Title	A Hybrid Method on the Design of C Band Microwave Rectifiers
Author(s)	Yu, C; Zhang, B; Sun, S; Liu, C
Citation	International Symposium on Antennas and Propagation (ISAP), Nanjing, China, 23-25 October 2013. In the Proceedings of the International Symposium on Antennas and Propagation (ISAP), 2013, v. 1, p. 310-312
Issued Date	2013
URL	http://hdl.handle.net/10722/201215
Rights	Proceedings of the International Symposium on Antennas and Propagation (ISAP). Copyright © I E E E.

A Hybrid Method on the Design of C Band Microwave Rectifiers

Chengyang Yu[1], Biao Zhang[1], Sheng Sun[2] and Changjun Liu[1]
[1]School of Electronics and Information Engineering, Sichuan University, Chengdu 610064, China
[2]The University of Hong Kong, Hong Kong, China
e-mail: cjliu@ieee.org

Abstract—**Microwave rectifiers have been developed in various forms since the microwave power transmission (MPT) began to attract researchers' attention. A hybrid simulation method is implemented by the combination of IE3D and ADS simulation to realize a fast and accurate rectifier design in this paper. A 5.8 GHz microstrip rectifier based on HSMS 286 Schottky diode is realized and fabricated based on the proposed method for demonstration. Microstrip structures are light and easy to be integrated into rectennas in a MPT system. The whole circuit is compact with a dimension of 55 mm by 18 mm. The measured MW-to-DC conversion efficiency is 68%, which is obtained at an input microwave power of 16 dBm. The simulated and measured results agree well, which proves the validity of the proposed design method.**

Keywords—microwave rectifier; hybrid simulation; microwave power transmission

I. Introduction

In wireless power transmission (WPT) systems, power is transmitted wirelessly from one place to another where it is then converted to DC output power [1]. In general, microwave (MW) or laser is used as the energy carrier to realize the system. A laser based power transmission system is very compact due to its natural narrow beams. It has extremely crucial environmental conditions. The power transmission efficiency suffers from rain, fog, dusts and so on. On the other hand, microwave power transmission may keep its transmission efficiency in various environments, and becomes a research hotspot [2]. The representative progress can date back to the work done by Brown W.C. in 1963 [3], which realized a rectifying antenna with conversion efficiency of almost 50% using Schottky diodes.

In order to operate the cost of a MPT system effectively, rectifiers with a high MW-DC conversion efficiency have been intensively researched and developed around the world [4]-[7]. Accurate and fast designs on microwave rectifiers are very important. A hybrid simulation method is implemented by the combination of Mentor Graphics IE3D and Agilent Advanced Design System (ADS) to realize the goal in this paper. The hybrid design methods exhibits both the advantages of the IE3D in microstrip circuit design and ADS in active nonlinear components. A rectifier at 5.8 GHz is designed with the proposed method, and it is fabricated and measured to demonstrate its validity.

II. Analysis and Design

As a critical component in a microwave rectifier, Schottky diodes are widely applied to microwave rectifier designs. In this paper, a microwave rectifier based on the series diode configuration is shown in Fig. 1. It consists of a few key components: input and output filter, matching circuits, series Schottky diode and DC load.

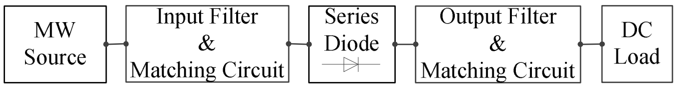


Fig. 1 The structure diagram of a microwave rectifier using a series diode

A. Rectifing diode

The rectifier diode greatly determines the total conversion efficiency and power capability of a rectifier, and even the circuit dimension. An analytical model for a rectifier diode has been built by the research team of K. Chang [8]. Schottky diodes are most suitable to microwave rectifiers due to their low turn-on voltage and low junction capacitance. The drawback of Schottky diodes is the power capacitance. An Avago Schottky diode HSMS-286C is applied to this work with considering on its zero-bias junction capacitance C_{J0} and series resistance R_S. Its equivalent parameters are shown as follows: the series resistance $R_S = 6\ \Omega$, the reverse breakdown voltage $V_B = 7$ V, the forward bias turn-on voltage $V_{BI} = 0.65$ V, the zero-bias junction capacitance $C_{J0} = 0.18$ pF. This diode model may also be found in ADS component library.

B. Designing the input and output filter

An input filter is introduced between the microwave source and the diode, which prevents the high-order harmonics generated by the nonlinear diode in the rectifier from reentering the microwave source. In this paper, split ring resonators based on defected ground structure (DGS) are utilized as the input filter to pass the power at 5.8 GHz and block its harmonics. Two Murata high frequency chip capacitors (GQM2195C2A3R3CB01) are applied to output DC filter, which avoid microwave power dissipation on the DC load. The input and output filter work cooperatively that the harmonics are reflected between the input filter, i.e. the split ring resonators, and the output DC filter, i.e. the two capacitors, until they are eventually converted to DC by the diode as shown in the harmonic recycling theory.

C. Design impedance matching circuits

The input impedance of a rectifier diode is calculated to obtain its imaginary part based on the closed form equations in [9]. The imaginary impedance is mainly generated from

This work was supported in part by the NFSC 61271074, 863 Program2012AA120605, and National Key Basic Research Program of China 2013CB328902

the junction capacitance C_J. This part can be canceled out by adjusting dimensions of the microstrip between chip capacitors and rectifier diode. Then, a quarter-wavelength impedance transformer is designed to match the real part of the diode impedance into the input filter. Furthermore, a short-ended shunt stub is placed after the input filter, which protects the MW source from the DC voltage of the diode and fine-tunes the matching circuit.

III. HYBRIDE SIMULATION DESIGN

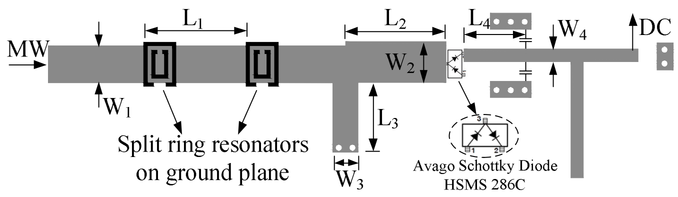


Fig. 2 Configuration of the proposed 5.8 GHz rectifier

Fig. 2 shows the configuration of the proposed 5.8 GHz rectifier. An HSMS 286C diode package contains a pair of Schottky diodes in series. We have used only one of them. This circuit is printed on a F4B-2 substrate with a dielectric constant of 2.65 and a thickness of 1 mm. Its metal layer is 17 □m copper. The new hybrid simulation method mainly includes two aspects: microstrip circuit designs with Mentor Graphics IE3D, and co-simulation with Agilent ADS invoking the data obtained from IE3D. The main processes are showed as follows.

The IE3D, which has an excellent accuracy for frequency domain analysis on microstrip circuits, are used to accurately simulate and optimize the microstrip sections of the rectifier. In other words, the IE3D is applied to passive parts of the rectifier. The diode and capacitors are replaced by ports in IE3D. The simulated S-parameters in the text format (.SP) of the multiport passive circuit are obtained. As shown in in Fig. 3, all the ports including the lumped components, diode, and feeding points are defined as Localized for MMIC ports. The main optimized dimensions are shown in Table. I.

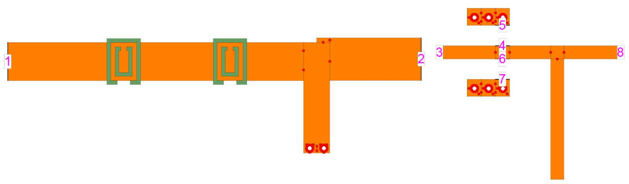


Fig. 3 Simulation view in Mentor Graphics IE3D

TABLE I. SUMMARY OF THE RECTIFIER DIMENSIONS

Item	L_1	L_2	L_3	L_4	W_1	W_2	W_3	W_4
(mm)	7.5	7.4	5.1	4.4	2.7	3	1.9	0.9

Then, the S-parameters of the microstrip circuits of the rectifier are treated as a multiport component. It is used in Agilent ADS along with the rectifier diode model of HSMS 286, lumped chip capacitors GQM2195C2A3R3CB01, and DC load to simulate the entire circuit. The detailed simulation configuration is shown in Fig. 4. In ADS, the harmonic balance simulation is a frequency-domain analysis technique for simulating nonlinear circuits and systems. It is well-suited for simulating analog RF and microwave circuits such as rectifiers.

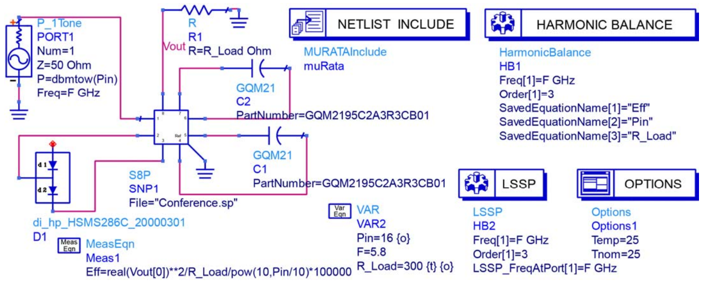


Fig. 4 Simulation view in Agilent ADS

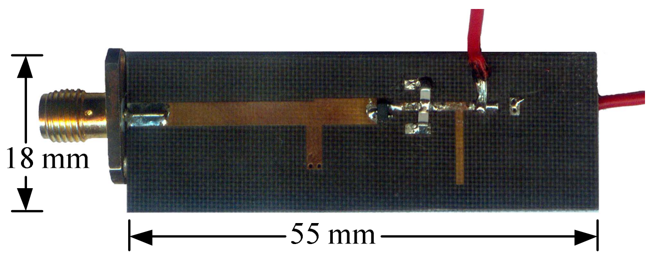
We optimize the MW-to-DC efficiency in ADS by means of adjusting the source power, load impedance, and the capacitors in ADS, and regulating the width and length of microstrip lines in IE3D. The optimal MW-to-DC efficiency is achieved after a few of iteration operations.

IV. MEASUREMENTS AND RESULTS

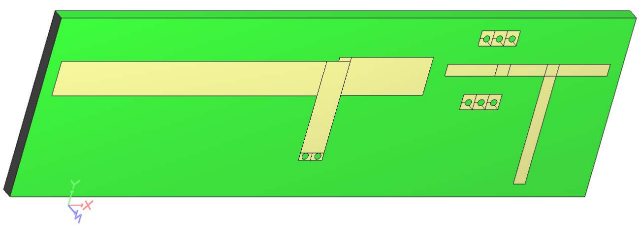
On the basis of simulation and optimization, a 5.8 GHz microwave rectifier is fabricated, as shown in Fig. 5(a), and measured. Fig. 5(b) and (c) show the top and bottom sides of the rectifier. An Agilent E8267C vector signal generator, which has a maximum output power of 20 dBm, is applied as the microwave source. An Agilent 34970A data acquisition is placed with a standard resistor box to monitor and display the output DC voltage at the DC load. The measured conversion efficiency is defined as

$$\eta = \frac{(V_{DC})^2}{R_L} \times \frac{1}{P_{MW}} \times 100\% \qquad (1)$$

where V_{DC} is the measured voltage across the DC load R_L and P_{MW} is the output microwave power generated by the Agilent E8267C generator.



(a) Fabricated rectifier



(b) Top view

(c) Bottom view

Fig. 5 Photograph of the fabricated microwave rectifier

A comparison between the measured and simulated output voltages is shown in Fig. 6, where the simulated results show a very agreement to the measured results, when the microwave power is less than 17 dBm. The greater difference at a higher input power is mainly due to the breakdown voltage of a real rectifier diode. The nonlinearity is much higher when the output DC voltage is close its breakdown voltage. Furthermore, Fig. 7 shows a comparison between the measured and simulated MW-DC conversion efficiency. The difference in output voltage is apparently amplified in the efficiency comparison since there is a quadratic relationship between them. However, experimental results are still good and both the measured and simulated data show an equal optimal load resistor. The measured highest conversion efficiency is 68% an input power of 16 dBm, where the optimal load resistor is 300 ohm.

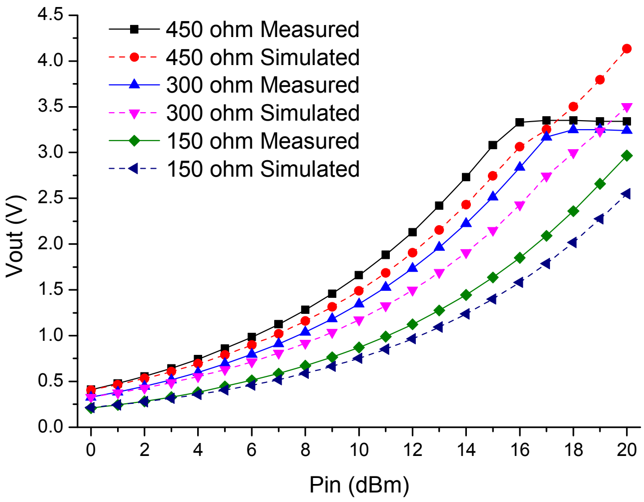


Fig. 6 Comparison of measured and simulated output voltage

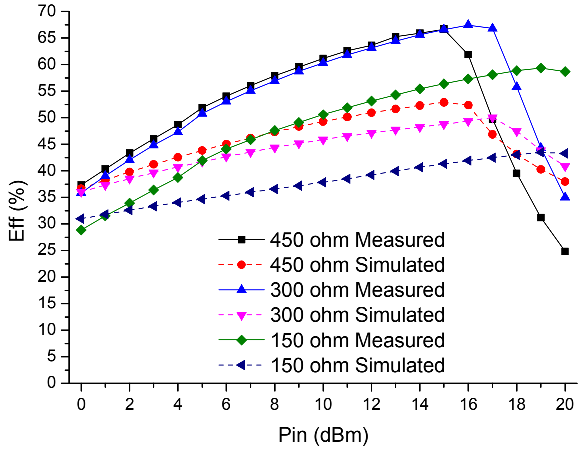


Fig. 7 Comparison of measured and simulated MW-DC conversion efficiency

V. CONCLUSIONS

In the design of microwave rectifiers, this paper proposed a hybrid design method using Mentor Graphics IE3D electromagnetic simulation software and Agilent ADS circuit simulation software in order to achieve a fast and accurate simulation. A 5.8 GHz microwave rectifier was then designed with the proposed method, and fabricated and measured. Experimental measurements showed that the rectifier achieved a maximum MW-DC conversion efficiency of 68% when the input power was 16 dBm and the optimal load resistor was 300 ohm. The measurements showed a good match to the simulated results at low power level, which validate the proposed design method.

REFERENCES

[1] Tesla, N., "The transmission of electric energy without wires," The thirteenth Anniversary Number of the Electrical World and Engineer, March 5, 1904.

[2] Matsumoto, H., "Microwave power transmission from space and related nonlinear plasma effects," The Radio Science Bulletin, no.273, 1995, pp. 11-35.

[3] Brown W. C., "The history of power transmission by radio waves," IEEE Transactions on Microwave Theory and Techniques, vol. 32, no. 9, 1984, pp. 1230-1242.

[4] Strassner, B. and K. Chang, "5.8-GHz circularly polarized rectifying antenna for wireless microwave power transmission," IEEE Transactions on Microwave Theory and Techniques, vol. 50, no. 8, 2002, pp. 1870-1876.

[5] Saka, T., Y. Fujino, M. Fujita, and N. Kaya, "An experiment of a C band rectenna," Proceedings of the Conference on Space Power Systems, Energy and Space for Humanity, 1997, pp. 251-253.

[6] Zibitou, J., M. Latrach, and S. Toutain, "Wide band power rectenna with high sensitivity detection," Proceedings of the 4th International Conference on Solar Power from Space (SPS'04), 2004, pp. 251-255.

[7] C. Yu, C. Liu, B. Zhang, X. Chen, and K. Huang, "An intermodulation recycling rectifier for microwave power transimisson at 2.45 GHz," Progress in Electromagnetics Research, vol. 119, 2011, pp. 435-447.

[8] Jonathan Hansen and K. Chang, "Diode modeling for rectenna design," Antennas and Propagation (APSURSI), July2011, pp. 1077-1080.

[9] J. O. McSpadden, L. Fan, and K. Chang, "Design and experiments of a high-conversion-efficiency 5.8-GHz rectenna," IEEE Trans. on Microwave Theory and Techniques, vol. 46, no. 12, pp. 2053-2059.