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MICROWAVE RECTENNAS FOR RF ENERGY HARVESTING

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***Abstract*— . This work describes a compact and efficient rectenna based on a dual-diode microstrip rectifier at 2.45 GHz. Rectennas are combination of antenna and a rectifying circuit which can be used to generate DC Energy from microwaves. The 2.45-GHz microwave rectifier has been developed and optimized using a global simulation technique which associates electromagnetic and circuit approaches in order to accurately predict the rectifier performances. The presented device doesn't need neither input HF filter nor bypass capacitor. This makes the structure more compact and low cost. A 2.45-GHz linearly polarized patch antenna has been designed an associated to the microwave rectifier to obtain the full Rectennas.**

***Keywords*— Rectennas, Antenna, Schottky Diodes, RF, Polarization**

I. INTRODUCTION

Microwaves are those electromagnetic waves in electromagnetic spectrum whose frequency ranges from 300MHz to 300GHz. Microwave Engineering deals with the study and design of microwave circuits, components, and systems. Wireless Power Transmission is not new to the world,

Nikola Tesla is the one who first conceived the idea Wireless Power Transmission and demonstrated "the transmission of electrical energy without wires" that depends upon electrical conductivity as early as 1891.

The rectenna is an important component for converting RF or microwave power into DC power. Rectennas are combination of antenna and a rectifying circuit. The rectifying diodes are essentially Schottky diodes which can be operated at microwave frequencies. The wireless energy can be collected by the antenna attached to rectifying diodes through filters and matching circuit. The rectifying diodes convert the received wireless energy into DC power. The low-pass filter will match the load with the rectifier and block the high order harmonics generated by the diode in order to achieve high energy conversion efficiency which is the most important parameter of such a device.

The "rectenna" was invented by Brown and has been used for various applications such as the microwave power helicopter and the receiving array for Solar Power Satellite. The experiment on the microwave powered aircraft which was conducted in Canada under the project SHARP (Stationary High Altitude Relay Platform), in which the structure of rectenna was evolved from a bulky bar-type to a planar thin-film type. It was found that the weight to power output ratio reduces effectively, and the power conversion efficiency of 85% is observed at 2.45 GHz

II .RECTENNAS

The rectenna has been a growing area of research in recent years, as the microwave integrated circuit and monolithic microwave integrated circuit technologies became more mature allowing for high level integration. The rectenna termed as rectifying antenna, is combination of an antenna and a nonlinear rectifying element (Schottky diode, IMPATT diode…etc.) where the two elements are integrated into a single circuit. A rectenna is useful as the receiving terminal of a power transmission system where dc power needs to be delivered to a load, through free space, for which physical transmission lines are not feasible. It is also suitable in applications where dc power needs to be distributed to more numbers of load elements that are spatially distributed. Such power distribution is achieved by the dispersive nature of microwave energy in space, eliminating the need for physical interconnects to individual load elements. Such a system is capable to receive and detect microwave power and converts the RF power into dc voltage at high frequencies (THz). Here we are implementing a 2.45 GHz micro strip

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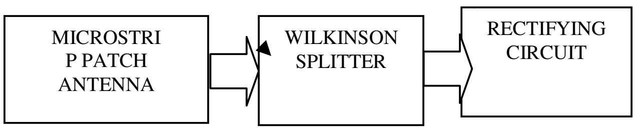
square patch antenna and a rectifier section in which a schottky diode HSMS 2820 is used for converting RF to DC which has been accurately optimized using HFSS



A. MICROSTRIP PATCH ANTENNA

Microstrip patch antennas are commonly used in high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required. These antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology.one of the main property of microstrip patch antennas is that, which is mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance. In addition, by adding loads between the patch and the ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency, impedance, polarization, and pattern can be designed. The radiating fields and basic structure of Microstrip patch antenna is shown in fig1.

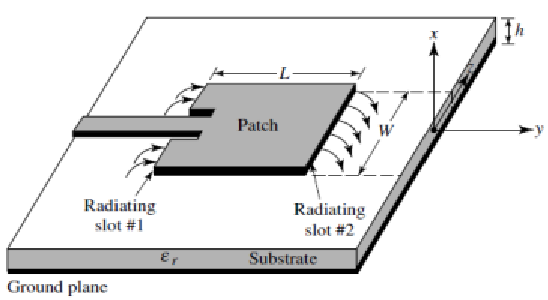


Fig1 Microstrip patch antenna

The Microstrip Square patch antenna for 2.45 GHz has been designed used the following equations:
The substrate on which antenna is designed is FR4. The dielectric constant of FR4 is 4.4. The height is 0.1588 cm.
The resonant frequency of the antenna is 2.45GHz.

The width of the antenna is ;

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}} \cdot \frac{2}{\sqrt{\varepsilon_r + 1}}$$

The effective dielectric constant can be calculated using the following relation;

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

The dielectric extension length can be found out from the following equation;

$$\Delta L = h * 0.412\frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)}$$

Actual Length of the antenna is

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$$

The substrate parameters are

$$L_g = 6h + L$$

$$W_g + 6h + w$$

By using the above equations the different dimensions has been calculated.

B. WILKINSON SPLITTER

Wilkinson splitter is actually power divider used in microwave transmission system, in this splitter transmission line followed by resistors and diodes. which provides isolation between output ports, and becomes lossless when the output ports are matched.

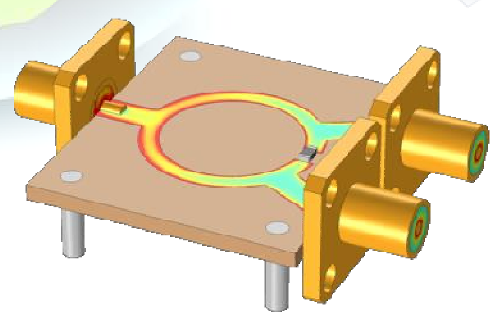


Fig2 Wilikinson splitter

In our project the output from microstrip patch antenna is fed to Wilkinson splitter followed by pair of schottky diodes for rectification and stubs for impedance matching. The stub lengths are carefully designed for the FR-4 substrate to obtain proper output. [5] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

C. RECTIFYING CIRCUIT

in rectifying circuit section the RF output from microstrip patch antenna is fed to rectifier section consisting of pair of schotkky diodes (HSMS 2820).

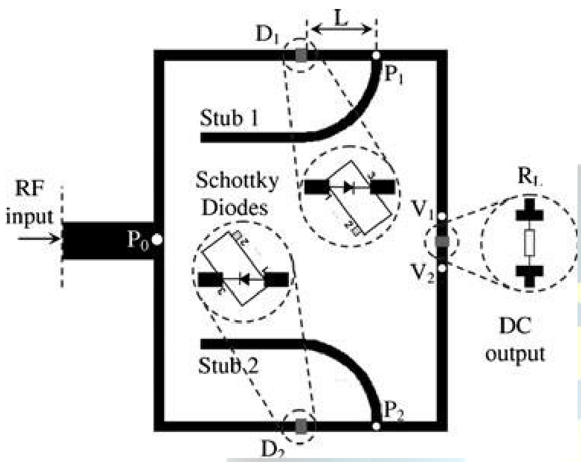


Fig. 3 Layout of the dual-diode rectifier at 2.45 GHz.

1.Schottky diode (HSMS 2820)

HSMS 2820 is a surface mount schottky diode, commonly used for rectification. These diodes are specifically designed for both analog and digital applications, which offers a wide range of specifications and package configurations to give the designer wide flexibility. Typical applications of these Schottky diodes are mixing, detecting, switching, sampling, and wave shaping. One the important thing about this diode is that it has low series resistance, low forward voltage at all current levels and good RF characteristics, so that it is suitable for microwave applications.

Features

- Low Turn-On Voltage (As Low as 0.34 V at 1 mA)
- Low FIT (Failure in Time)Rate
- Unique Configurations in Surface Mount SOT-363 Package
  – increase flexibility
  – save board space
  – reduce cost
- HSMS-282K Grounded Center Leads Provide up to 10 dB Higher Isolation
- Matched Diodes for Consistent Performance
- Better Thermal Conductivity for Higher Power Dissipation

III. RECTENNA STRUCTURE

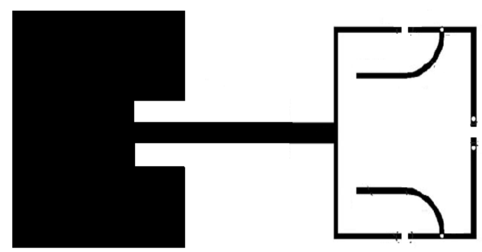


Fig4.Proposed Structure

The RF-to-dc microwave rectifying circuit shown in Fig. 3
contains two Schottky diodes (D1 and D2) mounted with a differential topology. It contains a 50-V characteristic impedance microstrip feed line. At point P0, the RF input power is divided into two equal entities that are rectified by diodes D1 and D2. These two diodes have the same impedance at 2.45 GHz and behave identically. The rectifier contains also two folded quarter wavelength open stubs, connected to points P1 and P2, which act as short circuits at 2.45 GHz and therefore isolate the resistive load RL during the measurement step. In addition, due to the differential measurement of the output dc voltage over the load (VDC ¼ V1–V2), no via-hole connection is necessary. Both diodes exhibit high impedances at 4.9 GHz. At this frequency, the distance between each diode and the point P0 is equal to a quarter wavelength resulting in a small impedance at the input of the circuit (P0). The point P0 behaves like a short circuit at this frequency. Note that the HSMS 286x series is designed to operate from 915 MHz to 5.8 GHz and this circuit has been designed at 2.45 GHz. However, the same rectifier topology can be developed and optimized at other frequencies using when possible another specific Schottky diodes well dedicated in the frequency band of interest.

IV. SIMULATION AND RESULTS

The proposed antenna at 2.45GHz was first simulated using the HFSS Software and obtained satisfactory radiation measurements. Later antenna was designed for inset feed and stub was designed.

The system was designed and etched on the FR-4 substrate and measurements was taken using Network analyzer. The values of voltages obtained are listed below;

Distance	Voltage Obtained
Near Field	1.592v
Far Field	0.666v

V. CONCLUSION

In this paper, a 2.45 GHz efficient dual-diode rectenna and rectenna arrays have been developed. The system is able catch RF signals from from surrounding environment and it can be converted to useful DC power.In order to compare and evaluate the performances of a single rectenna element etched on substrate(low-cost FR4) and using pair of Schottky diodes (HSMS 2820) .Rectenna arrays have been investigated and experimentally characterized for more power consumption. A combination of two and four identical rectenna elements were interconnected either in series or in parallel. Measured results are in good agreement with theoretical predictions, showing that the rectenna elements are equally illuminated, have the same characteristics and are correctly isolated. We were able to notice that the methodology used for interconnection of rectenna is reliable and able provide maximum power compared to a single rectenna These results can be useful for wireless power transmission applications and for energy harvesting applications.

The developed rectifier and rectenna arrays are particularly suitable to power remote supply of wireless and low consumption sensors, sensor nodes and actuators.

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