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DESIGN OF RF TO DC CIRCUIT FOR ENERGY HARVESTING

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Abstract: This article describes an RF-to-DC energy harvesting circuit designed using a microstrip patch antenna, impedance matching network, and voltage doubler rectifier. The design was implemented in Keysight ADS software. The microstrip patch antenna operates at 915MHz, and the impedance-matching network ensures efficient power transfer. The voltage doubler rectifier achieves an output voltage of 2.305 V and a current of 0.006 mA and an input of 17 dBm and a Radiation intensity of 60%. This research demonstrates a promising method for collecting radio frequency and establishes the foundation for future research into low-power applications

Keywords: Antenna, Energy harvesting, Impedance matching, Impedance-matching network, Voltage doubler rectifier

I. INTRODUCTION

The increasing popularity of low-power and wireless devices has led to a growing interest in the energy harvesting method as a means of alternative power. Radio Frequency harvesting has become popular as a solution to powering these devices because of the common presence of RF signals in the environment. This article describes the design and execution of an RF-to-DC power conversion circuit that is intended to harvest energy efficiently.

The primary goal of this research is to create a puissant RF-to-DC conversion circuit that can transform RF power into useful DC power. The introduced circuit includes a microstrip patch antenna, a network that matches the impedance characteristic, and a voltage doubler that rectifies the voltage. These components are intentionally designed and optimized to facilitate efficient power conversion. Previous research in the field of RF energy harvesting has primarily concerned improving the efficiency and effectiveness of the circuitry used to harvest energy [6]. Several methods, including impedance matching networks and rectifier configurations, have been attempted to enhance power transfer and maximize energy conversion. However, there is a chance for additional improvements and enhancements to the design of RF to DC converters [8]. This article aims to contribute to the existing knowledge by presenting a comprehensive approach to designing an RF-to-DC converter circuit. The primary contributions of this research are the microstrip patch antenna that operates at a frequency of 915 MHz [9], the creation of an impedance network that is designed to match the frequency of the antenna, and the implementation of a voltage doubler used to convert power more efficiently.

In summary, the paper presents the design and simulation of a high-efficiency DC rectifier circuit for energy harvesting. High-efficiency power conversion of RF signals is achieved using microstrip patch antennas, impedance-matching networks, and voltage doubler rectifiers. The proposed design methodology and optimized circuit parameters help advance RF energy harvesting techniques for low-power applications.

II. RF TO DC CIRCUIT

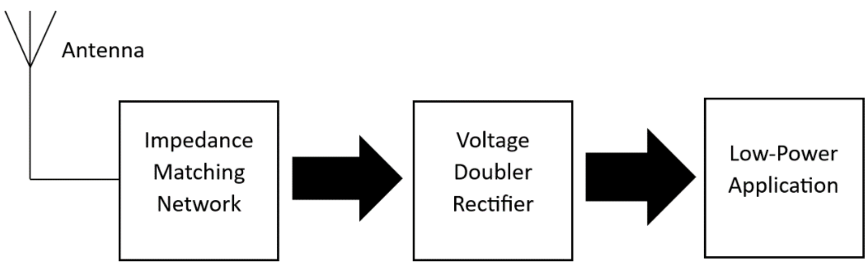

Fig.1 Block diagram of RF-to-DC conversion

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A. Microstrip Patch Antenna

A microstrip patch antenna functions by creating and broadcasting waves of electricity. It's made of a metallic layer on top of a dielectric substrate that has a ground plane. When an RF signal is inputted, the patch produces a magnetic field that results in waves. The size of the patch is dependent on its dimensions, and the pattern of radiation is affected by its shape and size. The optimal performance is achieved through the careful design of parameters like the substrate material, the size of patches, and the matching of impedance. They are popular in wireless communications due to their compact size and integrity.

Our proposed microstrip antenna for the patch is constructed using the Keysight ADS software. The antenna employs an FR-4 substrate with a dielectric constant of 4.3. It's intended to give out and receive a frequency of 915 MHz. The substance conducting electricity is copper. The length, width, and the height of antenna (or its substrate) are approximately 31.7 mm, 24.4 mm, and 1.6 mm, respectively.

Through simulation and analysis in Keysight ADS, the proposed antenna has an effective angle of 3.828 degrees, a radiation intensity of 60%, and a gain of 2.9 dB. These values are obtained when the antenna is powered up to 17 dB input power.

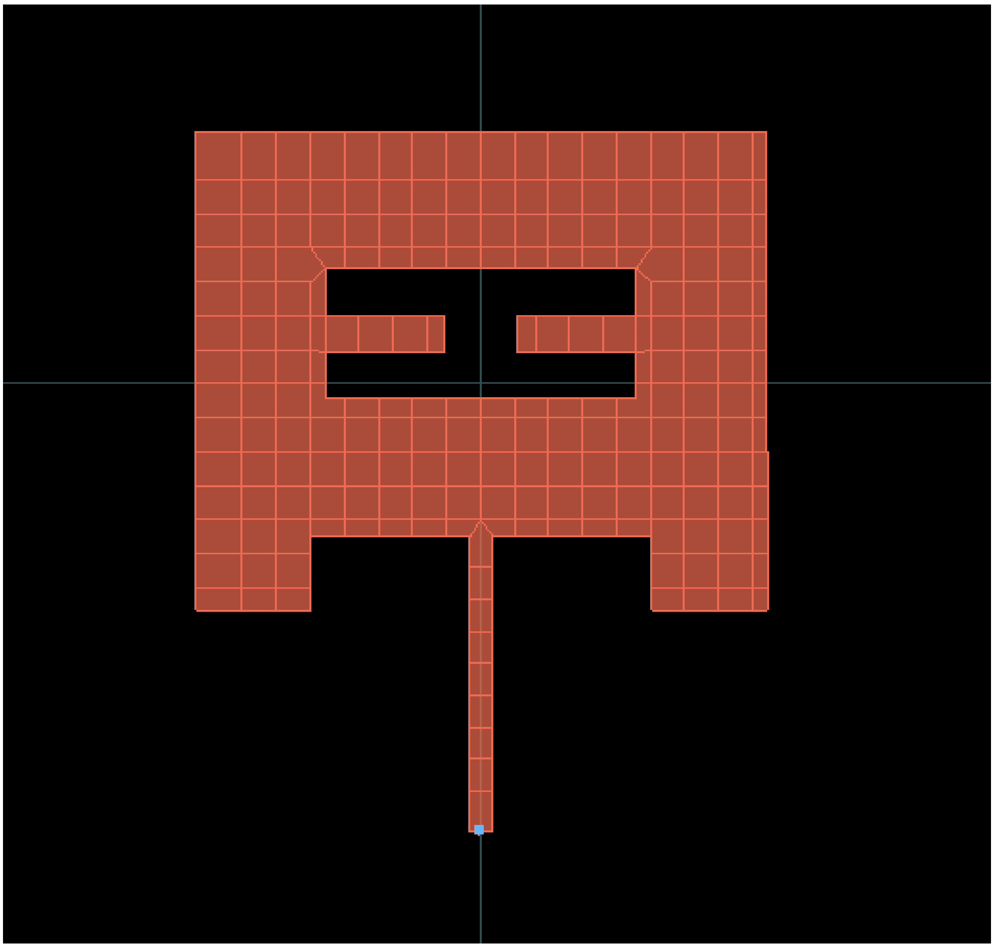

Fig. 2 Antenna design

The design of this microstrip patch antenna takes into consideration the properties of the substrate and its dimensions, it is intended to maximize its capacity for radiation and gain. The utilization of Keysight ADS promotes accurate modeling and optimization, which results in a successful proposal for an antenna design with a dependable outcome. Fig 2. Represents the proposed microstrip patch antenna and Fig 3. Represents the various antenna parameters.

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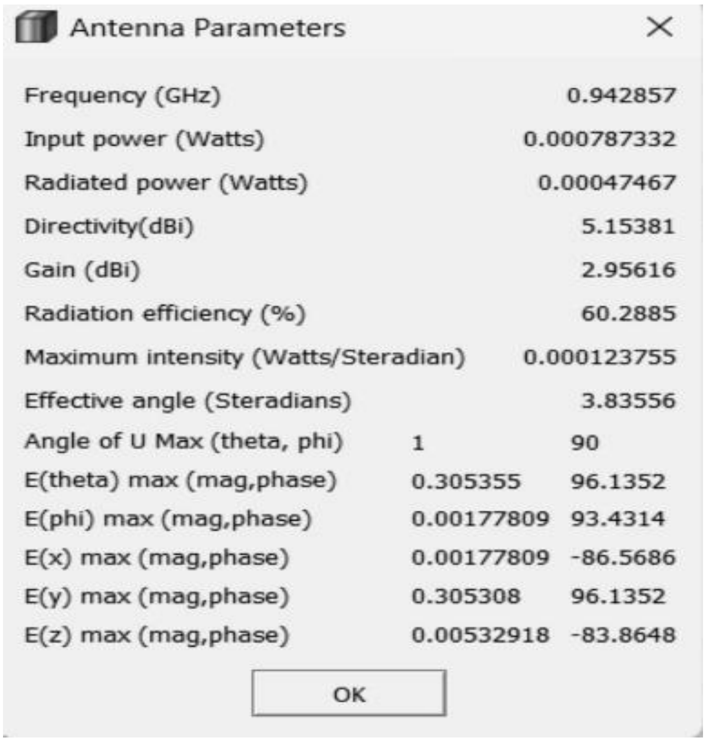

Fig. 3 Antenna parameters

B. Impedance Matching

In our design, the impedance matching circuit is an important part to ensure effective impedance matching between the microstrip patch antenna and the voltage doubler rectifier. It plays a key role in maximizing power transfer and minimizing signal reflections, thereby optimizing the energy-harvesting process of RF signals. The impedance-matching network is carefully designed and configured to bridge the impedance mismatch between the antenna and the rectifier. By choosing appropriate values for the inductance and capacitance in the network, we achieve an ideal impedance transformation that matches the impedance of the antenna. Through careful analysis and simulation using tools such as Keysight ADS, the matching network is tuned to operate efficiently at a resonant frequency of the antenna, which in our case is 915 MHz. This frequency alignment ensures optimal impedance matching and efficient power transfer. The impedance transformation is given by the formula:

$$Z_{in} = \sqrt{Z_{out} * Z_{ant}}$$

Zin is the input impedance of the LC matching network.
Zout is the output impedance of the LC matching network.
Zant is the impedance of the antenna at the resonant frequency.
An impedance transformation of approximately 50 ohms is determined in this circuit. This value corresponds to the output impedance of the network (Zout) and the impedance of the microstrip patch antenna (Zant) at its resonant frequency.

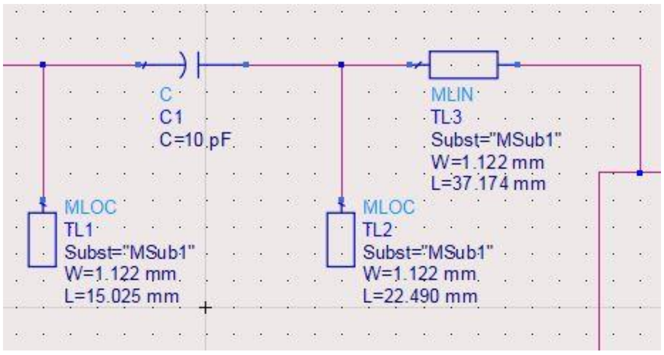

Fig. 4 Impedance matching network

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Fig 4. represents the impedance matching network, The circuit has two microstrip lines: MLIN and MLOC. MLIN is a microstrip line with a width of 1.122 mm and a length of 15.025 mm. MLOC is also a microstrip line with the same width of 1.122mm and a longer length of 22.490mm. This circuit consists of a 10pF capacitor, capacitors are used to provide the required capacitance to a circuit and to help with impedance matching or filtering requirements depending upon the particular design environment. These specific dimensions and component values play a vital role in circuit performance and function, contributing to impedance transformation, signal propagation, and other desired characteristics.

C. Voltage Doubler Rectifier

A voltage doubler rectifier is commonly used in power harvesting applications to convert an RF signal into usable DC power, based on the principle of rectifying and multiplying the input voltage using diodes and capacitors.

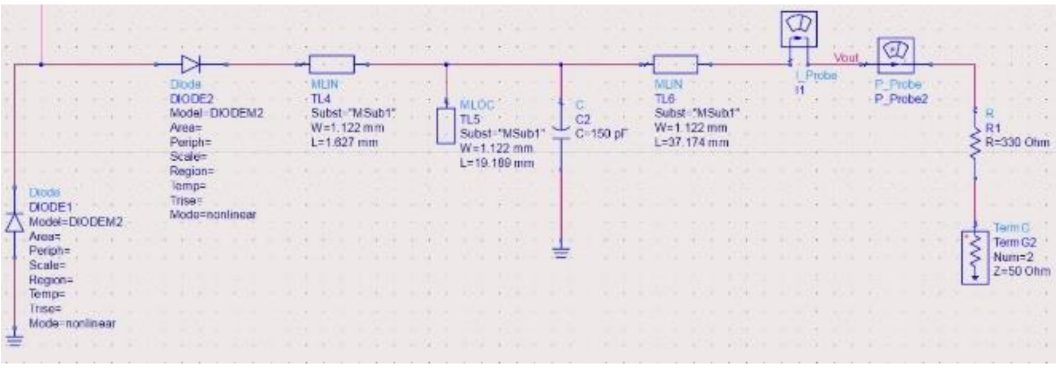

Fig. 5 Voltage doubler rectifier circuit

Here in Fig 5. Represents the proposed Voltage doubler rectifier It consists of two diodes and one capacitor arranged in a particular way. During the positive half-cycle of the input AC signal, one of the diodes conducts current and charges the capacitor. During the negative half cycle, the other diode conducts, and the previously charged capacitor discharges through the load resistor. This arrangement effectively doubles the voltage across the load resistor. The circuit's voltage doubler rectifier uses HSMS 2868 diodes and 150 pF capacitors. The microstrip line MLIN has a width of 1.122 mm, while the corresponding MLOC has the same width. The length of the MLOC is 19.189 mm.

The resistance of the load connected to the voltage doubler rectifier is 330 ohms. An I_PROBE and a P_PROBE with impedances of 50 ohms are attached to the circuit to assess its performance. The voltage doubler rectifier circuit rectifies the AC input signal using HSMS 2868 diodes and capacitors, essentially doubling the voltage across the load resistor. To optimize power transmission and circuit performance, the size and component values of the microstrip lines, diodes, capacitors, and load resistors are carefully designed.

The I_PROBE and P_PROBE connected to a 50 Ohm impedance allow precise measurement and analysis of the behavior of the circuit and ensure accurate evaluation of the efficiency and voltage doubling capability of the voltage doubler rectifier.

In the following sections, we present the integration of the individual blocks, including the impedance matching network, and voltage doubler rectifier, and their respective simulations.

All the simulations and analyses are done in the Keysight ADS tool and the parameters of all individual circuits are documented and analyzed in the paper.

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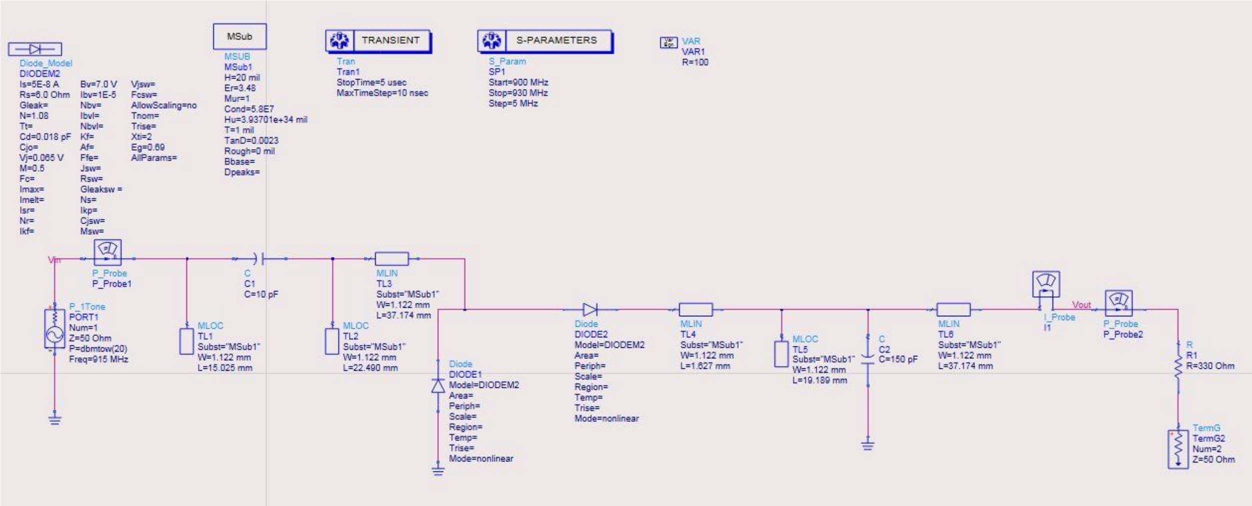

Fig. 6 Overall Circuit

In Figure 6, we present a comprehensive block showing the integration of all individual circuits, namely the impedance-matching network, and voltage doubler rectifier. The diagram provides a visual representation of the combined system and illustrates the connections and relationships between the various components.

III. SIMULATION & RESULTS

A. Antenna Simulation

The simulation in Keysight ADS provides insightful results regarding the performance of the antenna operating at a frequency of 915 MHz. By analyzing the simulation output, we can observe important parameters that characterize the antenna's behavior. The electric field strength (Emax) is determined to be 0.021 V/m. This value represents the peak amplitude of radiated electromagnetic waves, indicating the intensity of the antenna's radiated field.

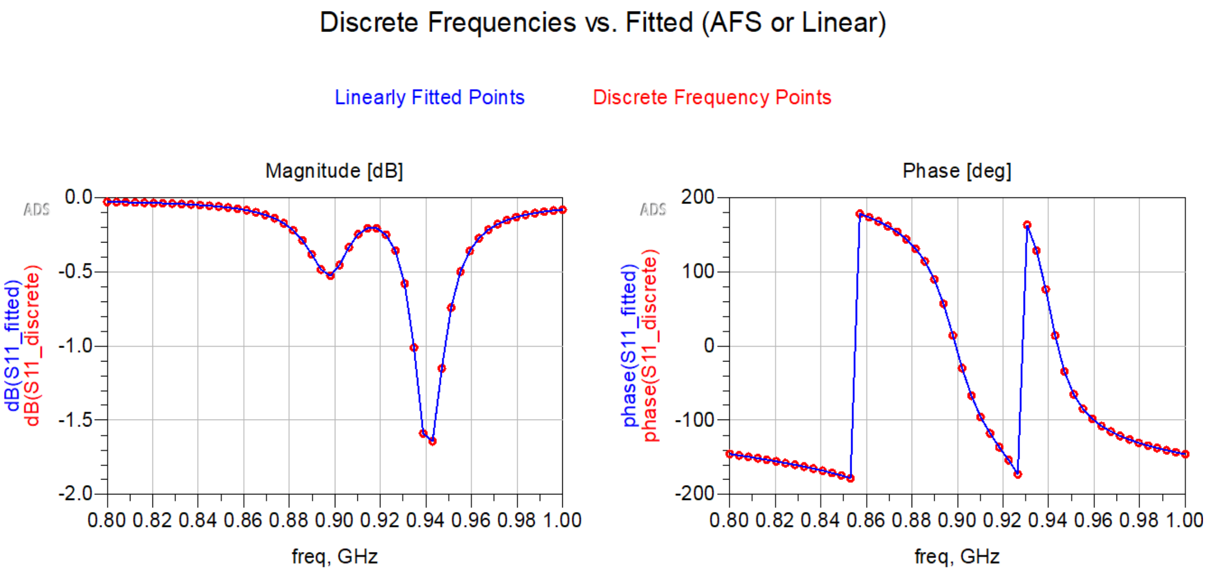

Fig. 7 Magnitude and phase plot

Examining the radiation pattern, we find that the antenna exhibits its maximum radiation intensity at a vertical angle of 79 degrees (Theta max) and a horizontal angle of 180 degrees (Phi max). The simulation also reveals the directivity max value of 6.015, which implies that the antenna can concentrate its radiated power in a specific direction. This characteristic allows for enhanced signal strength and coverage in desired areas. Moreover, the maximum gain (Gain max) is

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determined to be 2.95 dB, reflecting the antenna's ability to amplify and direct the radiated energy. In terms of radiated power, the simulation yields a value of 1.764E-3 milliwatts, quantifying the strength of the signals emitted by the antenna. This parameter is critical for assessing the overall performance and signal transmission capability of the antenna. The efficiency is found to be 60.2%, the simulation output specifies the radiation pattern cut type as "Phi" (horizontal plane) with a cut angle of 0 degrees. This information makes it possible to analyze the antenna's radiation pattern within a specific plane and angle, aiding in the optimization of the antenna's design for desired signal coverage. All the obtained outputs from the antenna simulation are in Fig 8.

Frequency	E_max	Theta_max	Phi_max	Directivity_max	Gain_max	RadiatedPower	InputPower	Efficiency	CutType	CutAngle
8.000E8	0.021	79.000	180.000	6.015	-3.893	1.764E-6	1.727E-5	0.102	Phi	0.000

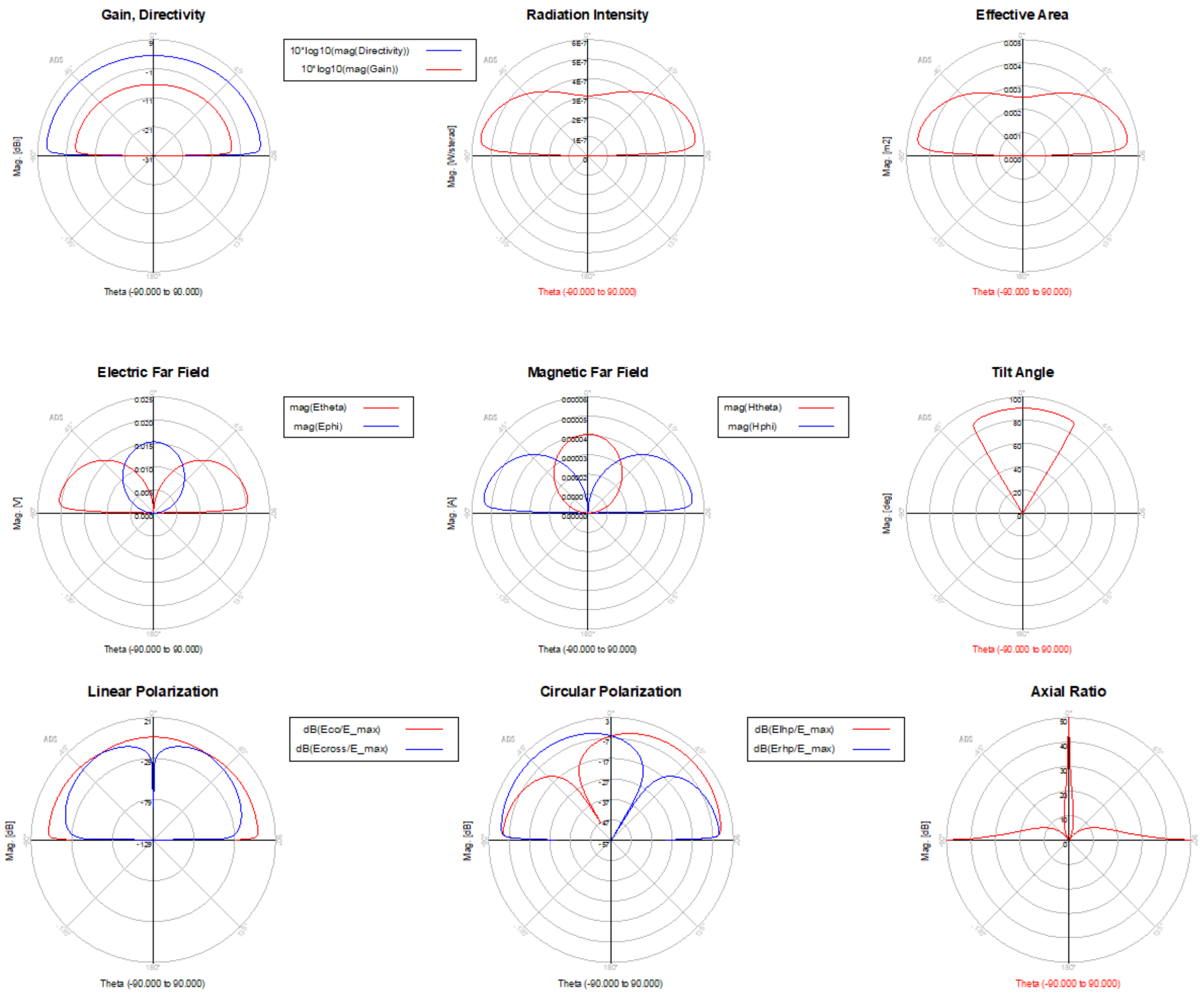

Fig. 8 Antenna plots

B. RF-to-DC Simulation

The simulation of the RF-to-DC converter was carried out using Keysight ADS, a robust software tool widely used for electronic design and simulation. The main objective was to achieve a stable DC output voltage of 2.305 V and a current of 6 mA. To ensure accurate results, the circuit design was thoughtfully crafted, taking into account the specific requirements. Careful consideration was given to selecting suitable components and configuring their parameters to meet the desired specifications. The simulation in Keysight ADS accurately models the behavior of the circuit components, accounting for various factors such as their individual characteristics, signal frequencies, and impedance matching.

Throughout the simulation process, the performance of the RF-to-DC converter was closely monitored. Special attention was given to observing the stability and consistency of the output voltage and current, which were critical in meeting the

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desired specifications. Fortunately, the simulation yielded positive results. A stable DC output voltage of 2.305 V was achieved (Fig 9.), demonstrating the successful conversion of RF signals into a reliable and constant voltage level.

Additionally, the measured output current was 6 mA (Fig 10.), signifying the flow of current within the circuit. These findings are significant because a constant DC output voltage and current are critical for guaranteeing continuous power supply in a variety of applications. By running the simulation in Keysight ADS and obtaining the necessary output parameters, confidence in the circuit's design and practical implementation are achieved. The simulation results validate the circuit's operation and give useful information for prospective modifications or customization, if necessary.

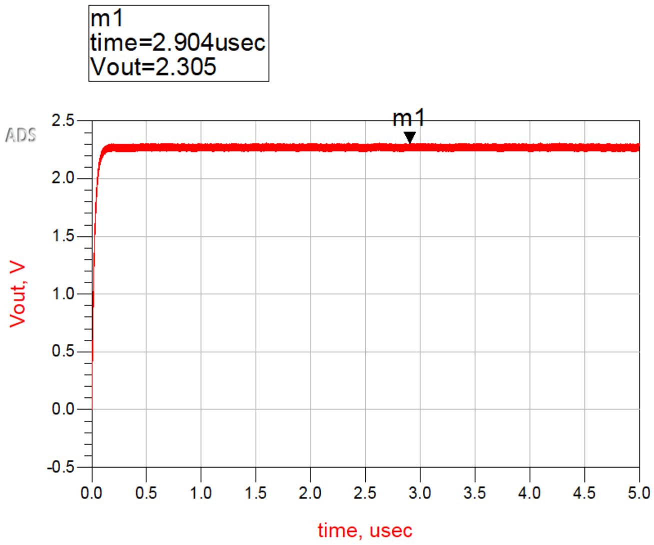

Fig. 9 Voltage plot

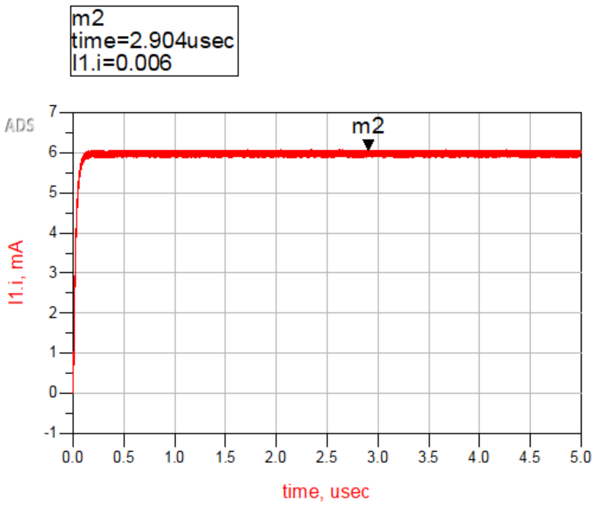

Fig. 10 Current plot

IV. CONCLUSION

Finally, the simulation results of the RF-to-DC converter using Keysight ADS were promising and attained the required results. The acquired consistent DC output voltage of 2.305 V and current of 6 mA support the circuit design's efficacy and the simulation software's correctness. These findings demonstrate the converter's capacity to transform RF signals into a dependable DC voltage, guaranteeing a steady power supply for a wide range of applications. The simulation's insights give useful information for further optimization and modification, making it a vital tool in the design and assessment of RF-to-DC conversion system

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