

# Optimizing the Size of SAW filter using GA

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**ABSTRACT:** This paper discusses the existing optimization techniques and then Genetic Algorithm has been applied as optimization technique in order to enhance the response. Surface Acoustic Wave Filters are particular Band Pass Filters which are currently used in electronic equipments for qualitative communication. Developers of SAW Filters have faced challenges that arise from design complications, limited practical upper frequency, high manufacturing costs, selection of waveguide material, filter dimensions, limited power handling and examining frequency characteristics corresponding to given specifications. The size of the SAW filter is also a main issue because frequency response of a filter depends on its size. The structure of Inter Digital Transducer (IDT) decides its frequency response. So, in order to have desired response, the structure must be known. The best structure is one for which the Frobenius norm distance is minimum. The structure includes the number of units to be cascaded and their positions. It is a combinatorial optimization problem. The paper presents Genetic Algorithm technique for finding the combinations of the IDTs for which the Frobenius norm distance is minimum. By obtaining desired frequency response at multiple frequency points, it results in reduction of size of the filter.

**KEYWORDS:** SAW, IDTs, P-matrices, IF, RF, GA, DE, BFO, PSO, MA, STW, SNR, COM, PCS, GED3, CDMA.

## I. INTRODUCTION

SAW Filters are being proving day by day the most emerging and efficient band pass filters with compact size and light weight. SAW is a type of mechanical wave motion which travels along the surface of a solid material. It was discovered by Lord Rayleigh in 1885 and is often named after him [5]. Surface Acoustic Wave (SAW) devices have been emerged as a key component in radio-frequency (RF) and intermediate frequency (IF) stages of many communication systems such as satellite receivers, remote control units, keyless entry systems, television sets, and mobile phones, thereby greatly contributing to the growth [4]. SAW filters operating at IF in cellular/personal communications service (PCS) receivers are required to reject out of band interferers with minimal distortion of the in-band signal [7].

Some characteristics of SAW filters are as follows [6]:

- a. Low insertion attenuation (< 2.5 dB max.)
- b. Very good far away selectivity
- c. Balun functionality possible
- d. Impedance transformation Possible

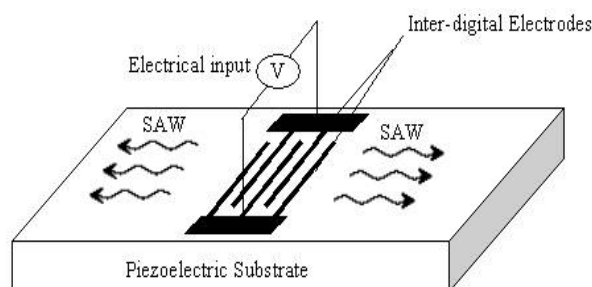


Fig. 1. A basic SAW device [4]

Figure shows the basic structure of a SAW device. It consists of two Inter Digital Transducers (IDTs) i.e. Input IDT and Output IDT placed on a piezoelectric substrate such as quartz. The input IDT converts signal voltage variations into mechanical SAW waves and output IDT converts mechanical SAW vibrations into output voltages [5]. IDTs consist of interleaved electrodes alternately connected to two bus bars. These have comb shape.

The size of the SAW filter is always a main issue because frequency response of a filter depends on its size. The structure of IDT decides its frequency response. So, in order to have desired response, the structure must be known. IDTs having desired structure may be used to construct a particular SAW filter. Then, the SAW filter will be able to have desired frequency response. This type of SAW filter can be used as per application. It will also increase the applications of SAW filters.

The best structure is one for which the Frobenius norm distance is minimum. The structure includes the number of units to be cascaded and their positions. It is a combinatorial optimization problem. Each IDT have corresponding p-matrices. The p-matrix corresponding to a structure can be obtained by cascading various number of basic unit cells. The cascading formulas are given in [3]. These basic unit cells have their corresponding T and R values. T is transduction coefficient and R is reflection coefficient. Possible values of T and R are +1, 0, -1. So, there will be nine possible combinations of T and R [2].

Evolutionary Computation [14-16, 18, 19, 21-23, 25-32, 35, 40, 41] is a subfield of Artificial Intelligence which mimics the biological evolution for solving Combinatorial Optimization Problems [17, 18, 20, 24, 31, 33, 34, 36, 37, 38, 39]. These techniques [14, 15, 17, 18, 20, 27] are probability based optimization approaches which are inspired by biological evolution and/or social evolution. Such kind of techniques have been developed to arrive at near-optimum solutions to large scale optimization [17, 20, 33] problems, for which traditional mathematical techniques may either fail or may give results at prohibitive costs. The paper presents a survey of the techniques for finding the combinations of the IDTs for which the Frobenius norm distance is minimum.

The rest of the paper is organized as under:

In section II, size of the filter is formulated as an optimization problem. In section III, some approaches are stated which are already applied in SAW filters. Then, suitable approaches from above section are discussed that suits well to the optimization problem. All this is done in section IV. Finally, conclusions are drawn in section V.

## II. PROBLEM FORMULATION

In order to use SAW filters as per application, a particular desired frequency response must be given by the filter which improves the quality of the filter. To obtain desired frequency response, it is essential to know the size of the filter which means combinations of the IDTs that are used to design a SAW filter. As combinations of IDTs are nothing else but cascaded basic unit cells. These combinations have the issue of number of units or basic cells to be cascaded and their positions. Finally, this paper deals with structure of IDT that is based upon nine different combinations of T & R having particular p-matrices. So, there are two main issues which are to be solved. Therefore, this combinatorial optimization problem is regarding the size of the SAW filter which may be solved using an effective optimization algo-

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rithm. It will create more applications of SAW filters.

### III. STATE-OF-THE-ART APPROACHES

Earlier there are number of techniques applied to solve different or may be the same issue in SAW filters. Each of them having different way of solving problem and with different number of costs and benefits. It is upto the problem whether cost is more effective or the benefits. Problems are classified in two categories i.e. Deterministic or Probabilistic. Deterministic means to go through every solution of the problem while solving it which becomes very difficult for MATLAB to work on it. While, Probabilistic means to find solutions randomly in the search space and to take iterations of it until it reaches up to desirable result. Some of the researches done that may be helpful for the above stated problem are as follows:

Priyanka et. al. [2] presents an iterative technique for the same problem. It was a good technique. A number of iterations have been taken to optimize the objective function so that desired frequency response may be retrieved. In this technique, in order to find an optimal solution, every solution of the search space was accessed. But, it really becomes very difficult to search iteratively every solution even when the search space is so large. This technique is deterministic which go through every possible solution. However, it is too slow process to go through so many solutions. System may not be able to do so. Secondly, the obtained solution was matched with the desired solution at only single frequency point. By matching the solution at multiple frequency points, the results will be improved.

Kiyoharu Tagawa [8] presents two Evolutionary Algorithms (EAs) i.e. Differential Evolution (DE) and Genetic Algorithm (GA) to the optimization problem. The problem was nearly same. It was to find the desirable structures and designs of balanced SAW filters. The geometrical structures decides the frequency response characteristics of balanced SAW filters. Here, both types of EAs were compared in the quality of solution with same cost. Finally, DE was proved better than GA for providing better results at same computational cost. However, their objective function was having complicated decision of weighting coefficients. So, it is not suitable for multi-objective problem.

Gunter [9] presents a generalized p-matrix model for SAW filters. The p-matrix model analyzes the electro-acoustic properties of IDTs and reflector gratings in a SAW filter. Here, he tried to remove the problem of capacitive coupling between neighboring elements of IDT and change electro-acoustic excitation and detection of forward and backward propagating SAW. He presents the generalization of the classical p-matrix model that relates outgoing acoustic surface waves and all electric currents to incoming acoustic surface waves and all electric voltages in a general acoustic track. This track may consist of many number of IDTs, reflectors and delay lines. Also, this model may be applied to the tracks with floating fingers.

Ventsislav et. al. [10] presents a theoretical that allows one to conduct Coupling-of-Modes (COM) Surface Transverse Wave (STW) loss analysis and estimate the resonator Q from material and layout parameters. There are substantial advantages of STW resonators over conventional SAW resonators. The COM transmission coefficient  $x_{11}$  is derived by Floquet analysis. Its imaginary part is obtained by numerically fitting available experimental data for the Q-factor of particular resonators. It is a measure of STW propagation loss that adds to the electrode. However, the considerations are restricted to real values of transmission and reflection coefficients i.e.  $x_{11}$  and  $x_{12}$ .

Kiyoharu et. al. [11] presents a robust optimization technique for the structural design of SAW filters. This optimization technique consists of Taguchi method and Memetic algorithm. It was the first application of Memetic Algorithm with Taguchi method. Here, the optimization problem was to maximize the SNR of SAW filters without losing their specified functions. So, they proposes Memetic algorithm for this problem. The hybridization of Memetic algorithm had the ability to improve local search drastically. Finally, the maximization of SNR of SAW filter reduced the fluctuations of the frequency responses of the SAW filters caused by the variations of uncertain parameters.

Kathiravan Krishna et.al. [7] presents a simple and effective technique of characterizing a SAW filter in-situ. By SAW resonator, the errors involved in vector measurements are avoided. It is very useful for a fast-paced product development environment where quick insight into SAW impedances is required for CAD & optimization. A simple model offers insight into the Q of the SAW input and output to estimate matchability. The effect of EM interaction on the SAW package is also determined by the resonance method with the matching inductor.

Kiyoharu Tagawa et. al. [12] applies an Imanishian GA to the optimum design of a resonator type SAW filter. First of all, they formulates the structural design of a three-IDT type SAW filter as an optimization problem. In order to evalu-

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ate the frequency response characteristics of the SAW filter, they employ the least equivalent circuit model of IDT. Then, they propose an Imanishian CA inspired by Imanishi's evolution theory for the optimization problem. Introducing a new concept of species into the population enabled the Imanishian GA to exploit the local search without losing the diversity of population. Furthermore, they discuss the suitable distance threshold that brought the advantage to the Imanishian CA [12]. Finally, experimental results demonstrate that the Imanishian GA could find multiple optimum solutions. Because of its simplicity in both the theory and the implementation, the proposed Imanishian CA is applicable to all sorts of optimization problems. On the other hand, a number of efficient optimization methods that rely on an analogy to the natural evolution have been reported.

Bajeh, A. O. et. al. [1] presents examination timetabling problem like all scheduling problems are hard problems in which the complexity and time needed to solve the problem increase with the problem size. The paper aims to compare Genetic Algorithm and Tabu Search approaches to solve this kind of problem. Both algorithms are tested with regard to the quality of generated timetables and the speed with which the timetables are generated using collected test data. The test shows that though both algorithms are capable of handling the examination timetabling problem, the Tabu Search approach can produce better time tables than Genetic Algorithm, even at a greater speed [1].

David P. Morgan [13] gives formulas for cascading identical P-matrices to obtain the P-matrix of a periodic transducer structure. As for COM solutions, the response of SAW transducers is calculated rapidly, but they are much more rigorous despite being hardly more complicated. The formulas are very general since the only assumptions made are reciprocity and the validity of the P-matrix description. Consequently they apply, for example, to simple gratings, simple transducers, and to complex transducers where individual sections are composites of transducer-grating combinations. Propagation loss can be included because the formulas do not assume power conservation. Some constraints are associated with the use of the P-matrix. For example, this is not generally valid in a SAW device if bulk wave excitation or diffraction is occurring. Also, the use of identical P-matrices for the sections implies that end effects are ignored, though this is often an adequate approximation. Applying these results to a directional transducer, i.e., a SPUDT, gives a general relation between the directivities of the transducer and of one section, and shows that the directivity can be simply related to the short-circuit reflectivity.

A. Slowik [43] presents an application of evolutionary algorithm to design minimal phase digital filters with non-standard amplitude characteristics and with finite bit word length. He designs four digital filters with infinite impulse response using the above method. These digital filters possess some characteristics like: linearly falling characteristics, linearly growing characteristics, nonlinearly falling characteristics, and nonlinearly growing characteristics, and they are designed using bit words with an assumed length. The bit word length is then connected with a processing register size which depends on hardware possibilities where digital filter is to be implemented. A modified mutation operator is also introduced in this paper. Due to which better results are obtained in relation to the results obtained using the evolutionary algorithm with other mutation operators. In this paper, the given method is also compared with Yule Walker method. The results of this paper can be directly implemented in the hardware (DSP system) without any additional modifications. By doing small modifications, this method can be used to design FIR digital filters.

Kiyoharu Tagawa [44] presents a multi objective optimum design method for balanced SAW filters. As, discussed earlier, the frequency response characteristics of a filter is governed by their geometrical structures. Here, the filter specifications are given by using several criteria. In order to have desired frequency response characteristics, the structural design of the balanced SAW filter is taken as optimization problem. Then, he applies a recent evolutionary multi objective optimization algorithm i.e. Generalized Differential Evolution 3 (GED3). The relationship between the structure of a filter and its frequency response characteristics is clarified. Finally, the method is demonstrated in the three and the two objective optimum design problems of a practical balanced SAW filter. Future work may proceed in the direction of investigation of the set of pareto-optimal solutions in the design parameter space.

Kuldeep Singh et. al. [45] recently presents the optimization of SAW filter using Particle Swarm Optimization (PSO). Here also, the structure of the filter is formulated as optimization problem. Then, PSO algorithm which is a hybrid optimization technique is applied on the problem. Particle Swarm Optimization is a recently proposed random search algorithm and has been applied to many real-world problems, has a good global searching algorithm [45].

Kiyoharu Tagawa [46] presents An optimum design technique for balanced surface acoustic wave (SAW) filters is proposed. First of all, in order to evaluate the performance of balanced SAW filters by the computer simulation, a numerical model of balanced SAW filters is derived by using mixed-mode scattering parameters. Then the structural design of

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balanced SAW filters is formulated as a function optimization problem that aims to improve their balance characteristics and satisfy specifications for filter characteristics. Furthermore, in order to solve the function optimization problem successfully, a simple and efficient global optimization method, i.e., the differential evolution (DE), is employed.

Priyanka et. al. [47] presents the realization of IIR filters on SAW devices; which can lead to substantial reduction in filter size. With the help of reflections, poles are realized poles in SAW filter. A model is given to get the p-matrix for a SAW unit cell having reflections. Then they analyzes this to retrieve the transfer function of a SAW transducer made up of cascades of such unit cells. Although, most of work related to SAW filters go through the realization of SAW filters. A SAW structure to realize a rational transfer function with proper second order denominator polynomial is given in this paper. Since the coefficients of the resulting transfer function depend on device parameters, it establishes the claim that it is possible to realize IIR filters on SAW devices [47]. Simulation results are given showing the validity of the given model.

A. Slowik et. al. [48] presents an application of differential evolution algorithm to design digital filters with non-standard amplitude characteristics is presented. Three filters are designed with characteristics: linearly growing, linearly falling, and non-linearly growing, using the proposed method. The digital filters obtained using this method are stable, and their amplitude characteristics fulfill all design assumptions [48] The main advantage [48] of proposed method is setting up only one parameter, which determines a number of individuals in population; elaborated algorithm possesses very good convergence. This proposed method allows for full automation for design of digital filters.

Danny King et. al. [49] describes the evolution of SAW designs to meet the challenging demands of reducing the size and cost for CDMA IF filters. SAW filters have applications in Intermediate Frequency (IF) filtering stage which is used in both Code Division Multiple Access (CDMA) handset and infrastructure. Also, SAW filters are superior than other types of filter technologies due to their high performance with low cost and small size which makes them very qualitative. Without having any frequency planning, CDMA systems uses steep filtering to avoid capacitive losses. The evolution of the

CDMA PCS IF receive filter commonly used at 210.38 MHz [49]. Such kind of trends have also been shown in this paper at the CDMA cellular IF receive filter at 85.38 MHz. The single-phased unidirectional transducer enables the design of low-loss SAW IF filters in order to improve their noise figure, dynamic range and to reduce excessive gain requirements. Reflective low-loss and multi-track designs allow SAW designers to achieve filter shaping with smaller die size, which reduces the cost. Further, the successful implementation of SAW filters in surface mount packages reduces weight and size. Continued innovative design techniques will satisfy the aggressive demands of wireless applications.

K. Tagawa [50] proposes a computer-aided two-stage design method and applies to the structural design of a practical SAW duplexer which is made up of two DMS filters and four SAW resonators fabricated on a piezoelectric substrate. Due to the complex structure, it was difficult to formulate it as an optimization problem directly. Therefore, we contrived the two-stage design method for the structural design of the SAW duplexer [50]. In the first stage of the proposed design method, the optimization problem is formulated. Then, in order to obtain feasible solutions as many as possible, a new version of DE called DECS was applied to the constraint satisfaction problem [50]. In the second stage of the proposed design method, considering the information about the SAW duplexer obtained in the first stage and the knowledge of engineers, the structural design of the above SAW duplexer is reformulated again as a constrained optimization problem[50]. In order to an optimum solution of the constrained optimization problem effectively, another version of DE called DECO is applied. Finally, the usefulness of the proposed two-stage design method is demonstrated. It can also be applied to other SAW devices. Therefore, in the future works, DECS and DECO can be improved by using the latest optimization techniques.

## IV. GENETIC ALGORITHM AND ITS ADVANTAGES

In contrast to evolutionary computation techniques, GA is a simple but effective optimization technique. Mainly, it has three operations that differs it from other evolutionary computation techniques. These are:

- a. Selection
- b. Crossover
- c. Mutation.

After these operators, the fitness of the new population is evaluated. After operating these operators for generations, there is every likely that problem is optimized. The following are the steps of GAs:



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1. First of all, initialize population  $p(t)$  at time=0.
2. Apply objective function on individuals of population  $p(t)$ .
3. If result gets optimized, then stop the algorithm otherwise proceed to next step.
4. Select two parents randomly from initial population  $p(t)$ .
5. Then, make them crossover with specific crossover rate.
6. Mutate them with mutation rate.
7. Create two off springs from above two parents to have new generation [42].
8. Recombine the off springs with the remaining initial population  $p(t)$ .
9. Now, it will be the new generation of population i.e.  $p(t+1)$ .
10. Apply, objective function on the new generation of population  $p(t+1)$ .
11. Repeat all this from step 4 until desired result comes.

The GAs is one of the very effective optimization technique having edge over other competing techniques in terms of the followings:

1. It can solve combinatorial optimization problems.
2. This is an evolutionary algorithm inspired by natural evolution introduced in Holland in 1962.
3. Population of individuals
4. Individual is feasible solution to problem
5. Each individual is characterized by a Fitness function
6. Higher fitness is better solution
7. Based on their fitness, parents are selected to reproduce offspring for a new generation
8. Fitter individuals have more chance to reproduce
9. New generation has same size as old generation; old generation dies
10. Offspring has combination of properties of two parents
11. If well designed, population will converge to optimal solution.
12. It has complete balance between exploration and exploitation.
13. It gives better fitness values.
14. It is simple and effective.
15. It has good heuristic for combinatorial problems means combines information from good parents (crossover) [43].

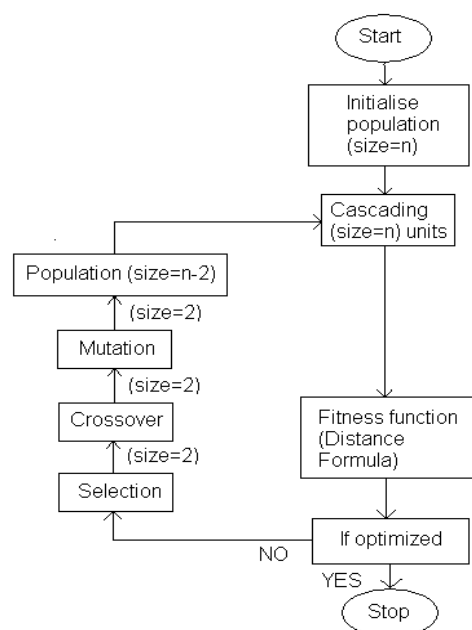


Fig 2. Flow chart of Genetic Algorithm

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There is an experimental test that compares Tabu Search and GA. In this experiment, we aimed to analyze the quality of the timetables generated by both algorithms. This was done by comparing the fitness function of the generated timetable and varying the maximum number of iteration (Maximum evolution for GA).

Table 1 compares the quality of the generated timetables by the fitness function of the timetables, it shows that the average fitness of GA and TS is 5083 and 708.5 respectively.

Table 1: Parameters taken for comparing GA and TS [1].

Parameters	GA	TS
Number of days for examination	12	12
Maximum evolution	Listed in table 2	
Population size	100	100
Weight of class size error	10	10
Weight of group clash error	10	10
Weight of consecutive exam error	5	5

Table 2: Fitness of Generated Timetable at different given maximum iteration [1]

Maximum Iterations	GA (Fitness)	TS (Fitness)
100	7260	1035
200	7430	810
300	7295	730
400	7530	635
500	7475	705
600	7105	765
700	7835	650
800	7430	620
900	6185	560
1000	7270	575
Average	5083	708.5

Table 2 shows that Genetic Algorithm provides better fitness than provided by Tabu Search. GA can produce several different near optimal solutions at the same time because of its holds the whole generation of chromosomes which may not originate from the same parents [1].

## V. GENETIC ALGORITHM IN SIZE OPTIMIZATION PROBLEM

On behalf of above discussed techniques, it is concluded that use of Evolutionary Algorithms gives better results. Solutions may be of any number, but best solution closest to desired p-matrix may be found probabilistically means instead of going through every possible solution, random solutions may be taken. Also, multiple frequency points may be matched. All this may be done using an optimization technique that suits it well.

There are various techniques that come under evolutionary computation techniques such as Tabu Search, Genetic Algorithm and Hybrid techniques like Memetic Algorithm (MA), Bacteria Foraging Optimization technique (BFO), Particle Swarm Optimization technique (PSO), etc. Starting from the beginning, if Tabu Search and Genetic Algorithms are compared, then as per literature in [1], Genetic Algorithm provides better fitness of individual solutions than provided by Tabu Search. Although, other techniques are hybrid, so GA may be applicable in this optimization problem.

Implementing GA as an optimization technique for reducing the size of SAW filter, the required parameters are as follows:

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1. Initial Population: To generate initial population, random solutions are taken.
  2. Objective Function: Objective function is applied on every solution checking whether it is optimized solution or not. If result is optimized, then algorithm is stopped, if not, next parameter is calculated .
  3. Selection: Randomly two solutions are selected from the initial population and they are further modified.
  4. Bit Representation: The above two selected solutions are represented in bit form.
  5. Crossover: Their bits are cross over by a probability of 0.5.
  6. Mutation: After their cross over, bits are mutated by a probability of 0.2.
  7. Population Regeneration: The mutated result is converted back into original form. These two solutions together with remaining solutions from initial population constitutes new generation.
- Then, step 2 onwards is repeated until result gets optimized.

## VI. TOOLS AND TOOLKIT USED

The steps of GAs need to be converted into codes with the help of programming languages. It is an interactive, high-level, high performance matrix-based environment performing scientific and technical computation and visualization faster than traditional programming languages such as C, C++ and Fortran [42]. It is an acronym of MATrix LABoratory and was conceived and developed by Cleve Moler who was involved with LINPACK and EISPACK library projects. It is a registered trademark of Math Works, Inc., USA. It is very simple with powerful graphical capabilities. It contains many in-built functions and various toolboxes. However, user defined functions have been developed by most of the researchers.

## VII. RESULTS AND DISCUSSIONS

To achieve the set goal, the fitness function has been evaluated for different number of generations. In every generation, different number of units or basic unit cells has been cascaded. Although, GA is based on randomization. So, all the solutions are taken randomly. The relation between fitness function and number of generations has been shown graphically. Results may be obtained for:

- Multiple frequency points
- For large number of cascaded units
- For large number of generations taken

These are the three input parameters for having desired frequency response. X-axis shows number of generations taken while y-axis shows the objective function. Results have following cases :-

- When there are 101 frequency points and slowly increasing the number of cascaded units or taken almost same, the results are as follows for different generations :

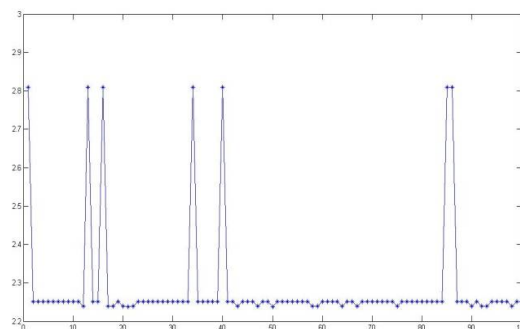


Fig. 3. Plot of fitness with respect to number of generations (Units=50 and Generations=100)



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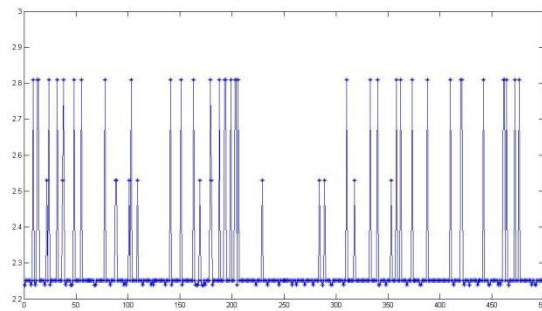


Fig. 4. Plot of fitness with respect to number of generations (Units=50 and Generations=500)

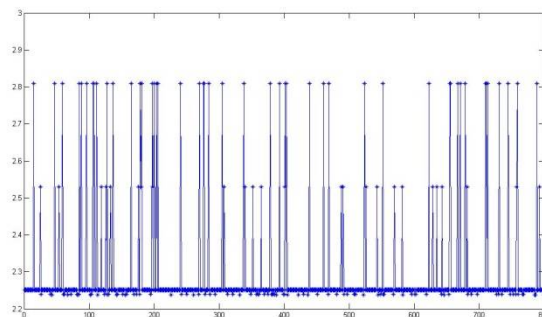


Fig. 5. Plot of fitness with respect to number of generations (Units=50 and Generations=800)

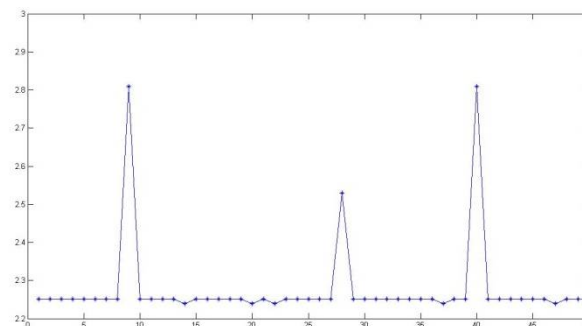


Fig. 6. Plot of fitness with respect to number of generations (Units=100 and Generations=50)

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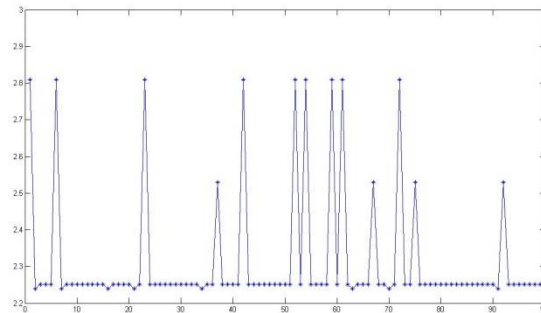


Fig. 7. Plot of fitness with respect to number of generations (Units=100 and Generations=100)

- When there are 101 frequency points and number of generations are constant, results for different number of cascaded units are as follows :-

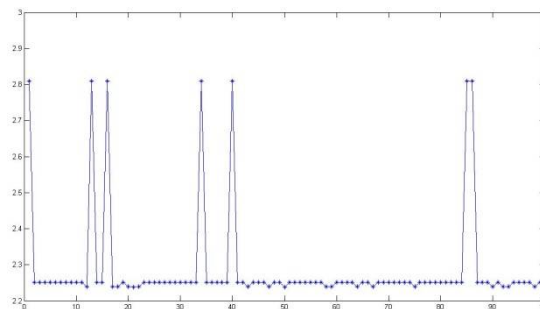


Fig. 8. Plot of fitness with respect to number of generations (Generations=100 and Units=50)

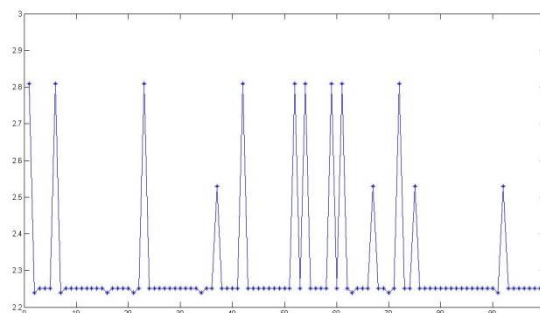


Fig. 9. Plot of fitness with respect to number of generations (Generations=100 and Units=100)

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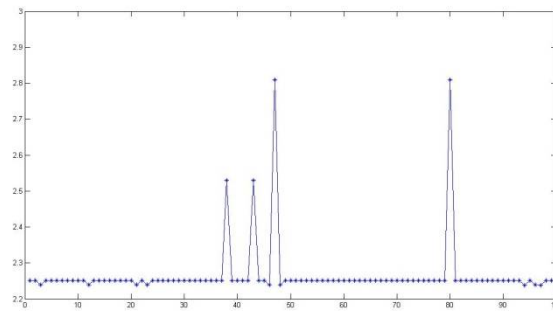


Fig. 10. Plot of fitness with respect to number of generations (Generations=100 and Units=500)

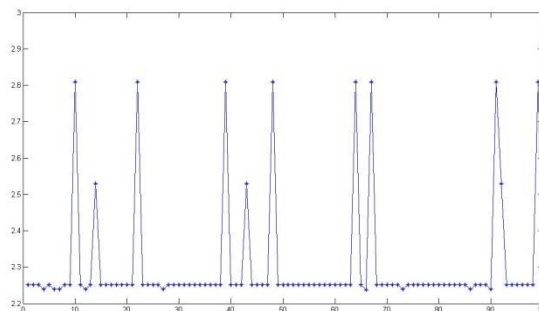


Fig. 11. Plot of fitness with respect to number of generations (Generations=100 and Units=1000)

Fig. 10. gives the best result in which there are 100 generations taken for 500 cascaded units for 101 frequency points. This graph is said to be the best graph because it contains only four points other than minimum points for objective function. Out of these four points two are maximum and other two are average of minimum and maximum. So, fig 11 shows the best case when solutions are optimized.

## VIII. CONCLUSION

In the presented work, GA has been used as optimization technique for size optimization problem after making a careful survey of the work done by other researchers in this field. Further, an effective and qualitative discussion for applying suitable algorithm in optimization problem of SAW filters is presented. With GA, a probabilistic technique that is used to find the solutions randomly inspite of searching with every possible solution, results with three input parameters, i.e., number of frequency points, cascaded units and number of generations involved are obtained. As number of iterations increases, the solution tends to move away from the optimal solution. When number of units to be cascaded increases, it tends to move towards the optimal solution which was our objective. To achieve better frequency response, large number of units should be taken. The GA is used to match with desirable conditions and to improve the results within the given conditions and constraints.

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