An Optimal Design of Compact Ring-Slot type Rectenna with Numerical Manipulation

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***Abstract*— An improved design process for a compact ring-slot type rectenna which has superior and controllable properties in size, directivity and harmonics radiation is proposed. The rectenna has axial slits and side-cuts to control the in-out frequency band and the depth of circular polarization. All parameters are optimized using the Particle Swarm Optimize method. The designed rectenna shows a desirable performance of return loss of 21.36dB and axial ratio of 2.92 at the frequency of 2.45GHz with compact size.**

***Index Terms*— Rectennas, Particle Swarm Optimization**

I. Introduction

The rectenna (rectifying antenna) is a very useful component for wireless sensor network nodes or other low power consumption telecommunication devices, which supplies power and wireless communication simultaneously. Several studies of the patch type rectennas has been reported [1]-[2] in various shapes, and most recently Takhedmit et al. [3] suggested an integration of the rectifying circuit and the antenna in same area, reverse side without any filters, using a ring-slot type structure, which becomes most attractive in achieving compactness and efficiency altogether.

The essences of rectenna design are size, flatness and harmonic reduction. The flatness in radiation can be accomplished by adding circular polarization to the circular patch-type antenna, while the axial rate is fluent. The harmonics radiation which transpires by use of the built-in rectifier is the most harmful operation of the rectenna, and must be suppressed to reduce unwanted power radiation.

In this paper, an optimal design procedure of reduced size ring-slot rectenna is presented. Axial slits are added to the conventional circular patch antenna, which is effective in reducing its size and can control the reduction range in frequency for suppressing the harmonics radiation. Also the side-cutting technique is applied to generate circular polarization. To choose proper values of so many design parameters, a suitable optimization technique is needed. We adopted the particle swarm optimization (PSO) algorithm [4] which is regarded as powerful tool for a multi-variable, multi-objective optimization problem.

The proposed design is tested and verified to have the desired performance by simulations and experiments.

II. Optimal Rectenna Design

The ring-slot patch antenna is operated in TM_{11} mode. The circumference of the ring is the half wavelength of the operating frequency. If we insert axial direction slits as shown in Fig.1, the effective length of the circumference of the ring is increased, so that the diameter of the ring can be reduced.

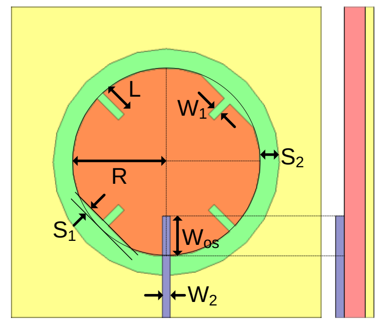

Fig. 1. The proposed design of the modified ring-slot patch antenna and design parameters

And the slit also can change the center frequency of the main and the local return loss distributions, so that we can possibly avoid the harmful harmonic band effectively. The bands of harmonics arisen in the rectifier circuit are usually restricted in 2nd harmonics, which is a relatively small area in the whole range. The harmonic radiations can be suppressed effectively by inserting slits and adjusting the parameters.

The selected design parameters are notated with W_{os}, L, R, S_1, S_2, W_1, W_2 which are the distances between the feeding point to the origin, the length of the slit, the radius of the inner disk, the depth of side-cut, the width of the ring-slot, the width of the slit, and the width of the feeding line respectively.

The PSO is adopted to produce the optimal solution of the design. The power of PSO is tested and compared with other algorithm. As shown in Fig.2, PSO has fast convergence than ES(Evolutional Strategy), and has less influence with initial guess than ES.

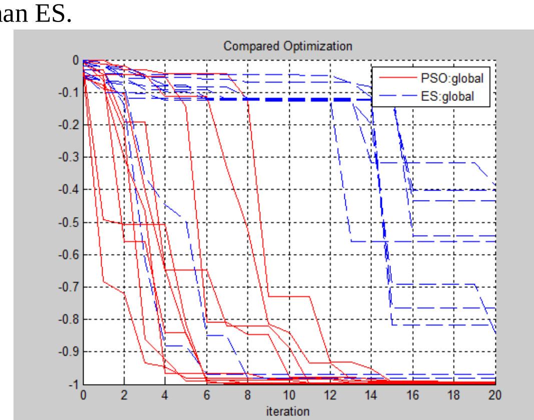

Fig. 2. Comparison of convergence between PSO and ES algorithm.

For our system, he dimension of the system is 7, which is the number of the above design parameters, and the number of particles selected is 15. The fitness function (objective function) for PSO in this rectenna design should be defined so that it includes not only the frequency matching, but also the Axial Ratio(AR) improving, as follows,

$$F_2 = \alpha(f_t - f_i)^2 + \beta(A_t - A_i)^2 \qquad (3)$$

where α, β are weighting factors, and f_t , f_i are the target resonance frequency to fit and the calculated one, which can be extended as many as wanted. The function also contains a new parameter of AR of antenna as denoted A_t for target and A_i for each calculation to obtain a smooth distribution of CP. The target value of resonant frequency and AR are 2.45 GHz and 3 dB, respectively, and weight factors are set by normalizing manner for equal weighting. A numerical manipulation is applied to exclude the satisfied values in band width.

The initial and the optimized values of the parameters are denoted in Table 1. The final results show that the size of the ring is reduced against the previous work [3] and all the properties meet the desired goal satisfactorily.

TABLE I
THE VALUES OF DESIGN PARAMETERS [MM]

State	W_{OS}	R	S_1	S_2	L	W_1	W_2
Initial	3	14	2	0.8	4	1.5	1
At 1st conv.	2.29	13.97	2.63	0.8	3	1.02	1.28
Final	1	13.52	1.7	0.31	2	1.89	1

The variation of the return loss and AR are shown in Fig. 2 and 3. The final result of return loss is -21.36 dB and the AR goes down to 2.92 dB at the target frequency.

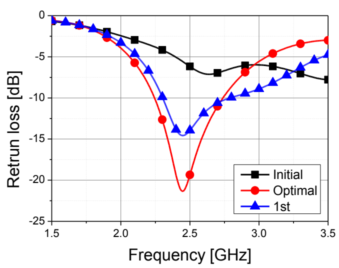

Fig. 2. Variation of resonant frequency of the rectenna with optimization

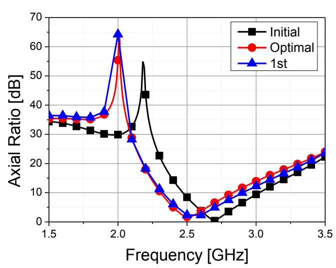

Fig. 3. Variation of Axial Ratio of the rectenna with optimization

Additionally, we also checked the suppression of the 2nd harmonics. It reveals that the band of 2nd harmonic frequency 4.9GHz is successively suppressed as shown in Fig. 4. Thus no extra treatment for the harmonic frequency is needed.

The proposed designs are fabricated and measured as shown in Fig. 5. ~ 6. The radiation pattern is also shown in Fig. 7, which denotes no distortion due to adding the slit. In both cases, good agreement between the simulated results and measured ones are achieved. The rectifying circuit is also implemented and tested on the same PCB. It can produce over 1.2 V for more than 5 dBm input power in this structure.

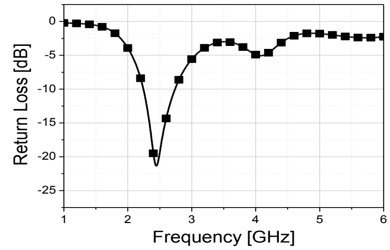

Fig. 4. The return loss distribution in expanded range of frequency

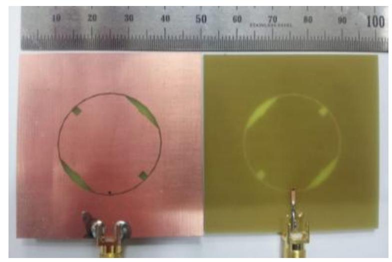

Fig. 5. The fabrication of proposed rectenna model

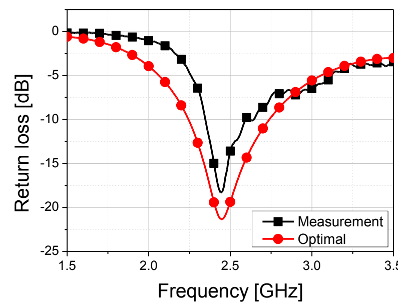

Fig. 6. Comparison of the measured and the simulated return loss for the final model

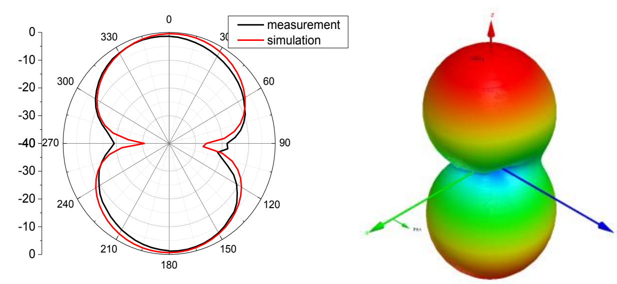

Fig. 7. Comparison of the measured and the simulated radiation pattern for the final model

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