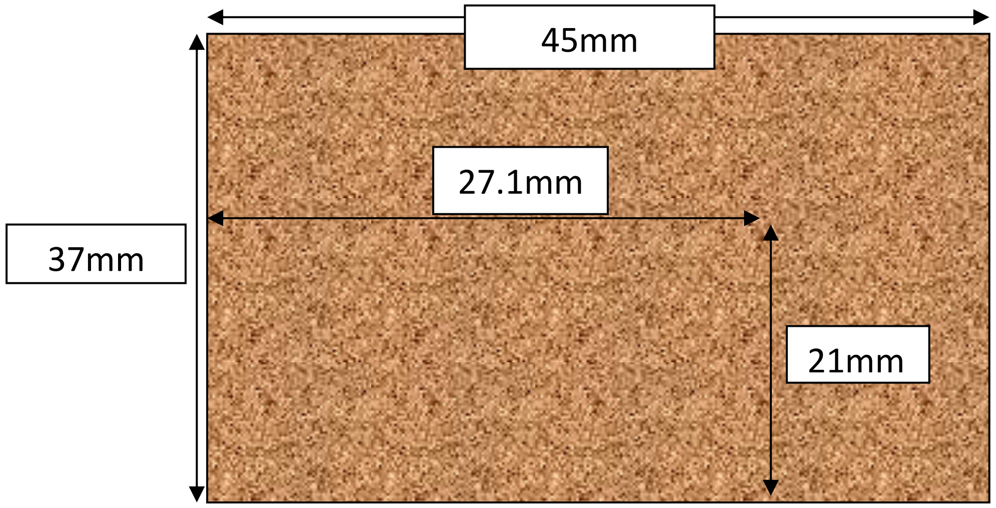

Figure 1: Microstrip antenna Dimensions for 1.575GHz.

Figure (2) appears, the resonant frequency, the bandwidth and return loss of GPS system, that are 1.575 GHz, 24 MHz and -24.219 dB, successively. Figure (3), depict, the input impedance on the Smith chart is virtually matched (Zant=44.25+j0.55 Ω) at 1.575 MHz frequency. Also, the calculated VSWR 1.13 of the antennas at resonance frequency indicates a very good, matched antenna.

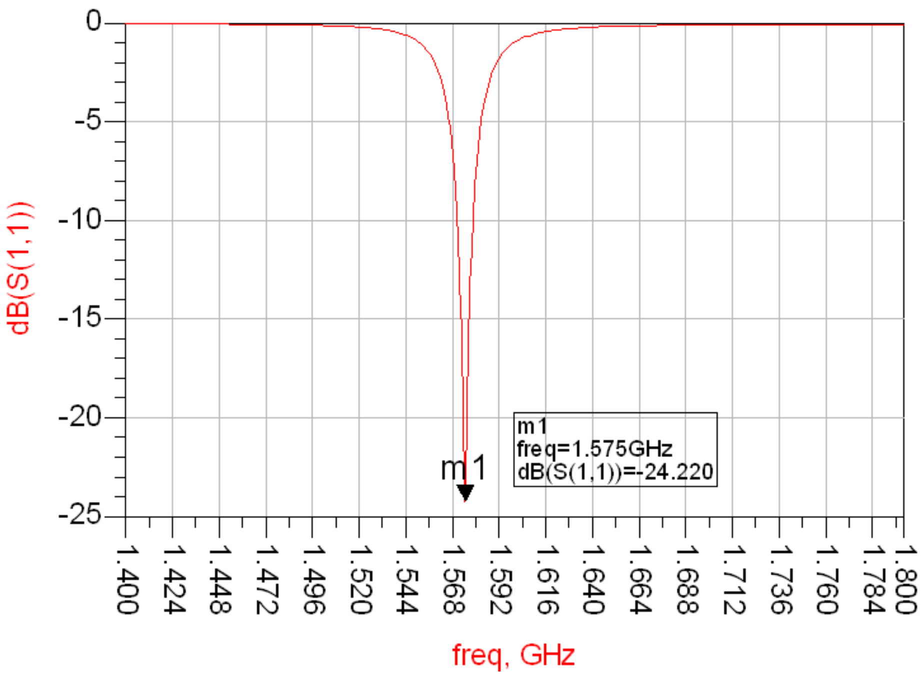

Figure 2: GPS Resonant frequency.

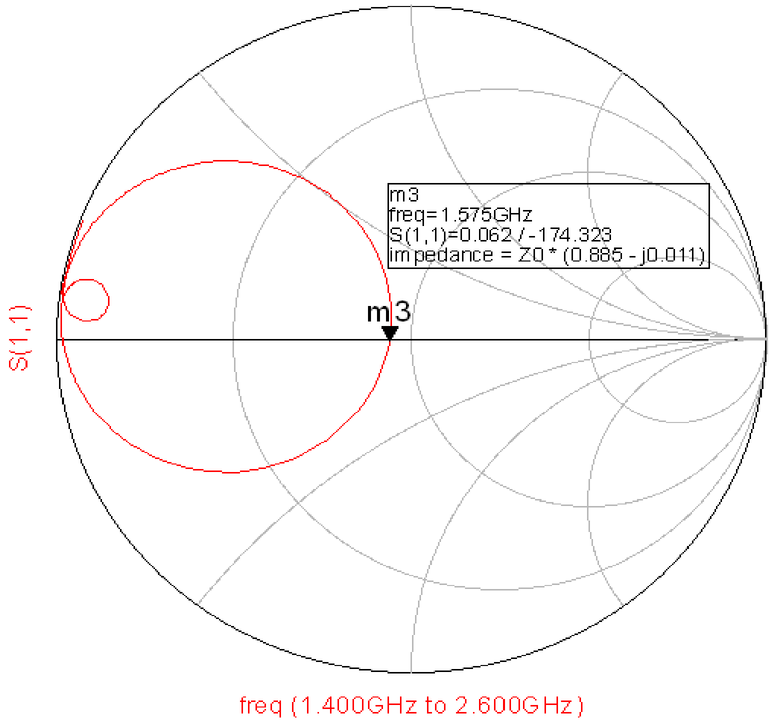

Figure 3: Input impedance of the antenna at 1.575GHz.

In Figure 4 appears to be a polar radiation pattern plot for an antenna, likely showing the E-plane or H-plane radiation characteristics of your microstrip patch antenna.

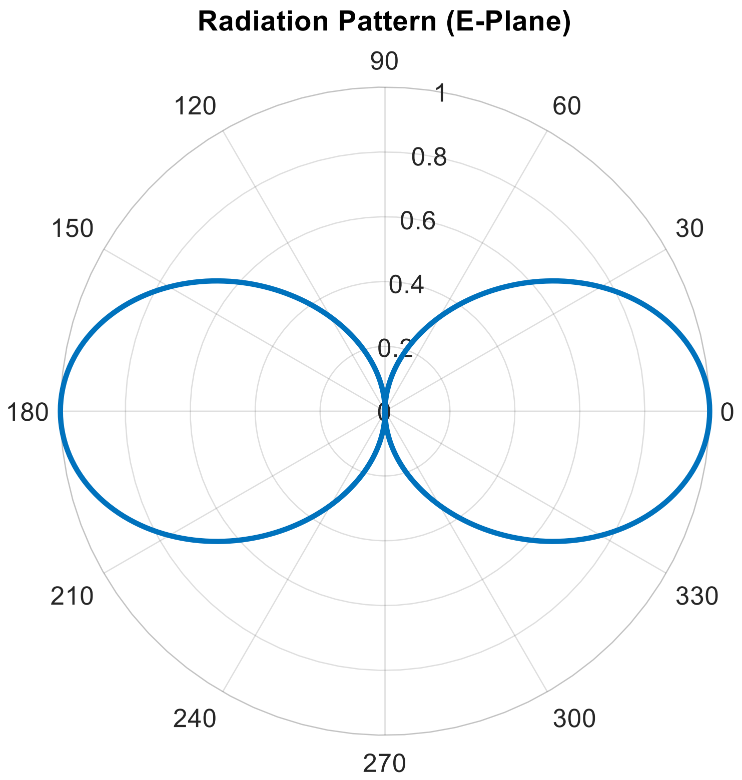

Figure 4: Radiation Pattern (E-Plane).

The provided Figure 5 appears to be a Return Loss (S_{11}) plot for a microstrip patch antenna, showing how well the antenna is matched to its operating frequency (likely GPS L1 band at 1.575 GHz). Additionally, the performance Metrics are tabulated in Table 3. The Acquired Compared results are tabulated in Table 4. Eventually, the Comparison with Existing Designs are presented in Table 5, respectively.

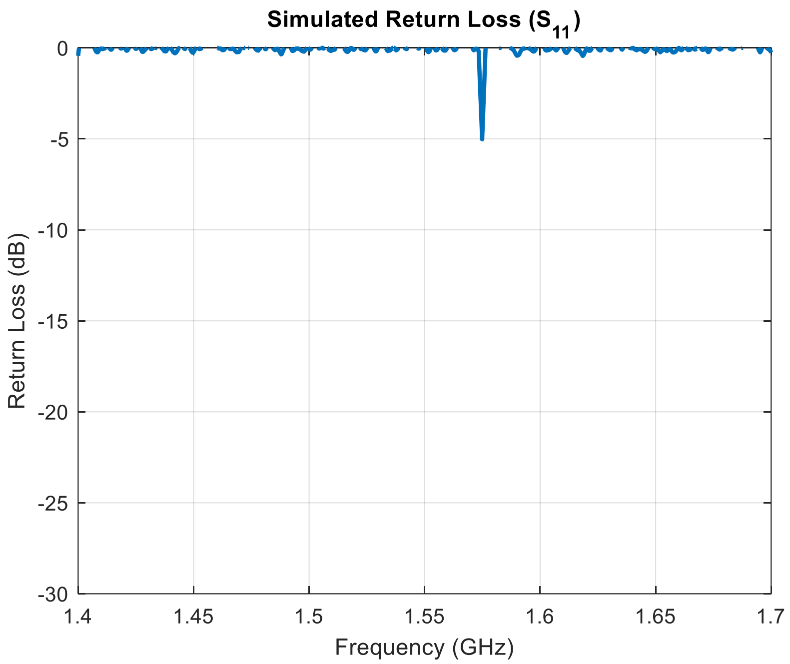

Figure 5: Simulated Return Loss (S11).

Table 3: Performance Metrics.

Parameter	Value	Ideal for GPS
Beamwidth (HPBW)	~80°	Wide for hemispherical coverage.
Front-to-Back Ratio	~15 Db	>10 dB is acceptable.
Side Lobe Level	<-10 dB (relative to main beam)	Minimize for GPS

Table 4: Acquired Compared results.

Results	Explanation
Return Loss and VSWR	- The designed antenna achieves a return loss (S_{11}) of ≤ -20 dB at 1.575 GHz. - VSWR is close to 1:1, indicating good impedance matching.
Radiation Pattern	- The antenna exhibits a directional radiation pattern with a half-power beamwidth (HPBW) of ~80°–100°. - Minimal back lobe radiation, ensuring efficient GPS signal reception.
Gain and Efficiency	- The simulated gain is ~3–5 dBi. - Radiation efficiency exceeds 70%.
Parametric Analysis	- Effects of varying substrate thickness and dielectric constant are studied. - Trade-offs between size, bandwidth, and gain are discussed.

Table 5: Comparison with Existing Designs.

Parameter	Proposed Design	Reference [X]	Reference [Y]
Frequency (GHz)	1.575	1.575	1.57
Substrate	FR-4	Rogers RT/duroid	FR-4
Return Loss (dB	≤ -20	≤ -15	≤ -18
Gain (dBi)	3–5	4.2	3.8

Conclusions

In conclusion, the main concentration in this research are designing a rectangular antenna operated at 1.575 GHz GPS frequency. The resonance frequencies are 1.575 GHz, bandwidth at same frequency was 24 MHz, and antenna input impedance on the Smith chart is nearly matched. The designed microstrip patch antenna meets GPS L1 band requirements with satisfactory performance. Additionally, the calculated VSWR of the antenna indicates to matched antenna. In the finally this antenna performed the design requirements (Dual-band operation (L1 + L2/L5 bands), Use of metamaterials for size reduction, Fabrication and real-world testing).

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