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Survey on optimization techniques for microstrip bandpass filter design

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Abstract. Microstrip bandpass filters are used in contemporary communication systems due to the growing need for systems with improved performance capabilities. One recent development that has showed promise is the use of bio-inspired algorithms for filter parameter optimization. This work focuses on the importance of such algorithms in improving filter features, summarizing and discussing important contributions from recent literature. Through a synthesis of existing techniques, the paper seeks to help future design strategies and highlights the applicability of these approaches for applications like WiMAX.

1 Introduction

Microstrip bandpass filters are really important in RF and microwave communication systems. They are cheap and small which makes them easy to integrate with technologies. We use them a lot in 5G networks, satellite communications and new broadband standards like WiMAX and UWB [1]. However it is not easy to make them work well. We want them to be selective have a bandwidth and not lose too much signal. This is a challenge especially when we use old design methods like Chebyshev or Butterworth models [2]. These methods have a time getting the structure just right and dealing with complicated design rules.

To get around these problems researchers are looking at ways to design Microstrip bandpass filters. They are using methods that are inspired by nature like Genetic Algorithms (GA) [3], Ant Colony Optimization (ACO), Differential Evolution (DE) [4], and Biogeography Based Optimization (BBO) [5]. These methods are good at solving problems and can look at many things at the same time. They are very useful for designing Microstrip bandpass filters, where the old methods do not work well. When we use these methods with structures like Defected Ground Structures (DGS) we can make Microstrip bandpass filters that are small, selective and efficient. This is important for wireless communication technologies. Microstrip bandpass filters are getting better and better. They will be very important, for the future of wireless communication.

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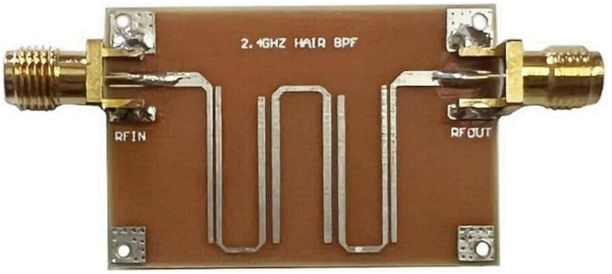

Fig. 1. Physical structure of a 2.4 GHz microstrip bandpass filter.

2 Optimization strategies in microstrip bandpass filter design

2.1 Optimization algorithms for filter parameter tuning

Microstrip bandpass filter optimization has made extensive use of a number of bio-inspired algorithms. The most popular methods are briefly reviewed in this part, with an emphasis on their mechanics and applicability to filter design.

2.1.1 Ant colony optimization (ACO)

ACO is an optimization algorithm that draws inspiration from ants' natural foraging habits. It investigates possible solutions using a colony of artificial ants, leaving pheromone trails to direct others toward more effective solutions. Based on the caliber of the solutions discovered, the program iteratively modifies the pheromone levels. The number of ants, the exploration-exploitation balance, and the pheromone evaporation rate are important ACO algorithm parameters. By controlling the search dynamics, these factors enable ACO to efficiently investigate vast design areas.

In filter design, ACO is very helpful for improving characteristics like selectivity, bandwidth, and insertion loss since it effectively handles challenging optimization issues. The key steps of the ACO process are outlined in Figure 2.

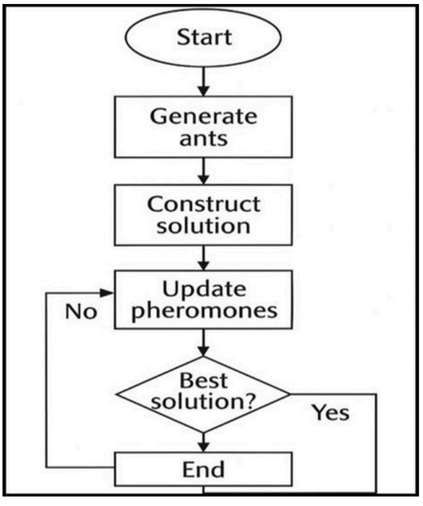

Fig. 2. Ant colony optimization process flow.

2.1.2 Biogeography-based optimization (BBO)

BBO is an evolutionary algorithm built on the ideas of how animals migrate through various environments. A Habitat Suitability Index (HSI) is used to assess the quality of each solution, which reflects a habitat specified by a set of Suitability Index Variables (SIVs). Immigration and emigration rates allow habitats to share features (SIVs). To preserve diversity and enhance solution space search, the method employs mutation. The number of elites, population size, and mutation probability are some of the factors that affect its performance [5]. The standard BBO workflow is shown in Figure 3.

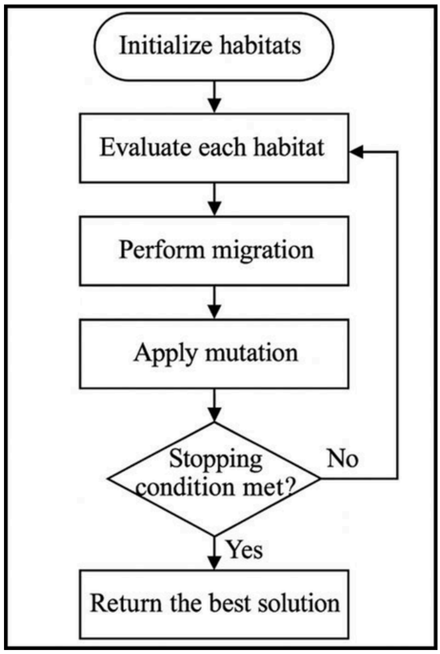

Fig. 3. Illustrative diagram of the BBO algorithm.

2.1.3 Differential evolution (DE)

DE is a technique for optimization that develops solutions through mutation, crossover and selection [4]. Differential Evolution works by changing existing solutions to create ones, which helps to look at all the possible solutions. Then Differential Evolution combines these solutions with the old ones, which makes the solutions more different from each other. After that Differential Evolution picks the solutions based on how well they work so they can be used to make the next set of solutions.

The technique is actually very useful in designing microwave filters, since it assists in obtaining values for the various parameters that determine the amount of signal loss, the bandwidth of the filter, and its performance in terms of selecting desired signals.

2.1.4 Population-based incremental learning (PBIL)

PBIL is an algorithm that evolves a probability vector representing the entire population, rather than individual members. Each gene is associated with a probability value, which is updated based on the best-performing solutions. Mutation is used to maintain diversity and avoid premature convergence.

2.1.5 Genetic algorithm (GA)

Genetic Algorithms are used a lot for making microstrip filter designs. They work through several steps. These steps are initialization, selection, crossover, mutation and evaluation. The process starts with creating a group of possible solutions. Then it picks the ones based on how well they work. The Genetic Algorithms help optimize microstrip filter designs by repeating these steps.

The genetic algorithm uses crossover to make solutions by combining old ones. It also uses mutation to make changes so that all the solutions are not the same. The genetic algorithm does this over and over again for generations until it finds the best solution. Designers must select parameters like the number of initial solutions and how often to use crossover and mutation so that the genetic algorithm works well. For example in one study the researchers picked these things carefully so that the genetic algorithm could find the best filter design. Figure 4 shows what the genetic algorithm process usually looks like.

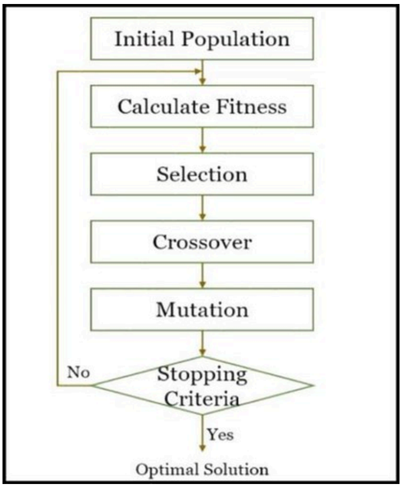

Fig. 4. Flowchart of the genetic algorithm optimization process.

2.2 Structural and physical optimization techniques

2.2.1 Defected ground structures (DGS)

Several studies have demonstrated that Defected Ground Structures (DGS) are effective in designing ultra-wideband (UWB) microstrip bandpass filters. For instance, [6] proposed a compact UWB filter using triangular DGS and two symmetrical dumbbell-shaped interdigital capacitors to enhance bandwidth and selectivity. In [7], a modified multimode-resonator-based UWB bandpass filter was combined with a compact DGS-based low-pass filter to achieve both ultra-miniaturization and an extended stopband.

Similarly, [8] introduced a wideband BPF based on a quadruple-mode ring resonator, combining a stepped-impedance ring resonator operating at a full wavelength with a half-wavelength resonator structure. In [9], a UWB bandpass filter was designed using an E-shaped resonator. A genetic algorithm is used to optimize the electrical parameters of the filter for enhanced performance. The filter presented in [10] was designed using stub-loaded ring resonator to obtain compact dual-band responses. In addition, [11] proposed microstrip bandpass filters based on stair-step patch resonators, while [12] investigated the use of DGS to enhance the performance of microstrip filters.

These designs exploit the DGS effect by enhancing slow-wave propagation, increasing effective inductance, and suppressing unwanted harmonics, leading to miniaturized and high-performance filters. Furthermore, DGS integrated with half-wavelength microstrip resonators has also been shown to improve the performance of compact band pass filters, providing better frequency response and reduced insertion loss [13].

2.2.2 Resonator-based design optimization

For ultra-wideband (UWB) applications, a compact microstrip bandpass filter (BPF) featuring a fractional bandwidth exceeding 100% has been proposed. The structure combines separately designed high-pass and stepped-impedance low-pass sections, along with quarter-wave stubs for stop-band control. Several configurations, with and without Defected Ground Structures (DGS), were developed and experimentally validated through measurements performed with a vector network analyzer.

Additionally, a dual-band BPF was developed by integrating microstrip ring resonators with coupling mechanisms and incorporating DGS elements, achieving two passbands at 1.6-2.0 GHz and 3.6-5.5 GHz, demonstrating the effectiveness of combining resonator and DGS techniques for compact, high-performance filtering [14].

Moreover, a compact dual-band bandpass filter utilizing substrate integrated wave guide (SIW) technology combined with complementary split-ring resonators (CSRRs) has been proposed for effective operation in the C and X frequency bands, highlighting the relevance of resonator-based approaches in designing dual-band and application-specific filters [15].

2.2.3 Dielectric material considerations

An optimization-based method is used to design matching layers for broadband dielectric lens antennas. It minimizes reflections at the dielectric–air interface and improves radiation performance. The approach allows using low-cost, commercially available materials, making it suitable for practical ultrawideband applications.

3 Comparative analysis

Table 1 summarizes selected structural and optimization techniques used in microstrip bandpass filter design. It highlights their main advantages, limitations, and typical application domains.

Table 1. Comparative analysis of structural and optimization techniques for microstrip bandpass filter design.

No.	Category	Technique used	Advantages	Disadvantages	Applications
1	Structural technique	DGS-based structures	Harmonic suppression and size reduction	Requires precise fabrication	Compact high-performance filters
2	Bio-inspired algorithm	Genetic algorithm (GA)	Global search ability and multi-parameter handling	Slower convergence and parameter tuning required	Parametric optimization

3	Bio-inspired algorithm	Ant colony optimization (ACO)	Efficient exploration of complex search spaces	Sensitive to pheromone and evaporation parameters	Optimization of bandwidth, selectivity, and insertion loss
4	Evolutionary algorithm	Differential evolution (DE)	Good convergence and effective continuous parameter tuning	May require many simulations	Microwave filter parameter optimization
5	Evolutionary algorithm	Biogeography-based optimization (BBO)	Good diversity preservation and flexible search mechanism	Performance depends on migration and mutation settings	Multi-parameter filter optimization
6	Optimization strategy	Multi-objective optimization strategy	Simultaneous control of size, bandwidth, and loss	High computational cost and trade-off management	Constrained filter tuning using GA, PSO, DE, or hybrid methods
7	Resonator-based structure	Dual-mode resonator design	Dual-band response and simple layout	Mutual coupling issues in some cases	Multiband filtering behavior
8	Coupling structure	Capacitive coupled lines	Compact layout and dual-band support	Coupling control may be sensitive	High-integration filter designs

As can be seen in Table 1, each approach provides unique contributions to the microstrip bandpass filters optimization and improvement in terms of its characteristics. In particular, structural techniques including the use of DGS structures and resonators help to improve the compactness, frequency selectivity, and stopband properties of a filter. At the same time, their effectiveness is constrained if one wants to achieve high selectivity, low insertion loss, and efficient harmonic suppression simultaneously.

Among the structures, DGS-based approach proves to be the most effective for size reduction and stopband optimization. The core idea behind this technique is the possibility to change the current distribution on the ground plane that will allow suppressing the unnecessary harmonics. However, these structures need a precise geometrical design and fabrication because even small errors can influence the performance of the final product.

Bio-inspired optimization algorithms including Genetic Algorithm, Ant Colony Optimization, Differential Evolution,and Biogeography-Based Optimization provide more possibilities for changing the filter parameters. They prove to be especially effective when several design parameters including bandwidth, insertion loss, return loss, compactness, and selectivity need to be considered simultaneously. However, the efficiency of the mentioned techniques depends on the selected algorithm parameters, objective function, and the computational cost of the simulation process.

From this analysis, one can see that a promising way for designing microstrip bandpass filters is represented by hybrid approaches using structural elements like DGS and resonators together with optimization procedures.This combination allows improving the compromise between small sizes, selectivity, and performance of a microstrip filter. In this way, the selection of optimization algorithm should not be performed independently of the physical filter design, but depending on the application, frequency range, fabrication conditions, and performance characteristics needed. In general, this comparative analysis shows that no technique can be regarded as universally optimal. The most suitable technique always depends on the task. DGS-based solutions should be used for tasks where small size and harmonic filtering are required. Bio-inspired optimization algorithms are more convenient for multivariable optimization of filter parameters. Resonators still are quite topical for dual-band filter design.

4 Conclusion

Optimization methods are important for designing microstrip bandpass filters for modern wireless communication systems, such as WiMAX, WLAN and UWB systems. These filters are used in wireless technologies. Bio-inspired algorithms like Genetic Algorithm, Ant Colony Optimization, Differential Evolution and Biogeography Based Optimization help control parameters. These parameters include size, bandwidth and insertion loss. Defected Ground Structures also help improve stopband rejection and reduce filter size. Each method has its advantages.

The choice of method depends on the design requirements and problem complexity. The idea of finding an optimal filter design is promising. If we combine these methods with intelligence systems we might get even better results. This would lead to flexible filter configurations for future wireless technologies.

This paper is intended for researchers, who are just entering this topic. They learn about possibilities of employing optimization algorithms for the design of microstrip filters. Moreover, it is supposed to become an algorithmic guideline for applying them in compact microwave devices. In further research, we plan to explore advanced meta-heuristics approaches, in particular, Genetic Algorithm. The purpose of the research is to improve speed of convergence and design performance of microstrip filters working in GHz range for IoT applications.

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