RTD application in low power UHF rectifiers

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Abstract. In the current work, the problem of UHF RFID passive tag sensitivity increase is considered. Tag sensitivity depends on HF signal rectifier efficiency and antenna-rectifier impedance matching. Possibility of RFID passive tag sensitivity increase up to 10 times by means of RTD use in HF signal rectifier in comparison with tags based on Schottky barrier diode is shown.

1. Introduction

Low power UHF rectifiers are used in UHF RFID passive tags. A passive tag consists of antenna and micro-chip. Chip includes detector (demodulator), controller, nonvolatile memory, modulator and UHF rectifier with voltage limiter those represent passive tag power supply.

Passive tag sensitivity increase is the important problem in UHF RFID system design. It gives a possibility to improve system's range and to enhance electromagnetic compatibility and ecological situation in the work area of RFID system.

2. Passive tag sensitivity increase

UHF RFID passive tag sensitivity is defined, as a rule, by the ability of tag to transform the reader's electromagnetic radiation energy into the energy of DC used for tag supply [1]. This function is performed by rectenna that includes antenna and UHF low power rectifier.

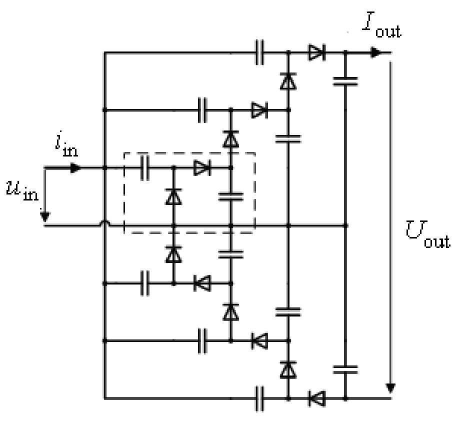

Figure 1. Low power UHF rectifier scheme.

Rectifier is a voltage multiplying scheme consisting of N nonlinear elements (Schottky barrier diode or MOS-transistors) and N capacitors (Figure 1). The multiplying factor is defined by the number of elemental cells. One cell is a voltage doubler (it is limited by dotted line on Figure 1). In the ideal case, the output voltage of the cell is

$$U_1 = 2 \cdot U_{\text{in}} \tag{1}$$

where U_{in} is the amplitude of input alternating voltage. Serial connection of N_C ideal cells allows to achieve output DC voltage

$$U_{\text{out}} = 2 N_C U_{\text{in}} = N U_{\text{in}}. \tag{2}$$

The model of multiplying rectifier is described in [2]. One can calculate input impedance, required input RF power and efficiency of the rectifier if specify output voltage, output current and IV-curve of nonlinear elements using this model.

Rectenna performance is described by efficiency coefficient:

$$K_{\text{eff}} = \eta_R \cdot 4 R_R R_A \left| Z_R + Z_A \right|^{-2} \tag{3}$$

where $Z_A = R_A + iX_A$ – input antenna impedance, $Z_R = R_R + iX_R$ – input rectifier impedance, η_R – rectifier efficiency. Last one is the rectifier characteristic, and it shows which part of input RF power P_{RF} is transformed into DC power P_{DC}:

$$\eta_R = P_{DC} / P_{RF} \tag{4}$$

The feature of low power UHF rectifiers is the necessity of low-amplitude alternating voltage rectification. Nonlinear elements such as Schottky barrier diodes have IV-curve with exponential character. It is described by the equation [3]

$$I(U) = I_S \cdot \left[\exp\left(\frac{U - IR_S}{0,026} \right) - 1 \right] \tag{5}$$

where I_S – saturation current, R_S – serial resistivity. IV-curve of Schottky barrier diode has nonzero threshold voltage that value is about 0.2 V (see Figure 2, dotted curve). This fact means that rectification of alternating voltage with amplitude less than 0.2 V is complicated. Thus, the efficiency of low power UHF rectifier based on Schottky barrier diode will extremely decrease with input power reduction.

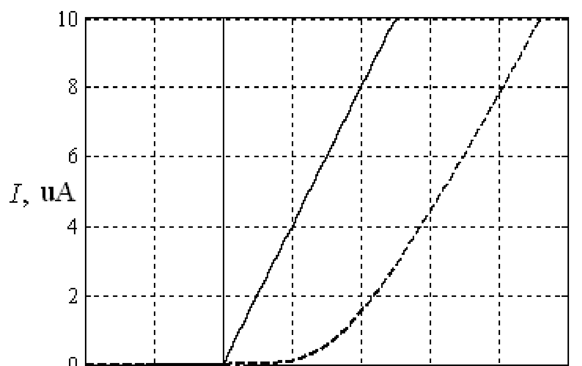

Figure 2. IV-curve of RTD (solid) and Schottky diode (dotted).

In [1],[4]-[6], it is shown that application of resonant-tunneling diodes (RTD) based on A_3B_5 semiconductor heterostructure that have optimized for low power signal rectification IV-curve allows to increase η_R up to 10 times. This IV-curve has zero threshold voltage (see Figure 2, solid curve) and it is described by the system of equations:

$$I(U) = \begin{cases} S_{fw}U & \text{if} \quad U \geq 0; \\ S_{bw}U & \text{if} \quad U < 0 \end{cases} \tag{6}$$

where S_{fw} and S_{bw} – conductivity of RTD in forward and backward direction respectively. Changing heterostructure layers parameters, it is possible to obtain RTD with different S_{fw} and S_{bw}. These values may vary from $1 \cdot 10^{-7}$ to $1 \cdot 10^{-1}$ Ohm^{-1}. Thus, the efficiency of low power UHF rectifier based on RTD is close to 100% even if the amplitude of input voltage is less than 0.2 V. Besides, it is possible to design rectifiers with input impedance from several Ohms to dozens of kilo-Ohms. Thanks to this, a perfect impedance matching can be achieved with any type of antenna without additional transformers.

Investigating the problem of antenna and rectifier impedance matching, it is necessary to take into account parasitic capacitance of nonlinear elements. That means that the rectifier impedance is capacitive. Typical values of high-speed Schottky diode or MOS-transistors parasitic capacitance are hundredth and tenth of pico-Farad [2], [3]. The input capacitance of the multiplying rectifier based on such nonlinear elements may achieve ones of pico-Farad. On UHF, it will lead to the antenna and rectifier inputimpedance mismatch because the antenna impedance has purely active component on resonant frequency. Regarding this fact, one should use a matching transformer in passive tag design in this case. Its dimensions may be compatible with dimensions of tag's antenna. In [2], it is shown that the absence of such transformer between antenna and rectifier leads to rectenna efficiency reduction up to 4 times or RFID system range decrease in 1.5-2 times.

RTD based on nanoscale A_3B_5 semiconductor heterostructures has noticeably less parasitic capacitance that can be equal to ones of femto-Farad [7]. Input capacitance of the multiplying rectifier based on RTD should be less than 1 pF even if multiplying factor *N* is equal to several dozens. At such a value of input capacitance of the rectifier, the need in matching transformer disappears or its dimensions are negligible comparing to antenna dimensions.

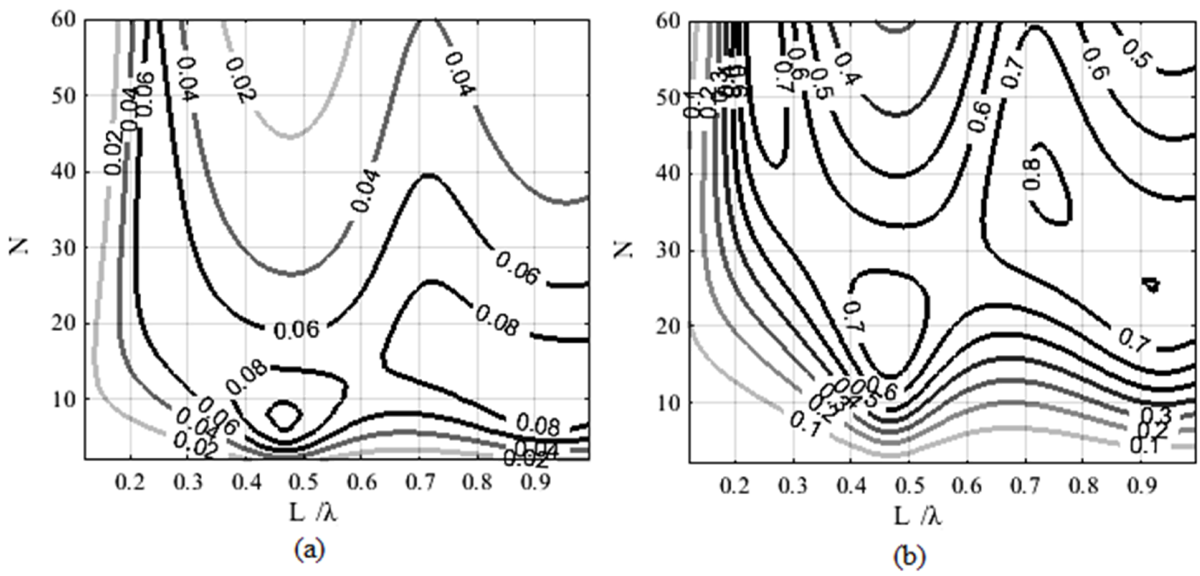

Figure 3. Efficiency coefficient of Shottky diode (a) and RTD (b) rectenna.

In this work, rectennas consisting of electric dipole antenna and rectifiers based on RTD and Schottky barrier diode were investigated. Figure 3 shows the efficiency coefficient as a function of the rectifier multiplying factor N and the length of antenna L normalized to wavelength λ of HF signal with frequency 910 MHz when DC power is 3 μW. Calculation shows that RTD rectenna's efficiency coefficient is up to 10 times greater than Schottky diode rectenna's one when DC power is 3 μW, 4.5 times greater when DC power is 10 μW and 4 times greater when DC power is 20 μW.

3. Conclusion

It is possible to achieve an advantage in rectenna efficiency up to 10 times by means of RTD use instead of Shottky barrier diode in UHF signal rectifier. Thus, the range of RFID system can be increased up to 3 times or radio emission of reader can be decreased up to 10 times that is crucial considering electromagnetic compatibility and ecological situation in the RFID system area of action. Besides, dimensions of a tag can be reduced because of additional impedance matching components absence. These advantages can extend the sphere of RFID application.

Acknowledgments

The research work was supported by Ministry of Education and Science of the Russian Federation under state task № 16.1116.2014/K.

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