Optimization of Resonant frequency in co-axial probe feed microstrip Patch antenna using Differential Evolution (DE) algorithm

Shashank Gupta

***Abstract*— An optimization technique of Resonant Frequency for co-axial probe feed microstrip patch antenna using Differential Evolution (DE) Optimization Algorithm is presented in this paper. The DE program for optimization of resonant frequency is developed and executed in C language and finally the optimized antenna parameters are simulated in Zeeland IE3D software. The superiority of convergence in DE algorithm over other optimization technique is also shown in this paper. "3dplotter.swf"-software is used for graphical representation of different optimized geometrical parameters of the patch antenna. Co-axial probe feed rectangular microstrip antenna is a popular type of microstrip patch antenna and has applications in communication and radar system. Differential Evolution (DE) optimization is also a popular optimization algorithm and recently it is used for design optimization of microstrip patch antennas. The investigation is made at different microwave frequencies ranging between 3 GHz to 10 GHz. The optimization problem has three variables namely patch length & width and the position of feed. Accuracy of the results encourages use of DE.**

***Keywords*- Co-axial probe feed rectangular microstrip antenna; Differential Evolution (DE); patch length (L); patch width (W); feed position (feedp).**

I. INTRODUCTION

A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. There are many configurations that can be used to feed microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling and proximity coupling. The Coaxial probe feed microstrip antenna is shown in the adjoining figure. It consists of a rectangular patch of dimensions **W** x **L** fabricated on a substrate of thickness h and dielectric constant ε_r .This patch is fed by a coaxial probe feed. The position of the feed with respect to an edge of the rectangular patch is given by X_{in}. This paper presents a method for resonant frequency optimization of such type of antenna where the optimization parameters are patch length(L), patch width(W) & feed position(feedp) respectively**.**

Shashank Gupta
Indian Institute of Technology, Banaras Hindu University
India
shashank.gupta.ece08@iitbhu.ac.in

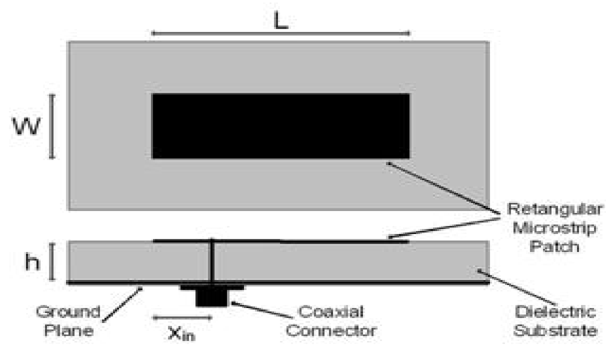

Figure 1 - Basic geometry of a rectangular Co-axial feed Microstrip antenna

In this project Differential Evolution (DE) optimization algorithm is used to determine the antenna parameters that provide accurate value of resonant frequency. DE is an absolutely intelligent technique that is used in recent times in designing antenna parameters**[1]**. Differential Evolution (DE) has recently proven to be an efficient method for optimizing real-valued multi-modal objective functions. Besides its good convergence properties and suitability for parallelization, DES main assets are its conceptual simplicity and ease of use **[2]**. The investigation is made at different microwave frequencies and it ranges from 3 GHz to 10 GHz. The optimization problem has three variables namely patch length, patch width and position of the feed. Accuracy of the results encourages the use of DE.

II. THEORY

The transmission-line model and the cavity model are approximate models often used to design and analyze microstrip antenna. Here we have used the transmission line model in this problem. The input impedance of a co-axial feed microstrip patch antenna **[3]** is given by

$$Z_{in} = Z_1 + Z_2 + j X_L \quad (1)$$

Where the first two terms give the impedances of the patches (the patch in this model is viewed as series connection of two patches with length L_1 and L_2 where $L_1+L_2 = L$ is the length of the patch) and the second term is the reactance of the co-axial probe. Here the microstrip antenna is modeled as a length of transmission line of characteristic impedance Z_0 and a propagation constant $\gamma = \alpha + j\beta$, where α is the attenuation constant and β is the phase constant. The total impedance ($Z=Z_1+Z_2=1/Y$) is obtained from the formula

$$Y = Y_0[\{(Y_0 + j\,Y_S \tan(\beta L_1))/(Y_S + jY_0 \tan(\beta L_1))\} + \{(Y_0 + j\,Y_S \tan(\beta L_2))/(Y_S + j\,Y_0 \tan(\beta L_2))\}] \quad (2)$$

$$Y_S = G_S + j\,B_S \quad (3)$$

$$G_s = (\pi/376)(a/\lambda_0) \quad (4)$$

$$B_S = 0.01668\,(\Delta L/h)(a/\lambda_0)\varepsilon_r \quad (5)$$

where Y_S is the edge admittance and G_S & B_S are the edge conductance and susceptance respectively and

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (6)$$

The inductive probe reactance is approximated as

$X_L = \sqrt{\mu/\varepsilon}\tan(2\pi h/\lambda_0) = (377/\sqrt{\varepsilon_r})\tan(2\pi h/\lambda_0)$ (7) **[4][6][8]**

Where h is the height of the dielectric substrate which is taken to be 60 mils or 0.1588 cm.

III. DIFFERENTIAL EVOLUTION (DE) OPTIMIZATION ALGORITHM

The Basic Algorithm [5][2]

Differential Evolution (DE) is a parallel direct search method which utilizes NPD-dimensional parameter vectors $X_{i,G}=[x_{1,i,G}, x_{2,i,G}, \ldots x_{D,i,G}]$ i = 1, 2, . . . ,NP. as a population for each generation G. NP does not change during the minimization process. The initial vector population is chosen randomly and should cover the entire parameter space. We assume a uniform probability distribution for all random decisions unless otherwise stated. In case a preliminary solution is available, the initial population might be generated by adding normally distributed random deviations to the nominal solution $x_{nom,0}$. DE generates new parameter vectors by adding the weighted difference between two population vectors to a third vector. Let this operation be called mutation. The mutated vector's parameters are then mixed with the parameters of another predetermined vector, the target vector, to yield the so-called trial vector. Parameter mixing is often referred to as "crossover" in the ES-community. If the trial vector yields a lower cost function value than the target vector, the trial vector replaces the target vector in the following generation. This last operation is called selection. Each population vector has to serve once as the target vector so that NP competitions take place in one generation.

Initialization

- Define lower and upper limit of each parameter. $X_J^L \le X_{j,i,1} \le X_J^U$.
- Randomly select the initial parameter values uniformly on the intervals $[X_J^L, X_J^U]$.

Mutation

- Each of the NP parameter vector undergoes Mutation, Recombination and Selection process.
- Mutation expands the search space.
- For a given parameter vector $X_{i,G}$, randomly select three other parameter vector $X_{r1,G}$, $X_{r2,G}$ and $X_{r3,G}$ such that the indices i,r1,r2,r3 are all different.
- Add the weighted difference of the two vector to the third.
  - $V_{i,G+1} = X_{r1,G} + F(X_{r2,G} - X_{r3,G})$.
- The mutation factor F is a constant from [0,2].
- $V_{i,G+1}$ is called the donor vector.

Recombination

- Recombination incorporates successful solutions from the previous generation.
- The trial vector $u_{i,G+1}$ is developed from the elements of the target vector, $x_{i,G}$ and the elements of the donor vector, $v_{i,G+1}$.
- Elements of the donor vector enter the trial vector with probability CR.

$u_{i,G+1} = (u_{1i,G+1}, u_{2i,G+1}, u_{3i,G+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots u_{Di,G+1})$

where $u_{i,G+1}$ is given as below

$$u_{ji,G+1} = \begin{cases} v_{ji,G+1} & \text{if } (randb(j) \le CR) \text{ or } j = rnbr(i) \\ x_{ji,G} & \text{if } (randb(j) > CR) \text{ and } j \ne rnbr(i) \end{cases}$$
where $j = 1,2, \ldots, D$.

Here, randb(j) is the jth evaluation of a uniform random number generator with outcome belonging to [0; 1]. CR is the crossover constant belonging to [0; 1] which has to be determined by the user. rnbr(i) is a randomly chosen index 2 1; 2; :::;D which ensures that $u_{i;G+1}$ gets at least one parameter from $v_{i;G+1}$.

Selection: The target vector $x_{i,G}$ is compared with the trial vector $v_{i,G+1}$ and the one with the lowest function value is admitted to the next generation.

$$x_{i,G+1} = \begin{cases} u_{i,G+1} & \text{if } f(u_{i,G+1}) \le f(x_{i,G}) \\ x_{i,G} & \text{otherwise.} \end{cases}$$

i = 1, 2, . . . ,NP

IV. DE BASED OPTIMIZATION OF RESONANT FREQUENCY

The objective of the work is to optimize the resonant frequency of a co-axial feed rectangular microstrip antenna. The parameters selected for optimization are as follows:

TABLE I - PARAMETER SPECIFICATION

Parameter	Lower Limit	Upper Limit
Length	$\lambda_0/5$	$\lambda_0/2$
Width	$\lambda_0/3$	$\lambda_0/1.5$
Feed Position	0	Length of the patch

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TABLE 2 - SPECIFICATION OF PARAMETER OF DE

Population Size	90
Maximum No of Generation	150
CR(Crossover Rate)	[0,1]
F(Mutation Factor)	[0,2]

Initially a 3D solution space (corresponding to 3 optimization parameters) is created from where the parameters should be chosen randomly. Each random vector is a 1D array with 3 elements, one in each dimension. Initial values for each parameter are randomly generated within the solution space and randomly selected one value among them is set to be the initial globally best optimized value. The fitness function is defined as :

$$F = fabs(f-f_r) + fabs(Z_{real} - 50) + fabs(Z_{img} - 0) \qquad (8)[7]$$

where Z_{real} and Z_{img} are real and imaginary parts of Z_{in}. At resonant frequency Z_{img} should be zero and return loss at resonant frequency can be minimized if Z_{real} is close to 50 Ω. In this paper, microstrip antenna with co-axial feed is considered for optimization. For each particle a fitness value is calculated which is the local best for the particle. This value is compared with the previous best value and if the any local best value is smaller than the previous best value then the previous best value is replaced by that local best. The process is repeated for 150 iterations which is the criterion for termination of the process.

V. CONVERGENCE OF POINTS USING DE ALGO OF PTIMIZATION (for a sample frequency of 8 Ghz)

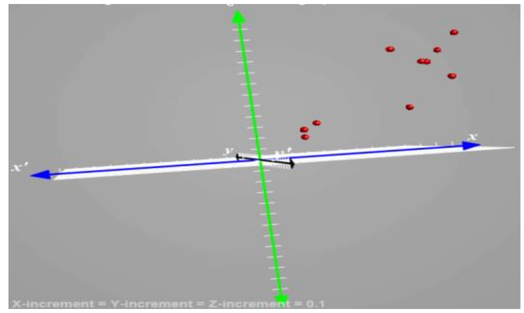
By using DE algorithm of optimization convergence to optimum point is achieved very fast and in precise manner. Here one example is given with respect to our Fitness function given in (8). Here the parameters are :

TABLE 3-PARAMETERS FOR OPTIMIZATION AT FREQUENCY 8 GHZ.

Frequency to optimize	8(GHz)
NP	90
G_MAX	150
CR	0.75
F	0.1
ε_r	2.4
H	0.1588(cm)

Values at initialization (with particles plotted in 3-D space):

L	W	Feedp
1.599228	1.989746	0.947541
1.742569	1.487350	1.207642
1.236259	1.427002	1.057921
1.393742	1.739502	0.419041
1.833961	2.345886	1.094455
0.585518	1.818390	0.242638
0.764652	2.277031	0.310897
1.544258	1.628571	0.912191



At 0TH Generation the values and the 3-D plot are: (G=0)

L	W	Feedp
1.582880	1.613804	0.878055
1.742569	1.487350	1.207642
1.236259	1.427002	1.057921
1.393742	1.739502	0.419041
1.304909	1.803238	0.343129
1.744894	1.416309	1.184544
1.643023	2.277031	0.769417
1.544258	1.628571	0.912191

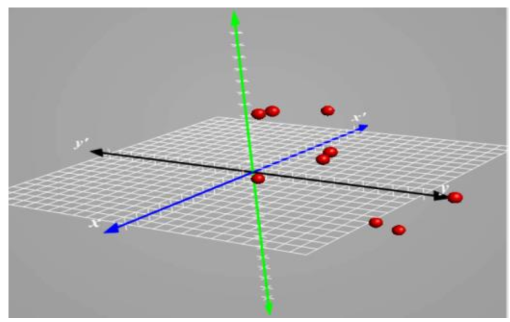


Figure 2.1

At G=10 the values and the 3-D plot are:

L	W	Feedp
1.237506	1.730246	0.454151
1.233924	1.798509	0.471690
1.238808	1.742303	0.461670
1.219620	1.730226	0.423271
1.240043	1.754867	0.478263
1.238466	1.722937	0.473292
1.238177	1.752653	0.473661
1.221737	1.725427	0.428152

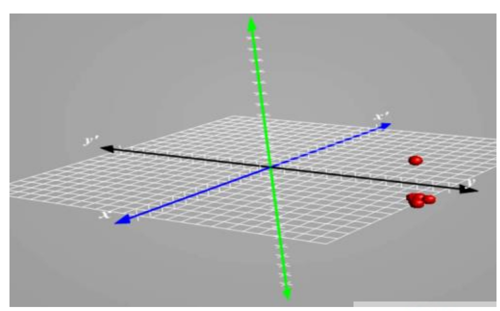


Figure 2.2

At G=20 the values and the 3-D plot are:

L	W	Feedp
1.238720	1.724838	0.497485
1.237148	1.725662	0.743541
1.238631	1.725114	0.743386
1.237203	1.725361	0.743478
1.238631	1.722427	0.496561
1.238684	1.724890	0.497489
1.237564	1.724838	0.743440
1.236454	1.726972	0.744443

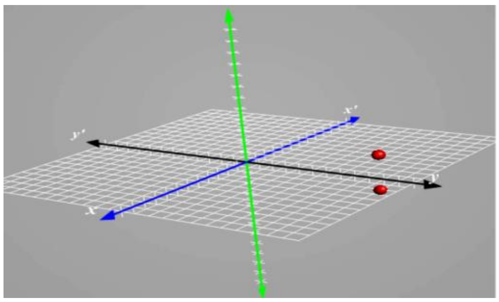


Figure 2.3

At G=30 the values and the 3-D plot are:

L	W	Feedp
1.237097	1.726902	0.743712
1.237196	1.726769	0.744417
1.237095	1.727012	0.744437
1.237031	1.727018	0.743641
1.237118	1.726763	0.743781
1.237015	1.727032	0.743660
1.237113	1.726887	0.743693
1.237040	1.727016	0.744447

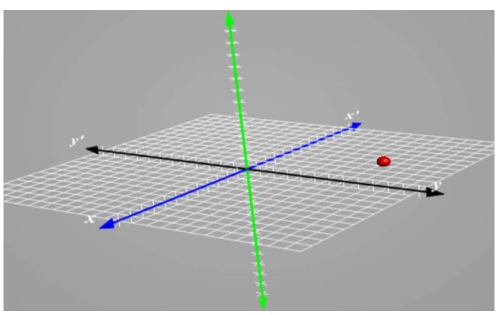


Figure 2.4

At G=55 the values and the 3-D plot are:

L	W	Feedp
1.237030	1.726754	0.744528
1.237030	1.726754	0.744528
1.237030	1.726754	0.744528
1.237030	1.726754	0.744528
1.237030	1.726754	0.744528
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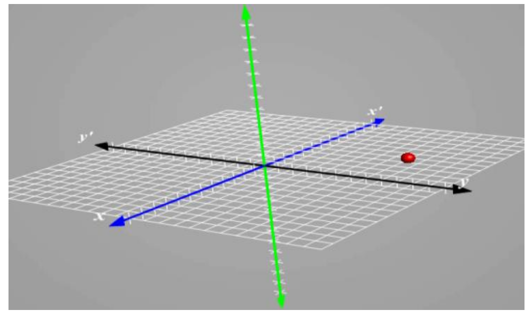

Figure 2.5

VI. RESULTS AND OBSERVATION

TABLE 4 - OPTIMUM PATCH LENGTH, WIDTH & FEED POSITION FOR DIFFERENT RANGE (3-10 GHZ) OF RESONANT FREQUENCY ARE OBSERVED AS :

FREQUENCY (GHZ)	LENGTH (CM)	WIDTH (CM)	FEED POSITION (CM)	FITNESS
3	2.9143	3.3611	0.3494	0.2464
4	2.1206	3.1933	0.3306	0.3751
5	1.7854	2.3333	0.3353	0.1701
6	1.5038	2.0813	0.3507	0.0645
7	1.2610	2.1627	0.3897	0.0910
8	1.1019	2.0908	0.4623	0.0084
9	1.0575	1.5260	0.5492	0.6331
10	1.0118	1.1064	0.5312	1.2017

Parameters chosen CR=0.75 and F=0.1
By Theory the value for aspect ratio (W/L) should be between 1 and 2.

As Expected the obtained value for aspect ratio lies well within the desired range. The fitness function should tend towards zero and given the random parameters chosen by the program, the fitness function is tending towards zero.

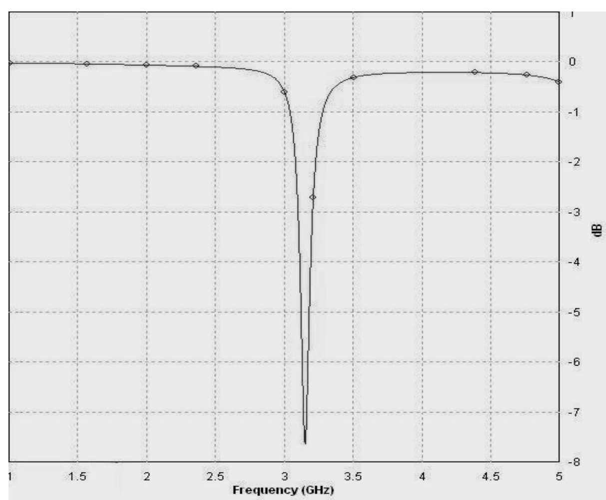

Figure 3 – Return Loss at 3.2 GHz

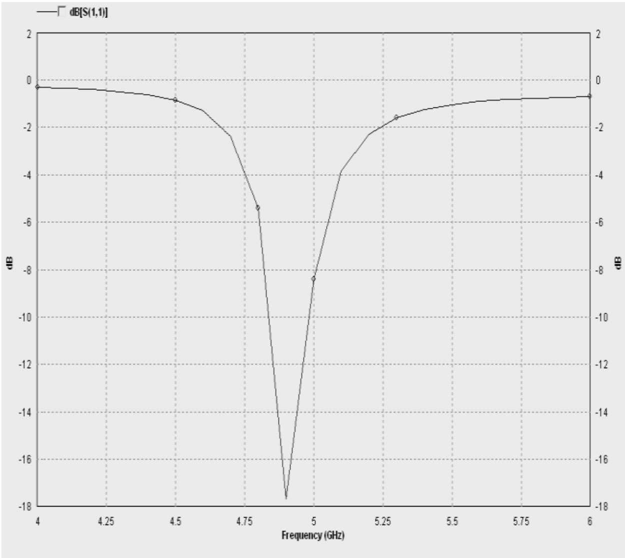

Figure 4 – Return Loss at 4.9 GHz

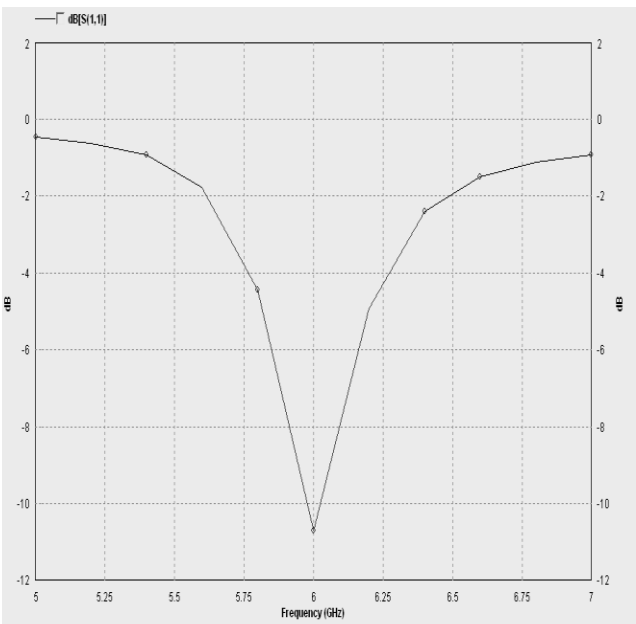

Figure 5 – Return Loss at 6 GHz

VII. CONCLUSION

The motivation of the project is to optimize the resonant frequency of microstrip patch antenna with respect to its length, width and feed position for different values of frequency. On the basis of results obtained in the project and the convergence achieved in 3-D plots as the generation (or number of iterations) is increased, it can be concluded that the DE can be efficiently used for optimization of antenna. The convergence of the optimization has been shown by sample values taken for frequency 8 GHz for different generations using the 3-D Plotter.

The advantage of DE is its simplicity. The return loss plots (Figures 3,4 and 5) show that the resonant frequencies obtained from the optimization process exactly matches with the desired values which proves the efficiency of the method. The optimization has been carried out for frequency range 3 to 10 GHz. CR the cross-over rate should be chosen between [0,1] and the mutation factor F should be in the interval [0,2].The higher the population size the lower the value of mutation factor F and higher should be the cross-over rate CR for better results. By Theory the value for aspect ratio (W/L) should be between 1 and 2. As expected the value lies well within the desired range. The feed position as expected is 30% to 50% of the patch length.

A comparison of results from the PSO algorithm and DE algorithm shows the better optimization property of DE. The understanding of the above project can pave way for understanding and solving of higher dimensional complex functions defined by real time problems.

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About Author:

Shashank Gupta received B.Tech degree in 2012 from Indian Institute of Technology, BHU, Varanasi, India in the discipline of Electronics Engg. His field of interest are Communication and Embedded Systems.