Design of Middle Range Microwave Power Transfer (MPT) System for the Mobile Power Receiver

Changyoung An and Heung-Gyoon Ryu
Department of Electronic Engineering
Chungbuk National University
Cheongju, Korea
acy890217@naver.com, ecomm@cbu.ac.kr

***Abstract* - Middle range MPT (microwave power transmission) is very important and hot issue, which uses RF (radio frequency) beamforming technology. To efficiently provide the power at distance, large dimension of array system is basically required in to the far end power receiver. In this paper, we design an antenna and phase conjugate circuit for the Retrodirective Array Antenna (RDA) - based microwave Power Transfer (MPT) system. Microwave power transfer is a technology that can effectively power various internet of things (IoT) devices that will explode in the future. Microwave power transmission is achieved through various methods, it is important to improve the power transmission distance and efficiency. In particular, long-range microwave power transmission system using microwave is less efficient than other transmission methods. Therefore, in designing the power transmitter and receiver, the link budget should be analyzed and the system should be designed based on this to maximize the power transmission efficiency. In this paper, we propose a multi-antenna design method of power transmitter and receiver via link budget analysis. Through the simulation and measurement results, it is confirmed that the antenna gain required in the system can be achieved through the multi-antenna configuration, and the optimal transmission power value should be calculated in consideration of the RF-DC rectifier efficiency. Based on this, it is possible to design a microwave power transmission system having acceptable power transmission efficiency.**

Keywords—MPT, mobile receiver, link budget, efficiency, multiple antennas

I. Introduction

Although there are various methods for wireless power transmission, the method using RF signals is mainly considered for middle range power transmission [1]-[4]. Since microwave power transfer (MPT) basically has low efficiency, when designing a transmission and reception system, maximum effort should be made to increase efficiency. As a method of increasing the power transmission efficiency, a method of increasing the antenna gain of the transmitting and receiving sides using a plurality of antennas and a method of improving the RF-DC conversion efficiency are mainly considered. In detail, as a method of increasing the gain of an antenna, a method using multiple antennas is mainly considered, and in this case, it is very important in terms of a form factor to select the minimum number of array antennas required to achieve a target power transmission efficiency. In this paper, link budget calculation and antenna design method are presented to design an efficient microwave power transmission system.

II. MPT System and Efficiency

An important goal in constructing a wireless power transfer system using microwave is to improve the distance and transmission efficiency. In general, in a trade-off relationship between these two factors, when the distance of the MPT system is increased, the transmission efficiency decreases, and in order to increase the transmission efficiency, the distance should be shortened. The power transmission efficiency of the MPT system may be calculated in consideration of transmit and receive antenna gains, RF-DC conversion efficiency, and transmission distance. This transmission efficiency E_p can be calculated as follows.

$$E_p = \frac{P_r}{P_t} = \frac{P_t G_t G_r E_{RF-DC}}{P_t L} \quad (1)$$

In equation (1), P_t, P_r, G_t, G_r, L, E_{RF-DC} are transmit power, receive power, transmit antenna gain, receive antenna gain, and RF-DC rectification efficiency, respectively. The target system assumed in this paper uses the 2.45GHz frequency, the power transmission efficiency is 5%, and RF-DC conversion efficiency is 60%. The path loss at a distance of 2m is calculated as 46.25dB.

RF-DC rectification efficiency and DC-DC conversion efficiency are generally considered to be about 60~70% and 80~90%, respectively. Other factors that affect efficiency include antenna insertion loss, atmospheric conditions, imperfect impedance matching of each connection, and loss of RF connectors and extension lines.

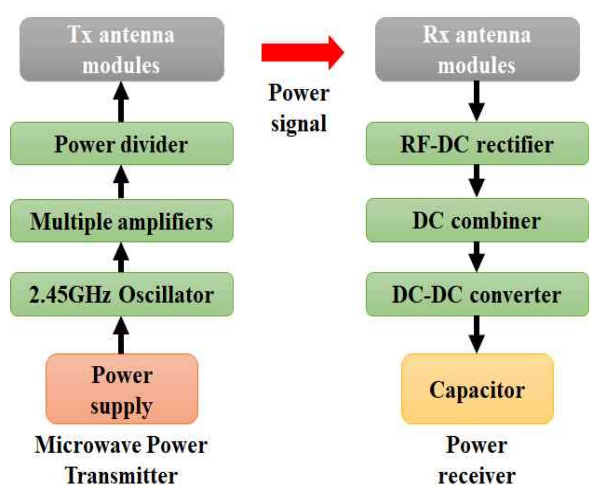

Fig. 1. Microwave power transfer system to achieve 5% power transfer efficiency at 2m distance.

According to Equation (1), efficiency is greatly affected by path loss and Tx/Rx antenna gain that varies according to distance. And finally, the efficiency of the wireless power transmission system is determined by the RF-DC rectification efficiency. Here, when the target efficiency and the transmission distance of a MPT system are determined, the gain of the Tx/Rx antenna may be calculated. In order to obtain the gain of the Tx/Rx antenna, the number and structure of transmit and receive antennas should be effectively selected. In general, the form factor of a power receiver is designed to be smaller than that of a power transmitter. However, depending on the application of the MPT system, this can be changed freely. If most of the required antenna gain is allocated to the power transmitter, the number of antennas will increase exponentially, and the form factor will also increase significantly. On the other hand, if the required antenna gain is appropriately distributed to the power receiver, both the transmitter and the receiver can satisfy the target by using an appropriate number of array antennas.

In this paper, an antenna module with a gain of 9dBi is considered to identify the antenna configuration to achieve this condition when 20dB is allocated to the transmitting antenna unit and 16dB is allocated to the receiving antenna unit. In general, if the number of antennas is doubled, the beam gain tends to increase by 3dB. In this paper, we design the system model as shown in Fig. 1 to achieve the goal of 5% power transmission efficiency at 2m. The power transmitter consists of a power supply, a 2.45GHz oscillator, a multistage amplifier, a power divider, and four antenna modules. The power receiver consists of two antenna modules and two RF-DC rectifiers. Here, the efficiency of the RF-DC rectifier may vary depending on the input power. If too high or too low power is applied to the RF-DC rectifier, the rectification efficiency drops dramatically. Therefore, the transmit output power should be set in consideration of the overall link budget.

III. Simulation and Measurement Results

TABLE I. Parameters for Measurement

Parameter	Value
target	Efficiency: 5% Distance: 2m
frequency	2.45GHz
RF-DC rectifier efficiency	60%
path loss	2m: 46.24dB, 3m: 49.77dB, 5m: 54.2dB
beam gain of an antenna module	about 9dBi
# of Tx antenna module used for measurement	4
# of Rx antenna module used for measurement	2
Transmit power	30dBm

TABLE II. Power Measurement Results in the MPT System

Condition / Parameter	Calculated (2.45GHz)	Measured	Error (P_r) [dB]
	P_r [dBm]	P_r [dBm]	
3m, 1x1 (Power)	-1.77	-1.15 (2.467GHz)	-0.62
3m, 2x1 (Power)	1.23	1.05 (2.467GHz)	0.18
5m, 2x1 (Power)	-3.2	-3.75 (2.47GHz)	0.55
5m, 4x1 (Power)	-0.2	-1.52 (2.47GHz)	1.32

Table I shows the parameters for the link budget calculation and measurement and table II shows the received power in the MPT system according to the number of Tx and Rx antennas.

Since the peak-to-peak value of the spectrum analyzer has fluctuated within about 2 dB in the measurement, the maximum value in the range of the measured values has been selected, and the value after the decimal point has been rounded up and finally expressed as an integer value. As a result of the actual measurement, when the number of antennas is increased to 1, 2, or 4, it has been confirmed that a gain of about 2.2 dB can be obtained when the number of antenna modules is doubled. Here, there is a fluctuation in the peak-to-peak value of the spectrum analyzer, so it is an effective analysis to focus on the trend of increasing the power of the received signal when the number of antenna modules is increased rather than the exact number. If the gain of an individual antenna module is lowered, it is necessary to configure more modules to increase the overall antenna gain. To summarize the experimental results, even when an uniform linear array is configured using a high-gain patch antenna module, the beam gain can be effectively improved. However, in consideration of the imperfection of the structure of arranging the antenna module and the case where the direction of the power transmitter/receiver does not exactly match, the system should be designed with a margin for the required antenna gain.

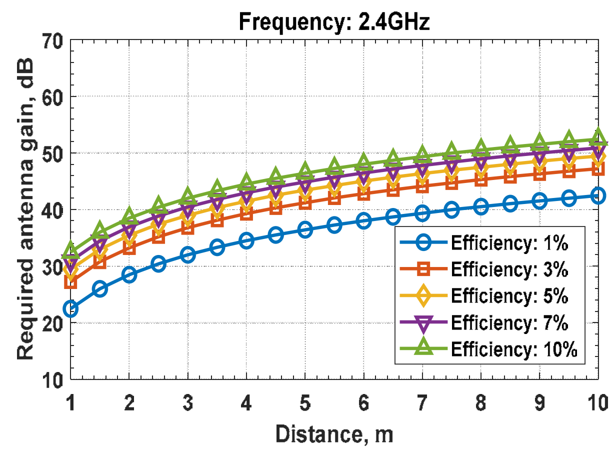

Fig. 2. Required antenna gain according to frequency, distance, and target efficiency for MPT.

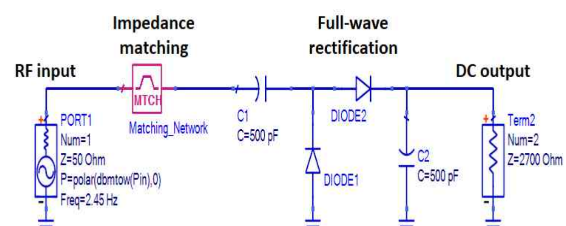

Fig. 3. Circuit diagram of the considered RF-DC rectifier.

Fig. 2 is a graphical representation of the total antenna gain required for a power transceiver according to distance and frequency used. Here, the ISM band, 2.45 GHz, has been considered for the frequency used, and the distance from 1 m to 10 m was considered. Then, 1%, 3%, 5%, 7%, and 10% have been considered for transmission efficiency. Overall, it can be seen that a higher antenna gain is required as distance and target efficiency increase. When the target efficiency is set to 5% at a distance of 2m, it can be seen that an antenna gain of 35.45dB is required when the frequency is 2.45GHz.

When a high frequency is used, the required antenna gain is also high, but since the size of the antenna is reduced, a higher gain can be obtained by arranging many antenna elements in a limited space.

Fig. 3 shows the basic circuit model of the RF-DC rectifier constructed using the SMS7630 diode. This rectifier uses two diodes and two capacitors to rectify the input RF signal in full wave. Then, by inserting an impedance matching network in the front part of the rectifier, the signal input from the antenna is not reflected and is well input to the rectifier. Here, impedance matching has been performed by adding a stub.

In this paper, the RF-DC rectifier with 60% conversion efficiency has been considered. Fig. 4 shows efficiency characteristic of the rectifier. In the rectifier, the maximum conversion efficiency can be achieved at an input power of 0dBm.

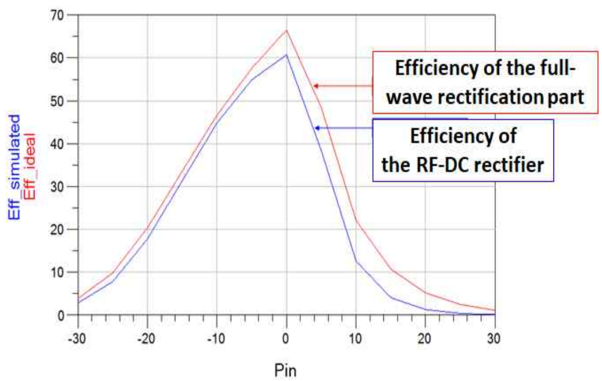

Fig. 4. Efficiency of RF-DC rectifiers using the basic schematic.

After obtaining the required antenna unit gain through the multi-antenna module configuration, it is necessary to check the input power value that can achieve the maximum efficiency in the RF-DC rectifier. Next, the transmission power must be determined by calculating the link budget so that the required power value is input to the RF-DC rectifier. In this way, an MPT system with excellent power transmission efficiency can be designed.

In conclusion, it is possible to calculate the required number of antennas when designing a specific target MPT system by considering the required antenna gain and the additional gain that can be obtained when the antenna is increased.

IV. Conclusions

In this paper, we show a method for designing an MPT system that satisfies a specific goal. First, if the link budget is calculated in consideration of the target efficiency and key parameters, the required antenna gain can be obtained. Then, by measuring the increase in gain according to the increase in the antenna module, the number of antennas required when actually configuring the array antenna can be determined. In this paper, this method has been demonstrated through simulation and measurement. It has been confirmed that an antenna gain of about 36 dB is required to satisfy the power transmission efficiency of 5% under the condition that the frequency used is 2.45 GHz and the distance is 2 m, and it has been shown that the required gain can be obtained by adjusting the number of antenna modules.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Education) (NRF-2016R1D1A1B01008046) and this work was supported under the framework of international cooperation program managed by the National Research Foundation of Korea (2019K1A3A1A39102995) and this work was supported under the framework of international cooperation program managed by the National Research Foundation of Korea (2020K2A9A2A08000106).

References

[1] J. Shin et al., "5.8 GHz 4-Channel Beamforming Tx IC for Microwave Power Transfer," IEEE Access, vol. 9, pp. 72316-72325, 2021.

[2] J. H. Park, D. I. Kim and K. W. Choi, "Analysis and Experiment on Multi-Antenna-to-Multi-Antenna RF Wireless Power Transfer," IEEE Access, vol. 9, pp. 2018-2031, 2021.

[3] A. A. Eteng, H. H. Goh, S. K. A. Rahim and A. Alomainy, "A Review of Metasurfaces for Microwave Energy Transmission and Harvesting in Wireless Powered Networks," IEEE Access, vol. 9, pp. 27518-27539, 2021.

[4] J. H. Park, N. M. Tran, S. I. Hwang, D. I. Kim and K. W. Choi, "Design and Implementation of 5.8 GHz RF Wireless Power Transfer System," IEEE Access, vol. 9, pp. 168520-168534, 2021.