Journal of Engineering and Applied Sciences 12 (16): 4284-4290, 2017
ISSN: 1816-949X

Miniaturization of Microstrip Filters Using the Particle Swarm Optimization Algorithm

[1]Ahmed Hathat and [2]Djamel Chikouche
[1]Department of Electronics, University of M'sila, Rue Ichebilia, M'sila, Algeria
[2]Department of Electronics, LIS Laboratory, University of Setif, Setif, Algeria

Abstract: In this study, we present our contribution to the miniaturization of microstrip low-pass filters using the Particle Swarm Optimization algorithm (PSO). After the synthesis of two microstrip low-pass filters of order three and five by the Chebyshev approximation technique we adapted the PSO algorithm parameters to filter lowpass miniaturization problem. Two examples of low-pass filter were presented. The procedure we developed showed that the first filter obtained by the PSO algorithm has a length of 21 mm, so, a mainiaturisation of 21% compared to the Chybeshev technique and the second filter obtained by the algorithm has a length of 55.9 mm, so a miniaturization of 57.15% compared to the the Chybeshev technique.

Key words: Microstrip low-pass filter, Particle Swarm Optimization algorithm, Chebyshev approximation technique, mainiaturization, algeria, compared

INTRODUCTION

Recently, the rapid development of technology is observed in all fields, particularly in the field of Radio Frequency (RF) and microwave. This development affects the design optimization of communications systems including the various components that comprise the system (Mahdi *et al*., 2015; Koziel *et al*., 2015; Chandran and Viswasom, 2014; Chemmangat *et al*., 2012).

Filters play an important role in many applications in the microwave field. They are used to separate or combine different frequencies. Filters are used to select or confine the radio-frequency/microwave signals in the assigned spectrum limits. Emerging applications in the microwave field continue to challenge filters with stricter requirements, higher performance, smaller size, lighter weight and lower cost. According to the requirements and specifications, microwave filters can be designed as circuits to localized or distributed elements they can be designed in various transmission line structures such as waveguides, coaxial line and the microstrip (Jia-Sheng, 2011).

In applications where the transport of high power signals is not an essential element, the use of planar technology is the solution to address congestion problems and weight volumetric structures. Planar filters are very attractive on two points but they are also on the implementation costs which are lower their good reproducibility and their interconnection facilities with other circuits including the active circuits (Kinayman and Aksun, 2005). The production of compact complete systems is possible because the interconnection part is simplified.

One of the planar technology, microstrip technology is widely used in the RF/microwave systems for decades. The advantages of this technology is insensitive to manufacturing tolerances, a wide range of bandwidth and easy design process. The microstrip line comprises a dielectric substrate material, one face of which is entirely metallic. The other side of the substrate that has a metal strip of width W and thickness t. Substrate height is denoted by h and the substrate dielectric constant is represented by ε_r. The general structure of a microstrip line is shown in Fig. 1 (Pozar, 2012).

In recent years the research is focused on new methods for optimized design of microwave devices (Gangopadhyaya *et al*., 2015; Koziel and Bekasiewicz, 2015; Samad *et al*., 2010; Hussein and Ghazaly, 2004). The particle swarm optimization belongs to the family of algorithms of artificial intelligence that shows greater reliability in solving optimization problems. This is a method using a population of agents, called particles but compared to other algorithms of the same family; it has some interesting features including the notion that efficiency is due to the collaboration rather than competition. The two main advantages of this algorithm are: the easiness of its application in many fields of research and design and the effective resolution capability of multi-design tasks with a large number of independent variables (Kennedy and Eberhart, 1995).

Corrosponding Author: Ahmed Hathat, Department of Electronics, University of M'sila, Rue Ichebilia, M'sila, Algeria

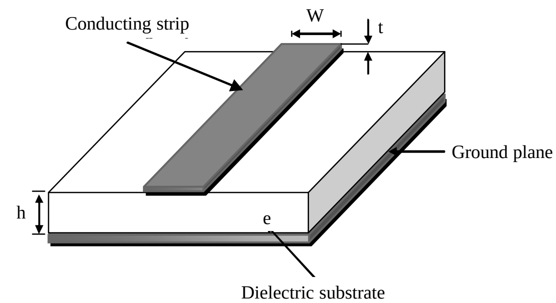

Fig. 1: General structure of the microstrip line

In this research, we developed a procedure for the synthesis and the miniaturization of stepped impedance low pass filters using the approach of circuit theory and the Particle Swarm Optimization algorithm.

MATERIALS AND METHODS

Design process of filters: Commonly the insertion loss method is used for the design of microstrip filters, it is flexible and allows the synthesis of arbitrary transfer function provided that the transfer function is physically realizable (Robert, 2001). According to the amplitude response of the transfer function we can classify the most commonly used types of filters that are Butterworth, Chebyshev, Bessel and elliptical filters. The design of microstriplowpass filters involves two main steps. The first is to select an appropriate lowpass prototype as shown in Fig. 2.

The choice of the type of response (Butterworth, Chebyshev) including the passband ripple and the number of reactive elements will depend on the required specifications. The element values of the lowpass prototype filter which are usually normalized to make a source impedance $g_0 = 1$ and a cutoff frequency fc = 1 are then transformed to the L-C elements for the desired cutoff frequency and source impedance which is normally 50 Ω for microstrip filters. Having obtained a suitable lumped-element filter design, the next main step in the design of microstrip lowpass filters is to find an appropriate microstrip realization that approximates the lumped-element filter.

The transformation of Richard and Kuroda identity has to convert the elements L and C in microstrip line for high frequency applications. A relatively easy way to implement low-pass filters in microstrip is to use alternating sections of very high and very low characteristic impedance lines. Such filters are usually referred to as stepped-impedance or hi-Z, low-Z filters,

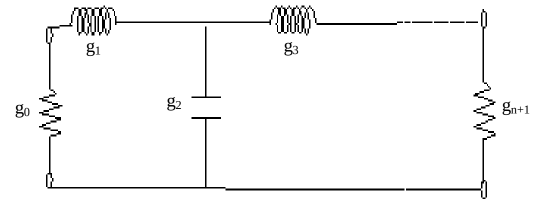

Fig. 2: Lowpass filter prototype

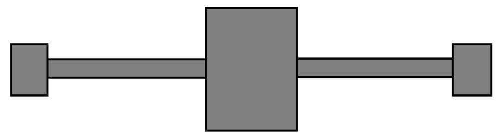

Fig. 3: Stepped impedance low-pass filter

and are popular because they are easier to design and take up less space than a similar low-pass filter using other technology (Tomar *et al*., 2015). Figure 3 shows a microstrip stepped impedance low-pass 3rd order filter.

Analysis of stepped impedance filters is usually done using commercially-available 3D EM simulation tools as HFSS, Sonnet, CST, etc. (ANSYS, 2016; SSI., 2016). These tools are able to predict the real-life performance of filters with sufficient accuracy. The main disadvantages of such 3D simulation tools are their high cost their somewhat cumbersome user-interfaces and the relatively longer design effort involved.

The circuit-theory based simulations thus remain an attractive option for designing stepped impedance filters. Analysis by the theory of circuits depends essentially on using the ABCD matrix of the microstrip line (Tomar *et al*., 2015; Zhang and Feng, 2006). Firstly, the ABCD matrix is calculated for each microstrip lines as shown in Eq. 1:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta & JZ_c \sin\theta \\ J\sin\theta/Z_c & \cos\theta \end{bmatrix} \quad (1)$$

Where:

θ = The electrical length

Z_c = The characteristic impedance of the microstrip line

Then, the overall ABCD matrix of the filter is computed by multiplying the ABCD matrices of the cascaded microstrip lines:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \prod_{i=1} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_i \quad (2)$$

Finally, the scattering matrix (S matrix) of the filter is obtained from the ABCD matrix of the filter using the following equations:

$$S_{2,1} = \frac{2}{A + B/Z_0 + CZ_0 + D} \quad (3)$$

$$S_{1,1} = \frac{A+B/Z_0-CZ_0-D}{A+B/Z_0+CZ_0+D} \quad (4)$$

Such as $S_{1,1}$ is the reflection coefficient and $S_{2,1}$ is the transmission coefficient.

Particle swarm optimization: The Particle Swarm Optimization (PSO) is a member to the family of artificial intelligence algorithms that shows greater reliability in solving optimization problems. This method uses a population of agents called particles but compared to other algorithms of the same family; it has some interesting features including the notion that efficiency is due to the collaboration rather than competition. In the PSO, each particle is a candidate solution in the search space (Eberhart and Shi, 2001; Boudjelaba *et al*., 2014).

The algorithm is generally randomly initialized and the particles are placed randomly in the search space of the objective function. PSO converges successfully to a global optimum. The main concept of the PSO is that possible solutions are accelerated towards the best solutions. The particles estimate iteratively the objective function of the candidate solutions and remember where they had their best value of the objective function. At each iteration, the particles move, taking into account their best position but also the best position for their neighbors. The goal is to change their path so that they approach as close as possible to the optimum.

The algorithm process followed the following steps (Eberhart and Shi, 2001); the general flow of PSO algorithm:

Step 1: We initialize the particle swarm in the search space (particle positions)
Step 2: We initialize speeds, randomly
Step 3: We define the neighborhood for each particle. There are two main methods;
Either a "geographical" neighborhood which must be recalculated at each time step which presupposes the existence of a distance in the search space, a neighborhood "social" defined once and for all
Step 4: We evaluate all particles and find the best particle in the group and the best particles in the iterations
Step 5: Change the position of each particle by introducing the following equations:

$$v_i^{(t+1)} = wv_i^{(t)}+c_1\,\text{rand}\left(p_i-x_i^{(t)}\right)+c_2\,\text{rand}\left(p_g-x_i^{(t)}\right) \quad (5)$$

$$x_i^{(t+1)} = x_i^{(t)}+v_i^{(t+1)} \quad (6)$$

Such as
$v^{(t+1)}_i$: speed of particle i at iteration t+1
w: the inertial coefficient

$$w = w_{max} - \frac{w_{ma} - w_{min}}{iter_{max}}\, iter \quad (7)$$

w_{max}: maximum inertial weight
w_{min}: minimum inertial weight
$iter_{max}$: maximum number of iteration
iter: current iteration
c_1: weighting factor (importance of personal best)
c_2: weighting factor (importance of neighbourhood best)
rand: random number between 0 and 1
$x^{(t)}_i$: the position of the particle i at iteration t
p_i: best position of the particle i
p_g: best position in the group
Step 6: Stopping criteria: if the stop criterion checked so close, if not go to step 4

Formulation of the problem: Synthesis filter can be considered as a function of characteristic impedances and electrical lengths of the distributed elements (self and capacity) and using the formulas of the microstrip line, the transfer function of filter is considered as a function of the filter dimensions (l_{c1}, W_{c1}, l_{l1}, W_{L1}, l_{c2} and W_{c2}) in our contribution we chose these dimensions as the coordinates of the particle (i.e., each particle represents a filter).

The definition of the search space is an important criterion in the application of the algorithm; our search space dimension is 2×n where n is the number of distributed elements (L and C). Example, n = 3 so the 6-dimensional search space is defined as following:

$$X_1 = W_{c1}, X_2 = l_{c1}, X_3 = W_l$$
$$X_4 = l_l, X_5 = W_{c2} \text{ and } X_6 = l_{c2}$$

For the miniaturization of microstrip filters we can limit the search space by dimension values of the optimized filter which are the lengths, the widths or both. For the selection of the best filter we have chosen the function sum of errors as the objective function. The function sum of errors is defined as following:

$$\sum_{i=1}^{n} Er_i,\ Er_i \begin{cases} \left|\left|S_{2,1}\right|-1\right| & f_i \le f_c \\ \left|S_{2,1}\right| & f_i > f_c \end{cases}$$

The speed of particle is the difference between the current position and the new position of the particle. Now the problem of miniaturization of microstrip filters becomes clear.

RESULTS AND DISCUSSION

The basic parameters of the algorithm are:

- The size of the swarm is 50 particles
- The number of iterations is 500 iteration
- The maximum inertial weight W_{max} = 0.9
- The minimum inertial weight W_{min} = 0.4

- The weighting factor C_1 = 1.4
- The weighting factor C_2 = 1.4

In determining the limits of the search space we synthesized the filter by the Chebyshev method to find the prototype filter and the transformation of lumped elements of the normalized filter to distributed elements (sections of microstrip lines). At this point we can find the limits of the search space by the dimensions of the distributed elements filter.

Example 1: Consider the design of a filter that has the following features:

- Cutoff frequency is 1 GHz
- Passband ripple is 0.1 dB
- Source impedance is equal to 50 Ω
- Load impedance is equal to 50 Ω
- Relative dielectric constant substrate ε_r = 10.8 and a height h = 1.27 mm

Table 1 shows the limits of the search space. We see in Fig. 4 that the algorithm converges to the best solution from iteration 351 and then stablise in the value of 54.56. Figure 5 shows the coefficients of transmission and reflection achieved by the Chebyshev method and the PSO algorithm.

We note that the transmission coefficients are similar in the passband and in the stop band the transmission coefficient obtained by PSO is better than the transmission coefficient obtained by the Chebyshev method.

The dimensions of the best filter obtained by the PSO algorithm are show in Table 2. Figure 6 shows the layout of the filter synthesized by the Chebyshev method and the best filter obtained by the PSO.

The low-pass filter designed by the Chebyshev method have an error equal to 71.55 and a length of 26.7 mm while the filter designed by the PSO algorithm have an error equal to 54.56 and a length of 21.1 mm. The algorithm reduces the filter length of 21% of the synthesized filter by the Chebyshev method.

Example 2: Consider the design of a filter that has the following features:

- Cutoff frequency of 0.862 GHz
- Passband ripple is 1 dB
- Source impedance is equal to 50 Ω
- Load impedance is equal to 50 Ω
- Relative dielectric constant substrate ε_r = 4.8 and a height h = 1.524 mm

Table 1: Search space limits

Limits of variables	Min. (mm)	Max. (mm)
X_1 (l_{L1})	3.0	9.81
X_2 (W_{L1})	0.1	1.00
X_3 (l_C)	3.0	7.11
X_4 (W_C)	2.0	8.00
X_5 (l_{L2})	3.0	9.81
X_6 (W_{L2})	0.1	1.00

Table 2: The dimensions of the two filters

Dimensions of filter	Chebyshev method L (mm)	Chebyshev method W (mm)	PSO L (mm)	PSO W (mm)
L1	9.81	0.2	7.9400	0.1050
C1	7.11	4.0	5.3072	9.5524
L2	9.81	0.2	7.9400	0.1050

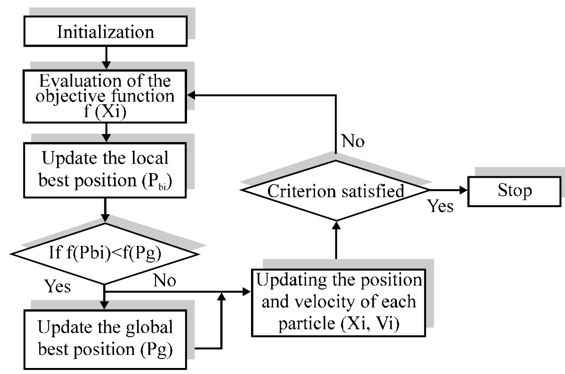

Fig. 4: The general flow of PSO algorithm

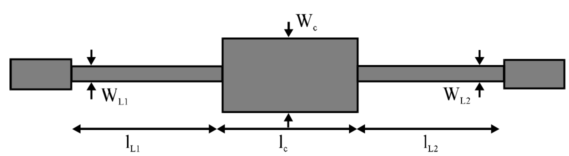

Fig. 5: Stepped impedance low-pass filter

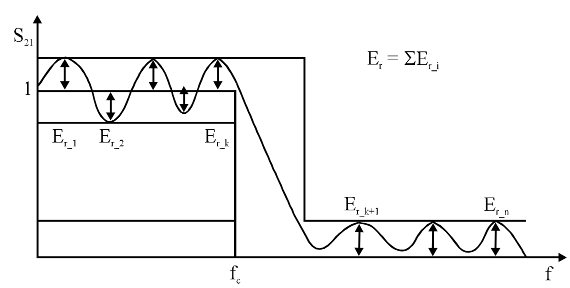

Fig. 6: Magnitude response of a low pass filter

We see in Fig. 7 that the algorithm converges to the best solution from iteration 410 and then stablise in the value of 15.04. Figure 8 shows the transmission and reflection coefficients achieved by the Chebyshev method and the PSO algorithm.

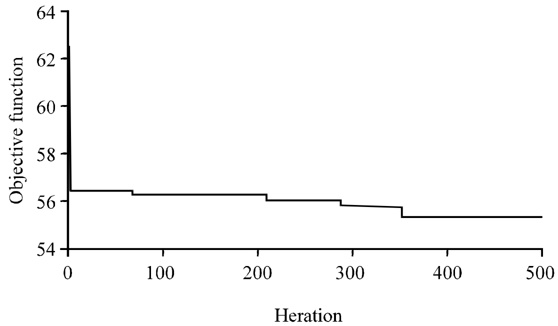

Fig. 7: Algorithm convergence to the optimum

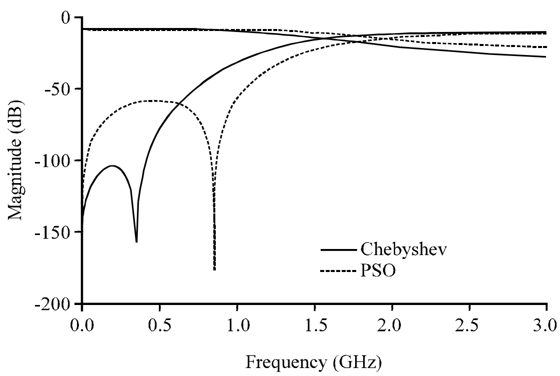

Fig. 8: The transmission and GDFG reflection coefficients achieved by the method of Chebyshev and PSO

We note that the two transmission coefficients are similar in bandwidth and the reflection coefficient obtained by the PSO is better than obtained by the Chebyshev method in the bandwidth and stop band. The dimensions of the best filter obtained by the algorithm are show in Table 3 and 4.

Figure 9 and 10 show the layout of the filter synthesized by the Chebyshev method and the best filter obtained by the PSO.

The low-pass filter designed by the Chebyshev method has an error equal to 18.35 and a length of 97.8 mm while the filter designed by the PSO algorithm have an error equal to 15.04 and a length of 55.9 mm. The algorithm reduced the filter length of 57.15% of the synthesized filter by the Chebyshev method.

The synthesis of microstrip low-pass filters by PSO is very efficient and produced almost similar results with the conventional method in terms of frequency response and miniaturization in the layout of filters.

The described process simulation was run on a laptop HP processor Intel Core 2 Duo 2 GHz, 2GB RAM and Windows XP Professional Service Pack 2.

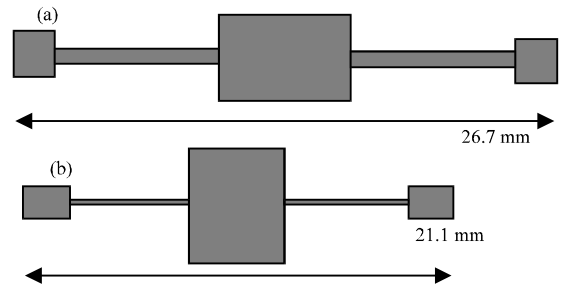

Fig. 9: Layout of low pass filters: a) Chebyshev method and b) PSO

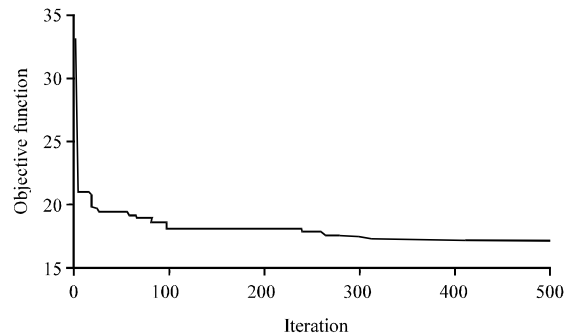

Fig. 10: Algorithm convergence to the optimum

Table 3: Limits of the search space

Limits of variables	Min. (mm)	Max. (mm)
l_{L1}	6.0	20
W_{L1}	10.0	30
l_{C1}	10.0	25
W_{C1}	0.1	1
l_{L2}	10.0	20
W_{L2}	10.0	30
l_{C2}	10.0	25
W_{C2}	0.1	1
l_{L3}	6.0	20
W_{L3}	10.0	30

Table 4: Dimensions of tow filters

Dimensions of filtre	Method of chebyshev l (mm)	Method of chebyshev W (mm)	PSO l (mm)	PSO W (mm)
L1	18.7	14.200	7.79	28.670
C1	21.0	0.882	14.55	0.100
L2	18.4	21.000	11.22	29.970
C2	21.0	0.882	14.55	0.100
L3	18.7	14.200	7.79	28.670

The computation time of a transfer function of a 3rd order low-pass filter is about 180 msec and for a 5th order filter 240 msec. The full implementation of example 1 (500 iteration, 50 particles and filter 3rd order) lasts 2 h and 15 min. The full implementation of example 2 (500 iteration, 50 particles and filter 5th order) lasts 3 h 3 min (Fig. 11 and 12).

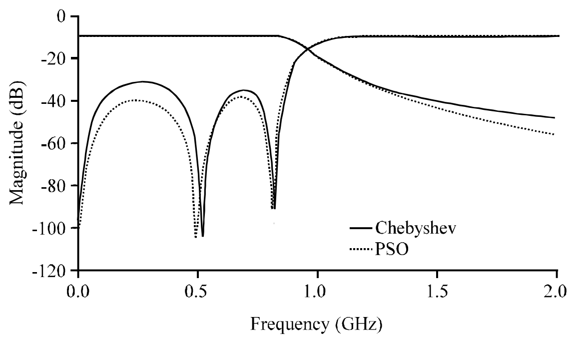

Fig. 11: The transmission and reflection coefficients achieved by the method of Chebyschev and PSO

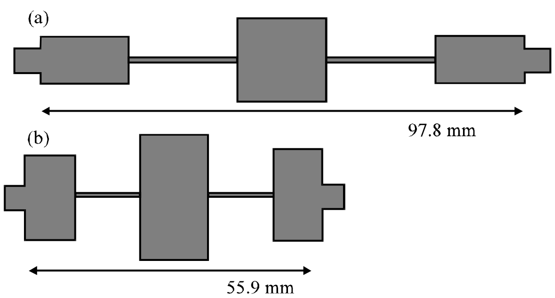

Fig. 12: Layout of filters: a) Method of Chebyshev and b) PSO

CONCLUSION

This study presents the miniaturization of stepped impedance microstrip low-pass filters by the particle swarm optimization algorithm. The particle swarm optimization algorithm is based on collaboration between the particles, it has some interesting features including the notion that efficiency is due to the collaboration rather than competition, it shows greater reliability in solving optimization problems in continuous or discrete variables.

The algorithm is easily applied in many fields, you only have to formulate the optimization problem, the three main parameters to be defined are: the particle, space research and the objective function. The filter synthesis by a conventional method (Butterworth, Chebyshe, etc.) is firstly done and then we formulate the optimization problem. We choose the particle as a filter and the position of the particle represents the filter dimensions. The limits of space are chosen for the algorithm research from the dimensions of the filter synthesized by the conventional method and the objective function which we used is a function sum of the errors on the magnitude response of the transfer function of the filter. The simulation results showed the effectiveness of the algorithm, the first example has given a reduction in the length of the filter about 21% while the second example has given a reduction in filter length about 57.15%. The performance of filters obtained by the PSO algorithm is better to that of the Chebyshev method. The use of PSO algorithm for the miniaturization microstrip filters is obvious and gives excellent results. The generalization of our contribution to the miniaturization of different microwave devices is possible.

REFERENCES

ANSYS., 2016. Academic student engineering simulation software. ANSYS Inc, Canonsburg, Pennsylvania. http://www.ansys.com/products/academic

Boudjelaba, K., F. Ros and D. Chikouche, 2014. Potential of particle swarm optimization and genetic algorithms for FIR filter design. Circuits Syst. Signal Process., 33: 3195-3222.

Chandran, P.P. and S. Viswasom, 2014. Gain and bandwidth optimization of a novel microstrip patch antenna. Proceedings of the 2014 Fourth International Conference on Advances in Computing and Communications (ICACC), August 27-29, 2014, IEEE, Cochin, India, ISBN:978-1-4799-4362-3, pp: 315-318.

Chemmangat, K., D. Deschrijver, I. Couckuyt, T. Dhaene and L. Knockaert, 2012. Fast optimization of microwave filters using surrogate-based optimization methods. Proceedings of the 2012 International Conference on Electromagnetics in Advanced Applications (ICEAA), September 2-7, 2012, IEEE, Cape Town, South Africa, ISBN:978-1-4673-0333-0, pp: 212-215.

Eberhart, R.C. and Y. Shi, 2001. Particle swarm optimization: Developments, applications and resources. Proc. Cong. Evol. Comput., 1: 81-86.

Gangopadhyaya, M., P. Mukherjee, U. Sharma, B. Gupta and S. Manna, 2015. Design optimization of microstrip fed rectangular microstrip antenna using differential evolution algorithm. Proceedings of the 2015 IEEE 2nd International Conference on Recent Trends in Information Systems (ReTIS), July 9-11, 2015, IEEE, Kolkata, India, ISBN:978-1-4799-8350-6, pp: 49-52.

Hussein, Y.A. and S.M. El-Ghazaly, 2004. Modeling and optimization of microwave devices and circuits using genetic algorithms. IEEE. Trans. Microwave Theory Tech., 52: 329-336.

Jia-Sheng, H., 2011. Microstrip Filters for RF/Microwave Applications. 2nd Edn., John Wiley and Sons, Hoboken, USA.,.

Kennedy, J. and R. Eberhart, 1995. Particle swarm optimization. Proc. IEEE Int. Conf. Neural Networks, 4: 1942-1948.

Kinayman, N. and M.I. Aksun, 2005. Modern Microwave Circuits. Artech House Microwave Library, London, UK., ISBN:97815805372542005, Pages: 604.

Koziel, S. and A. Bekasiewicz, 2015. Efficient design optimization of compact dual-band microstrip branch-line coupler using response features. Proceedings of the 2015 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), August 11-14, 2015, IEEE, Ottawa, Canada, ISBN:978-1-4799-6811-4, pp: 1-3.

Koziel, S., A. Bekasiewicz and L. Leifsson, 2015. Expedited design optimization of compact microwave structures using adjoint sensitivities and space mapping. Proceedings of the 2015 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), August 11-14, 2015, IEEE, Ottawa, Canada, ISBN:978-1-4799-6811-4, pp: 1-3.

Mahdi, N., S. Bila, M. Aubourg, C. Durousseau and J. Puech *et al*., 2015. Shape optimization of planar microwave components. Proceedings of the 2015 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), August 11-14, 2015, IEEE, Ottawa, Canada, ISBN:978-1-4799-6811-4, pp: 1-4.

Pozar, D.M., 2012. Microwave Engineering. John Wiley & Sons, Hoboken, New Jersey, ISBN:9788126541904, Pages: 732.

Robert, E.C., 2001. Foundations for Microwave Engineering. 2nd Edn., Wiley-IEEE Press, Hoboken, New Jersey, ISBN:9780780360310, Pages: 944.

SSI., 2016. 3D planar high-frequency electromagnetic software. Sonnet Software Inc, New York, USA. http://www.sonnetsoftware.com/products/sonnet-suites/

Samad, H.A.A., M.F.S. Azni, M.F.A. Karim, M. Yahya and M.A. Arifen, 2010. Rapid modeling, characterization, optimization methodology and analysis for low cost RF filter design. Proceedings of the 2010 IEEE International Conference on Wireless Communications, Networking and Information Security (WCNIS), June 25-27, 2010, IEEE, Beijing, China, ISBN:978-1-4244-5850-9, pp: 264-268.

Tomar, L., S. Gupta, R. Tomar and P. Bhartia, 2015. Design and analysis of low pass microstrip filters using MATLAB. Proceedings of the 2015 16th International Symposium on Quality Electronic Design (ISQED), March 2-4, 2015, IEEE, Santa Clara, California, ISBN:978-1-4799-7582-2, pp: 263-266.

Zhang, Q. and Z. Feng, 2006. A design of coupled transmission line filter for UWB system using PSO method. Proceedings of the 7th International Symposium on Antennas, Propagation and EM Theory ISAPE'06, October 26-29, 2006, IEEE, Guilin, China, ISBN:1-4244-0162-3, pp: 1-4.