
Naim Che Pee\textsuperscript{1, a)}, Hamzah Asyrrani Sulaiman\textsuperscript{1, b), Mohd Fairuz Iskandar Othman\textsuperscript{1, c), Yahaya Abd Rahim\textsuperscript{1, d), Zeratul Izzah Yusof\textsuperscript{1, e}) and Mohd Azlishah Othman\textsuperscript{2, f))}

\textsuperscript{1}Centre of Excellent (CoE), Faculty of Information and Communication Technology, Universiti Teknikal Malaysia Melaka (UTeM), 76100, Melaka, Malaysia.

\textsuperscript{2}Centre for Telecommunication Research and Innovation (CeTRI), Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), 76100, Melaka, Malaysia.

\textsuperscript{a})Corresponding author: naim@utem.edu.my
\textsuperscript{b})asyrrani@utem.edu.my
\textsuperscript{c})mohdfairuz@utem.edu.my
\textsuperscript{d})yahaya@utem.edu.my
\textsuperscript{e})zeratul@utem.edu.my
\textsuperscript{f})azlishah@utem.edu.my

Abstract. Energy-Saving Glass (ESG) is a specially coated glass with metallic oxide coating to maximize blocking of infrared and ultraviolet radiation into buildings. These are called low-emissivity or energy-saving windows since the metallic oxide coating on one side of the glass can reflect most of the incident infrared power. This coated glass acts as a filter for electromagnetic radiations in the infrared region, while being totally transparent to the visible part of the spectrum. Due to this property of coated glass, thermal insulation is obtained inside the buildings. However, it has several drawbacks where one of the major is the attenuation of the transmission of useful microwave signals and radio frequency (RF) signals, such as Global System for Mobile Communication (GSM) and personal communication signal, which leads to poor communication inside the building. Therefore, in order to overcome this problem, several solutions have been determined; where the first solution is to etch the structure design shape on the coated side of the glass by applying a regular shape, while the second solution is by using the different types of regular shapes as a combined shape on the coated glass developed by commercial software.

Keywords—Energy Saving Glass; Frequency Selective Surface (FSS); Genetic Algorithm

INTRODUCTION

One of the drawbacks of ESG associated with these coatings is metallic oxide coating that attenuates many useful microwave and radio frequency (RF) signals, such as the mobile Global System for Mobile Communications (GSM), Global Positioning System (GPS), 4G/3G wireless broadband system, and personal communication signal [1]. This occurs when the microwave signal is found in different frequencies from the maritime radio navigation at
30 kHz until satellite communications and Wi-Fi frequency at 30 GHz passes through the glass, where it attenuates signals within the frequency band of 800 MHz to 2200 MHz [2]. It is because nowadays, many modern buildings have applied the ESG techniques to solve this issue of attenuation [3].

This attenuation of signal is due to the design shape of the coating glass because with the current design shape, the glass manufacturers usually produce glasses with regular shape design. It also limits the efficiency of frequency of the ESG function in terms of useful microwave signals for communication inside a building [4].

Furthermore, many types of commercial glass windows have been offered by glass making companies. These types of glasses consist of soft coating and hard coating glasses. These types of glasses have been used by researchers for studies and experiments pertaining to transmitting useful signals. The ESG also has various types of coating available, for instance, float glass [5], soft coating, and hard coating. In fact, both soft and hard coating types offer easy handling while coating.

### BASIC DESIGN OF ENERGY SAVING GLASS (ESG)

Regular shape coatings have been introduced as the solution to overcome the signal losses of RF signal with ESG. Besides, the regular shape is denoted when all the sides of the shapes have the same length and angle values that should be equal for all the angles. The current approaches and researches about the several designs of regular shape, such as dipole, double square loop, and other shapes, have specified to increase the transmission signal (S21) of useful signal and at the same time, to reduce signal attenuation.

Apart from that, some researchers changed the design of regular shape into another shape that uses the basic regular shape in order to obtain the best transmission signal (S21). As noted, some popular combinations of basic regular shapes are cross dipole [6]. For example, a double square loop shape, which is designed in the square loop shape, is an addition to the second layer for another square loop where both shapes are still a regular shape.

Tab. 1 shows the more well-known design shapes of the regular shape, which are commonly used in coating glasses. They include dipole, cross dipole, double square dipole, and many other shapes. The color yellow represents the metallic oxide coating, while red represents the glass.

**TABLE 1.** The design regular shape that are commonly used in ESG

<table>
<thead>
<tr>
<th>Regular Shape</th>
<th>Design shape</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Square dipole shape (G. I. Kiani et al. 2008)</td>
<td><img src="image" alt="Square dipole" /></td>
<td>Employed CST software</td>
</tr>
<tr>
<td>b. Double square dipole shape (K. P. Esselle et al. 2011)</td>
<td><img src="image" alt="Double square dipole" /></td>
<td>Combination between two regular square shapes</td>
</tr>
<tr>
<td>c. Cross dipole shape (L. Olsson et. al. 2011)</td>
<td><img src="image" alt="Cross dipole" /></td>
<td>Cross dipole is a combination between square and rectangular shapes</td>
</tr>
</tbody>
</table>

### The Current Design of Energy Saving Glass

Frequency Selective Surface (FSS) is a planar periodic structure of the identical array of patch or aperture type elements arranged in one- (1D) or two-dimensional (2D) planes. The length of the element is a multiple of half of
the resonant wavelength ( ) [7]. Due to the frequency selective characteristics, which are narrow band and periodic in 2D, FSS is combined to be used in a wide variety of applications, such as the realization of reflector antenna, random design, and hybrid radomes [8].

By applying the FSS in the regular ESG shape, better transmission is obtained in the desired band while still keeping the thermal properties close to an acceptable level [2] because arrayed unit cell maintains static positions in the operation of geometrical shapes. In fact, FSS that is applied in regular shape leads to transmission loss at more than 25dB [2] for cross dipole shape. Fig. 1 shows an example of the typical element types arranged in a group in FSS shape.

![Typical element types arranged in groups](image1)

**FIGURE 1.** Typical element types arranged in groups

A study by [9] examined the theoretical of transmission loss for square loop shape, as illustrated in Fig. 2 at frequencies 900 MHz, 1800 MHz, 2.45 GHz, and 5.25 GHz for GSM, while Wi-Fi system at 33.5 dB, 33.1 dB, 32.6 dB, and 28.7 dB. The frequencies stated in the study were suitable to the application of ESG. The transmission was for perpendicular (TE) polarization from 0° to 60° angles of incidence.

![Square loop design shape](image2)

**FIGURE 2.** Square loop design shape
Synthesis method has two type where is analysis tool and optimizer/algorithm tool. In optimizer tool divide to
two methods which is global optimization and local optimization, Genetic Algorithm (GA) is included in the global
optimization method. GA was formally introduced in the United States in the 1970s by John Holland at the
University of Michigan. GA optimizers are robust, stochastic search methods, modelled on the principles and
cconcept of natural selection and evolution. As an optimizer, the powerful heuristic of the GA is effective at solving
complex, combinatorial and related problems [9].

The ongoing price/performance improvements of computational systems have made them attractive for some
types of optimization [4]. In specific project, GA work very well on mixed (continuous and discrete), combinatorial
problems. They are less susceptible to getting 'stuck' at local optima than gradient search methods. But they tend to
be computationally expensive [10].

To use a genetic algorithm, a solution to the problem is represented as a chromosome. Then GA creates a
population of solutions and applies genetic operators such as mutation and crossover to evolve the solutions in order
to find the best one [8]. From the few of process, GA generates chromosome that are composed of several genes
(variables). The following Fig. 3 shows the block diagram between chromosome and genes that generated from
optimization of the GA.

![Diagram of GA](image)

The GA operations have been introduced in many variations where the operations have to cope with problems
from premature convergence to lack of local search. Besides, GAs contain processes called encoding, initial

**METHODOLOGY**

This proposed method had been based on numerical modeling, as mentioned in the previous section, where this
numerical modeling offered some advantages in designing the shape. This is because of this method is easily
implemented into the structure by introducing six scalar equations based on the axis, as well as their electric and
magnetic fields. Then, it was combined with the optimization tool to determine the best parameters in order to
design the random FSS shape. Lastly, the final stage of the optimization tool, which was the GA tool, optimized the
simulation or the transmission simulation signal in ESG to obtain the best results as the objectives required.

Research planning is part of project management that normally outlines the steps taken in order to fulfill a task or
to accomplish a project. Thus, it is important to ensure that the project is carried out based on the steps. The
common method in exhibiting a project planning is by drawing a flow chart that shows all the processes; from the
start until the end of the project.
Designs of FSS Structure

This section clarifies the methods used in this research, as mentioned in the previous section, which was the FDTD as the numerical modeling method, while GA as the optimization method to generate binary chromosome in producing bits of it and FSS as the concept of design shape as the principle as periodic structure or repeated structure. In this research, a simulator tool had been introduced to design the random FSS shape in order to improve the transmission signal passing through the ESG, as specified in the problem statement.

Finite Difference Time Domain (FDTD) Code Requirement

In this simulator tool, three-dimensional (3D) structures were generated to develop the tool illustrated in Fig 5. Based on this figure, the structure of ESG was placed at the center of the structure in order to measure the transmission signal in the back of the structure. Then, the coated glass represented the metallic oxide, where the parameter used by ESG blocked the infrared penetrating into the building and allowed white signal into the building. The methodology to develop the simulation tool was determined based on the process below.

FDTD was employed to carry out numerical calculation for a considerable large space, as FDTD was capable in providing very large dynamic ranges that could reach up to 120 dB. In fact, many steps had to be carried out to obtain the output data. Therefore, it was necessary to draw the flow chart of the process to determine the process that came first before the other process.
CONCLUSION

This tool will be developed to synthesize the algorithm for a more efficient ESG in various incident angles and polarization of microwave/RF signal, which had been created by developing the algorithm FDTD and GA as the optimization tool. This process of simulation for designing the complex structure (shape) for ESG application involved many processes, as shown in Fig. 5 below.

FIGURE 5. The processes involved in developing the 3D FDTD simulator tool

ACKNOWLEDGMENTS

This research was supported by the Ministry of Higher Education, Malaysia and the Faculty of Information and Communication Technology, Universiti Teknikal Malaysia Melaka (UTeM). This research was funded through the Transdisciplinary Research Grant Scheme (TRGS).

REFERENCES


