Design of a High-Conversion-Efficiency X-Band Rectifier for Microwave Wireless Power Transmission

Feifei Tan[1], Changjun Liu[2]

[1]College of Communication Engineering, Chengdu University of Information Technology, Chengdu, 610225, China.

[2]School of Electronics and Information Engineering, Sichuan University, Chengdu, 610064, China.

***Abstract*—Microwave wireless power transmission technology has been applied to several applications with advantages, such as solar power satellites, remotely powered vehicles, surveillance platforms, wireless sensors, and radio frequency identification (RFID) tags. The design of a rectifier with high MW-DC conversion efficiency is crucial in microwave wireless power transmission technology due to its enormous influence in the overall system efficiency.**

Most of the studies of rectifier choose schottky diodes as the rectifying device [1-8]. However, due to the nonlinearity of the diode, it is hard to design a rectifier with high efficiency without large quantities of computer simulations, especially under large signals condition. Therefore, a theoretical analysis of diodes in a specific rectifier circuit is important. References [1] and [8] present two theoretical analysis methods based on one-diode circuit model. In this work, we will expand the one-diode model analysis further to voltage doubler model analysis.

Mechanism of diodes in a voltage-doubler rectifier has been studied. From the diode junction voltage waveforms and diode current-voltage characteristic curves shown in Fig. 1, closed-form equations for the diode input impedance and efficiency have been derived and expressed as (1) and (2).

The closed-form equations have been validated by comparing the calculated results with the simulated ones by the Advanced Design System (ADS) software. The comparison charts are shown in Fig. 2 and Fig. 3. The closed-form equations are applicable for microwave voltage-doubler rectifier and can be a useful tool for design.

In this paper, a rectifier which is work at X-band has been designed and tested. The selection of diodes was based on their MW-DC conversion efficiencies which can be calculated by equation (2). The design of impedance matching network was based on its impedance which can be calculated by equation (1).

The measured efficiency of the proposed rectifier is 72% which is in good agreement with the calculated results. This efficiency of the proposed rectifier ranks high on the list of the related works at X-band which are shown in Table. 1.

$$Z_{diode} = \frac{2\pi R_s}{\theta_i - \sin\theta_i + j2R_s\omega c_j\left(\pi - \frac{\theta_i}{2} + \frac{\sin\theta_i}{2}\right)} \quad (1)$$

$$\eta = \frac{V_L^2}{\frac{2R_L\left(2V_F+V_L\right)^2}{\pi R_s}\left(2\theta_i - 8\tan\frac{\theta_i}{2} + \frac{\theta_i+\sin\theta_i}{\cos^2\frac{\theta_i}{2}}\right) + \frac{14\omega^2 c_j^2 R_s R_L\left(2V_F+V_L\right)^2}{\pi\cos^2\frac{\theta_i}{2}}\left(\pi - \frac{\theta_i}{2} + \frac{\sin\theta_i}{2}\right) + \frac{4V_F R_L\left(2V_F+V_L\right)}{\pi R_s}\left(2\tan\frac{\theta_i}{2} - \theta_i\right) + V_L^2}$$

(2)

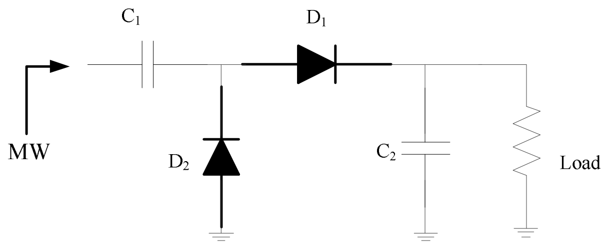

Fig. 1 The model of a voltage doubler rectifier

978-1-5386-2416-6/18/$31.00 ©2018 IEEE

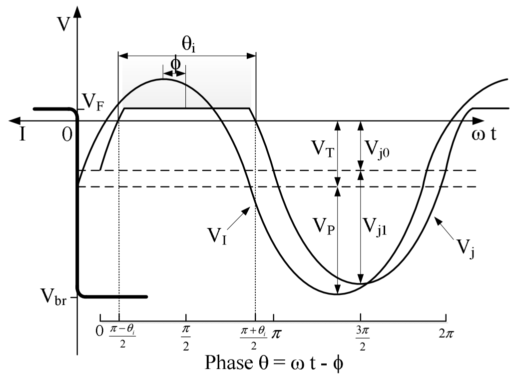

Fig. 2 Diode junction voltage waveforms and diode current-voltage characteristic curves.

In Fig. 2, V_F is the forward conduction voltage, V_I is the voltage across the diode. V_j is the diode junction voltage, θ_i is the diode conduction angle, V_{br} is the diode breakdown voltage. V_L is the dc output voltage, R_s is the diode series resistance, R_j is the diode junction resistance, c_j is the diode junction capacitor.

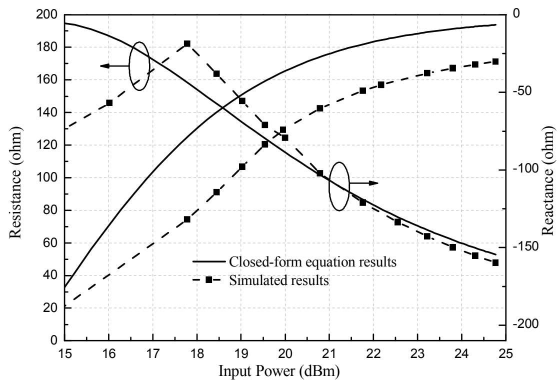

Fig. 3 Comparison of HSMS-286C diode impedances between calculated and simulated results in ADS.

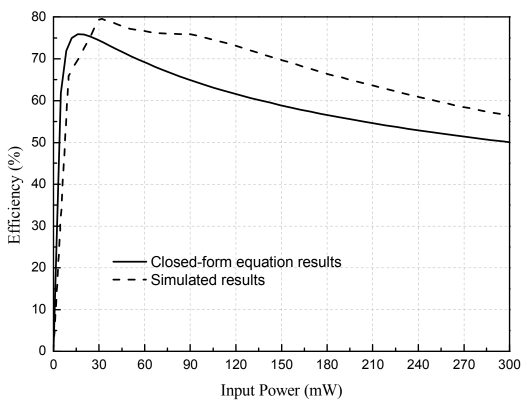

Fig. 4 Comparison of HSMS-286C diode efficiencies between calculated and simulated results in ADS.

In Fig. 4, the calculated efficiencies were calculated by equation (2). The feasibility of equation (2) has been validated by the high consistency of the calculated and simulated results in Fig. 4.

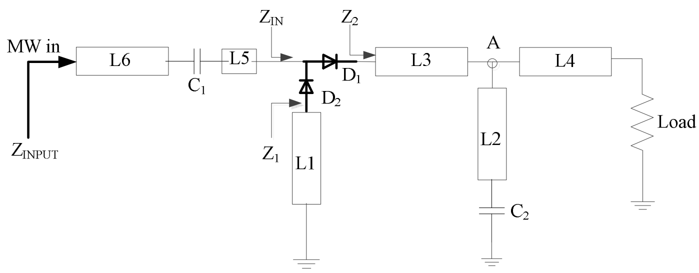

Fig. 5 The topology of the designed X band voltage doubler rectifier.

The special components which are different with other rectifiers in the circuit topology of Fig. 5 is microstrip lines L1 and L3. According to equation (1), the impedance of the diode has a capacitance. Then L1 and L3 are used to cancel the capacitance so as to make Z_{IN} in Fig. 5 to be a pure resistance. Therefore the impedance matching design will be easier. Based on this topology design, the optimal result can be obtained without too much computer simulation.

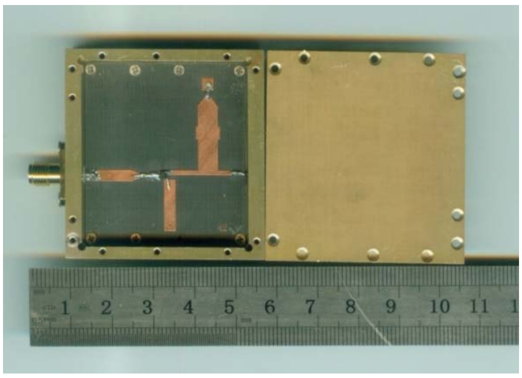

Fig. 6The fabricated voltage doubler rectifier.

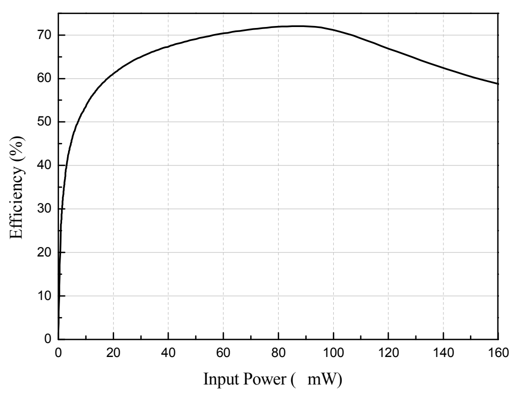

Fig. 7 The measured efficiencies.

The measured highest efficiency is 72.2%. This efficiency ranks high on the list of the related works at X-band which are shown in Table. 1. It proves from the side that equation (1) is feasible.

Table 1. Comparison table of the proposed rectifier and related work at X band.

Time	Reference	Device	Power	Efficiency
1992	[[1]	DMK6606, Alpha Industries	20.79 dBm	60%
2011	[2]	HSMS-8202 Avago	245 uW/cm^2	21%
2012	[3]	Diode-connected NMOS transistors	-8 dBm	3.1%
2014	[4]	GaN MMICs fabricated	34.14 dBm	64.4%
2014	[5]	HSMS-8101 Avago	15.5 dBm	67%
2014	[6]	HSMS-8101 Avago	17 dBm	71.9%
2015	[7]	MMIC	＞8 W	52%
2016	This work	HSMS-286C Avago	19.4 dBm	72.2%

REFERENCES

[1] Yoo, Tae-Whan, Changk Kai: Theoretical and experimental development of 10 and 35 GHz rectennas. IEEE Trans. Microw. Theory Techn., 40(6) (1992), 1259-1266.

[2] Monti, Guiuseppina; Tarricone, Luciano; Spartano, Michele: X-band planar rectenna. IEEE Antennas and Wireless Propagation Letters, 10 (2011), 1116-1119.

[3] Senadeera, Praharshin M.; Griggs, James; Xie, Zhijian; Dogan, Numan S.; Li, Neng; Behdad, Nader; Savci, Huseyin S.: X-band energy harvester with miniaturized on-chip slot antenna implemented in 0.18- um RF CMOS. 2012 IEEE International Conference on Ultra-Wideband, Syracuse, 448-452, NY, 17-20 Sept. 2012.

[4] Litchfield, Michael; Schafer, Scott; Reveyrand, Tibault; Popovic Zoya: High-efficiency X-band MMIC GaN power amplifiers operating as rectifiers. 2014 IEEE MTT-S International Microwave Symposium, 1-4, Tampa, FL, 1-6 June, 2014.

[5] Kim, Yuoungsub; Yoon, Young Joong; Shin, Jinwoo; So Joonho: X-band printed rectenna design and experiment for wireless power transfer. 2014 IEEE wireless power transfer conference (WPTC), 292-295, Jeju, South Korea, 8-9 may, 2014.

[6] Shin, Jinwoo; Seo, Mihui; Choi, Junho; So, Joonho; Cheon, Changyul: A compact and wideband circularly polarized rectenna with high efficiency at X-band. Progress in Electromagnetics Research, 145 (2014), 163-173.

[7] Schafer, Scott; Coffey, Mike; Popovic, Zoya: X-band wireless power transfer with two-stage high-efficiency GaN PA/rectifier. 2015 IEEE Wireless Power Transfer Conference, 1-3, Boulder, CO, 13-15 May, 2015.

[8] Valenta, C.R.; Morys, M.M.; Durgin, G.D.: Theoretical energyconversion efficiency for energy-harvesting circuits under poweroptimized waveform excitation. IEEE Trans. Microw. Theory Tech., 63 (2015), 1758–1767.