Design of Short-Circuited Microstrip Antenna Using Differential Evolution Algorithm

Arindam Deb, Jibendu Sekhar Roy, Bhaskar Gupta[1]

Abstract – **Differential evolution (DE) algorithm is used to design a microstrip antenna, loaded with a shorting pin. The position of probe and the position of shorting pin are optimized using DE. The fitness function for DE is obtained using multiport network modelling technique. Antenna is fabricated and measured results are compared with the theoretical results.**

Keywords – **Differential algorithm, Cavity analysis, Microstrip antenna, Short-circuited patch.**

I. Introduction

Microstrip antenna, in its basic form, is a structure consists of a metallic radiating patch, etched on a dielectric substrate and backed by a ground plane. These types of antenna are used in low profile applications [1-3]. Miniaturization of microstrip antennas has been a challenging task to adapt the size to fit it into smaller, space limited modules used for different wireless communication systems. Various techniques for miniaturization are proposed in recent literatures among which shorting pin is a favourable option [4-7] due to its ability to miniaturize the antenna to nearly 50% of its original size with possibility of good impedance matching at the resonant frequency[4]. Miniaturized dual frequency microstrip antennas can be designed with reduced gain using short circuited microstrip antennas [5, 7]. The main difficulty in designing a short circuited microstrip antenna is to find out the proper position of coaxial feed and position of shorted pin on the radiating patch. In this paper, the position of coaxial feed and position of shorted pin a rectangular patch antenna, fed by a coaxial line and loaded with a shorting pin, is optimized using differential evolution algorithm. The antenna is designed to resonate at 1.58 GHz. For antenna optimization, using differential evolution algorithm, the fitness function is evaluated using cavity analysis [1-2] of microstrip antenna. Differential Evolution [8-12], a variant of genetic algorithm (GA) and evolutionary algorithm, has given superior performance compared to contemporary optimization algorithms and hence its performance is evaluated in this paper with respect to the design of a short-circuited microstrip antenna.

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Recently, attention has given to apply DE in antenna problems [13-24], though in most of the cases DE is applied to antenna array optimization problems. In [16], DE is applied to design broadband patch antenna, where fitness function is derived using method of moment (MoM) simulations. Hybrid DE and self-adaptive DE are also applied to antenna and antenna related problems [18-22]. In [23], DE is applied to design coaxial probe-fed microstrip antenna and aperture-coupled microstrip antenna, where cavity method and transmission line method are used to obtain fitness functions. In this paper, MATLAB is used for DE optimization. The short circuited microstrip antenna is fabricated and its characteristics are measured by vector network analyzer and compared with the theoretical result.

II. Antenna Analysis

The co-axial fed microstrip antenna with shorting pin is shown in Fig. 1. Substrate with dielectric permittivity of 4.36, loss tangent of 0.01 and height of 1.6 mm is used. Length and width of the patch are designated by L and W. xp represents the distance of the probe feed from the left radiating edge whereas xs denotes the distance of the shorting pin from the same radiating edge.

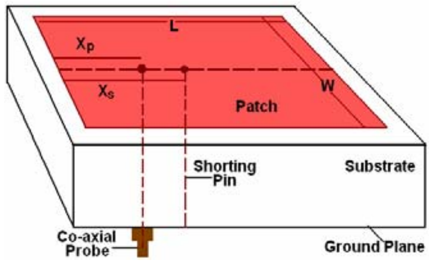

Fig. 1. Microstrip antenna with shorted pin

The proposed antenna can be treated as a two port network with the probe feed at the input and the output port being shorted. The driving point input impedance is given by [2]:

$$Z_{in}=Z_{11}-Z_{12}^2/Z_{22} \quad (1)$$

Where, Z_{11}, Z_{12} and Z_{22} represent Z-parameters of the two port network. These Z parameter values for TM_{mn} mode can be calculated by using cavity model analysis [1, 2] of the antenna.

$$Z_{11}= V_1/I_1 \ (I_2=0)$$
$$= jw\mu_0 I_0 . \sum\sum \frac{\Psi_{mn}^2(x_p,y_p)}{k^2-k_{mn}^2} \text{sinc}(m\pi D_x/2L) \ \text{sinc}(n\pi D_y/2W) \quad (2)$$

$Z_{22}= V_2/I_2\ (I_1=0)$

$$= jw\mu_0 I_0.\ \frac{\sum\sum\Psi_{mn}^2(x_s,y_s)\ \mathrm{sinc}(m\pi D_x/2L)\ \mathrm{sinc}(n\pi D_y/2W)}{k^2-k_{mn}^2} \quad (3)$$

$Z_{12}= V_1/I_2\ (I_1=0)$

$$= jw\mu_0 I_0\ .\sum\sum\Psi_{mn}(x_p,y_p)\ \Psi_{mn}(x_s,y_s)\ [\mathrm{sinc}(m\pi D_x/2L)\ \mathrm{sinc}(n\pi D_y/2W)]/\ (k^2-k_{mn}^2) \quad (4)$$

Where, $\Psi_{mn}(x,y)= \sqrt{(\epsilon_m\epsilon_n/(LW)}\ \cos(m\pi x/L).\ \cos(n\pi y/W)$ (5)
$\epsilon_p = 1$ for p=0, and $\epsilon_p = 2$ otherwise.

Here, p=m or n, depending on mode of excitation.

Here, I_o is the feeding current, (x_p,y_p) represents position of probe feed, (x_s,y_s) represents position of shorting pin, k is the wave number and $k_{mn}=[(m\pi/L)^2+(n\pi/W)^2]^{1/2}$ D_x and D_y represents the dimensions of probe feed when the cross sectional area of the inner conductor is taken to be a rectangle. For simplicity, cross sectional area of the shorting pin is taken to be same as that of the probe feed.

In measurement, commercially available probe connectors and the shorting pins are used whose cross sections are circular. Although, the cross sections of the shorting pin and the inner conductor are chosen to be square shaped for mathematical simplicity in theoretical explanations and MATLAB simulations, but their areas of cross section are maintained exactly same as that used in the fabricated antenna. When the conductor is very thin, the inductive effect produced by square and circular cross sections of same area of the pins, are almost same. Once, Z_{in} is calculated, S_{11} can be found as:

$$S_{11}= 20\ \log_{10}|(Z_{in}-Z_o)/(Z_{in}+Z_o)| \quad (6)$$

III. ANTENNA DESIGN USING DIFFERENTIAL EVOLUTION ALGORITHM

The steps to design the antenna using DE are briefly outlined below:

Step 1: Define an initial population (40) of trial vectors. Each trial vector ($[X_{i1}\ X_{i2}\ X_{i3}\ X_{i4}]$ contains different real coded parameters of the design; i represents the serial number of the trial vector in the population. For each parameter, a lower limit and an upper limit are defined ($X_i^L< X_i, j < X_i^U$). In this particular problem, the parameters in each trial vector are length and width of the microstrip antenna and the distance of the probe feed and shorting pin from one of the radiating edge along the center line of the patch.

Step 2: Randomly select the initial parameters of the design with the upper and lower limits defined for each parameter.

Step 3: For each trial vector (i) from 1-40, repeat steps 4-6.

Step 4: For each trial vector i, choose another three trial vectors numbered as n1, n2 and n3 randomly from the rest of the population where n1, n2, n3 and i are all different. The last three trial vectors are combined to form a donor vector indicated as V_i corresponding to the original trial vector X_i.

$$V_{i,j}=X_{n1,j}+F^*(X_{n2,j}–X_{n3,j)}\ \text{where, j=1,2,3 and 4} \quad (7)$$

Where F(scaling factor) ranges from 0-2.

Step 5: A crossover probability is set: CR=0.35, (determined through trial and error).For each trial vector, X_i and donor vector V_i, a target vector T_i is formed. For each of the four parameters defined in step 1, a random number is generated in MATLAB which is compared with the fixed CR, depending on which the parameters of the target vector are chosen either from the corresponding trial vector or the corresponding donor vector as shown below:

$$T_{i,j} = X_{i,j}\ \text{if rand(0,1)<CR}$$

$$=V_{i,}\ \text{otherwise} \quad (8)$$

Step 6: Once the target vector is available along with the trial vector, fitness functions of both are evaluated. If the trial vector yield a better fitness value than the target it remains as it is for the next generation otherwise the trial vector is replaced by the target vector to be a part of the population for the next generation.

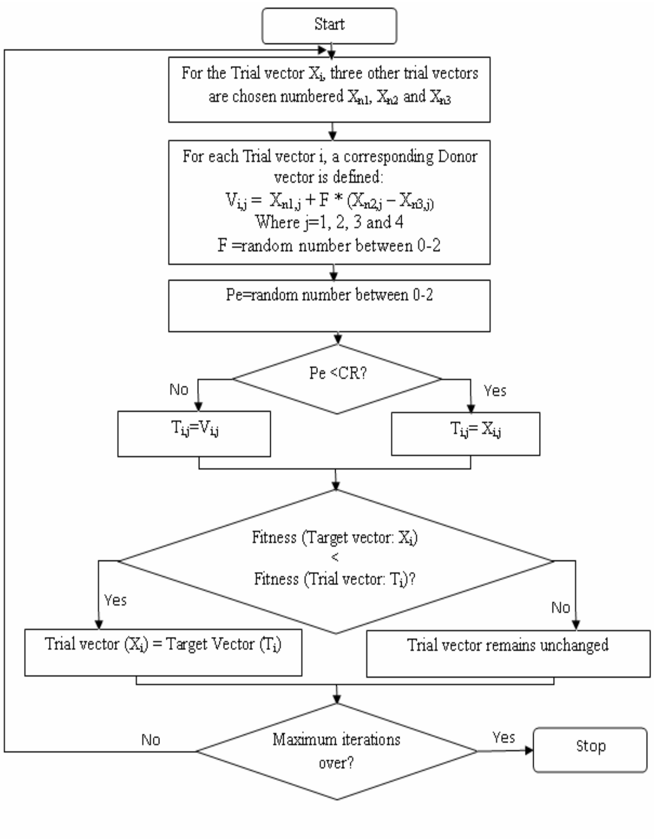

Fig. 2. Flowchart for the design of antenna using DE

The fitness function used for computation is

$$F=|\Gamma_i| \quad (9)$$

Where, Γ_i represents reflection coefficient and represented as $\Gamma_i = (Z_{in}-Z_o)/(Z_{in}+Z_o)$.

A flowchart for the design of antenna using differential evolution algorithm is presented in Fig. 2.

The differential evolution is run for 40 iterations with a population size of 40 after which the optimized values of the dimensional parameters i.e L, W, x_p and x_s are obtained. The optimized values are: L=18.40 mm, W=17.86 mm, x_p=12.87 mm and x_s=11.65 mm. The differential evolution algorithm is run for 50 independent trials. Each time it is run for 40 generations. The best result out of those 50 independent trials is shown in Fig. 3 as the best fitness curve. The best fitness graphs from each of the trials (from 1-50) are averaged and is presented in Fig.3 as the mean fitness graph. This is done because stochastic optimization algorithm does not ensure the best optimized result in a single run.

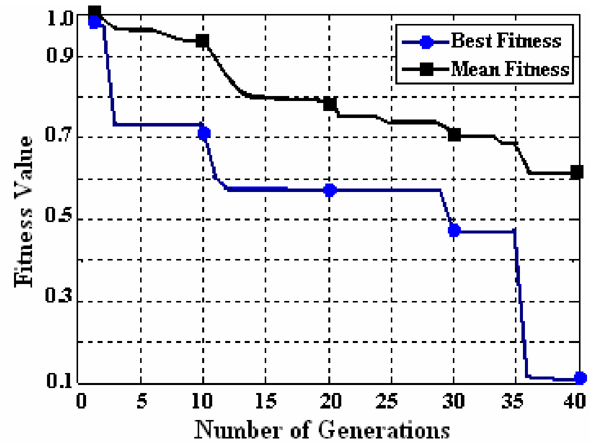

Fig. 3. Variation of best and mean fitness with number of generations

Antenna is fabricated on Glass Epoxy substrate with dielectric permittivity of 4.36, loss tangent of 0.01 and height of 1.6 mm. Dimensions of the antenna are given above along with feed position and the position of shorting pin. The diameter of the shorting pin is 0.3 mm. Measurement is done using vector network analyzer. In Fig. 4, measured return loss of the antenna is compared with the result obtained using DE.

The variation of maximum directivity near the resonant frequency is shown in Fig. 5. From cavity model analysis, electric and magnetics fields, inside the cavity, are computed and from these fields far field components E_θ and E_φ are calculated. Then from E_θ and E_φ, directivity is computed [1-2]. Directivity at resonance frequency is 2.93 dB.

The radiation pattern of the short circuited microstrip antenna is shown in Fig. 6. Due to short circuit by a pin, the radiation patterns of short circuited patch antennas become distorted [4-7].

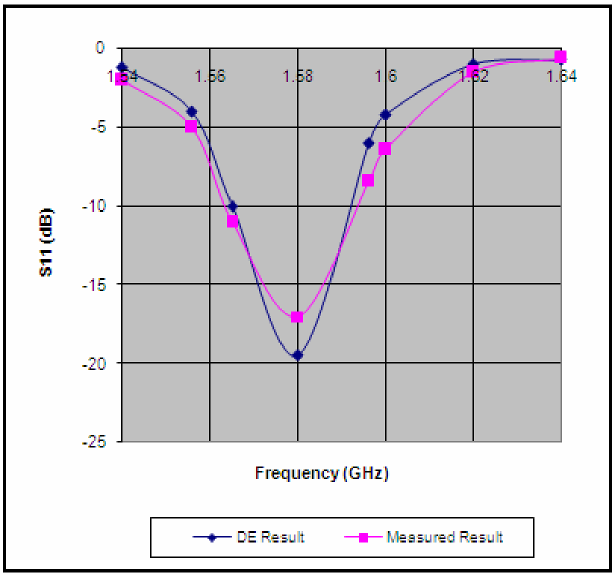

Fig. 4. Comparison of return losses

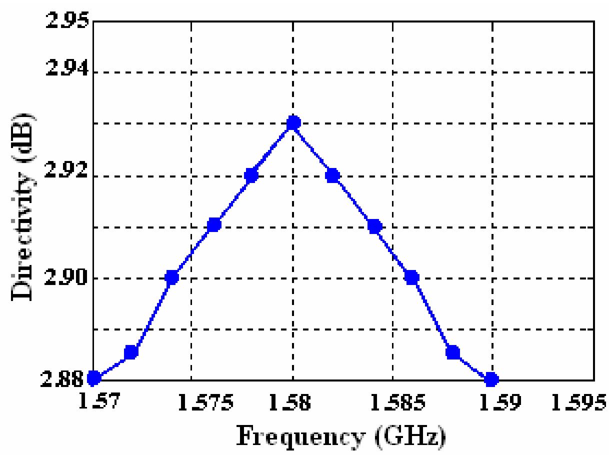

Fig. 5. Variation of maximum directivity with frequency

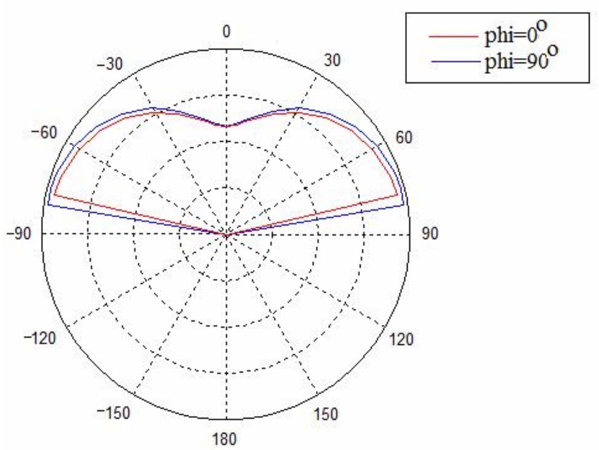

Fig. 6. Radiation pattern of the antenna

IV. Conclusion

The scheme of differential evolution used here, is DE/rand/1. DE is easier to use compared to other conventional optimization algorithms like genetic algorithm (GA) and particle swarm optimization (PSO) because it has fewer variables to control. The DE algorithm for this particular optimization is run for 50 times independently and the best result is presented here. The optimized values of different parameters are obtained after 37 runs. In a short circuited microstrip antenna, due to reduction in overall size of the antenna, the directivity reduces.

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