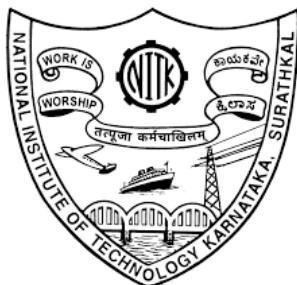


Wireless Power Transmission System



A Term Project Report

Submitted by

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Table of Contents

Abstract	1
1. Introduction	2
2. Objective and Problem Statement	3
3. Design Specifications	4
4. Implementation	6
5. Conclusion and Future Scope	14
References	15

Abstract

Wireless Power Transfer (WPT) is a rapidly advancing technology that enables the transmission of electrical energy without the need for physical wired connections. This capability offers significant benefits for powering remote, portable, and battery-constrained devices, particularly in Internet of Things (IoT) networks, biomedical systems, and sensor-based applications. In this project, a radio-frequency (RF) based WPT system is designed and simulated using microstrip patch antennas for both transmission and reception. The system comprises an RF source, a pair of optimized patch antennas, an impedance matching network, a rectifier circuit, and a resistive load. Harmonic Balance (HB) and Large Signal S-parameter (LSSP) analyses were used to evaluate impedance behavior, nonlinear rectification performance, and overall power transfer efficiency. The design process involved iterative tuning of antenna parameters, matching components, and rectifier configuration to minimize losses and improve RF-to-DC conversion.

The final optimized system achieved a maximum Power Conversion Efficiency (PCE) of 88.228 percentage, demonstrating effective end-to-end wireless energy transfer and confirming the suitability of microstrip antennas and RF rectifier circuits for low-power WPT applications. This high efficiency validates the integration of impedance matching and rectification strategies as a practical approach to enhancing performance in compact, low-cost WPT systems. The work highlights the potential of RF-based WPT for energy harvesting scenarios, enabling autonomous device operation without traditional battery maintenance. Future research may explore multi-stage rectification, antenna array configurations, adaptive matching, real-world prototype fabrication, and system validation under practical deployment conditions.

CHAPTER 1: Introduction

Wireless Power Transfer (WPT) technology enables the delivery of electrical power from a transmitter to a receiver without the need for physical wired connections. With the rapid growth of portable electronics, sensor networks, biomedical implants, and Internet of Things (IoT) devices, the demand for reliable and efficient wireless powering techniques has increased significantly. Traditional battery-based solutions require periodic replacement or recharging, which may be impractical or costly in many applications. WPT offers an attractive alternative by extending device lifetime and enhancing system reliability through contactless energy transfer.

Among various WPT techniques, radio frequency (RF) based power transfer is widely utilized due to its long-distance capability, flexibility, compact hardware requirements, and compatibility with existing communication bands. The efficiency of RF-WPT systems largely depends on the performance of transmitting and receiving antennas, impedance matching networks, and the RF-to-DC rectification stage. Microstrip patch antennas are particularly suitable for such systems because of their lightweight structure, low profile, ease of fabrication, and ability to integrate with printed circuits.

This project focuses on the design and implementation of an RF wireless power transfer system using microstrip patch antennas operating at the chosen resonant frequency. The system consists of an RF power source, transmitting and receiving patch antennas, an impedance matching network, a rectifier circuit, and a load. The goal is to analyze and improve power transfer efficiency by optimizing antenna design parameters, minimizing reflection losses, and enhancing rectifier performance. Simulation and performance evaluation are carried out to assess output DC power and overall system efficiency under various operating conditions.

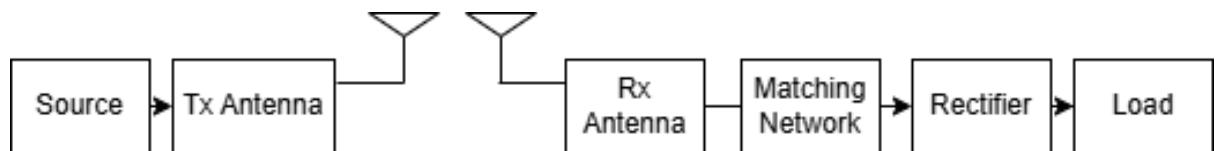


Figure 1: Block diagram of the WPT system

CHAPTER 2: Objective and Problem Statement

2.1 Problem Statement

Wireless Power Transfer (WPT) has gained significant attention as a promising solution for providing electrical energy to devices without physical wired connections. However, the efficiency of WPT systems is strongly influenced by factors such as antenna design, impedance matching, transmission distance, and RF-to-DC conversion performance. Achieving high power transfer efficiency while maintaining compact geometry and low cost remains a technical challenge, especially for low-power energy harvesting applications.

In this project, a microstrip patch antenna-based WPT system is designed and implemented, consisting of an RF power source, transmitting and receiving antennas, a matching network, an RF rectifier, and a load. The problem addressed is optimizing the RF link and rectification stages to maximize the delivered DC power at the load under realistic operating conditions. The focus is on improving system efficiency through accurate antenna design, impedance matching, and rectifier circuit optimization.

2.2 Objective

- To design and simulate microstrip patch transmitting and receiving antennas suitable for RF Wireless Power Transfer applications.
- To establish an end-to-end WPT system comprising RF source, patch antenna pair, matching network, rectifier, and load.
- To analyze power transfer efficiency.
- To design and optimize impedance matching network to ensure maximum power transfer between antenna and rectifier stages.
- To develop a high-efficiency RF-to-DC rectifier circuit and evaluate its performance for various load conditions.
- To validate the complete WPT system using electromagnetic and circuit-level simulations and measure DC output power and efficiency.

CHAPTER 3: Design Specifications

The design of the Wireless Power Transfer (WPT) system is centered around ensuring reliable RF energy transmission and efficient RF-to-DC conversion at the receiving end. To achieve this, each subsystem including the transmitting antenna, receiving antenna, matching network, and rectifier is engineered with precise electromagnetic and circuit-level constraints. The system operates at 1.8 GHz, a frequency selected due to its favorable trade-off between antenna size, propagation characteristics, and availability within industrial communication bands.

A microstrip patch antenna topology is chosen for both transmission and reception owing to its compact form factor, low fabrication cost, planar geometry, and ease of integration with RF circuits. The specifications summarized in Table 1 define the core performance requirements of the WPT link, ensuring sufficient radiated power, minimal reflection losses, and optimal load conditions for efficient rectification. These parameters form the basis for antenna dimensioning, feed optimization, and the non-linear behavior of the rectifier stage.

Parameter	Value
Operating Frequency (F)	1.8 GHz
Antenna Type	Rectangular microstrip patch
Substrate Material	FR-4
Return Loss	-11.8 dB at 1.8 GHz
Impedance (Z_0)	50 Ω
Gain (Gt, Gr)	3 dBi
Transmitted Power (Pin)	3 mW
Input Impedance (Z_{in})	50 Ω
Optimal Load Impedance (Z_l)	2.7 kΩ
Target Efficiency (η)	75–90 %

Table 1: Specifications of the WPT System

These system-level specifications ensure that the antennas resonate at the desired frequency, provide adequate directional gain, and maintain impedance compatibility with standard RF components. The chosen load impedance of $2.7\text{ k}\Omega$ corresponds to the rectifier's optimal operating point, enabling maximum RF-to-DC power conversion.

Antenna (Patch) Detailed Parameters

The microstrip patch antenna was designed using electromagnetic synthesis equations and subsequently refined through simulation to achieve stable resonant behavior. The physical parameters of the patch, ground plane, and substrate directly influence the antenna's resonant frequency, bandwidth, and radiation efficiency. Table 2 summarizes the optimized geometric and material specifications obtained from the MATLAB Antenna Designer tool.

Patch Parameter	Value (units)
Patch Length (L)	0.03687 m
Patch Width (W)	0.047512 m
Substrate Height / Thickness (h)	0.0007602 m
Ground Plane Length	0.07602 m
Ground Plane Width	0.07602 m
Patch Center Offset	[0 0] m
Feed Offset	[0.007762 0] m
Tilt (degrees)	0
Tilt Axis	[1 0 0]
Substrate Catalog / Name	FR-4
Dielectric Constant (ε_r)	4.8
Loss Tangent	0.026

Table 2: Microstrip patch (antenna) design parameters

The patch dimensions were initially calculated using the cavity model equations and then fine-tuned to ensure precise resonance at 1.8 GHz. The feed offset was adjusted to improve impedance matching and reduce return loss. Although FR-4 introduces moderate dielectric losses, it remains suitable for cost-effective WPT applications where compactness and manufacturability are prioritized. The ground plane dimensions provide adequate suppression of edge diffraction, contributing to stable radiation characteristics and efficient surface current distribution.

These optimized parameters ensure that the antenna exhibits acceptable bandwidth, consistent radiation patterns, and correct impedance alignment with the RF source and rectification circuitry. As a result, the antenna serves as a key enabling component for achieving high-efficiency energy transfer within the WPT system.

CHAPTER 4: Implementation

The implementation of the Wireless Power Transfer (WPT) system consists of the structured development and electromagnetic/circuit-level validation of its core components: the transmitting antenna, receiving antenna, impedance matching network, nonlinear RF rectifier, and the end-to-end RF-to-DC conversion chain. Each subsystem is designed using specialized tools; MATLAB Antenna Designer and Keysight ADS—to ensure accurate modeling of electromagnetic behavior, nonlinear circuit characteristics, and system-level performance under realistic operating conditions.

The process begins with the design of a rectangular microstrip patch antenna using MATLAB's Antenna Designer tool. This antenna topology is selected due to its low profile, planar geometry, and compatibility with printed circuit board (PCB) implementations, making it ideal for compact wireless power transfer systems. The antenna is designed on an FR4 substrate, whose dielectric constant, thickness, and loss tangent critically determine the resonant behavior and efficiency of the radiating structure. These substrate parameters are incorporated into the electromagnetic model, and iterative tuning is performed to optimize the patch dimensions and feed offset. The design objective is to achieve resonance precisely at 1.8 GHz with minimal reflection losses and stable radiation characteristics suitable for far-field power transfer.

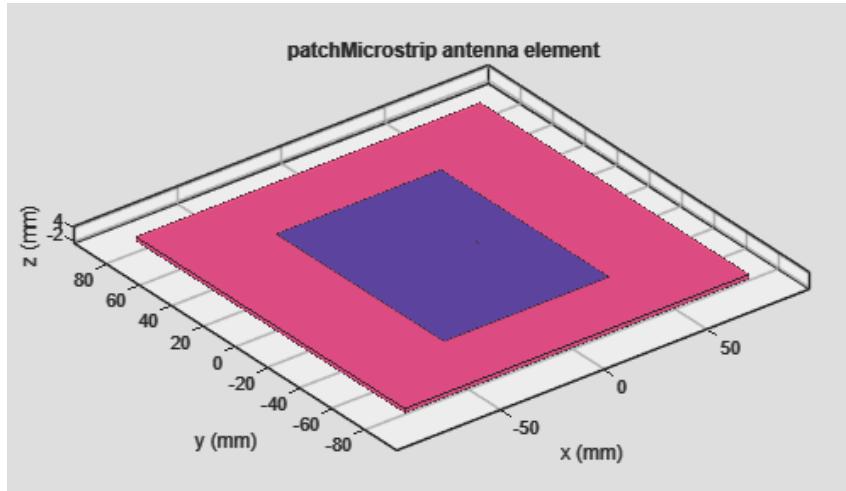


Figure 2: Microstrip Patch Antenna

Detailed electromagnetic simulation yields multiple key performance plots. The S11 curve confirms impedance matching and resonance behavior, while the input impedance plot reveals the real and imaginary components around the operating frequency. Radiation pattern evaluation,

including both elevation and azimuth cuts, provides insight into antenna directivity, half-power beamwidth, and side-lobe distribution. Additionally, current distribution plots illustrate surface current flow over the patch, validating excitation of the fundamental TM_{10} mode. Once validated, the antenna geometry is exported to MATLAB workspace for later integration in link-budget estimation and RF propagation analysis.

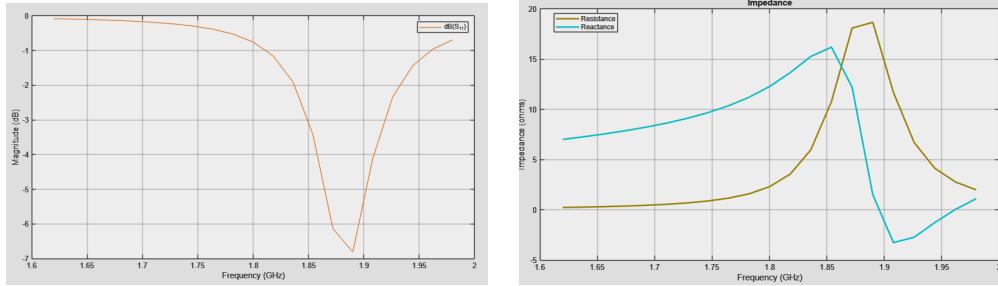


Figure 3: S11 parameter and impedance plot of the designed antenna

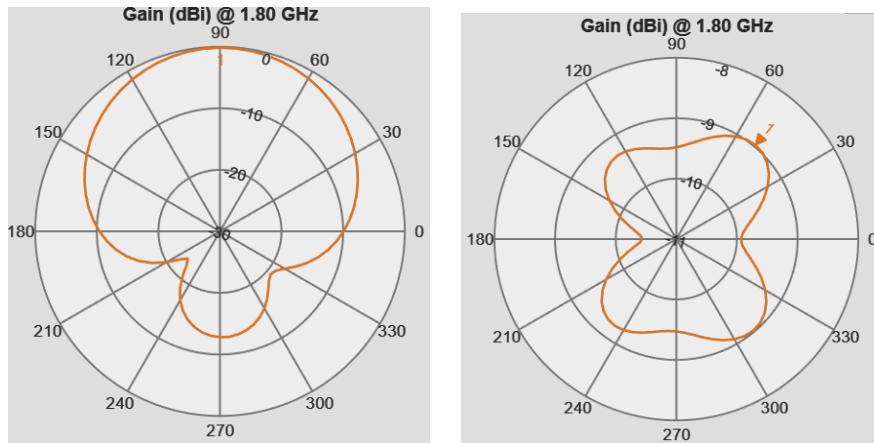


Figure 4: Elevation and Azimuth plot of the designed antenna

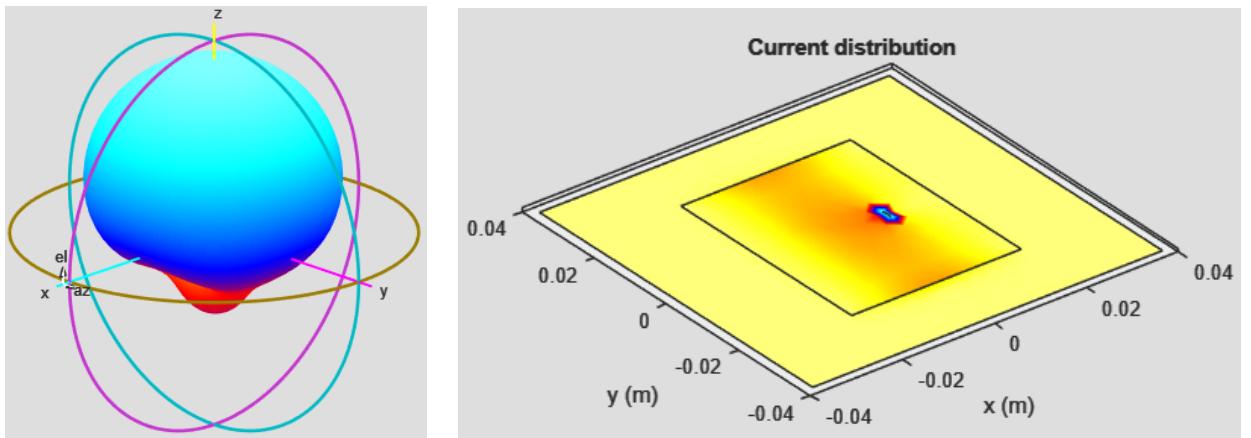


Figure 5: Radiation Pattern and Current Distribution of the designed antenna

After validating the antenna subsystem, the rectification and matching blocks are developed in ADS. The first step is to construct an accurate diode model that captures nonlinear junction behavior, parasitic capacitances, and forward conduction properties essential for RF-to-DC conversion. This diode model serves as the core element of the voltage doubler rectifier as well as the impedance matching network, ensuring that system simulations reflect realistic device performance at GHz frequencies.

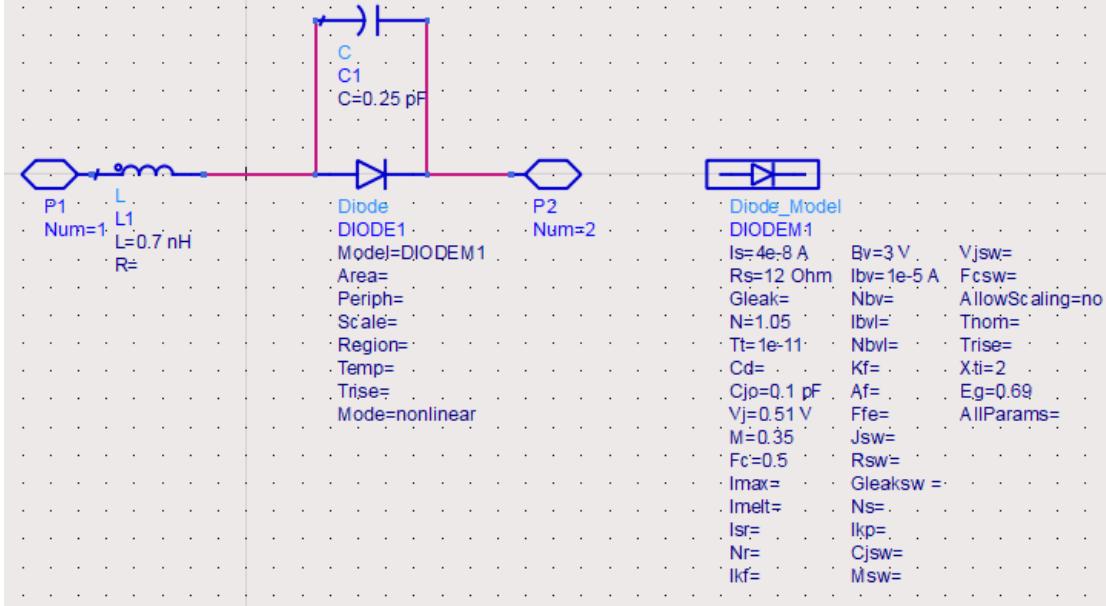


Figure 6: Schematic of Diode Model

An input impedance matching circuit is then designed to minimize reflections between the receiving antenna and the nonlinear rectifier. Since rectifier impedance varies with frequency and input power level, achieving broadband or power-adaptive matching is inherently challenging. A lumped-element matching network is initially synthesized to bring the real and imaginary impedance components toward the 50Ω reference. This is followed by Smith chart-based fine tuning, allowing more precise placement of reactive components and enabling accurate transformation of the complex impedance onto the desired matching circle.

Smith chart analysis assists in ensuring that the impedance trajectory intersects the 50Ω center at the operating frequency, thereby reducing return loss and maximizing power delivered to the rectifier. This step is essential because even small impedance mismatches can significantly degrade the effective RF-to-DC conversion efficiency.

The matching network is analyzed by applying a 5 dBm RF input signal, resulting in a measured Power Conversion Efficiency (PCE) of approx-

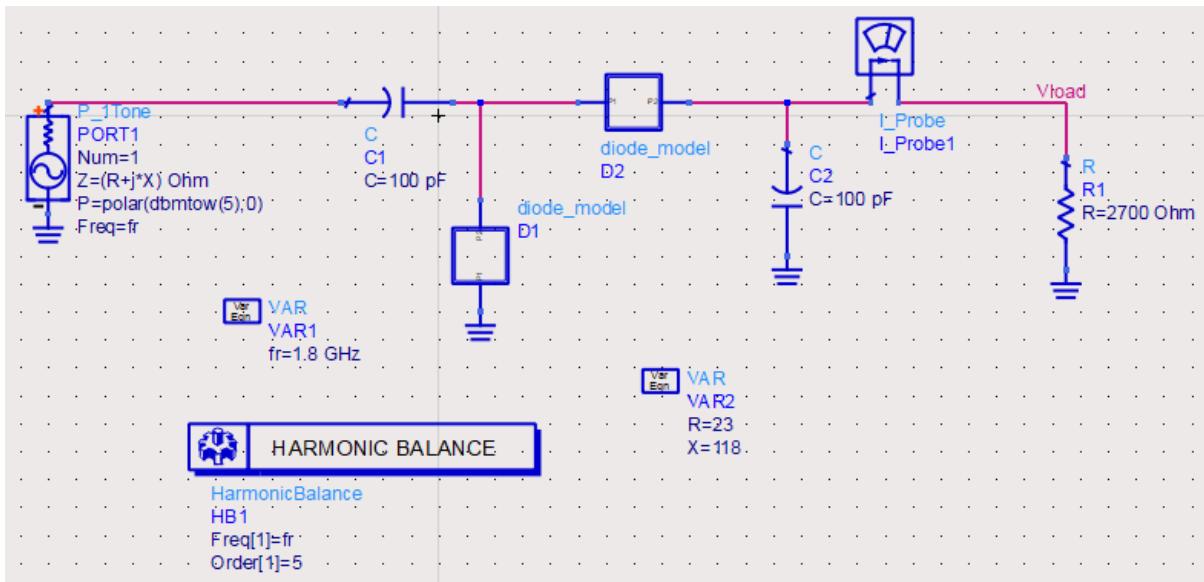


Figure 7: Schematic of Input Impedance Matching Circuit

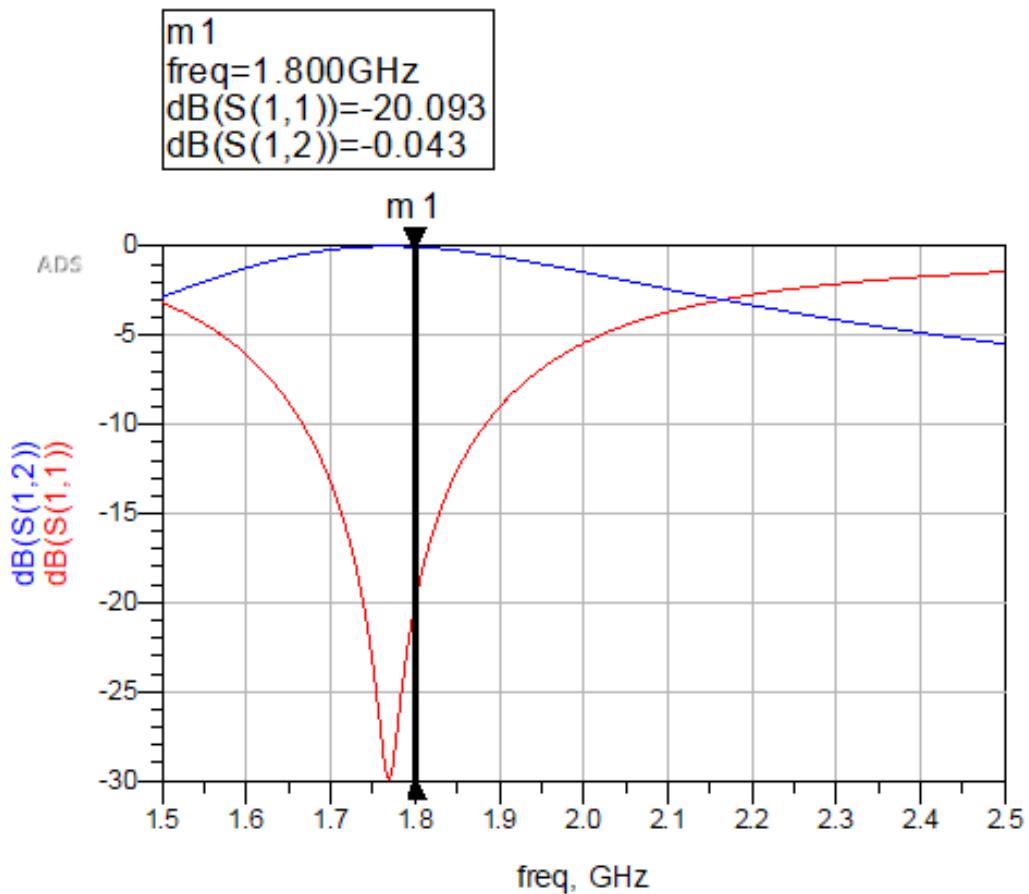


Figure 8: S-parameter plot for Matching Circuit

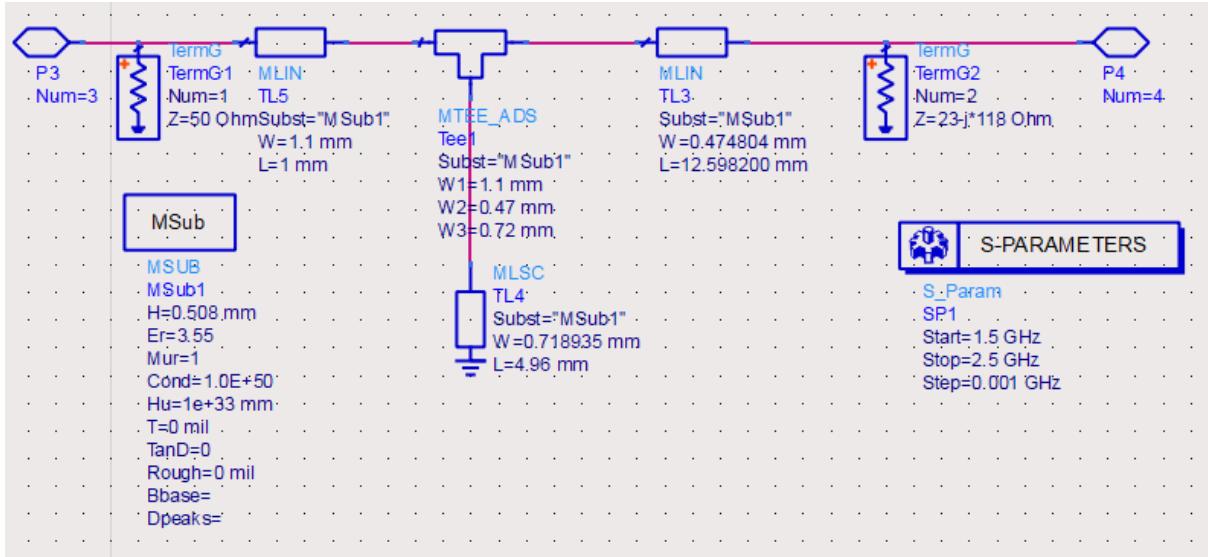


Figure 9: Smith Chart Matching Circuit

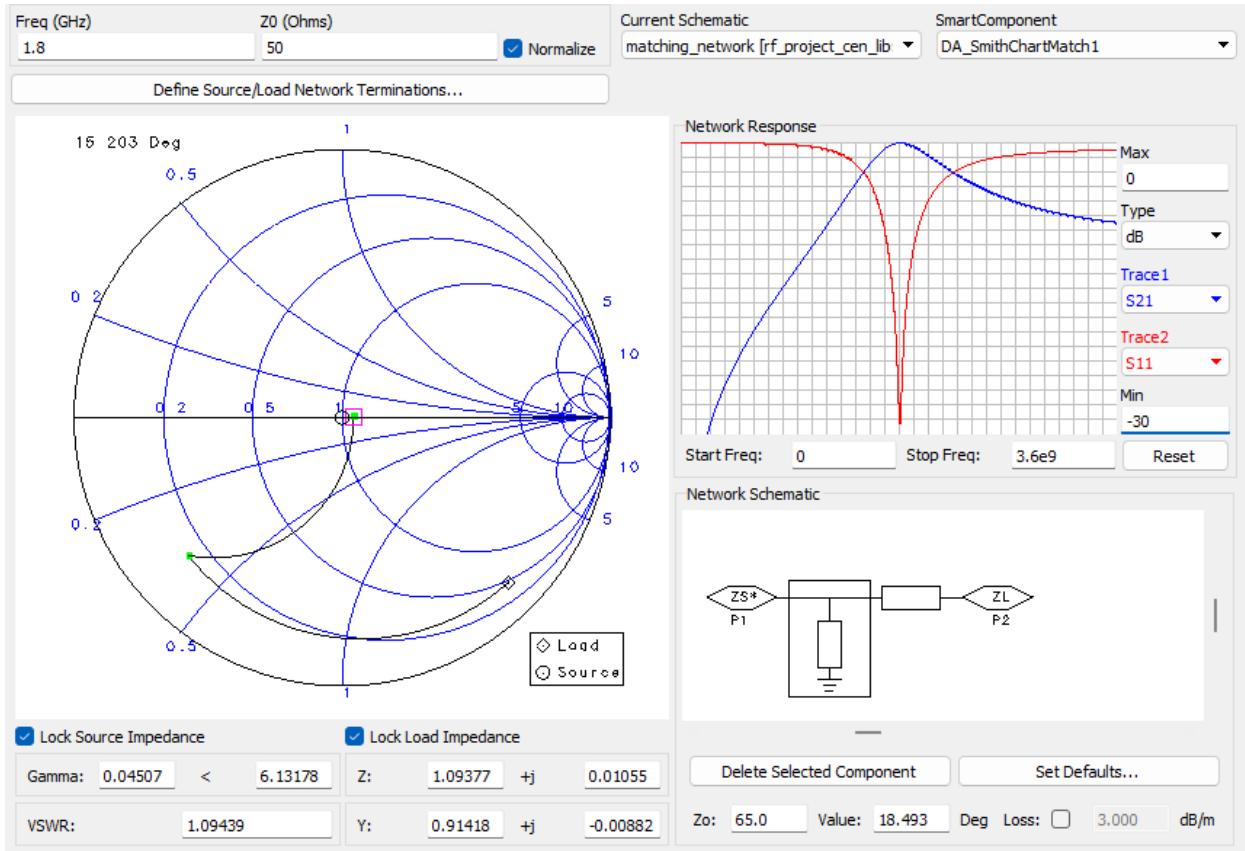


Figure 10: Smith Chart Impedance Matching

imately 73.96%. This confirms that reactive compensation is effective and that the majority of the incoming RF energy reaches the rectifier.

The rectifier stage uses a voltage doubler configuration to enhance the

$$\text{Eqn PCE} = 100 * \text{real}(V_{\text{load}}[0] * V_{\text{load}}[0]) / (2700 * 0.003)$$

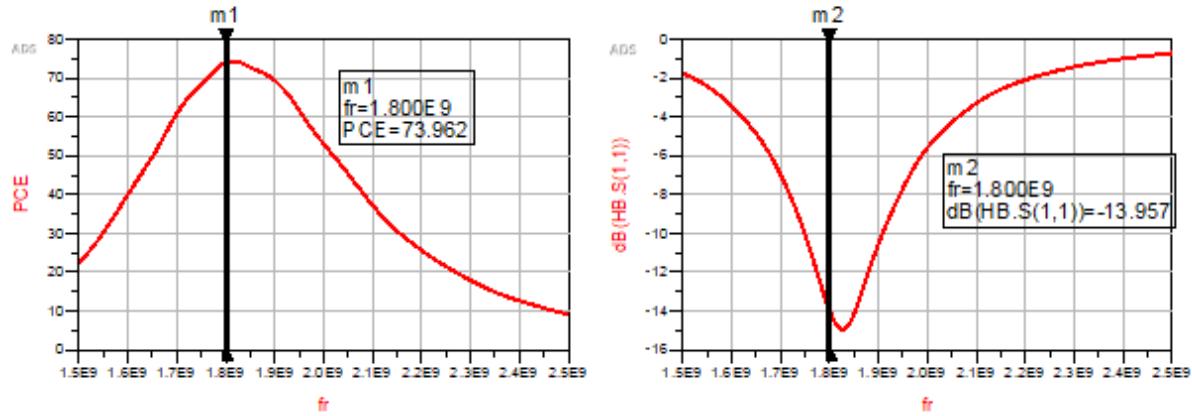


Figure 11: Efficiency after matching stage

DC output voltage. This architecture consists of two capacitors and a Schottky diode arranged such that the RF input is successively rectified and stored, effectively doubling the peak voltage at the output node. An additional RC smoothing filter provides ripple suppression and ensures that the load receives a stable DC voltage suitable for low-power electronics.

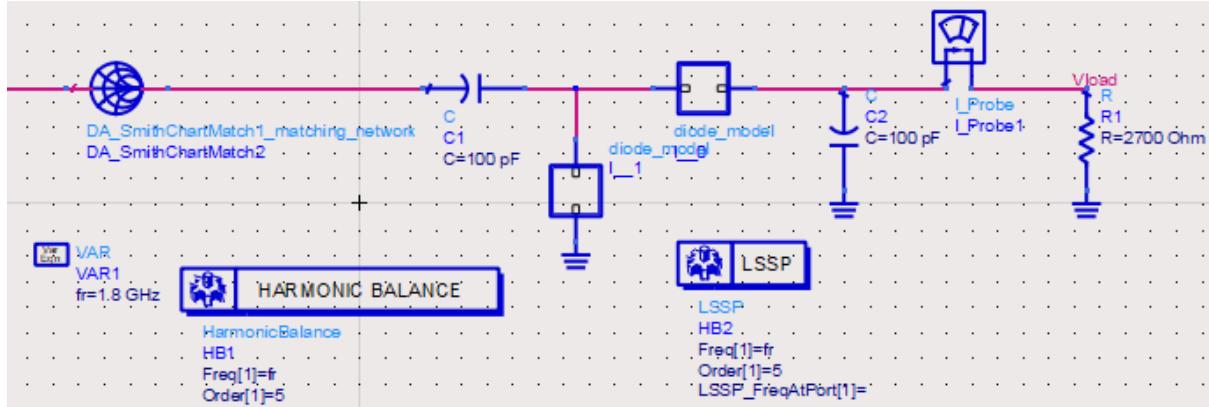


Figure 12: Schematic of RF Rectifier

After completing the antenna, matching network, diode model, and rectifier design, all subsystems are integrated into a unified WPT system schematic in ADS. This full-system environment allows simulation of realistic energy transfer, accounting for antenna coupling, impedance transformation, nonlinear rectification, and load power consumption simultaneously.

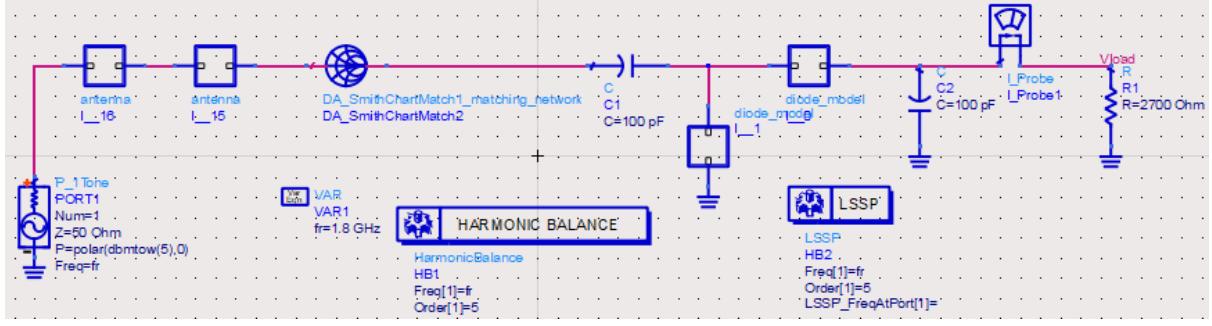


Figure 13: Schematic of WPT system

The RF source (**P1_Tone**) generates a continuous-wave signal at 1.8 GHz, which is radiated by the transmitting antenna. The receiving antenna captures this energy and delivers it to the Smith chart–optimized matching network. A coupling capacitor $C_1 = 100 \text{ pF}$ provides DC blocking and assists in fine-tuning the impedance. The rectifier, consisting of a Schottky diode and smoothing capacitor $C_2 = 100 \text{ pF}$, converts the received RF waveform into a DC signal across the load resistor $R_1 = 2700 \Omega$.

Harmonic Balance (HB) analysis is used to accurately capture diode nonlinearities, harmonic content, and steady-state DC output power. Large

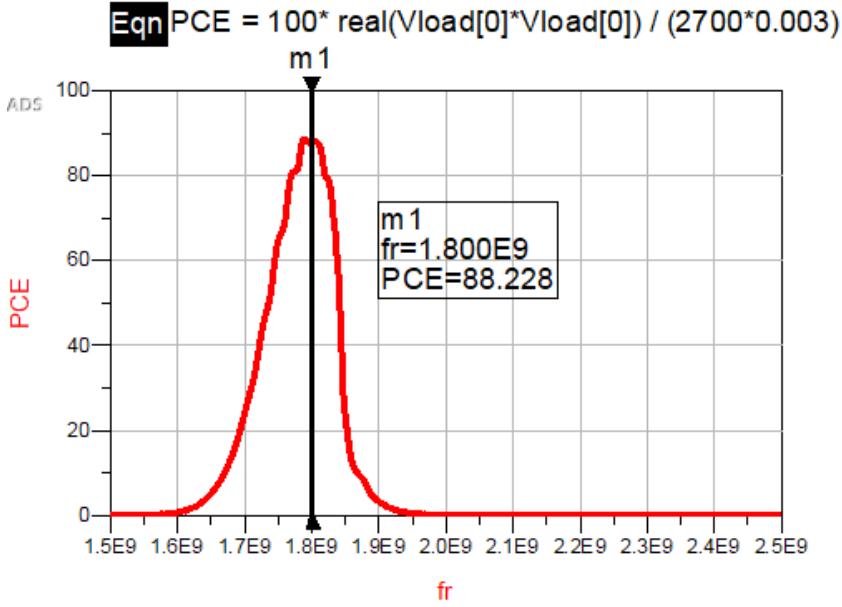


Figure 14: Efficiency of the complete WPT system

Signal S-Parameter (LSSP) simulations further characterize matching behavior under operating power levels, ensuring that impedance conditions remain favorable throughout the conversion process. The RF-to-DC efficiency is computed as:

$$\eta_{\text{PCE}} = \frac{P_{\text{DC,out}}}{P_{\text{RF,in}}} \times 100\% \quad (1)$$

where $P_{\text{DC,out}}$ represents the DC power delivered to the load and $P_{\text{RF,in}}$ is the RF power launched by the transmitter.

Simulation results reveal that the proposed WPT system achieves a maximum PCE of 88.228%, representing a significant improvement compared to conventional designs. This high efficiency highlights the effectiveness of the optimized antenna geometry, the Smith chart-based matching methodology, and the voltage doubler rectifier architecture. The system successfully demonstrates robust RF energy harvesting capability suitable for low-power sensing and IoT applications.

Table 3: Comparison of Parameters between [1] and This Work

Parameter	[1]	This Work
Technique	Near-field coupling	Antenna-based coupling
Impedance	75Ω	50Ω
Load Impedance	$1 \text{ k}\Omega$	$2.7 \text{ k}\Omega$
Matching	No matching	Smith chart-based matching
Capacitance (C)	0.1 pF	100 pF
Inductance (L)	0.25 nH	0.7 nH
Efficiency	51.2 percentage	88.23 percentage

CHAPTER 5: Conclusion and Future Scope

In this project, a complete RF Wireless Power Transfer (WPT) system was designed, simulated, and evaluated using microstrip patch antennas, an impedance matching network, and an RF-to-DC rectifier circuit. The system successfully demonstrated efficient power transmission from the RF source to the load over a defined distance. Through iterative optimization of antenna parameters, impedance matching, rectifier topology, and load tuning, a maximum Power Conversion Efficiency (PCE) of 88.228 percentage was achieved. This result confirms that microstrip patch antenna-based RF WPT systems can provide reliable and effective energy transfer for low-power electronic and IoT applications. The presented approach ensures compact design, low cost, and good integration capability with printed RF circuits.

Although the designed WPT system achieved promising performance, several enhancements can be explored in future work to further improve efficiency and practicality. Multi-stage rectifiers or adaptive impedance matching circuits may be incorporated to achieve higher DC output voltage and maintain optimal efficiency under varying load and distance conditions. The use of circularly polarized antennas or antenna arrays can enhance link robustness against orientation and alignment errors. In addition, integrating energy storage components such as supercapacitors or rechargeable batteries would enable continuous powering of standalone systems. Future development may also include real-time experimental testing under practical environmental conditions, accounting for factors such as multipath effects and mobility. Moreover, exploring higher frequency bands or multi-band operation can support extended transmission range and simultaneous powering of multiple devices. Finally, the miniaturization and fabrication of a complete prototype will be essential to demonstrate real-world applicability and transition the system toward consumer and commercial deployment.

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