

Beamforming Design of the Wireless Power Transfer System into Multiple IoT Sensors

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Abstract— Recently, wireless power transfer (WPT) to the IoT sensors wirelessly over the far distance has been attracted too much and this WPT system is based on the radio frequency (RF) antenna technology. In this paper, we propose a wireless power transfer (WPT) to multiple IoT sensor system using an electronically steerable parasitic array radiator (ESPAR) antenna based on microstrip patches. An ESPAR antenna design method and evaluation results for the WPT system are also presented. The WPT system is characterized by very low power transmission efficiency due to path loss of the RF signal. Therefore, the WPT system mainly utilizes a beamforming technique using multiple antennas to improve this characteristic. A phased array antenna is generally used for beamforming. However, there is a disadvantage in that the network configuration for beamforming is complicated. The ESPAR antenna has the advantage of being able to perform beamforming without such a complicated circuit configuration. When the ESPAR antenna is applied to an WPT system, a low-complexity and high-efficient WPT system can be designed. Through the simulations, it is confirmed that the ESPAR antenna can support a wide range forward through 3D beamforming.

Keywords— beamforming, ESPAR antenna, microstrip patch, reactance, WPT

I. INTRODUCTION

Recently, a technology for transmitting power wirelessly is being considered to effectively supply power to the internet of things (IoT) devices, which are one of the main support targets of 5G and 6G mobile communication [1-5]. Wireless power transfer (WPT) systems use RF signals to transfer power [6], which is called as another name of microwave power transfer (MPT) since the main RF signal is the microwave. This technology has the advantage of being able to power devices over long distances wirelessly [7-9]. However, it has low power transmission efficiency due to path loss according to distance and radio frequency (RF) to direct current (DC) conversion efficiency [10]. To improve these characteristics and increase power transmission efficiency, the WPT system should use a beamforming technique.

In general, to use beamforming technology, an antenna composed of multiple elements is required [11]. In addition, an RF chain composed of active elements consuming power is connected to each element. That is, when the number of antennas of the array antenna increases, the number of RF chains also increases, which may cause problems such as interference between circuits, heat generation, increase in

form factor size, and increase in power consumption. When an conventional array antenna is used in an WPT system, the power transmission efficiency of the overall system may decrease due to an increase in power consumption caused by multiple RF chains. To solve this problem, this paper presents a method to apply an electronically steerable parasitic array radiator (ESPAR) antenna capable of beamforming using a single RF chain to an WPT system. In this paper, we also design an ESPAR antenna using microstrip patch elements that can be used on the power transmitter side for effective WPT system design and evaluate how wide a designed antenna can support.

II. WIRELESS POWER TRANSFER TO IoT SYSTEM

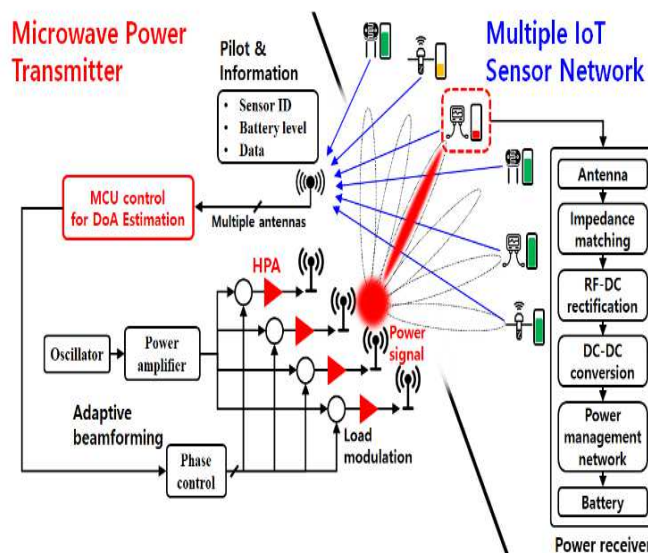


Figure 1. WPT system to multiple IoT sensors

Figure 1 shows the block diagram of the MPT system. MPT belongs to the WPT since the microwave signal can convey the power to the IoT sensors. The WPT system consists of a wireless power transmitter and a wireless power receiver. The power transmitter amplifies the signal generated by the oscillator and transmits it through multiple antennas after phase shifting. Through this method, a high-power output signal can be beam-formed and transmitted to the power receiver. The power receiver consists of multiple antennas, impedance matching circuits, RF to direct current (DC) rectifiers, a DC-DC converter, a power management network,

and a battery. The power receiver receives RF power through a plurality of antennas, converts it into DC power, and stores it. In the WPT system, the overall power transmission efficiency is greatly affected by the distance-dependent attenuation, impedance matching, and RF-DC conversion efficiency. Therefore, an effective impedance matching circuit configuration and a high-efficiency RF-DC rectifier should be used in the power receiver. In addition, in the power transceiver, it is necessary to overcome the decrease in power transmission efficiency due to path loss by increasing the antenna gain of the transmitter and the receiver by using a plurality of antennas.

III. ESPAR ANTENNA FOR WPT SYSTEM

An ESPAR antenna consists of an active element with one RF chain connected to the center and passive elements with variable reactance around it. In the antenna, the beam pattern is changed according to the reactance value of each passive element. In order to perform beamforming in a desired direction, after designing an antenna, it is necessary to identify a beam pattern generated by applying each reactance set. In this paper, we design an ESPAR antenna that consists of a two-dimensional array to overcome the shortcomings of a general two-dimensional array antenna and present reactance sets that enable effective 3D beamforming. The antenna design and simulation are performed using the CST antenna design program, and the beam pattern characteristics extracted from the CST are analyzed using the MATLAB program.

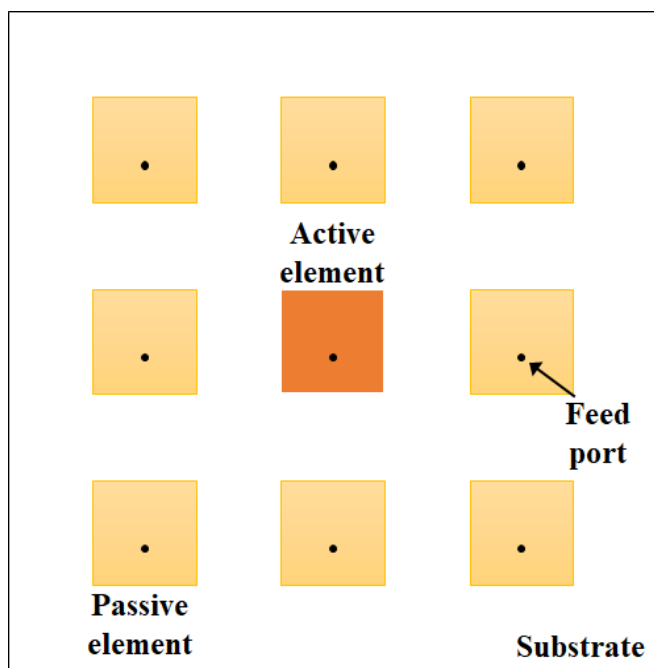


Figure 2. Structure of the 3x3 ESPAR antenna

An ESPAR antenna for 3D beamforming can be designed by arranging microstrip patch elements in two dimensions. In this paper, we design an ESPAR antenna with a 3x3 structure and figure out the reactance sets for 3D beamforming. Figure

2 shows the configuration diagram of the 3x3 ESPAR antenna designed in this paper. Firstly, looking at the front view, an active patch element to which an RF signal is applied is located in the center, and passive patch elements to which varactor diodes are connected are located in the periphery. An RF signal is fed to the active element using a feed port. A substrate and a ground plane are sequentially positioned at the bottom of the patch element. Next, looking at the rearview, varactor diodes capable of adjusting capacitance are connected to the port connected to the passive element. Finally, looking at the side view, the RF port connected to the active element is configured in a protruding shape to connect the connector.

IV. SIMULATION RESULTS AND EVALUATION

The ESPAR antenna has been designed. The operating frequency of the antenna is a band near 2.45 GHz. The patch element has a width and length of 27.12 mm, and an interval between the one patch element and the nearest one is 22.8 mm. The substrate size is 160 mm wide, 155 mm long, and 2.54 mm thick. The feed port of each element is located 10.56 mm off from the bottom of the element. Next, the material of the elements and the ground plane is copper, and the material of the substrate is FR-4 (lossy).

To confirm the beamforming characteristics of the designed ESPAR antenna, a simulation has been performed while changing the reactance value applied to each passive element to 1 or 150. Since each of the eight passive elements has two reactance states, 256 simulations have been performed.

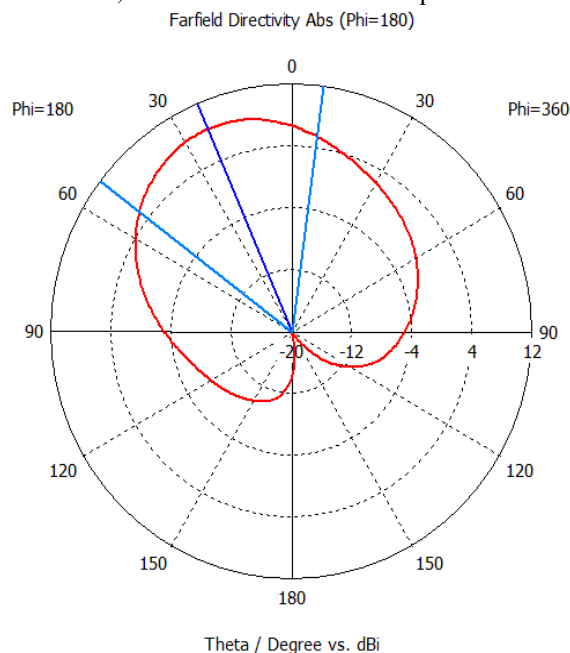


Figure 3. One example beam pattern the designed antenna can create (side view)

Figure 3 shows one example beam pattern of the 3x3 ESPAR antenna. This figure is captured from the side. The beam direction angle is about 23° to the left. The beam directivity is about 8.43 dBi. The 3 dB beamwidth is about 60° .

Figure 4 shows the direction and gain of beamforming according to 256 reactance combinations as vectors. The elevation angle of the generated beam pattern can be changed from about 60° to about 90° when the bottom surface is 0° and the front direction is 90° . That is, it can support a 60° range in the front direction.

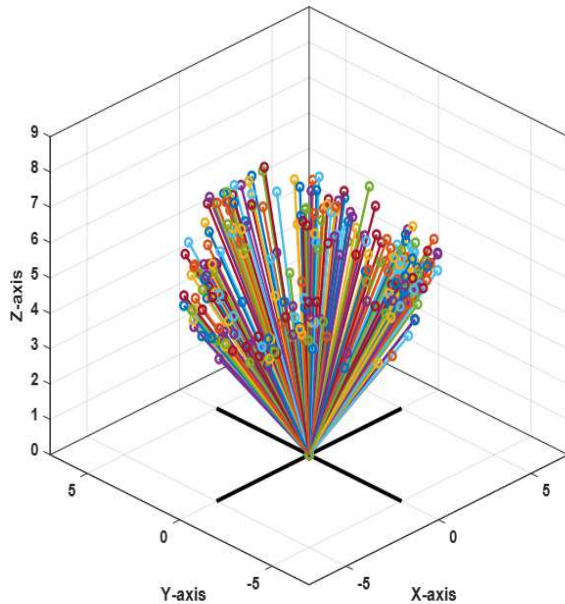


Figure 4. Beam direction vectors according to reactance set

V. CONCLUSIONS

In this paper, we have proposed an ESPAR antenna based WPT system and presented the 3x3 ESPAR antenna design method and performance evaluation results that can be effectively used in the WPT system. In detail, the design specifications of the 3x3 ESPAR antenna that can operate in the 2.45 GHz band have been presented, and through beam pattern analysis, it has been confirmed that the designed antenna can effectively support the front direction of the antenna from 60° to 90° in elevation.

ACKNOWLEDGMENT

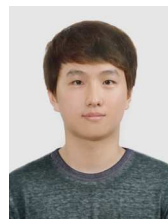
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