A Robust Design of an Isotropic Planar Antenna for Wireless Power Harvest Using Evolution Strategy and Taguchi's Method

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Abstract — This paper deals with a robust design of an isotropic planar antenna for the rectenna design which is important in the power conversion of a wireless power harvest system. Using evolution strategy, optimum dimensions of slots are first sought for receiving the incident wireless power in all directions. Then the optimized dimensions are modified by Taguchi's method in order to obtain robustness against the change of material constant. From the numerical and experimental results, it is confirmed that the final design is insensitive to noise factors.

I. INTRODUCTION

In recent years, rectifying antenna (rectenna) which is one of the most important components for microwave power transmission received more attention owing to its potential for many wireless power needed applications. Various small antennas and array antennas have been proposed of improving the performance of rectenna[1].

This paper proposes a small planar antenna structure for rectenna application and very efficient design method for improving the antenna efficiency. The application of the proposed antenna is designed for receiving the incident wireless power in all directions, and its advantage is that the size of the antenna is smaller than the basic microstrip patch antenna. The proposed antenna uses single frequency band of 915 MHz, which is the center frequency of the most upper channel of the UHF RFID band in Korea. This frequency band in Korea only has the CW for powering the Tags. Thus, 915MHz in Korea is often used to be power carrier frequency for wireless power transmission in UHF band. In order to improve the power harvesting performance, antenna should have good gain and matching performance at designed frequency. The proposed antenna can provide the excellent gain performance compared to the conventional patch antenna with same volumetric condition. The proposed antenna has the advantage of the easy implementation of the rectifying and charging circuits on its metallic backside ground plane with both RF and DC grounds. Furthermore, it is also easy for the proposed one to implement the combining circuits for the array implementations with diminishing the antenna pattern coupling between the array elements.

The structure of patch antenna is determined by evolution strategy (ES) to enhance the matching performance to 50ohm at 915MHz. The excellent matching performance to the cascade rectifying circuit improves the RF to DC converting efficiency of rectenna. [2] A highly reliable substrates should have been used for antenna implementation to minimize the tolerance of fabrication and to guarantee the good performance. Meanwhile, the most applications make use of generally reliable substrates such as FR4 with a small outlay. This produces unexpected deviations. So, the result of ES cannot guarantee the robustness of the antenna performance with respect to the uncontrollable factors that may deteriorate good performance predicted, such as the variations in permittivity of the substrate. Therefore, the optimized values obtained from ES is modified by Taguchi's method (TM) [3] to achieve the variation-tolerable design with permittivity and mismatch patch and ground plane.

II. OPTIMAL DESIGN OF PATCH ANTENNA

A. Size Optimization Using Evolution Strategy

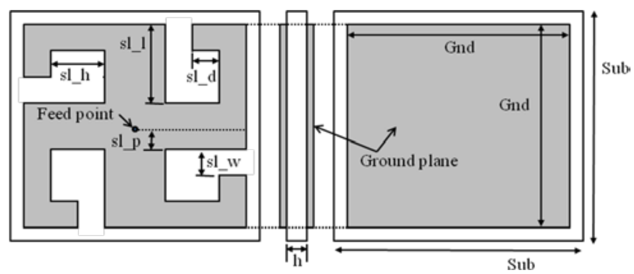

Fig. 1. The configuration of proposed patch antenna (h=1.6mm, Sub=89.6mm, Gnd=80mm, substrate is FR4-Epoxy).

The schematic of the analysis model and definition of the 8 size design parameters are illustrated in Fig. 1. Among 8 design parameters, five crucial parameters, sl_p, sl_w, sl_l, sl_h and sl_d, forming slots are selected for sizing optimization with (1+1) ES. The initial value was set to have nondirectional polarization. The design goal is to obtain optimal dimensions of the slots for resonant frequency of 915MHz and good gain. To achieve this, the multi-objective function with constrains on the reflection coefficient (S_{11}) is defined as :

$$\begin{aligned} &\text{Minimize} \quad F = \alpha_1 (f - f_o)^2 + \alpha_2 (G_f - G_o)^2 \\ &\text{subject to} \quad S_{11}(f_i) \le -15 \text{ dB} \end{aligned} \tag{1}$$

where α_i is the weighting factor which set to obtain good gain at 915 MHz, f and G_f are the resonant frequency and gain computed at each design iteration and f_0 and G_o are the target frequency and gain values. The initial and optimized design values are presented in Table I and the reflection coefficient values are compared in Fig. 2. It is observed that the performance of the optimized design coincides well with the design goal.

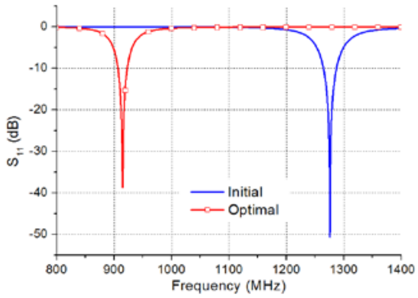

Fig. 2. Comparison of reflection coefficient before and after sizing optimization.

TABLE I
DESIGN PARAMETERS AND PERFORMANCE

Parameter	Unit	Initial values	Optimal values
sl_p	mm	10.00	13.25
sl_l		25.00	30.83
sl_w		5.00	9.83
sl_h		5.00	9.23
sl_d		20.00	18.59
Frequency	MHz	1,276	915
S_{11}	dB	-49.288	-38.689
Gain	dB@MHz	-7.046@1,276	-10.09@915

B. *Robust Design Using Taguchi's Method*

The robust optimization is carried out by TM in order to find a new optimal solution insensitive to noise factors. The substrate permittivity and mismatch between patch and ground plane are considered as noise factors and four size design parameters are chosen as control factors. Based on the settings considered in Table II, standard orthogonal arrays (OA) L9(3^4) was selected for control and noise factors, respectively. Then a 9×9 matrix was set up for the numerical experiments, where the parameters are assumed to be mutually independent.

TABLE II
DESIGN AND NOISE PARAMETERS FOR ROBUST OPTIMIZATION

Type	Parameter	Level		
		1	2	3
Control Factor	sl_p	13.05	13.25	13.45
	sl_l	30.63	30.83	31.03
	sl_w	9.63	9.83	10.03
	sl_h	8.03	9.23	9.43
Noise Factor	*Mismatch* x *coordinate*	-1	0	1
	Mismatch y coordinate	-1	0	1
	Substrate permittivity(ε_r)	4.4	4.5	4.6

The performance sensitivity with respect to the parameters is represented by the value of the SN ratio. For the "nominal the best characteristic" case, which resembles the minimization of the performance in (1), the SN ratio is given by

$$\mathrm{SN} = 10\log\left[\frac{1/n\,(S_m - V)}{V}\right]$$
$$V = \frac{1}{(n-1)}\sum_{i=1}^{n}(y_i - \bar{y})^2,\quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i,\quad S_m = \frac{1}{n}\left(\sum_{i=1}^{n} y_i\right)^2 \qquad (2)$$

where n is the total experimental number, y_i is the performance of the ith experiment and S_m , V and y denote the mean squared derivation, variance, mean of the performance, respectively. Through the somewhat routine process of Taguchi quality control, an optimal setting of the design parameters can be determined. The optimal design values between the typical and the robust optimization are presented in Table III.

TABLE III
OPTIMAL CONDITIONS BETWEEN ES AND TM

Parameter	Unit	Optimized (ES)	Robust (TM)
sl_p	mm	13.25	13.45
sl_l		30.83	31.03
sl_w		9.83	9.83
sl_h		9.23	9.23
Frequency	MHz	915	918
S_{11}	dB	-38.689	-36.054
Gain	dB@MHz	-10.09@915	-8.55@917
SN ratio	dB	1.3573	-0.7545
Sensitivity		20.2664	12.9372

C. *Measurement*

The proposed antenna was fabricated as shown in Fig. 3. The predicted and the measured reflection coefficient are compared with each other in Fig. 4. The measured resonant frequency is 915 MHz.

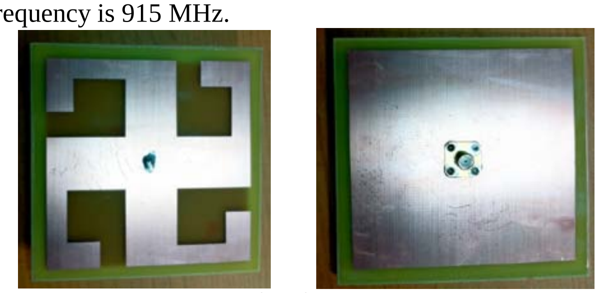

Fig. 3. A photograph of the fabricated 915 MHz Antenna.

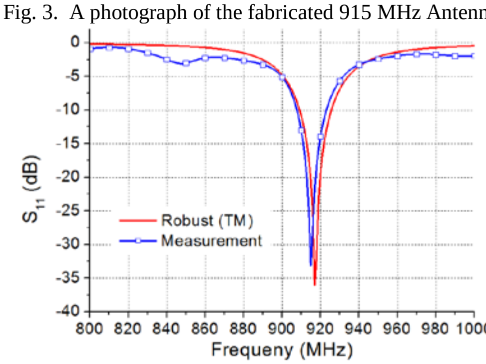

Fig. 4. Comparison of reflection coefficients between the simulation and the experiments.

III. Conclusion

In this paper, ES and TM are applied to the design of the planar antenna. A robust design of antenna with excellent matching performance is obtained with reliable substrate with a small outlay by TM. Our extended paper will include experiments of the designed antenna, such as radiation pattern, and more details in the wireless power harvest application.

IV. References

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