Design of RF-DC conversion circuit for the batteryless Transponder

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Abstract RFID system is applied to identify, locate and track people, cars, animals. In RFID system, the passive transponder without battery has some benefits than active transponder, such as no restriction in battery exchange and in battery's life. But it needs auxiliary RF-DC conversion circuit. RF-DC conversion circuit originated from Wireless Power Transmission (WPT). In this paper, RF-DC conversion circuit consists of a microstrip patch antenna and impedance matching circuit, Cock-croft Walton circuit. And RF-DC conversion circuits have two kinds of T-type and Cross-type impedance matching circuits.

1. Introduction

Today, the majority of applications of microwaves are related to radar and communication systems. Radar systems are used for detecting and locating air, ground, or seagoing targets and for air-traffic control systems, missile tracking radars, automobile collision-avoidance systems, weather prediction, motion detectors, and a wide variety of remote sensing systems. Microwave communication systems handle a large fraction of the world's international and other long-haul telephone, data, and television transmissions. Specially, there has been rapid development of radio frequency identification (RFID) such that the products appearing today can be considered to be a totally new technology.[1] Depending upon the existence of the battery, the RF transponder is generally divided into active and passive transponder in RFID system. Passive RFID systems are composed of two components. One is a reader and the other is a passive tag. And the tag is composed of an antenna and a low power chip for modulation circuitry and memory. The passive transponder without battery is required for RF-DC conversion circuit which originated from wireless power transmission (WPT). Solar Power Satellites in WPT use microwave to transmit energy from space. Firstly, the energy by the sun musts be convert to RF energy to achieve wireless power transmission to the space. Then the retenna in the earth accept a microwave from the solar satellites to generate the powers. As wireless RF system in this study uses a small microwave power (0dBm), it musts keep power consumption lower. And many applications of wireless power transmission need high efficiency. The RF-DC conversion circuit is composed of the impedance matching circuit to transmit a maximum power and the Cock-croft Walton circuit to convert an incoming power from antenna. In this paper, an analysis and design of the RF-DC conversion circuit is presented. Specially, an impedance matching circuit is studied to increase efficiency in RF-DC conversion.

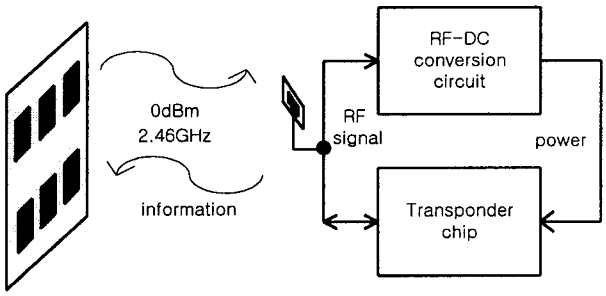


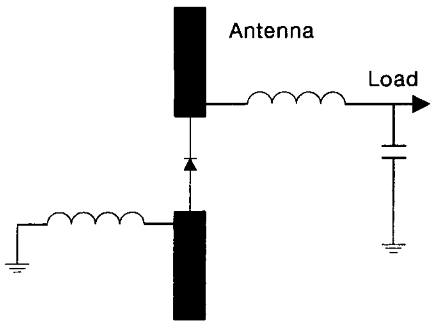
Figure1. A block diagram of system.

2. Wireless Power Transmission

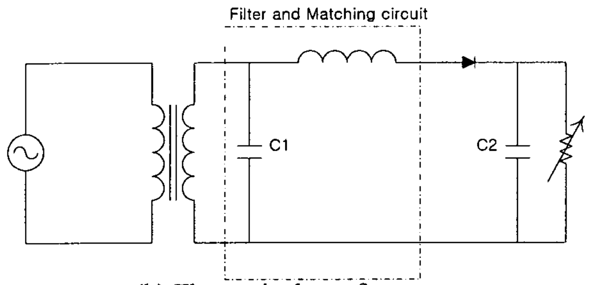
2.1 The history of RF-DC conversion circuit

A complete microwave power transmission system is defined as a step process. The microwave power is spread out over a transmitting antenna, the beam formed and directed at the tag (receiver), and microwave power is captured from the beam and converted back into DC power at the receiving location. Wireless Power Transmission (WPT) consists of converting dc power into microwave power at the transmitting end, forming the microwave power into electronically steerable microwave beams, and capturing the microwave power and converting it back into dc power at the receiving end. WPT dates back to the early work of Heinrich Hertz, who demonstrated electromagnetic wave propagation in free space in 1888.[2] The potential WPT applications for space include the Solar Power Satellite (SPS) and electrically propelled spaceships for solar system transport. The SPS supplies stable power for load because of the advantage of independent weather and gravity unlike generated powers at the earth. But it is required a power conversion network to transmit power through the space. Rectenna is designed to convert microwave. So the earth stations with rectenna accept power from the satellite. The concept of solar power satellites is still not widely known by the general public.

2.2 Rectenna



(a) The configuration of the rectenna.



(b) The equivalent of rectenna.
Figure2. The structures of rectenna.

The structures of the rectenna for wireless power transmission is shown in Figure2 are composed of a dipole antenna and the impedance matching network, rectifier[3]. In essence, an antenna is a component that converts a wave propagating on a transmission line to a plane wave propagating in free-space, or vice versa. The rectenna have two sorts of antenna, dipole antenna and microstip patch antenna. Generally, the microstip antenna is used because it is light and easy to fabricate. In order to transmit a maximum power, the matching network is usually designed so that the impedance seen looking into the matching network is the characteristic impedance

3. Design of RF-DC conversion circuit

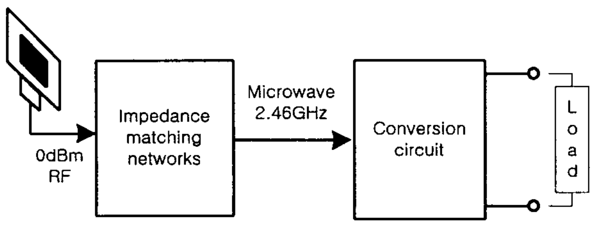


Figure3. The block diagram of the RF-DC conversion circuit.

At this paper, we introduce two RF-DC conversion circuits, T-junction and Cross-junction RF-DC conversion circuit, which is separated form the impedance matching network. The designed RF-DC conversion circuit is shown in Figure3 consists of three components, an antenna (patch type) and impedance matching circuit and Cock-croft Walton circuit. At this study, an antenna is designed a microstrip patch antenna. And the impedance matching circuit is fabricated to FR4 microstrip line. Finally, Cock-croft Walton voltage multipliers are quite practical for generating thousands of volts or just a few volts at high current.

3.1 Cock-croft Walton circuit

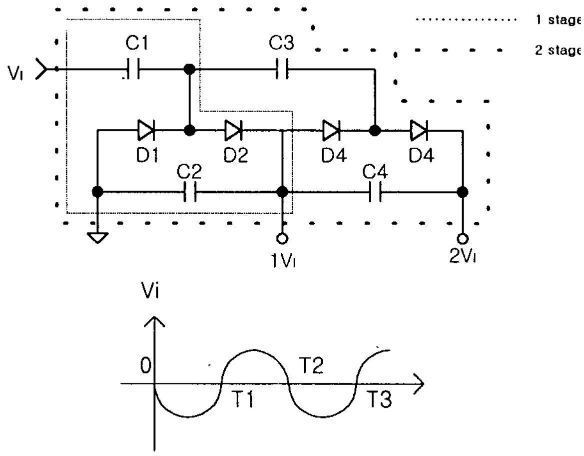


Figure4. Cock-croft Walton circuit.

Figure4 shows the configuration of the Cock-croft Walton voltage multipliers. The basic principle of this circuit at 1 stage is as follows.

1) For $0 < t < T_1$

When the input voltage through the impedance matching circuit is negative, D1 conducts and C1 charge to Vi.

2) For $T_1 < t < T_2$

For this period, D1 is cut off and D2 conducts. Then the voltage of C2 will double by the charged C1.

3) For $T_2 < t < T_3$

D1 conducts and D2 is cut off at this interval. The above course repeats. Thus, the value of load has two times than input voltage.

3.2 Charateristic Impedance

Before impedance matching, we are considered the characteristic impedance and the property of microstrip line (FR4). Table1 shows the property of FR4 microstrip line.

Table1. The property of FR4.

Characteristic impedance[Zo]	50[Ω]
Thickness of Copper plate[t]	35μm
Thickness of plate[h]	1mm
Permittivity(ε_r)	4.65

As the characteristic impedance of microstrip line is a 50[Ω], the equation for characteristic impedance is as follows[4]. Where, W/h = J.

1) J < 1

$$Zo = \frac{60}{\sqrt{\varepsilon_{ff}}} \ln(8/J + 0.25J)$$

$$\varepsilon_{ff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[(1 + 12/J)^{-1/2} + 0.04(1 - J)^2]$$

2) J >1

$$Zo = \frac{120\pi / \sqrt{\varepsilon_{ff}}}{J + 1.393 + 0.667\ln(J + 1.444)}$$

$$\varepsilon_{ff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12/J)^{-1/2}$$

As the above formulas, Effective dielectric constant (εff) is 3.476 and the characteristic impedance is 50[Ω] , when the width (w) of plate is 1.75[mm].

3.3 Impedance matching

The basic idea of impedance matching is defined as impedance matching network placed between a load impedance and a transmission line. The matching network is ideally lossless, to avoid unnecessary loss of power, and is usually designed so that the impedance seen looking into the matching network is the characteristic impedance. Then reflections are eliminated on the transmission line to the left of the matching network, although there will be multiple reflections between the matching network and the load. This procedure is also referred to as tuning. We should be measure for load impedance using Network Analyzer. The value of a load impedance by network analyzer equipment is A (1.8 + j1.36). To match the impedance, A point is compelled to move to B. Then B spot is obliged to move in the middle of smith chart.

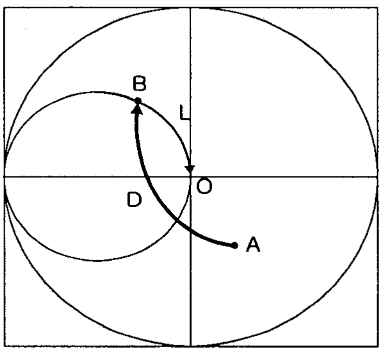


Figure5. The load impedance on the smith chart.

3.3.1 T-junction open stub

In single stub tuning, the two adjustable parameters are the distance D, from the load to the stub position, and the value (L) of reactance provided by the open stub. D parameter is shown as Figure6 means a 50Ω line which the impedance seen looking into matching point is the characteristic impedance. And L parameter means a single open stub of reactance. In order to match the characteristic impedance, open stub musts have the L stub with large the length. Thus, we are acquired the exact L by tuning. But it is difficult to match the impedance as T-junction circuit has a sensitive property.

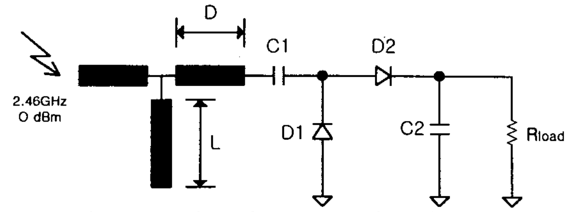


Figure6. T-junction conversion circuit.

3.3.2 Cross type open stub

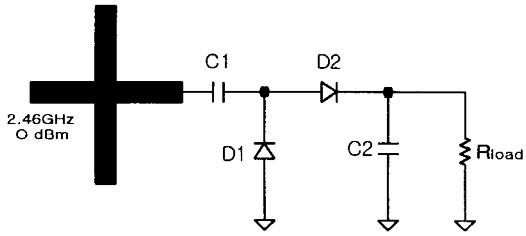


Figure7. Cross-junction conversion circuit.

Cross-junction circuit is shown in Figure7 have two stubs. T-junction RF-DC circuit is sensitive in the tuning. But Cross-junction RF-DC circuit has a diminished sensitivity as compared with T-junction circuit. Cross type has the parallel impedance for the loss component of power. So Cross-junction RF-DC conversion circuit has not only the reduction for the total loss of impedance but has the increase of the efficiency.

5. Experimental results and Analysis

The condition of the experiment is following as:

- Microwave power : 0dBm(1mW)
- Frequency : 2.46GHz
- Load : 12[kΩ]
- Diode : Schottky Diode(HSMS-2852)

Though the experiment, we are confirmed that the RF power by the proposal RF-DC circuit converts to DC power and the efficiency of RF-DC conversion depend on the impedance matching circuit. Table2 shows the value of the load power for T-junction and Cross-junction RF-DC conversion circuit. The maximum efficiency of T-junction RF-DC conversion circuit is shown in Table2 is approximately 30% and the efficiency of Cross-junction type is 41%. Figure 8 shows graphically the efficiency of conversion between T-junction and Cross-junction. The impedance matching circuit is set to a 12kΩ load in this study. So the maximum efficiency of power conversion is 41%. If the load of RF-DC conversion circuit is set to 5~8kΩ, the efficiency would increase to 45%. Thus, we are realized *that Cross-junction type has a good performance than the* T-junction type.

Table2. The value of power in T-junction and Cross –junction circuit.

L[kΩ]	T type stub		Cross type stub	
	E[V]	P[mW]	E[V]	P[mW]
4	1.1	0.3025	1.272	0.404
5	1.2	0.288	1.43	0.409
6	1.28	0.273	1.57	0.411
8	1.51	0.285	1.8	0.405
10	1.73	0.3	1.89	0.357
12	1.9	0.3	2.05	0.35
14	2.08	0.31	2.12	0.32
16	2.2	0.3025	2.2	0.303
18	2.32	0.3	2.32	0.3

(L : load, E : output voltage, P : output power)

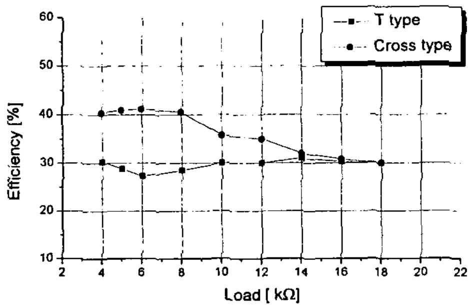


Figure8. The efficiency of T and Cross type.

6. Conclusions

In this paper, we suggested RF-DC conversion circuits in 2.46GHz microwave and analyzed the method for the increase of the efficiency. Specially, we designed two impedance matching circuit, T-junction and Cross-junction. Therefore, T-junction RF-DC conversion circuit is hard to match by tuning and has a lower efficiency than Cross-junction type. On the other hand, Cross-junction RF-DC conversion circuit has more benefits that the loss of power is decreased and the efficiency of power conversion is increased approximately 10% as compared with T-junction RF-DC conversion circuit (31%).

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