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Optimization of a 5.82 GHz Microstrip Patch Antenna for Sustainable EV Wireless Power Transfer Using Parasitic Elements and Dual Substrates of Polypropylene and Fused Quartz

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Abstract. As interest in sustainable and energy conscious technologies continues to rise, wireless power transfer (WPT) has become an important component in advancing green innovation by minimizing transmission losses and enabling contact-free power delivery. This work investigates the optimization at 5.82 GHz. The study examines how antenna performance can be improved through variations in substrate type, substrate thickness and slot geometry. A set of simulation models was developed using Fused Quartz and Polypropylene substrates with multiple thickness options, as well as a dual layer configuration in which the secondary substrate's thickness was varied. Additional performance gains were explored through several slot arrangements integrated into the patch. The optimized design, featuring a dual-substrate structure and a centrally positioned slot placed nearer to the feedline, achieved an efficiency of 95%. These findings support the advancement of high efficiency WPT systems that contribute to border sustainable and environmentally conscious energy solutions.

Introduction

Wireless Power Transfer (WPT) has become a major enabler for the next generation of electric vehicle (EV) charging systems, providing a more user friendly and efficient alternative to conventional plug-in methods by removing the need for physical contact [1]. By improving convenience and supporting scalable charging infrastructure, WPT contributes to overcoming several barriers that still limit widespread EV adoption. Within the family of WPT methods, magnetic resonant coupling (MRC) stands out because it can deliver power efficiently over moderate distances, making it a strong candidate for EV use cases [2,4]. The transmitting antenna, a key element of any MRC system, plays a central role in determining how effectively energy is delivered.

Recent work has emphasized optimizing microstrip patch antennas, especially through substrate material and thickness selection. Yakub et al. [5] demonstrated their strong influence on antenna characteristics, while comparative studies linked dielectric constant to antenna gain and size [5]. High permittivity substrates reduce antenna dimensions but introduce losses, highlighting design trade-offs. To improve bandwidth, Upadhay and Dwivedi [6] proposed a dual-layer substrate configuration, reinforcing the importance of tailored substrate engineering.

Geometric modifications such as slots have also been widely explored. Slots can enhance bandwidth, impedance matching, and efficiency. Hkanoglu et al. [7] reported bandwidth improvements, Paul et al. [8] introduced a compact wrench shaped slot antenna for higher efficiency, and Nornikman et al [9] optimized dual-layer structure combined with slots. These studies underscore the potential of structural modifications to advance antenna performance.

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While many techniques target far-field WPT [10], limited research focuses on near-field EV charging. This paper therefore investigates microstrip patch antenna optimization for EV WPT, examining substrate selection, thickness and slot integration. Using Ansys simulations, return loss, VSWR, and radiation patterns are analyzed to identify effective substrate configurations and slot designs for High-performance stationary WPT.

Methodology

Objective. The goal behind this paper is to optimize a microstrip patch antenna capable fo delivering efficient WPT for EV application at 5.82 GHz. The study aims to generate a strong electromagnetic field while ensuring high impedance matching and maximizing near-field radiated power to improve overall antenna performance. The key performance metrics evaluated in this study are summarized in Table 1.

Table 1. Performance Metrics

Performance Metric	VSWR	S Parameter	Beam Efficiency	Near E	Near H
VSWR	<1.7	<-10	>95%	>5	>4

Description of the Simulation Setup and Parameters

Effect of Substrate Material and Thickness on Antenna Performance. The first step of the study examined sic microstrip patch antenna configurations operating at 5.82 GHz, each differing in substrate material and thickness as listed in Table 2. Fused Quartz and Polypropylene were selected as the substrate materials for this study. The simulations aimed to analyze the impact of these two substrates, each with varying thicknesses of 2mm, 4mm, and 8mm, on the performance of the simple microstrip patch antennas, Fig. 1.

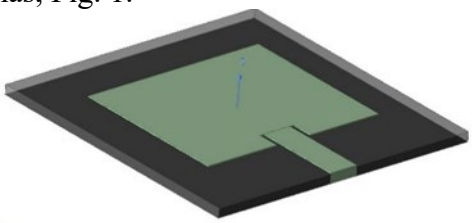


Fig. 1. Microstrip Patch Antenna: Initial Design

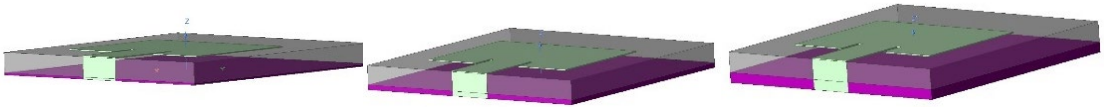
Table 2. Step 1 Simulation Parameters

Model	Substrate Material	Dielectric Constant ε_r	Substrate Height (mm)	Width (mm)	Height(mm)
1	Fused Quartz	3.78	2	16.729	12.440
2	Fused Quartz	3.78	4	16.729	11.177
3	Fused Quartz	3.78	8	16.729	8.627
4	Polypropylene	2.2	2	20.446	19.868
5	Polypropylene	2.2	4	20.446	14.627
6	Polypropylene	2.2	8	20.446	11.528

Dual-substrate configuration and thickness optimization. In the second step, a secondary substrate is introduced to the best-performing model identified in step 1. This additional substrate is positioned between the ground plane and the initial substrate. The antenna's performance is then evaluated by varying the thickness of the secondary substrates from 0.2mm to 0.5mm and 1mm,

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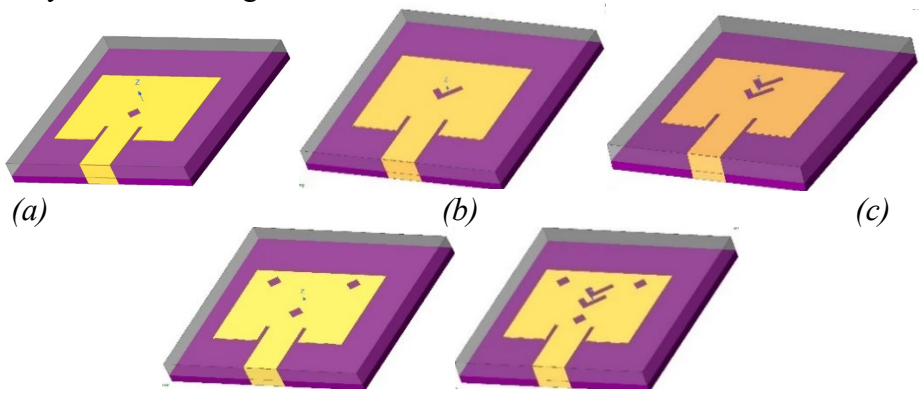
as illustrated in Fig. 2. The objective of this step is to investigate he impact of a dual-substrate configuration and the influence of substrate thickness on the antenna's performance.



(a) (b) (c)

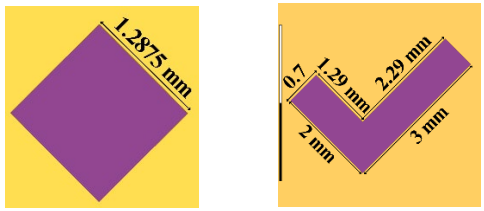
Fig. 2. Dual-Substrate Microstrip Patch Antenna (a) 0.2mm (b) 0.5mm (c) 1mm

Slot design and placement optimization for enhanced antenna performance. In the third step, slots are introduced into the patch antenna. These slots are openings or parasitic elements incorporated into the antenna structure. Five different slot designs are compared using the best-performing antenna model from step 2, as demonstrated in Fig. 3. Fig. 4 provides the dimensions of the slots used in the design. The aim of this step is to assess the impact of slot shape and placement on the antenna's performance, specifically regarding impedance matching, radiated power, reflectivity, and the strength of the Near H and Near E fields.



(a) (b) (c) (d) (e)

Fig. 3. Slots designs (a) Model 1: Single Centered (b) Model 2: Centered Checkmark (c) Model 3: Two Centered Checkmarks (d) Model 4: Scattered Slots (e) Model 5: Combined



(a) (b)

Fig. 4. Slots Dimensions (a) Squared Slot (b) Checkmark

Results and Discussion

Results

Effect of substrate material and thickness on the antenna performance. Based on Fig. 5, Model 2 (FQ – 2 mm) and Model 5 (PP – 2 mm) emerge as the best performers among the six tested. Model 2 provides the lowest VSWR at 2.62 and reaches the highest efficiency of 0.807, making it the most dependable choice for reducing losses and improving overall power transfer. Model 5, in comparison, delivers the highest gain of 6.04 dB but falls behind with an efficiency of 0.669 and a VSWR of 3.79, suggesting better directionality but weaker efficiency.

The beam pattern results also reflect this contrast. Model 5 produces the most concentrated beam with the smallest beam area of 2.101 sr, while Model 2 offers an area of 2.6105 sr. Their

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S11 values reinforce the same trend with Model 2 achieving -6.992 dB which is lower than that of Model 5.

The near-field behavior evaluation shows that both designs have close E-field performance, but Model 2 produces a stronger H-field level of 3.72 dB. In summary, Model 2 provides the most balanced behavior across all evaluated metrics; However, Model 5 remains for higher gain and beam concentration applications.

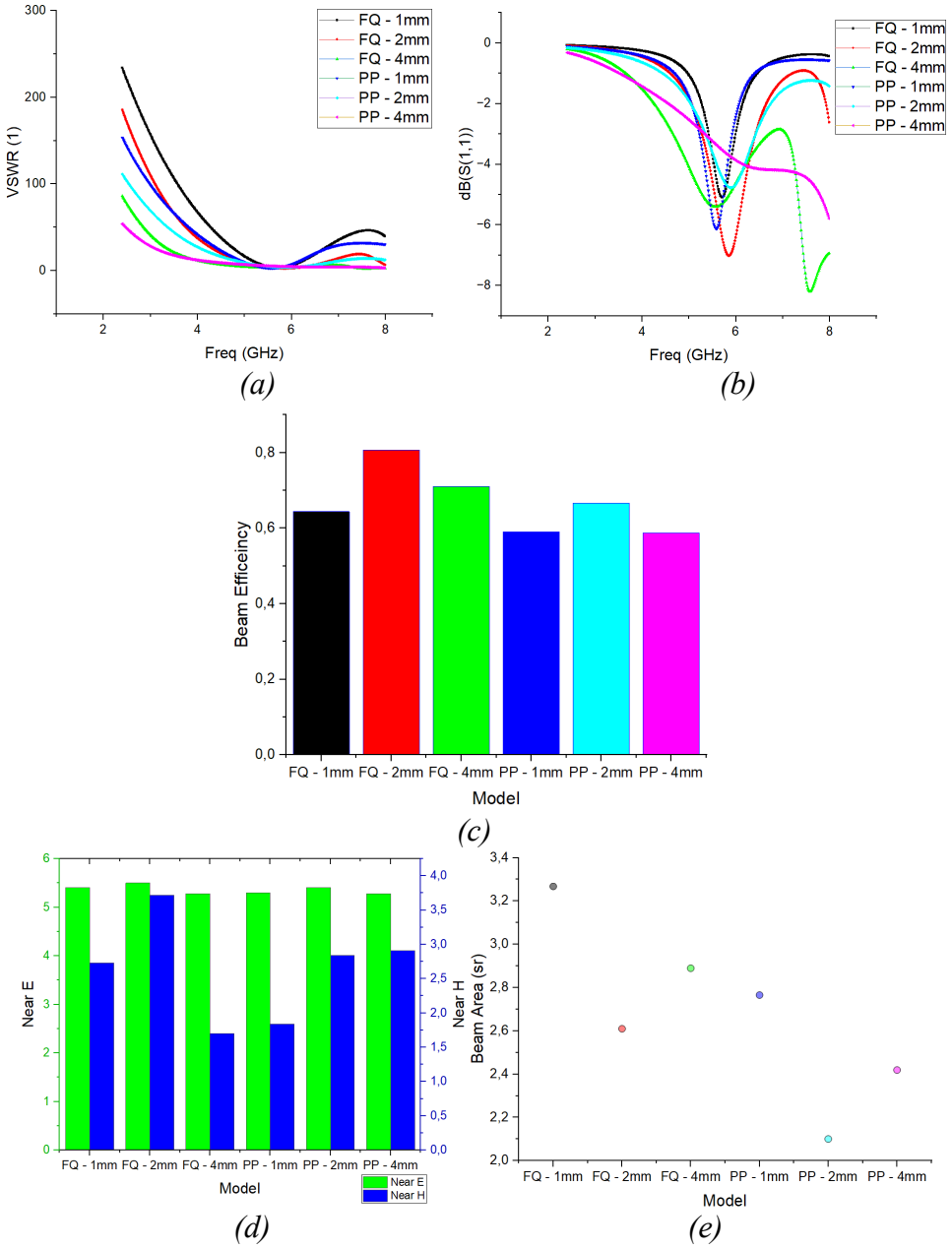


Fig. 5. Impact of substrate material and thickness on: (a) VSWR (b) S Parameter (c) Beam Efficiency (d) Near E and Near H (e) Beam Area

Table 3 illustrates how substrate thickness influences antenna behavior, showing that a moderate value of 2 mm provides the most balanced performance across the evaluated metrics.

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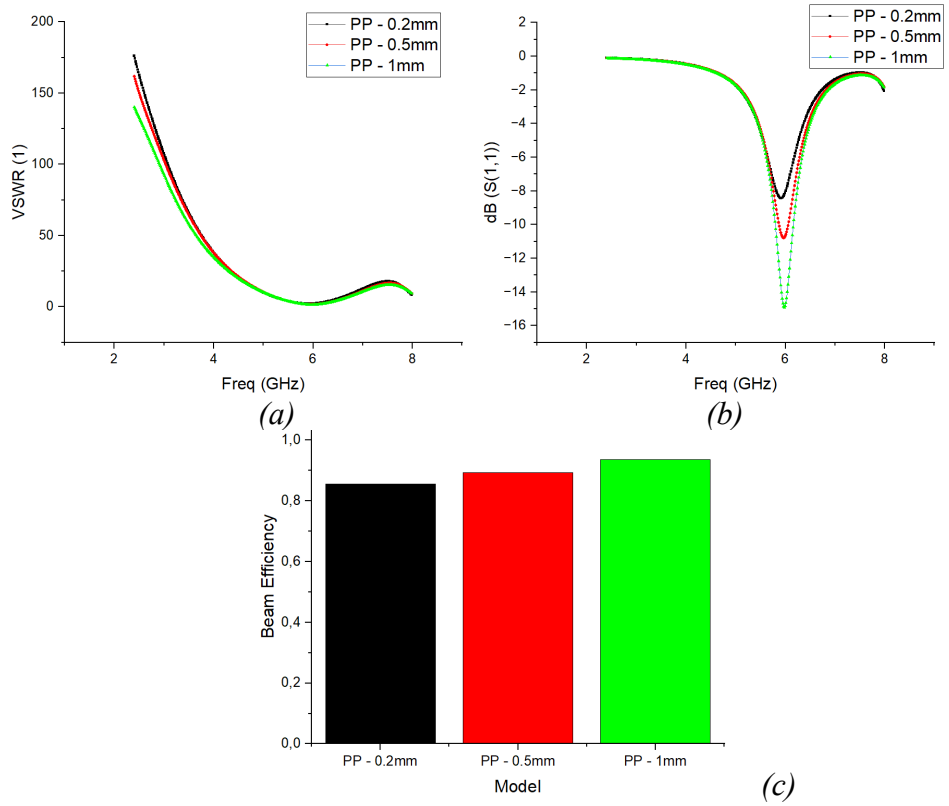
Table 3. Substrate Thickness Impact on the Antenna Performance

Subs. Thickness	Effect on Performance
1mm	High VSWR - Low Gain - Low Efficiency - Large Beam Area
2mm	Low VSWR - High Gain - High Efficiency - Small Bear Area
4mm	Low VSWR - High Gain - Low Efficiency - Small Beam Area

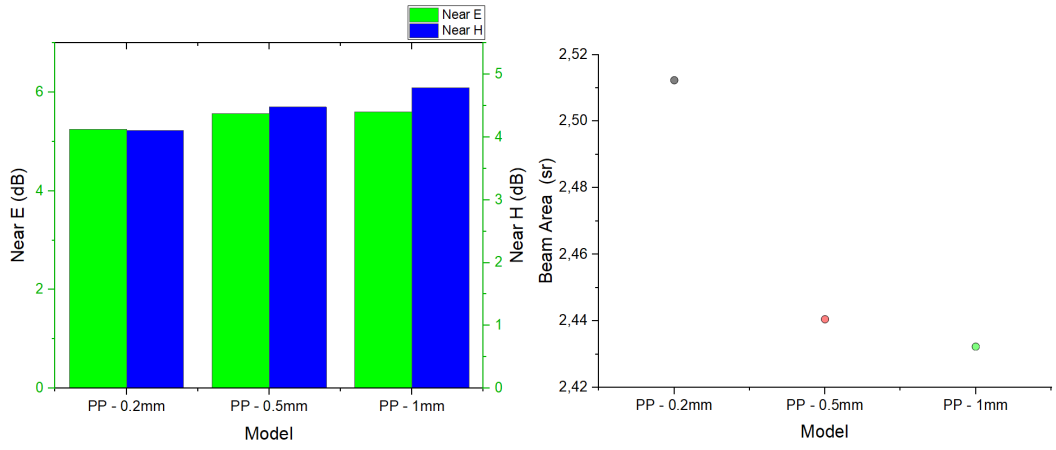
Dual-substrate configuration and thickness optimization. As shown in Fig.6, increasing the thickness of the secondary polypropylene (PP) layer leads to consistent improvement in antenna performance. The VSWR drops from 2.322 in Model 1 to 2.080 in Model 2, and further to 1.822 in Model 3 indicating better impedance matching. A similar pattern appears in the efficiency values, which rise from 0.855 to 0.893 and reach a peak of 0.936, suggesting stronger electromagnetic confinement and lower energy losses.

The radiation pattern also becomes slightly more focused as thickness increases. The beam area is reduced from 2.512 sr in Model 1 to 2.432 sr in Model 3. Reflection performance improves as well. S11 decreases from -8.002 dB to -10.714 dB, reinforcing the improvement in matching quality.

Near-field measurements follow the same upward trend. The E-field grows from 5.52 to 5.60 dB, while the H-field shows a more substantial increase, rising from 4.11 to 4.79 dB. This stronger magnetic field response highlights the advantage of thicker substrates in WPT systems, where magnetic coupling plays a key role.



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(d) *(e)*

Fig. 6 Dual-Substrate Simulation Results (a) VSWR (b) S Parameter (c) Beam Efficiency (d) Near E and Near H (c) Beam Area

Among the tested configurations, Model 5 shows the strongest overall results. It attains the lowest VSWR of 1.667, the highest efficiency of 0.953, and the greatest radiated power, demonstrating its ability to reduce losses and improve energy transfer.

The beam area shows only minor variation across the designs, ranging from 2.403 sr in Model 1 to 2.459 sr in Model 3. This indicates that slot geometry has a limited effect on beam spread. Reflection behavior also highlights Model 5 as the top performer, with an S11 value of -12.042 dB, confirming its superior impedance matching.

Near-field analysis reveals similar trends among the models, though Model 3 achieves slightly higher peak E field and H fields strengths, making it favorable in cases where near field intensity is the priority.

Table 4. Slots Effect Simulation Results

Model	VSWR	S 11 Parameter	Beam Efficiency	Near E (dB)	Near H (dB)	Beam Area (sr)
1: Centred Slot	1.726757	-11.485147	0.95	5.59641	4.82441	2.403499
2: Centred Checkmark	1.76723	-11.142393	0.94	5.5966	4.83002	2.434855
3: Two Centred Checkmarks	1.741372	-11.358632	0.94	5.60014	4.83996	2.458565
4: Scattered Slots	1.836031	-11.088892	0.92	5.58437	4.71065	2.441693
5: Combined	1.666634	-12.041521	0.96	5.59744	4.84201	2.445187

As shown in Fig. 1, Model 5 outperforms the baseline design. The corresponding Near E field and Near H field distributions for this optimized configuration are presented in Fig. 7.

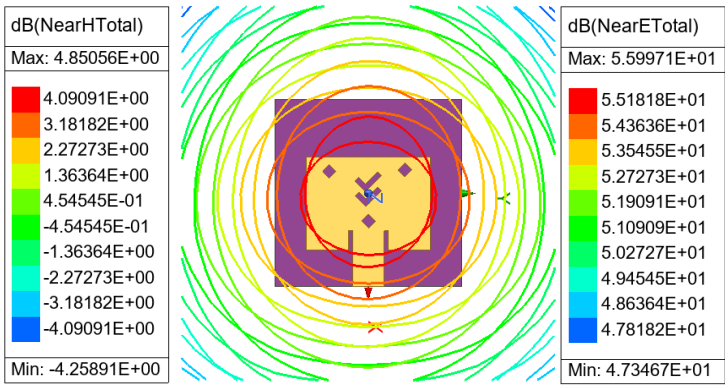


Fig. 7. The Near E and Near H fields distribution and strength

Discussion

The results show that FQ outperforms PP as a substrate for the microstrip patch antenna, particularly at 2 mm. Its lower dielectric constant and loss tangent support better impedance matching and higher efficiency by limiting internal losses. FQ's stable and homogeneous structure also improves signal clarity and beam, focus. In contrast, PP delivers weaker overall performance at all thicknesses, with reduced radiation efficiency. Its higher thermal expansion and less favorable dielectric properties lead to poorer wave propagation, making FQ the more effective substrate choice.

Performance improvements observed with the added PP layer in the dual-substrate configuration arise from how the differing dielectric constants confine and guide the electromagnetic fields. This adjustment enhances wave propagation, reduces internal power loss and increases radiated output. The corresponding rise in near-field levels indicates a stronger magnetic component, which benefits WPT efficiency.

Slot incorporation further enhanced antenna behavior by introducing parasitic elements that intentionally disturb the surface current paths. These disruptions force currents to travel along longer routes, which in turn creates additional resonant modes, shifting ethe primary resonant frequency. And broaden the bandwidth. The single slot in Model 1 perturbed the current near its maximum, altering the local field density. The double checkmark slots acted as parasitic resonators, strengthening both Near H and Near E fields by increasing localized currents, reducing concentration. The scattered edge slots helped suppress surface wave currents, reducing the S-parameter and improving impedance matching. Together, these parasitic features reshape the field distribution and support multiple resonance pathways, yielding higher radiation efficiency and reduced losses.

Conclusion

This work demonstrated that combining a high-performance substrate such as FQ with carefully designed slot geometries significantly enhances the efficiency, matching, and near-field behavior of microstrip patch antennas for EV WPT. These improvements support more reliable and energy efficient wireless charging in stationary settings. Future studies should extend these findings to dynamic charging conditions, explore new materials and geometries, and integrate beamforming or metamaterial techniques for next generation WPT Systems.

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