# Optimization Technique for Bandwidth Control of 3D Bandpass Frequency Selective Structure

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***Abstract*—In this study, a 3D bandpass frequency selective structure with the desired bandwidth for bandpass shielding enclosure application is designed using a multi-objective optimization algorithm. The ant colony optimization technique is applied in continuous domain to archive the optimal design properties of 3D frequency selective surface. The performance of the optimized structure is simulated with different fractional passbands at different resonant frequencies for a normal incident angle. It is proposed that the simulation results can be confirmed in future experimental work by designing the optimized structure using 3D printing technology and comparing performance results.**

***Keywords—3D frequency selective structure, bandpass shielding enclosure, optimization, bandwidth control***

## I. Introduction

The enclosure shielding that protects an electronic device or circuit must be specially designed to allow the transmission of radio signals from the outside and to block potentially large amounts of electromagnetic interference (EMI) from entering the internal digital circuitry. However, when using conventional shielded enclosures made of metal or plastic coated with a conductive medium, it is difficult to achieve both characteristics simultaneously. Unlike traditional shield enclosures, a bandpass shielding enclosures can provide solutions to these problems. The bandpass shielding enclosures should have a high transmittance in the specified radio signal band, have a high shielding effect outside this band, and have a minimal effect on the radiation characteristics of the enclosure's internal antenna. To achieve this goal, the Frequency Selection Surface (FSS) concept can be adopted for the bandpass shielding enclosure designs.

FSSs are periodic structures used as electromagnetic spatial filters [1]. One of the trends attracting increased attention in the study of FSS is 3D structure because of the degree of freedom in design. An external device that protects a digital device or circuit must be specially designed to allow the transmission of radio signals and to block potentially large amounts of electromagnetic interference (EMI) from essential digital circuits inside the device.

In this work, we present a new designed 3D bandpass FSS structure using a 3D printing technique. A bandpass filter FSS was proposed with different pass band characteristics at the normal incident angle. To realize these characteristics for a miniaturized unit cell, we applied an optimization algorithm to get the optimal 3D FSS unit cell structure. Several studies on optimization techniques for FSS have been made using evolutionary such as the genetic algorithm (GA) [4][5], particle swarm optimization (PSO) [6] and combinational optimization [7]. In these previous studies [4-7], the advantages of artificial intelligence optimization techniques in multi-objectives FSS design were presented. With the results in simulation and measurement about the performance of optimized structure for different objectives, optimization algorithms gave the optimal design with high effectuation. In [8], A. E. Yilmaz designed different square loop type of FSS by applying PSO via the equivalent circuit (EC) model and made comparison with traditional method in literature. EC model is an effective way of FSS design approach, but it is not easy to find the EC model which match with geometrical parameters at different structure.

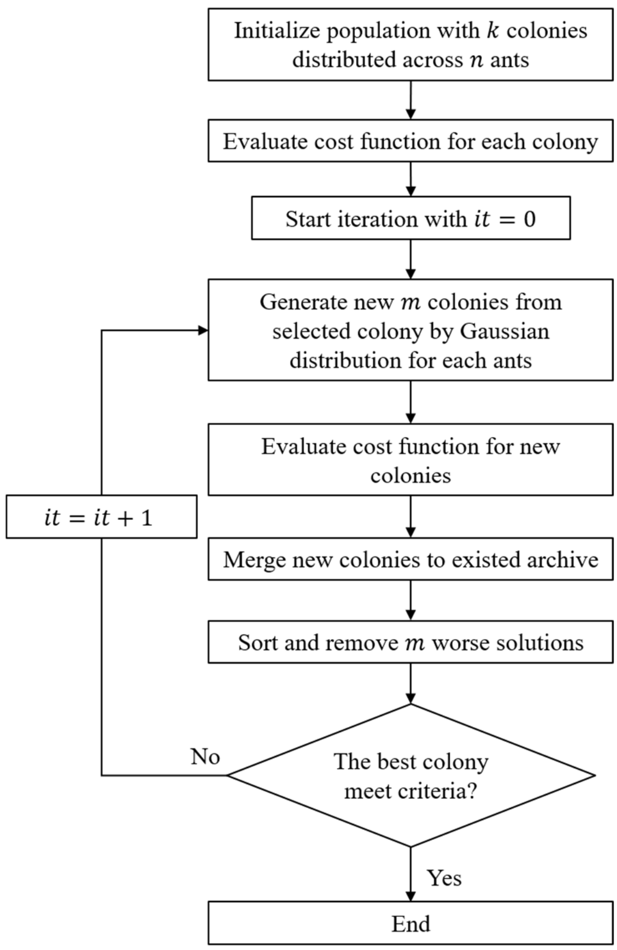


Fig. 1. Flowchart of the $ACO_R$ algorithm

According to optimized design parameter, the solution accuracy archived is high and evolutionary techniques are suitable to apply in different type of FSS design with different goals. A new evolutionary algorithm in continuous domain based on ant colony optimization (ACO) [9] is proposed in this research paper, namely ant colony optimization for continuous domain ($ACO_R$) [10]. The simulation was executed using commercial ANSYS HFSS software with the propagation results analyzed in MATLAB. This paper is organized as follows. Section II details the basic concept and flow process of the $ACO_R$ algorithm. It also details FSS unit cell design parameters and the fitness function for optimization. The optimization and simulation results are presented in Section III. Finally, section IV presents the conclusion of this paper and proposals for future work to improve the performance.

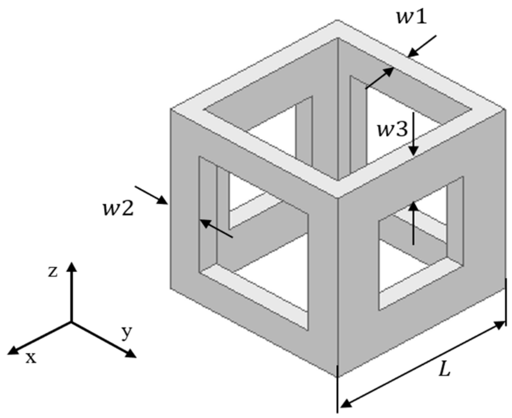


Fig. 2. Proposed 3D unit cell

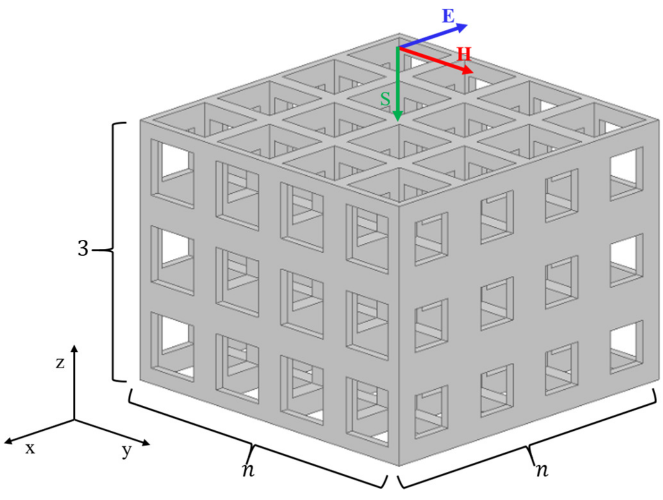


Fig. 3. $3 \times n \times n$ 3D FSS lattice and incident wave propagation

## II. Method and Design

### A. Ant Colony Optimization for Continuous Domain

The original ACO algorithm was described in Dorigo's thesis in 1992. It modeled ant colony communication by pheromone deposition while foraging for food. Over time, the ACO algorithm models the ants as they are attracted to the best route marked by the highest concentration of pheromones. Various discrete optimization problems can be successfully solved by applying the traditional ACO algorithm, such as in the travelling salesman problem and in network design [11][12].

The $ACO_R$ algorithm was first introduced in 2008, was an improvement over the traditional ACO when applied to a continuous search space. Based on the optimally placed ant's position, the entire colony will move continuously during each iteration to find a better position for food foraging. In this study, $ACO_R$ was applied to the solution of multi-objective 3D FSS design optimization problem. Fig. 1 shows the flow cart of the $ACO_R$ algorithm used for this problem. With $n$-ants represent the $n$-dimensions of the problem and $k$ represents the number of colonies to be archived within the total population.

### B. FSS unit cell design parameters

The proposed 3D cube-based FSS structure is assumed to comprise polylactic acid (PLA), which is commonly used in 3D printing. Its characteristics include relative permittivity $\varepsilon_r = 2.7$ and a loss tangent $tan\delta = 0.02$. It is coated with a conductor, which has a resistance of $0.2\Omega/Sq$. The fundamental design of the unit cell is shown in Fig. 2. The primitive cell is made up of a 3D cube with length $L$ and three different square apertures piercing its walls. These apertures have lengths $L - 2w1, L - 2w2, and\ L - 2w3$ in the z, x and y direction, respectively. In this study, we evaluate performance of FSS by free space measurement method, so we simulate the proposed grid which is composed of volume elements of $3 \times n \times n$ unit cells with the incident wave as Fig. 3. The design parameters required for a stable simulation and realizable design are presented in the Table. I.

TABLE I. Design Parameters

| Parameter | Range of value [mm] | |
|---|---|---|
| | *Min* | *Max* |
| $L$ | 5 | 25 |
| $w3$ | 0.3 | $\frac{L}{2} - 0.5$ |
| $w2$ | 0.27 | $w3$ |
| $w1$ | 0.25 | $w2$ |

### C. Fitness function

In order to design an ideal FSS for a given specific passband frequency, we can assume that $FRBW$ is the target fractional bandwidth in each mode. Practically, the fractional bandwidth must lie in the range [0.1; 0.6]. We designed the fitness function for controlling the bandwidth of the passband in (1).

$$minimize\ F = A * |BW - FRBW| + B * \sigma \quad (1)$$

Where $A$, $B$ are associated weight for each component. $BW$ is the fractional bandwidth calculated as shown in (2) and σ is the standard deviation of the transmission coefficient in the passband.

$$BW = \frac{f_h - f_l}{f_0}, \quad f_l < f_0 < f_h \quad (2)$$

The resonant frequency is $f_0$ which is controlled in analysis process and varying to fit with the target center frequency. And the frequencies $f_l$ and $f_h$ are the beginning and ending frequencies of the continuous frequency range where the transmission coefficient $S_{21} > -3dB$. With this analysis process and fitness function, we can control not only the fractional bandwidth but also the center frequency of bandpass shielding enclosures.

## III. Numerical Results

The simulation was executed for four separate cases with different center frequency and bandwidth as shown in Table. II to test the convenience of the algorithm and performance of the aperture in controlling the bandwidth of the proposed 3D FSS structure.

TABLE II. OPTIMIZATION CASES

| Case | Resonant Frequency(GHz) | Fractional Bandwidth(%) |
|---|---|---|
| 1 | 5.4 | 20 |
| 2 | 5.4 | 25 |
| 3 | 10 | 25 |
| 4 | 10 | 40 |

TABLE III. ACO$_R$ PARAMETERS

| Parameter | Value |
|---|---|
| $k$ | 30 |
| $n$ | 4 |
| $MAX\_ITERATION$ | 100 |
| $m$ | 30 |
| $\xi$[a] | 0.5 |

[a] A constant parameter that is similar to the pheromone evaporation rate in the ACO algorithm.

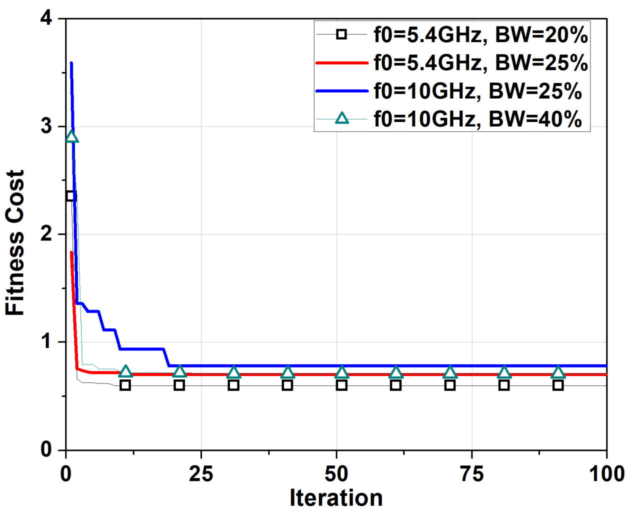


Fig. 4. Convergence of ACO$_R$ over multiple iterations for four optimization cases

The parameters of ACO$_R$ algorithm used in this problem are shown in Table. III and the convergence progress is shown in Fig. 4. The ACO$_R$ algorithm converged on the optimal value in the shortest execution time. In the first test case, with a resonant frequency of 5.4 GHz, the algorithm converged on the optimal value at the 9th and 12th iteration with fitness costs of 0.5979 and 0.6995 for fractional bandwidths of 20% and 25%, respectively. In the further test case, with a resonant frequency of 10 GHz, the algorithm converged at the 20th iteration for a fractional bandwidth of 25%, and at the 25th iteration for a fractional bandwidth of 40% with fitness costs of 0.7798 and 0.7055, respectively.

TABLE IV. OPTIMIZED PARAMETERS

| Parameter | Case [mm] | | | |
|---|---|---|---|---|
| | *1* | *2* | *3* | *4* |
| $L$ | 25.1 | 24.12 | 15.26 | 12.98 |
| $w1$ | 0.25 | 0.67 | 0.99 | 0.37 |
| $w2$ | 2.37 | 3.1 | 2.46 | 1.34 |
| $w3$ | 3.35 | 10.29 | 3.54 | 2.09 |

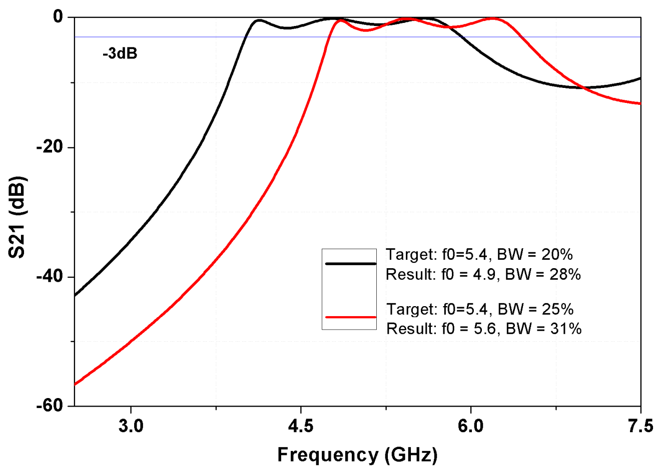


Fig. 5. Transmission coefficient of optimization cases: $f_0 = 5.4GHz$, BW = 20% and $f_0 = 5.4GHz$, BW = 25%

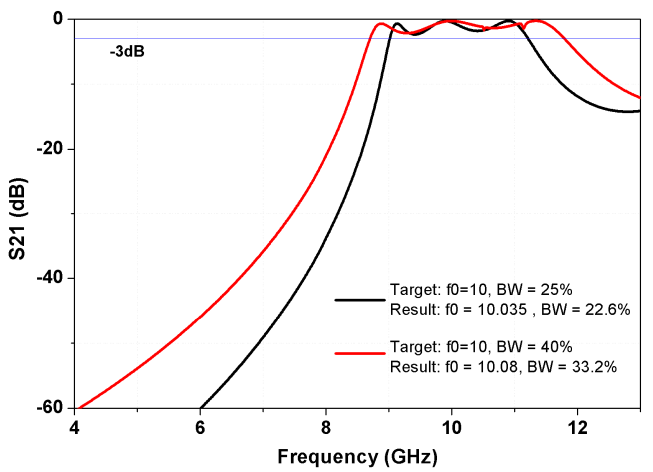


Fig. 6. Transmission coefficient of optimization cases: $f_0 = 10GHz$, BW = 25% and $f_0 = 10GHz$, BW = 40%.

Fig. 5 and 6 show the transmission coefficient simulation results of each design case which were performed using ANSYS HFSS commercial software with the optimized parameters shown in Table. IV. Fig. 5 shows the summarized transmission properties of the design FSS for center frequency of 5.4 GHz and a fractional bandwidth of 20%, the transmitted wave had a center frequency of 4.9 GHz with a bandwidth of 1.91 GHz. The center frequency deviates from the target frequency by approximately 8%. In the second case, the resonant frequency of the optimized structure was 5.6 GHz with a fractional bandwidth of 31%, which is only 6% greater than expected value. The optimized structure resonant frequency was very close to the target in this case.

With a target resonant frequency of 10 GHz and fractional bandwidths of 25% and 40%, the results is displayed in Fig. 6. The center frequencies after optimization were 10.035 GHz and 10.08 GHz, respectively. In the third case, the passband had a bandwidth of 2.27 GHz from 8.9 GHz to 11.17 GHz. There was only a 2.4% difference with the target fractional bandwidth set to 25%. The final case had a resultant bandwidth of 3.34 GHz for the passband signal. This is a 6.8% difference with the target fractional bandwidth set to 40%.

## IV. Conclusion

This paper proposed a novel 3D FSS optimization structure for bandpass shielding enclosures is designed to control the bandwidth of a bandpass filter. The $ACO_R$ algorithm used to design the 3D-FSS confers the advantage of ease of design from broadband to narrowband filters. However, in future work, we aim to improve the flatness in the passband. We also aim to deal with the stability of the incident angle by applying dielectric loading effect also the proposed 3D FSS lattice would be fabricated by using 3D printing techniques to validate the effectiveness of the optimization algorithm with a stable passband and low fluctuation.

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