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SYNTHESIS OF DUALBAND BAND PASS FILTER USING MULTI OBJECTIVE PSO

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ABSTRACT

A novel synthesis procedure for the design of microwave dualband bandpass filter using multi objective Particle Swarm Optimization (PSO) for 3.5 GHz and 5.5GHz Wimax applications is presented in this paper. This filter provides an insertion loss within the pass band is around -5 dB and return loss is -35 dB at the first pass band and insertion loss within the pass band is around -7 dB and return loss is -15 dB at the second pass band.

Keywords: dualband, bandpass filter, multiobjective, particle swarm, microwave filter, Wimax.

INTRODUCTION

Multiple frequency bands are necessary for reducing the number of components and size of the modern wireless communication applications. Recently wireless communication systems have increased demand for compact and multifunctional and multiband microwave filters. Two or more single band filters are combined together to form a dualband or multiband filter respectively. However, the size of the filter is increased and tuning between them is critical. Hence, a single filter having two pass bands in desired locations is intricate.

Several structures have been developed for achieving dualband filters [1-9], during 2000s and 2006s, using UIR, SIR, OLRR, combline and hairpin structures. Another approach is to cascade a band pass filter with a band stop filter, requires an additional matching network to connect them [10].

The synthesis of a microwave filters with the selection of transfer function that fulfills the electrical specifications such as low insertion loss, good flatness high rejection level, size and cost. This methodology is very attractive for planar filters because of reduced bulk and low production cost. Moreover, the location of the transmission zero is controlled on either side of the pole [11-13]. Unfortunately, more attention is required to eliminate the spurious harmonics on either side of the side band [13]. Low frequency spurious response is eliminated by short circuited stubs, due to via holes complexity is increased, and open circuited Capacitive coupled structure, getting desired value of capacitance is difficult. Another method is to place zeros on either side of the pole using robust optimization techniques. Reduction of spurious response is searching the optimal electrical parameters of a given circuit topology, although convergence is not guaranteed for high selectivity requirements. Genetic algorithm has been used to synthesize dual band band pass filter using circuit topology as well as corresponding electrical parameters [14]. However, the genetic operators such as choice, crossover and mutation are relatively complex and more space is required [15]. To overcome this, a relatively original approach for global stochastic optimization is Particle Swarm (PS). Particle Swarm Optimization (PSO) is similar to Genetic Algorithms (GA) for performing a global search in the parameter space but does not get trapped in local minima.

In most real world problems multi objective (MO) optimization is very common. Twoor more, sometimes competing and/or incommensurable fitness functions have to be minimized simultaneously [16]. The objective functions may be in conflict, thus, in most cases it is impossible to obtain for all objectives the global minimum at the same point. The goal of MO is to provide a set of optimal solutions to the aforementioned problem [17]. This paper proposes a novel PSO based synthesis procedure for a class of dual band bandpass filters using multi objective technique.

METHODOLOGY

Arbitrary filter structures, satisfying the constraints, are formed with the help of transmission line elements [18]. The type of transmission line, the mode of connection with the neighboring circuit elements and the electrical parameters of the corresponding elements are shown in Table-1.

Table-1. Basic filter elements.

Type	Name	Network topology	Connection	Electrical parameters
0	TL		Cascade	$Z_{o1}\ \theta_1$
1	Sh_TL_OC		Cascade	$Z_{o1}\ \theta_1$
2	Sh_TL_SC		Cascade	$Z_{o1}\ \theta_1$
3	Sh_TL2_OC		Cascade	$Z_{o1}\ \theta_1\ Z_{o2}\ \theta_2$
4	Sh_TL2_SC		Cascade	$Z_{o1}\ \theta_1\ Z_{o1}\ \theta_2$
5	Null		0	0 0

Zo1, Zo2 - Characteristic impedance of the transmission line sections. θ_1, θ_2 are denoted Electrical length of the transmission line section at f0, degrees.

A typical filter structure is shown in Figure-1. Null is a special element used to describe a circuit with an arbitrary number of basic circuit elements and orders.

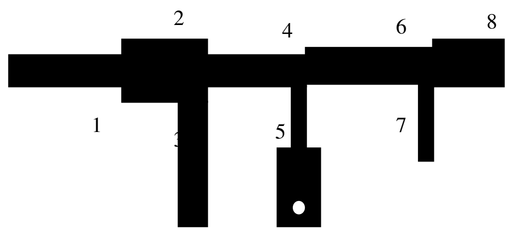

Figure-1. Basic filter structure.

The Scattering matrix of the filter structure plays major role in the evaluation of fitness value. The scattering parameter of each filter structure is calculated from the ABCD parameters. ABCD parameters of the single filter element are decided by their electrical parameters [19]. ABCD-matrix T_1 for a transmission line by characteristic impedance Z_1 and electrical length θ_1 is

$$T_1 = \begin{bmatrix} \cos\theta_1 & jZ_1 \sin\theta_1 \\ j\dfrac{\sin\theta_1}{Z_1} & \cos\theta_1 \end{bmatrix} \quad (1)$$

The ABCD-matrix T_2 represents the short-circuited stub section as

$$T_2 = \begin{bmatrix} 1 & 0 \\ j\dfrac{1}{Z_2 \tan\theta_1} & 1 \end{bmatrix} \quad (2)$$

The entire ABCD parameter is the multiplication of individual element's ABCD parameter. For an example eight element band pass filter structure is shown in Figure-1. The ABCD-matrix of the whole structure is

$$\boldsymbol{T} = \prod_{i=1}^{8} \boldsymbol{T}_i \quad (3)$$

The S-Parameter value of a structure is obtained from the resultant ABCD values as given by

$$S_{21} = \frac{2}{A + B/Z_0 + CZ_0 + D} \quad (4)$$

$$S_{11} = \frac{A + B/Z_0 - CZ_0 - D}{A + B/Z_0 + CZ_0 + D} \quad (5)$$

With this scattering parameter value and the suitably selected weight values are used to calculate the fitness value for the constraint satisfied filter structures.

Let X be an n-dimensional search space and $f_i(x)$, i = 1,... ,k, be k objective functions defined over X [16]. Assuming, $g_i(x) \le 0$, i= 1,... ,m, be m inequality constraints, the MO problem can be stated as finding a vector $x^* = \left(x_1^*, x_2^*, \ldots\ldots x_n^*\right) \in X$ that satisfies the constraints and optimizes (without loss of generality and

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consider only the minimization case) the vector function $f(x)=[f_1(x), f_2(x), \ldots\ldots f_k(x)]$.

According to this approach, the overall fitness value can be expressed by [17],

$$S=\left[\sum_{i=1}^{M}(W_iF_i)^2\right]^{\frac{1}{2}} \tag{6}$$

where W_i is the weighting value on the i^{th} fitness value, M is the number of fitness values, F_i is the i^{th} fitness value, and is given by

$$F_i=\sum_{j=1}^{k} w_j f_j(x) \tag{7}$$

Where w_j, $j = 1, \ldots, k$, are non-negative weights. These weights can be either fixed or dynamically adapted during the optimization [16].

Fitness sharing was introduced by Goldberg and Richardson (Goldberg and Richardson 1987), and applied successfully to a number of difficult and real world problems. The target of fitness sharing is to distribute the population over a number of different peaks in search space, with each peak receiving a fraction of the population in proportion to the height of that peak. To achieve this distribution, sharing calls for the degradation of an individual's objective fitness *fi* by a niche count, calculated for that individual. Then the shared fitness is [20, 21]

$$f_{share}(i)=\frac{f_{raw}(i)}{\sum_{j=1}^{a} Sh[d[i,j]]} \tag{8}$$

where *fraw (i)* is the fitness value of *i*th population which was not undergone the sharing function.

Fitness function with constraints

In this proposed method the design problem can be originated from

$$P^* = arg\left(\min_P F(S(P))\right)$$
(9)

where P^* is the optimum particle, P denotes the particle of the PSO, *S(P)* is the simulated scattering parameter of the particle and *F* is the fitness function to be minimized. The fitness function (*F*), for the synthesis of microwave filter defines the error between the actual and the simulated response [5] is given by

$$F=\sum_{j=1}^{N} w_j f_j \tag{10}$$

where w_j is the weighting value at the j^{th} sampling point, $f_j=(d_j-S_j)^2$ and d_j and S_j are the magnitude of the desired and simulated scattering parameters at the j^{th} sampling point respectively. The weight values are chosen such that the fitness function is minimized. Constraints for this fitness function in the synthesis of filters are that the electrical parameters must lie within the lower and upper limits so that the fabrication issues and discontinuity effects are reduced, the stubs have to be connected in cascade if it is in parallel practical realization is difficult [19], junctions are to be either step-, tee- or cross-junctions other than these cannot be realized practically and the location of transmission zero must be defined clearly so that the time required to compute frequency response for a filter structure is reduced.

Evaluation of fitness function

The fitness function is minimized by a population based stochastic optimization method called PSO. Each solution in PSO is like a bird in the solution space, which is called particle. All particles have positions representing possible solutions that are evaluated by the fitness function formed by problems to be optimized, and velocities that direct the flying of the particles. The first step is to generate n number of random filter structures satisfying the constraints, called as particles. The S-Parameter and fitness value of all particles are evaluated using equations (4), (5) and (6) depends upon the requirement. In PSO, each particle represents an alternative solution in the multidimensional search space. The arbitrary filter structures formed are the particles in the PSO method. Thus these particles are multi-dimensional vectors whose trajectories are updated based on the velocity defined by its before best success, p_{best}, and the best success achieved by the best particle in the swarm, g_{best}. The velocity and position of the particles are updated based on the following equations:

$$v_{i,n}(t+1)=wv_{i,n}(t)+c_1r_1\left[Z_{pbest}-Z_{i,n}(t)\right]+c_2r_2\left[Z_{gbest}-Z_{i,n}(t)\right] \tag{11}$$

$$x_{in}(t+1)=x_{in}(t)+v_{in}(t+1) \tag{12}$$

where $x_{i,n}(t)$and $v_{i,n}(t)$ are the current location and velocity vector of the i^{th} particle in its n^{th} dimension.*w* is the inertia weight used to control global exploration and local exploitation of the particles and typically decreases linearly from 0.9 to 0.4 during a run, has provided improved performance in a number of applications [22]. c_1 and c_2 are the acceleration constants that act as weights to provide the relative pull for each particle toward p_{best} and g_{best} positions. r_1 and r_2 are two uniformly distributed random variables in the range [0,1] to provide a stochastic variation in the relative pull towards p_{best} and g_{best}. In most cases, a parameter V_{max} that acts as an upper limit for the achievable velocity of the particles is also used to control the ability of the particles to search and be confined within the search space. However, it has been noted in [23] that the particles may still occasionally fly to a position beyond the search space, and hence produce an invalid solution. Fitness value for this proposed filter synthesis method is zero. This algorithm is iterated until the evaluation count reaches the maximum value or one of a particle in the group reaches the target fitness value. The selection of the optimum filter structure depends upon the fitness value. Minimum or least fitness value provides the response of the filter structure which comes closer to the desired output that will provide the optimum filter structure.

VALIDATION OF THE PROPOSED METHODOLOGY

To show the validity of the proposed PSO based filter synthesis methodology, a set of band pass filters representing various orders in a chosen wireless band is designed. A dual-band band-pass filter with the first centre frequency at 3.5GHz (fc), second center frequency at 5.5 GHz, bandwidth of 200 MHz having near 0 dB insertion loss in the pass band and -20dB rejection in the transition bands of 2 to 3 GHz, 4 to 5 and 6 to 7 GHz is considered. To start with one lakh dual-band band-pass filters with various orders are generated. The filter structure consists of several basic filter elements which were taken from the Table-1. The formed filter structure is represented by a matrix form, 10x6, as its size is maintained by the null element of the filter structure. From this formed filter structures only ten structures/particles satisfied the constraints. The electrical parameters of the filter structures are generated for the given specifications, using Table I, that are taken as the initial particle position of the PSO. The electrical parameter values are changed iteratively with respect to the obtained Z_{pbest}, Z_{gbest}, θ_{pbest} and θ_{gbest}. The fitness value of the filter structures are calculated using equations (6), (7) and (10). The fitness value fully depends on the selection of weight value. The fitness sharing algorithm is used to cluster the fitness values, using equation (8), towards the dual band of the filter. The impedance values and electrical lengths of the filter structures are optimized using equations (11) and (12) until the evaluation count reaches the maximum value or one of a particle in the group reaches the target fitness value zero or close to zero.

The proposed PSO algorithm is coded in MATLAB. The fitness value of the optimum filter structure satisfying the specification is found to be 0.1017. The time taken for obtaining the converged filter structure solution, as given in Table II, is 102.2 seconds. The rate of convergence is shown in Figure-2. It can be seen from the figure, the sharp glitches that are seen and are automatically removed by the inertia weight values. For the chosen specification the optimum filter structure has three transmission lines and six open circuited shunt stubs. Filter elements and its electrical parameters of the Optimum filter structure are given in Table-2.

Table-2. Optimum filter structure and their electrical parameters using PSO.

Type	Impedance (Ω)	Electrical length (˚)	Impedance (Ω)	Electrical length (˚)
Sh_TL2_OC	100.14	65.12	52.97	89.9
Sh_TL_OC	100	92.3	0	0
TL	75	112.64	0	0
Sh_TL2_OC	108.08	107.04	40	94
TL	37.07	96.35	0	0
Sh_TL2_OC	71.5	49.42	98.2	41.8
TL	60.2	112.57	0	0
Sh_TL2_OC	100.14	65.12	52.97	89.9
Sh_TL_OC	81.0	121.71	0	0

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The optimum filter structure obtained from the PSO technique is simulated using the simulation software ADS2002C. Basic filter elements like TL, Sh_TL_OC, Sh_TL_SC, Sh_TL2_OC and Sh_TL2_SC are joined together to form the final filter structure. The layout of the filter structure is shown in Figure-3.

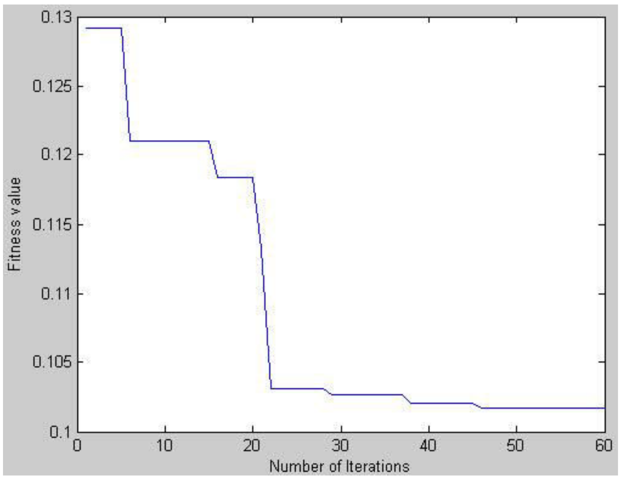

Figure-2. Convergence rate diagram for PSO based dual-band band pass filter.

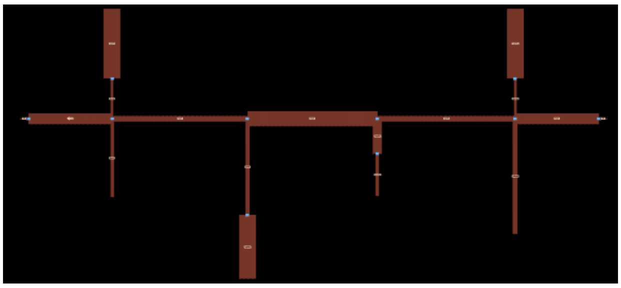

Figure-3. Layout of the optimum dual band bandpass filter structure.

The Insertion and return loss versus frequency are shown in Figure-4. For the simulated model, as shown in Figure-4(a), the insertion loss is < -2 dB in the required first and second pass bands of 200MHz, the return loss of -15.5 dB at the first center frequency and -35 dB at the second center frequency. The measured response is shown in Figure-5(b). The measured insertion loss within the pass band is around -5 dB and return loss is -35 dB at the first pass band and insertion loss within the pass band is around -7 dB and return loss is -15 dB at the second pass band. Insertion loss of the filter is around -5 dB in the pass band, due to the different types of filter elements which are connected together lead to discontinuity effect. It is also to be noted that time taken for the selection of optimum filter structure is less, roughly 102 sec. as compared to 7.0 hours taken for particle generation with constraint.

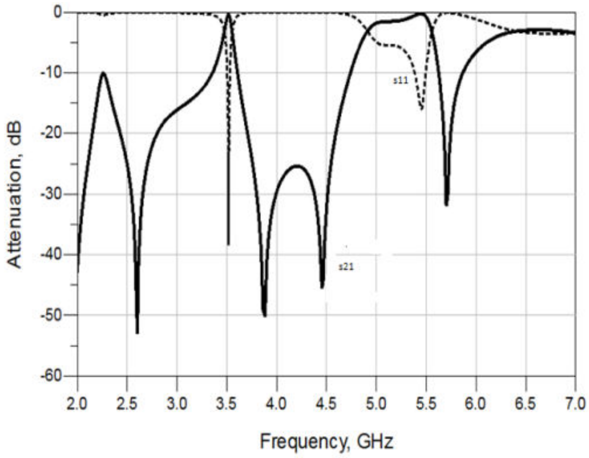

Figure-4(a). S11 and S21 responses of the simulated PSO based dual band filter.

CONCLUSIONS

This chapter proposes a novel and efficient synthesis method for a high performance dual band, multi objective band pass filter for wireless applications using PSO. The PSO has been used to model the distributed filter structure in terms of the scattering parameters. The proposed design approach is validated by simulation band pass filter on a microstrip platform using glass epoxy substrate. It is an efficient tool to design a filter but the insertion loss of the filter is high due to the discontinuity effect. It is to be noted that the fine tuning of the line dimensions is required to nullify the losses due to discontinuity.

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