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# SINGLE SQUARE LOOP DESIGN APPROACH USING GA-BASED FREQUENCY SELECTIVE SURFACE FOR ENERGY SAVING GLASS COATING STRUCTURE

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## ABSTRACT

Attenuation of GSM, GPS and personal communication signal leads to poor communication inside the building using regular shapes of energy saving glass coating. Thus, the transmission is very low. A brand new type of band pass frequency selective surface (FSS) for energy saving glass application is presented in this paper for one unit cell. Numerical Periodic Method of Moment approach according to a previous study has been applied to determine the new optimum design of one unit cell energy saving glass coating structure. Optimization technique based on the Genetic Algorithm (GA) is used to obtain an improved in return loss and transmission signal. The unit cell of FSS is designed and simulated using the CST Microwave Studio software at based on industrial, scientific and medical bands (ISM). A unique and irregular shape of an energy saving glass coating structure is obtained with lower return loss and improved transmission coefficient.

**Keywords:** *Genetic Algorithms, Energy Saving Glass, Periodic Method Of Moment, Return Loss, Transmission Coefficient, Frequency Selective Surface (FSS), Glass Coating Structure*

## 1. INTRODUCTION

Nowadays, energy saving glass has become very popular in modern building and vehicles. It was proven to be very useful to maintain the temperature level inside a building or vehicle using energy saving windows. This technology falls under the Green Technology category for it helps contribute saving the energy in a building or vehicles. It is in the late 1980s when low emissivity (low-e) glass first began to contribute to energy saving through window of a building with low-e properties. It works by applying a very thin metallic oxide (e.g. silver oxide or tin oxide) on one side of float glass.

This coating blocks infrared radiation due to heat from outside of the building and almost transparent to the visible light [1]. It provides a good thermal isolation inside the building, especially during winter. Even though energy saving glass plays the role of saving the energy, useful signals in wireless communication systems such as global positioning system (GPS), mobile communication system (GSM, UMTS, 3G), wireless network (Wi-Fi) and wireless broadband (WiMax, LTE) are attenuated due to metal-oxide coating on the energy saving glass [2]. These weaknesses limit the efficiency of the energy saving glass function in wireless communication of microwave signals. A significant amount of signal attenuation can lead to received signal level (RSL) or received power exceeding the fade margin, resulting in radio link breakdown between base stations and mobile devices. In addition, the functional aspect of an energy saving glass is limited when most wireless communication signals are attenuated through the use of low-e glass. One of the most common practices to overcome the signal attenuation is by employing numerous repeaters to enhance the useful signals. However, it is not a cost effective solution and consuming more electricity for installing and operating these additional repeaters. The current

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study [2] ascertains that attenuation of useful signals such as GSM, GPS and personal communication signal leads to poor communication inside the building.

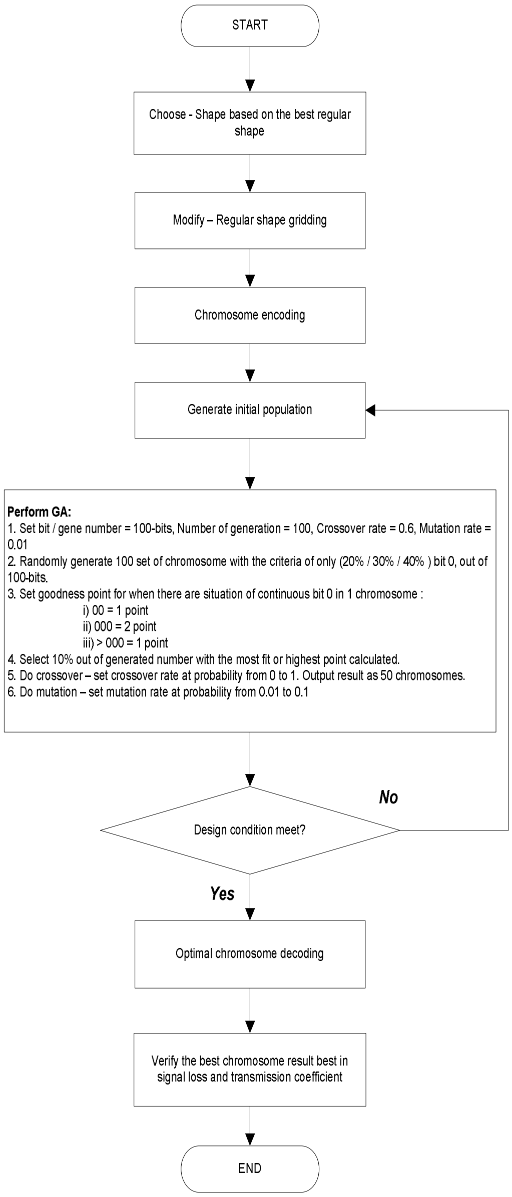


*Figure 1: Flowchart Of Design Cycle Utilizing The Genetic Algorithm Approach*

According to [3], metamaterials have the properties that cannot be found in nature. Its properties usually gained from their designed structures which consist of periodic structure and subwavelength characteristic with particle smaller than the light wavelength with which it interacts. Known as Frequency Selective Surface (FSS), it is a planar periodic structure of identical array of patches or aperture type elements arranged in one or two dimensional plane to electromagnetic (EM) waves. The frequency characteristics such as bandwidth, transfer function, phase feature and angle stability are determined by many critical parameters such as array periodicity, unit cell's pattern, element geometry size, property of dielectric substrate and others to form an FSS. There are various methods to analyze the periodic structures of the FSS such as the mutual impedance method, the method of moments (MoM), the finite element method (FEM), the finite-difference time-domain (FDTD) method and equivalent circuit method (EC) [6-10].

An optimization method such as Genetic Algorithm (GA) is a method that helps solve problems that is unsolvable using conventional techniques. Inspired by evolutionary mechanisms, it is a popular strategy used to optimize a large number of solutions or variables in a non-linear system. Implementation of numerical modeling can help improve the design process of a complex shape. Characterization of one design structure can be more accurate and more details by employing a numerical analysis such as Finite Difference Time Domain (FDTD). Issues on modeling, frequency range, material properties or dimensions that is none of the capability of optimization can be covered by a numerical modeling. Optimization problems in electromagnetic has been solve by using Genetic Algorithms (GA) optimization for a quite a long time.

In this paper, we proposed GA approach with the application of improved return loss and transmission coefficient. Pre-existing FSS designed by numerical method, Periodic Method of Moment (PMM) is optimized to be able to apply to an application such as the shape of a coating structure on energy saving glass [4]. A unique and irregular shape of an energy saving glass coating structure is obtained with lower return loss and improved transmission coefficient. The flowchart of this design method with the approach of FSS and GA is shown in Figure 1.

## 2. PROBLEM RELATED TO GA-BASED FSS APPLICATION IN ESG

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A study [2] proves that attenuation of GSM, GPS and personal communication signal leads to poor communication inside a building using energy saving glass. Thus, the transmission is very low. The coating on energy saving glass is usually etched in regular shapes. Cross dipole, circular loop, hexagon, square and tripoles are some of the popular geometries of shape coated on energy saving glass [1]. This coating works like a filter where the coating part is reflected part, while the etched part left, is where transmissions are allowed to pass through. Hence, the bigger size of the coating will reflect more signals and heat.

According to this situation, it can be assumed that attenuation of signals with energy saving glass involves the use of low-e glass. Recently, a study also attests that transmission of signals improved when at least 10% of metallic coating being removed, and transmission loss of cross dipole for instance results around 25dB [2]. As the bigger size of coating etched part the better the efficiency of the transmission signals. The smartest way to deal with this problem is by introducing a complex or irregular shape of coating as well as lessens the percentage of coating area.

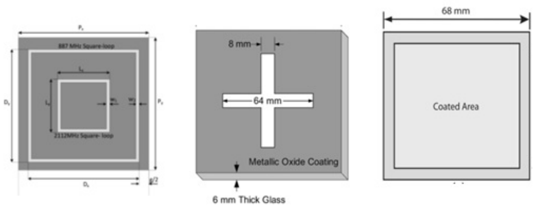


*Figure 2 : Regular Shapes Of FSS Design Structure*

## 3. DESIGN METHODOLOGIES

Designing a complex shape can be a difficult task and a specific method to get an optimum result is needed. This paper demonstrate the design method a complex shape of coating on an energy saving glass by modifying the best result of regular shape design based on previous study and experiment. In this work, optimization method is introduced to help in the design process. GA is implemented to randomly generate a set of 100-bits binary and selecting the best chromosome. In order to verify that the new tool is effective in selecting the best complex shape, the result is tested by measuring the transmission losses and return loss improved from the original. The GA starts with a random population and then it generates modification bits to form an FSS through selection, crossover and mutation. A GA-based optimization flowchart is presented in Figure 1.

First of all, the best design of existing method is chosen based on the numerical or analysis characteristics. As for this particular, an initial population generated by PMM was chosen. Then, the shape is modifying into grids of pixel of 400 bits in a dimension on 20 by 20. This is called a GA initialization when involve with the chromosome encoding process, followed by generating initial population.

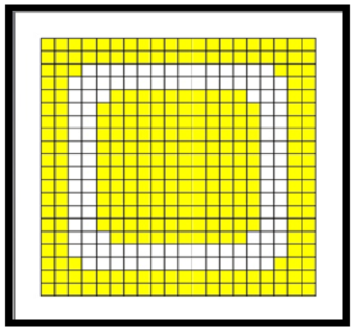

*Figure 3: Initial Design Of FSS Before Modification Using GA*

The next step is encoded into pixels of 400 bits binary number it represent as coated in binary 1, and uncoated as binary 0. Here, the operation of GA applies with the constraints stated as 5% , 10% and 15% of coated side 156 bits, and to uncoated side 244 bits. The characteristics of each chromosome that carries 100bits each are determined by a measure of goodness. Since it is almost impossible and time consuming to determine the losses of each chromosome, selection method used is by giving a 'goodness' value to chromosome that has the following criteria. Logically, uncoated part must be continued side to side to produce good result.

However, when the continued bit-0 is too long, it is not good either. Thus, goodness point will be given as 1 point will be given if there is two bit-0, for example: 00. Two points will be given if there is three bit-0, for example: 000. Finally, one point is given to situation when there is more than four bit 0, for example: 0000, 00000, 000000 and so on. Each chromosome will be determined by its goodness point. The fitness function stated must have to maximize good point. A chromosome that

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has maximum goodness point will be chosen for the next process which is crossover and mutation. Operators such as selection, crossover and mutation will determine the best and optimum result.

The fitness chromosome that has the maximum value of goodness is recognized as an optimum element shape. Otherwise, the process cycle to next generation is repeated until an FSS with desired characteristics is obtained. It is aimed to find the best solution for a complex design shape replacing the regular shape as well as to improve the transmission of microwave signal received inside a building using energy saving glass. Once the condition predefined is agreed, the optimum chromosome is decoded into design. Finally, using software for testing s-parameter the efficiency of the design is tested to verify the design.

## 4. RESULTS AND EXPERIMENTAL ANALYSIS

In this part, illustrative of experimental result is shown to demonstrate the efficiency of the method proposed. GA is used to generate random binary at coated side and uncoated side at the size of a total of 20 by 20, which consists of 400 bits. The coated side is marked as colored box, while the uncoated side is left uncolored. As discussed in the flowchart (Figure 1) above, initial population generated by PMM is used as the original shape to be optimized.

The best result chosen is preceded to the verifying process using CST microwave studio. A shape is designed according to binary result obtained from the process involving GA. Return loss and transmission coefficient are recorded and compared to the original PMM design. In figure 4, the result of the simulation of chosen design in PMM is presented. The initial return loss is at -30.096 db using this design, while transmission coefficient result is at -0.00015 db.

Figure 4 (a) and (b) (as in index) demonstrate the plot of s11 and s21 at frequency 4.48GHz are its initial design of a single square loop. The coated part with yellow colour represents the part that reflected the signals at certain frequencies. While the white colour pixels represent the part that is uncoated at which transmission is allowed to pass through.

Shown in Figure 5, are two of the best optimum results of transmission coefficient and return loss after GA is applied on the coated and uncoated part. It shows that at the average of only 10% modification on either coated or uncoated part, it results in the improvement of return loss and transmission coefficient. This brings to an improvement of efficiency of the system. In figure 5 (a) it can be seen that the coated side of the design is modified using GA. After 5%, 10% and 15% of criteria of 0s made in during the ga process, the results of S-parameter are as in Figure 5 (b) and (c).

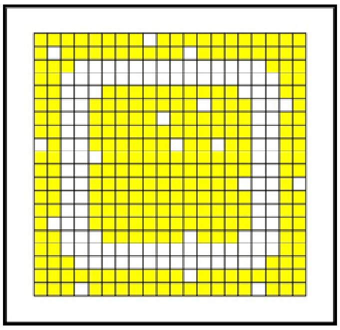

*Figure 5 (A) : Modified Design Using GA At The Optimum Of 10% On The Coated Part.*

At the frequency 4.33GHz, return loss is at -29.3044dB and -0.00031dB of transmission coefficient in Figure 5 (c) (as in index). For the uncoated side, transmission coefficient is also best at 10% GA optimization, which is 0.3426 dB. While the return loss, S11 at the uncoated side shows -33.1316 dB.

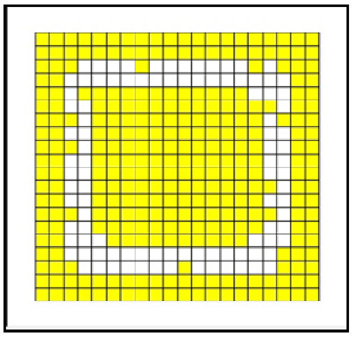

*Figure 6 (A) : Modified Design Using GA At The Optimum Of 10% On The Uncoated Part.*

It can be seen, that there are isolated pixels with or without the point of contacts in this design. In order to get a better design than a scattershot design and without having to deal with unnecessary fabrication complexity, these isolated pixels can be removed [11].

Based on the table below, it can be a lot easier to determine the most optimum result in

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return loss, S11 and transmission coefficient, S21 in dB. For coated part, the optimum result is at 10%, while for the uncoated part, the average result is determined at 10% criteria of GA.

*Table 1. Results Of FSS Design Structure After 5%, 10% And 15% Application Of GA On Coated And Uncoated Part.*

| Coated part | S11(dB) | S21(dB) |
|---|---|---|
| 5% | -28.5507 | -0.01467 |
| 10% | -29.3044 | -0.00031 |
| 15% | -28.6019 | -0.02229 |

| Uncoated part | S11(dB) | S21(dB) |
|---|---|---|
| 5% | -30.3863 | 1.321 |
| 10% | -33.131 | 0.3427 |
| 15% | -24.4957 | -0.0012 |

## 5. CONCLUSION

In this paper, a band pass single square loop FSS filter with sufficient performance is presented. For this process, a strong GA based optimization approach is demonstrated in detail to optimize the unit cell topology. Considering GA optimization procedure, FSS can be designed to meet wider goals, including the frequency, s-parameter, return loss (S11) and transmission loss (S21). Optimum result of signals shows improvement in signal losses and transmission coefficient at 10% ga application as the criteria of value 0s within the binary generation. It is shown in this paper that the present method is more robust and taking account of points on existing design that contributes to good result. Optimum result of signals shows improvement in signal losses and transmission coefficient. Compared to traditional design on the previous study, the return loss and transmission coefficient are affected and proven improved. For future work, the operating frequency can be varied according to other suitable application using periodic method of moment and GA. A lot of variation using the pre-existing numerical method can be applied and joined with GA to come out with a unique design of many purposes of application. Processing GA on a parallel processor can save a lot of time, by running greater number of individuals in parallel.

## ACKNOWLEDGEMENT

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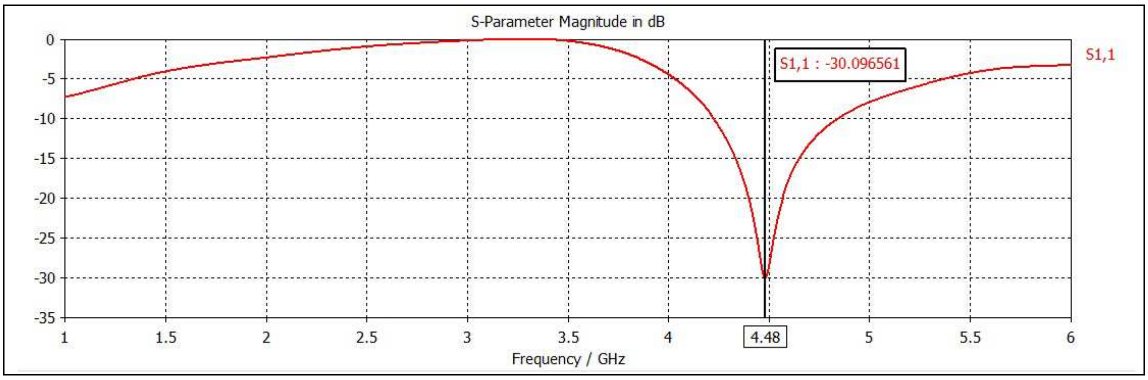


*Figure 4(a) : Plot of return loss at 4.425ghz shows – 29.57dB*

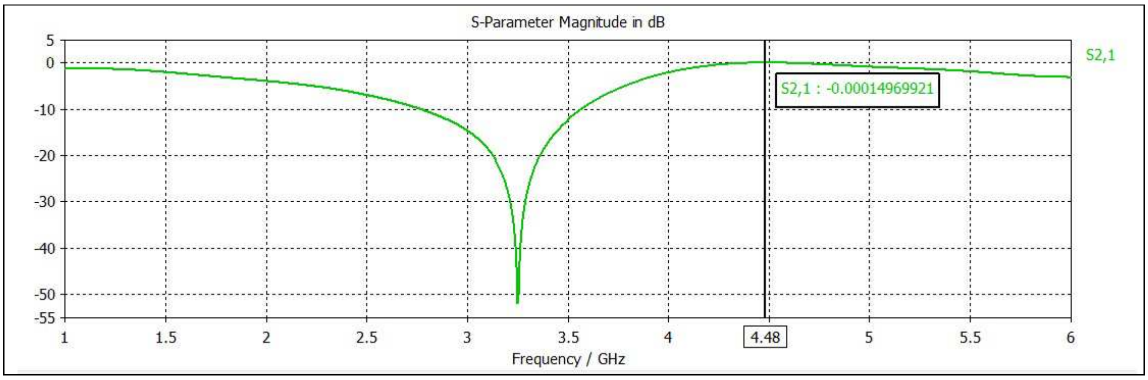


*Figure 4 (b) : Plot of transmission coefficient shows -0.00047dB*

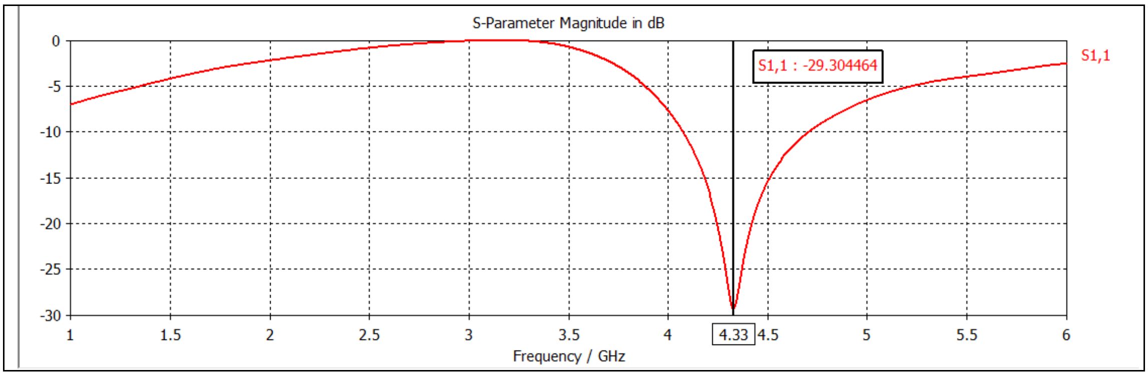


*Figure 5 (b) : Plot of return loss at 4.33GHz shows – 29.3044dB using GA at 10% of coated part*

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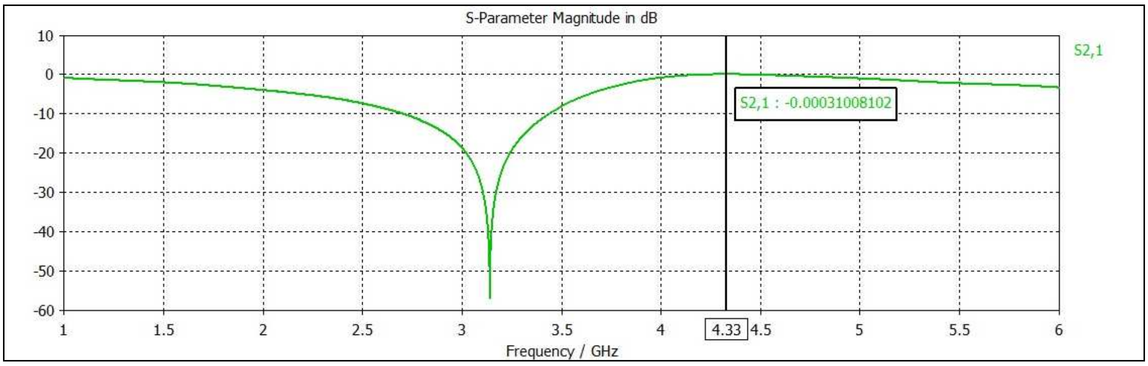


*Figure 5 (c) : Plot of transmission coefficient shows -0.00031dB using GA at 10% of coated part*

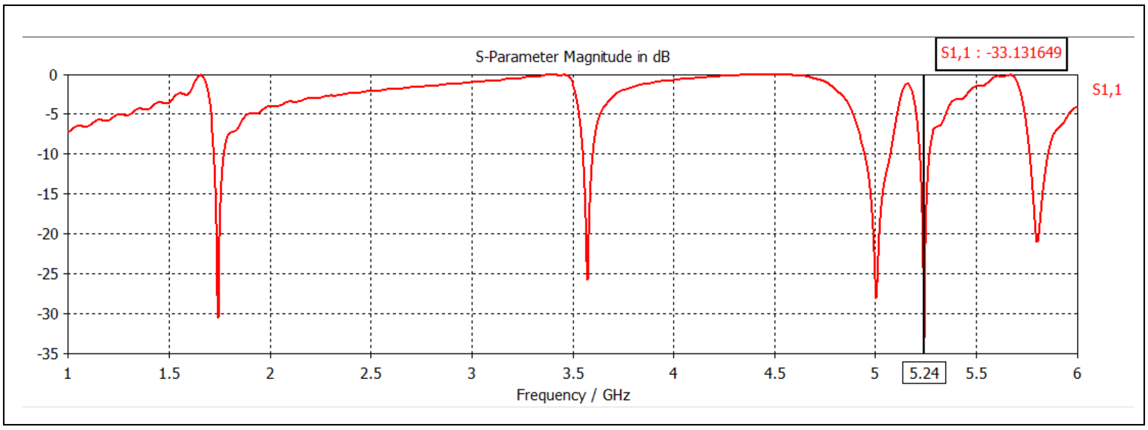


*Figure 6 (b) : Plot of return loss at 4.33GHz shows – 29.3044dB using GA at 10% of uncoated part.*

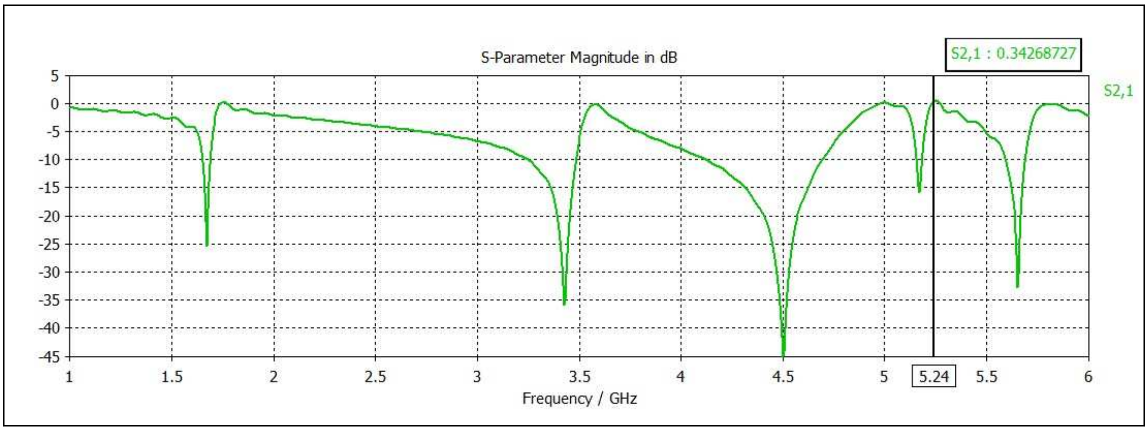


*Figure 6 (c) : Plot of transmission coefficient shows 0.3426 dB using GA at 10% of uncoated part*