Design of Aperture-Coupled Microstrip Antenna for HIPERLAN/2 using Differential Algorithm

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ABSTRACT
In this paper, design of an aperture-coupled microstrip antenna (ACMSA) using differential evolution algorithm (DE) is described. The classical transmission line model for microstrip antenna is used to determine fitness function for DE and computed results are compared with the results obtained using particle swarm optimization (PSO) and binary coded genetic algorithm (GA). The aperture-coupled microstrip antenna is fabricated and measured results are compared with the results obtained using differential evolution algorithm.

General Terms
Algorithm, Antenna, Local area network.

Keywords
Differential evolution algorithm, Microstrip antenna, Aperture-coupled.

1. INTRODUCTION
Differential evolution algorithm (DE) is a variant of genetic algorithm (GA), which attempts to replace the crossover operator in GA by a special type of differential operator for reproducing offspring in the next generation. It is a combination of original GA, evolutionary programming and evolutionary strategies [1-2]. The basic form of an ACMSA is a radiating patch on a dielectric substrate, fed by a microstrip line on another substrate, through a small aperture or slot on a ground plane [3-6]. Bandwidth of an ACMSA is higher than a single layer microstrip antenna. The basic configuration of an ACMSA is shown in Figure 1. HIPERLAN/2 operates in the frequency range 5.470GHz – 5.725GHz with high data rate and normally used for indoor applications. Recently, differential evolution algorithm is applied for antenna design [7-13]. In most of the cases, DE is applied to antenna array optimization. Some publications are available where DE is applied to optimize single layer patch antennas. In this paper, DE is used to design multilayered aperture-coupled microstrip antenna. The fitness function for DE is obtained using transmission line model of microstrip antenna. Parameters like patch length(a), patch width (b), slot length (L_a) and slot width (W_a), width of microstrip line (W) and open stub length (L_s) are optimized for the desired resonant frequency. In order to implement DE for ACMSA, an initial population of trial vectors is defined. Each trial vector contains different design parameters. For each parameter, a lower and upper limit is defined. Initial parameter values are randomly selected, uniformly in the interval. The weighted difference of any two of the parameters to the third vector is added to form a donor vector whose components enter into the trial vector with certain probability. Now the trial vector is compared with the target vector and with a better fitness and it is admitted to the next generation. The return loss of the antenna, obtained using DE, is compared with the results obtained using binary coded GA and particle swarm optimization (PSO), which are very popular optimization techniques [7, 14-15]. All the optimization techniques are implemented using MATLAB. The resonance frequency of the antenna is 5.59GHz. Return loss bandwidth (-10dB) of the ACMSA, obtained using DE is 360 MHz which is about 6.5% of the centre frequency. ACMSA is fabricated and measured by vector network analyzer. Measured results are compared with results obtained using DE and good agreement between the two is achieved.

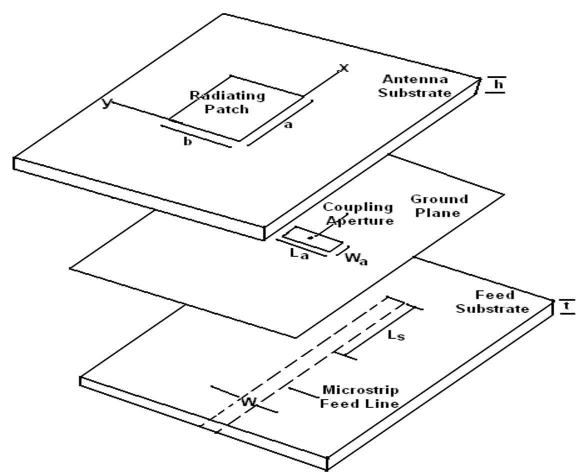

Figure 1. Geometry of aperture-coupled microstrip antenna.

2. DESIGN OF ACMSA USING DE
In order to obtain fitness function for DE the design of the ACMSA, transmission line model is used [6]. The equivalent transmission line model of the ACMSA of Figure 1 is shown in Figure 2. Various parameters like patch length(a), patch width (b),slot length(L_a) and slot width(W_a), width of microstrip line(W) and open stub length(L_s) are to be optimized for the desired resonant frequency.

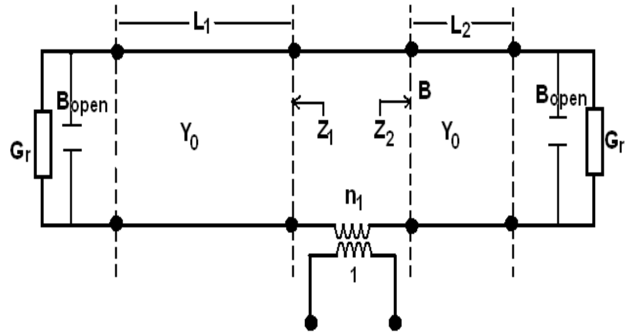

Figure 2. Equivalent transmission line model of ACMSA.

A population size of 30 is used in DE with 80 iterations per generation and ran for 50 times. The coupling of the patch to the aperture is described by an impedance transformer of turn ratio n_1 roughly equal to the fraction of patch current intercepted by the slot to the total patch current. The patch impedance is determined at the centre of the slot and its value can be obtained from the simple transmission line model [6]. The antenna is designed to operate in frequency range of HIPERLAN/2, 5.470GHz – 5.725GHz.

The input impedance of the transmission line can be expressed as [6]

$$Z_{in}=n_2^2/(n_1^2 Y_{patch}+Y_{ap}) - jZ_{om}\, \mathrm{Cot}(\beta_m L_s) \qquad (1)$$

where n_2 is the turns ratio of the transformer used to describe the coupling of the patch to the microstrip line and its expression in terms of various dimensions can be found in [6]as:

$$n2=(J_o(\beta_S W/2)J_o(\beta_m W_a/2)/(\beta_S{}^2+\beta_m{}^2)) \times$$

$$[\beta_m{}^2 k_2\varepsilon_{rf}/(k_2\varepsilon_{rf}\cos k_1 h - k_1 \sin k_i h)+$$

$$\beta_S{}^2 k_1/(k_1 \cos k_1 h + k_2 \sin k_1 h)] \qquad (2a)$$

and n1[6] is

$$n1=L_a/b \qquad (2b)$$

Where J_0 is Bessel function of order zero and other parameters are expressed as [6]

$$k_1 = k_0 \sqrt{|\,(\varepsilon_{rf} - \varepsilon_{res} - \varepsilon_{rem})\,|} \qquad (3)$$

$$k_2 = k_0 \sqrt{|(\varepsilon_{res} + \varepsilon_{rem} - 1)\,|} \qquad (4)$$

$$\beta_s = k_0 \sqrt{\varepsilon_{res}} \qquad \beta_m = k_0 \sqrt{\varepsilon_{rem}} \qquad (5)$$

Where W, ϵ_{rem}, $ß_m$, Z_{om} are the width, effective permittivity, phase constant and characteristic impedance of the microstrip line and W_a, ϵ_{res}, $ß_s$ and Z_{os} are the same parameters of the slot line respectively.

The aperture susceptance Y_{ap} can be obtained as follow as[6]:

$$Y_{ap} = -j2Y_{os}\, \mathrm{Cot}(\beta_s L_a /2) \qquad (6)$$

$$S_{11}=20\log_{10}\{(Z_{in}-Z_{om})/(Z_{in}+Z_{om})\} \qquad (7)$$

Where Z_{om} is the characteristic impedance of the microstrip feed line.

Directivity D can be obtained as:

$$D=2b^2/(15\ G_r\ \lambda_o^2) \qquad (8)$$

λ_o is the free-space wave length

Gain of the antenna can be obtained as

$$G = \eta D \qquad (9)$$

Where η is the antenna efficiency

A population size of 10 is used in DE with 80 iterations per generation. The steps for the antenna design, using DE, can be summarized as follows:

Step 1: Define an initial population of trial vectors. Each trial vector contains different parameters of the design. For each parameter, a lower limit and an upper limit are defined ($X_i^L < X_{i,j}(0) < X_i^U$).

Step 2: Randomly select the initial parameter values uniformly on the intervals (X_i^L, X_i^U).

Step 3: For each trial vector, select other parameter vectors randomly.

Step 4: Add the weighted difference of any two of the parameter to the third vector to form a donor vector.

$$V_{k,n}(t+1) = X_{m,n}(t) + F * (X_{i,n}(t) - X_{j,n}(t)) \qquad (10)$$

The scaling factor F scales the difference of two vectors and adds it to the third one, which can range from 0 to 2.

Step 5: Components of the donor vector enter into the trial vector with probability CR

$$T_{k,n}(t+1) = V_{k,n}(t+1) \text{ if rand } (0,1) < CR$$

$$= X_{k,n}(t) \quad \text{otherwise} \qquad (11)$$

Step 6: The trial vector is compared with the target vector and with a better fitness, is admitted to the next generation.

The fitness function used for computation is

$$F = (1/N) \sum | \text{Reflection coefficient at frequency } i|^2 \qquad (12)$$

Where the summation is done over the frequency range of interest and N is the number of frequency points, used in computation.

The best individual obtained with the parameter values:

a=15mm, b=12.87mm, L_a=5.68mm, W_a=3.05mm, W=2.54 mm and L_s=6.84 mm.

Where 'a' is the length of the patch, 'b' is the width, 'L_a' is the length of the slot, 'W_a' is the width of the slot, 'W' is the width of the feed line and 'L_s' is the stub length.

In binary coded GA, a population size of 30 is chosen. The crossover probability was taken to be 0.6 and the mutation probability as 0.05. The tournament selection is used for reproduction, which is a very important step in GA.

In Particle swarm optimization, the inertia factor, local acceleration and global acceleration constant was taken to be 0.5 and the swarm size was taken to be 10.

3. RESULTS

For the design of ACMSA, PTFE substrate of height 1.57 mm and dielectric constant of 2.32 is used. The natures of best fitness and mean fitness, obtained using DE are compared with those obtained using MATLAB GA and PSO in Figure 3 and Figure 4 respectively. In Figure 3, it can be seen that the GA has achieved a higher fitness function value compared to DE and PSO owing to its drawback of local minima trapping. Also, the convergence of the mean fitness value with the best fitness value in case of GA is not smooth owing to the ripples observed in Figure 4.The convergence time is also higher in the case of GA compared to DE and PSO. In case of DE and PSO the convergence time is almost same and the best fitness values are much better compared to GA. However the fitness value is better for DE (0.0023) compared to PSO (0.01)

In Figure 5, the return loss of the antenna, obtained using DE, is compared with the results obtained using GA and PSO. The resonance frequency of the antenna is 5.59GHz. The -10dB return loss bandwidth of the ACMSA, obtained using DE is 360 MHz which is about 6.5% of the centre frequency. Antenna is fabricated and measurement is done using vector network analyzer. Measured resonance frequency of the antenna is 5.6GHz and measured bandwidth (-10dB return loss) of the antenna is 400MHz. Ground plane of the antenna is 5 cm. X 5 cm. The measured return loss is also compared in Figure 5.

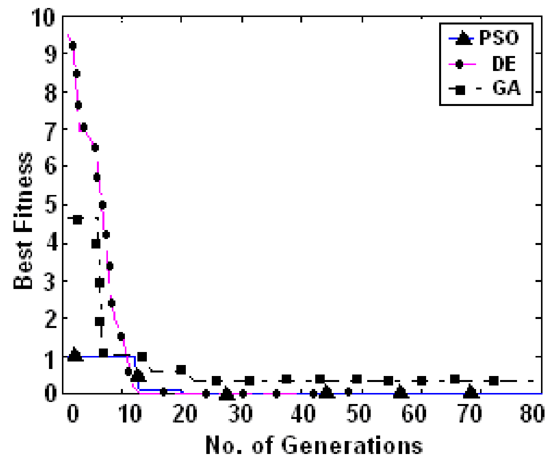

Figure 3. Comparison of best fitness

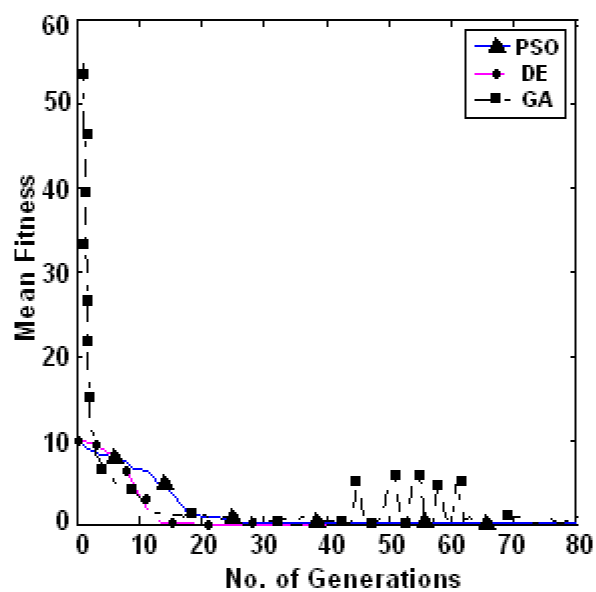

Figure 4. Comparison of mean fitness

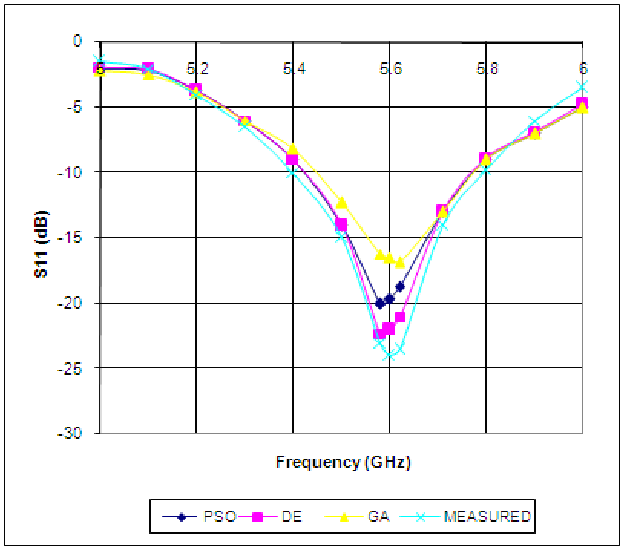

Figure 5. Comparison of measured return loss with the results obtained using DE, PSO and GA.

4. CONCLUSION

The application of differential evolution algorithm for the design of aperture-coupled microstrip antenna for HIPERLAN/2 is described where classical transmission line theory for microstrip antenna is used. The scheme used for DE is DE/rand/1. DE requires lesser control variables compared to GA and PSO and hence is easier to tune it to a particular optimization problem. It also requires lesser population size compared to other optimization techniques. Although the convergence time is almost same here for both PSO and DE, the latter has shown faster convergence in minimization of complicated functions like Rastrigin's function and Rosenbrock function and is expected to give superior performance in much more complicated optimization problems in antenna design.

5. REFERENCES

[1] Storn, R., and Price, K. 1997. Differential evolution – a simple and efficient heuristic for global optimization over continuous spaces. Journal of Global Optimization, vol. 11, 341–359.

[2] Yang, Z., Tang, K., and Yao, X. 2007. Differential evolution for high-dimensional function optimization. Proc. of IEEE Congress on Evolutionary Computation (CEC 2007), Singapore, 3523-3530.

[3] Sullivan, P. S., and Schaubert, D. H. 1986. Analysis of an aperture coupled microstrip antenna. IEEE Trans. Antennas Propagation, vol. 34, 977 – 984.

[4] Pozar, D. M. 1986. Reciprocity method of analysis for printed slot and slot-coupled microstrip antennas. IEEE Transaction Antennas and Propagation, vol. 34, 1439-1446.

[5] Himdi, M., Daniel, J. P., and Terret, C. 1989. Analysis of aperture-coupled microstrip antenna using the cavity method. Electronic Letters, vol. 25, 91-92.

[6] Garg, R., Bhartia, P., Bahl, I., and Ittipiboon, A. 2001. Microstrip Antenna Design Handbook. Artech House.

[7] J. Robinson, J., Sinton, S., and Rahmat-Samii, Y. 2002 Particle swarm, genetic algorithm, and their hybrids: optimization of a profiled corrugated horn antenna. Proc. Antennas and Propagation Society International Symposium, vol. 1, 314–317.

[8] Zhang, L., Cui, Z., Jiao, Y.-C., Zhang, F.-S. 2009. Broadband patch antenna design using differential evolution algorithm. Microwave & Optical Technology Letters, vol.51, 1692 – 1695.

[9] Aksoy, E., and Afacan, E. 2009. Planar antenna pattern nulling using differential evolution algorithm. AEU - International Journal of Electronics and Communications, vol. 63, 116 – 122.

[10] Zangh, L., Jiao, Y-C, Li, H., and Zangh F-S. 2010. Antenna optimization by hybrid differential evolution. International Journal of RF and Microwave Computer-Aided Engineering, vol. 20, 51-55.

[11] Pal, S., Qu, B.-Y. Das, S., and Suganthan, P. N. 2010. Optimal synthesis of linear antenna arrays with multi-objective differential evolution. Progress In Electromagnetics Research B, vol. 21, 87-111.

[12] Lin, C., Qing, A., and Feng, Q. 2010. Synthesis of unequally spaced antenna arrays by using differential evolution. IEEE Transaction Antennas and Propagation, vol. 58, 2553 – 2561.

[13] Wang, W., Gong, S., Wang, X., Guan, Y., and Jiang, W. 2010. Differential evolution algorithm and method of moments for the design of low-RCS antenna. IEEE Antennas and Wireless Propagation Letters, vol. 9, 295 – 298.

[14] Goldberg, D. E. 1975. Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley, Reading, MA.

[15] Deb, K. 2001. Multi-objective Optimization Using Evolutionary Algorithms, John Wiley & Sons.