Parametric Analysis of a Band-Pass FSS for Double Glazed Soft-Coated Energy Saving Glass

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Abstract—**Parametric analysis of a band-pass FSS for double glazed soft-coated energy saving glass is presented. An aperture type hexagonal FSS is etched in the coatingto improve transmission of useful RF/MW signals which is attenuated due to its presence. It providesa transmission improvement of up to 20 dB in the band of 0.1 GHz to 2.3 GHz (-10dB bandwidth of 2 GHz). The amount of area etched due to aperture is minimized to avoid heat loss. Parameters such as glass dielectric constant, coating impedance and aperture width are varied to get optimal solution. More than 10 dB and 25 dB attenuation is obtained at 2.45 GHz and 5.25 GHz, respectively, to ensure WLAN security for an indoor environment. Theoretical results for TE and TM polarizations are presented for normal and oblique incidence.**

Keywords— ***Frequency Selective Surface (FSS), Energy SavingGlass (ESG), Microwaves (MW), Infrared (IR), Sputtering.***

I. INTRODUCTION

Use of energy saving glass (ESG) in modern building architecture is becoming common practice to reduce energy consumption that may also help to minimize the quantity of CO_2 in the atmosphere due to its low-emissivity properties [1-2]. The primary objective of the ESG is to regulate the inside temperature of a building in extreme weather conditions by providing thermalinsulation without disturbing the visible part of the spectrum [3].

There are two types of coatings i.e. hard-coat and soft-coat. Soft coating is deposited on the surface of the ordinary glass through sputtering process. Soft coated layer is very sensitive and if not handled with extra care, can be damaged. To avoid damages, glass stacking can be used for its protection. On the other hand, hard coating is applied to the glasssurface using pyrolytic process, which is long-lasting and less prone to get damaged. One of the disadvantages associated with such coatings is that thesealso block the transmission of useful RF and MW signals such as GSM, UMTS, DCS, PCS, 3G, 4G GPS signals [2-6].

Frequency selective surfaces (FSSs) are spatial electromagnetic filters that can be designed by the periodic arrangement of metallic elementson a substrate or a conducting sheet which can be perforated with apertures. These periodic elements can be arranged on a substrate in one or two dimensional array to improve the transmission or reflection which depends upon the geometry of the FSS [7-12]. To improve the transmission of these useful signals through ESG, an aperture type FSS can be etched [13–14] in the coating of the ESG to provide significant transmission improvement in the respective band that can also maintain an acceptable level of IR attenuation.

This paper presents an aperture type FSS based on hexagonal elements for soft-coated ESG. By performing a parametric analysis, an optimal solution is achieved for transmission improvement. Its wide band response gives it an extra advantage over some of the other designs presented in literature.

II. FSS DESIGN

The 3D design of FSS unit cell is presented in Fig 1, while its side view is depicted in Fig 2. The horizontal and vertical periodicity of the unit cell is 60 mm and 51.96 mm, respectively. The thickness of both glass layers is 6 mmhaving a permittivity of 6.9 [4]. The distance between the ordinary and coated glass is 12 mm, while the surface resistivity of the coating is chosen as 6ohm/square.

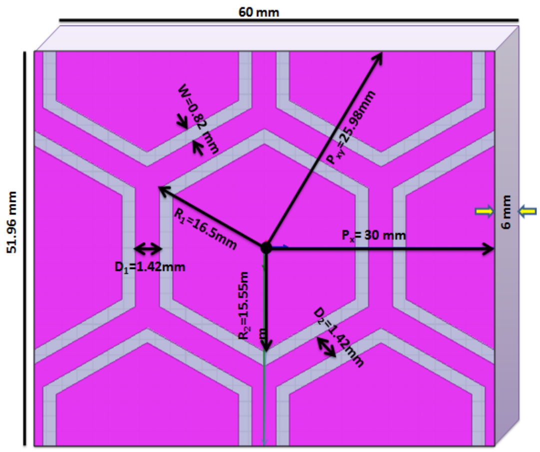

Fig. 1 3D View of hexagonal FSS etched in Coating

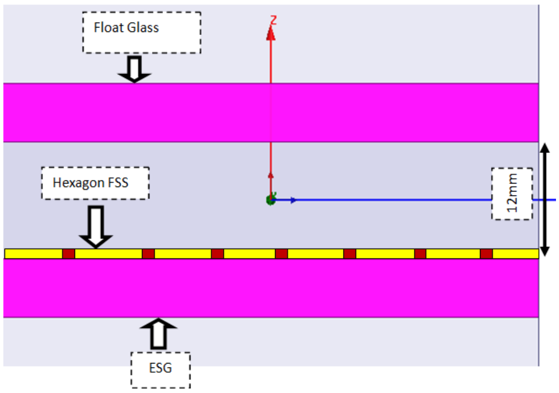

Fig. 2 Side view double glazed ESG with hexagonal FSS etched in coating.

III. SIMULATION RESULTS

The unit cell and the configuration shown in Figs 1 and 2 are simulated using ANSYS HFSS v 15 [15] and the results are presented in this section.

A. With Full Coating (TE Polarization)

Simulation transmission results of double glazed coated ESG with full coating for TE polarization are shown in Fig. 3. Initially, transmission through dual-layer ESG has been analyzed with full coating (without FSS etched in it).An average transmission loss of about 25 dB is observedat normal impedance in the band of interest. Some of the important observations are:

1. Transmission loss is increasing with the increase in incident angle.
2. A resonance frequency for two layer glass stacking isobtained at 1.9 GHz.
3. There is almost no variation in the transmission loss at 2.1 GHz for normal and oblique incidence.

B. FSS etched in the Coating (TE Polarization)

Simulation transmission results of double glazed coated ESG with hexagon FSS etched in the coating for TE polarization are also shown in Fig.3. For all angle of incidences, a transmission loss of less than 10 dB is observed making an average transmission improvement of more than 20 dB, also a good angular stability is achieved with use of closely packed hexagonal FSS. Results are only shown up to 45^0.

These transmission improvements can be considered significantfor such configurations with minimal loss of heat as only 10% of coating area is removed. The design is simple and can easily be fabricated. One of the important achievementsofthis configuration is that almost a flat transmission response has been achieved for all important setof frequencies by removing minimal coating from the surface of the glass, which is better than [4] in terms of bandwidth and stability. Another

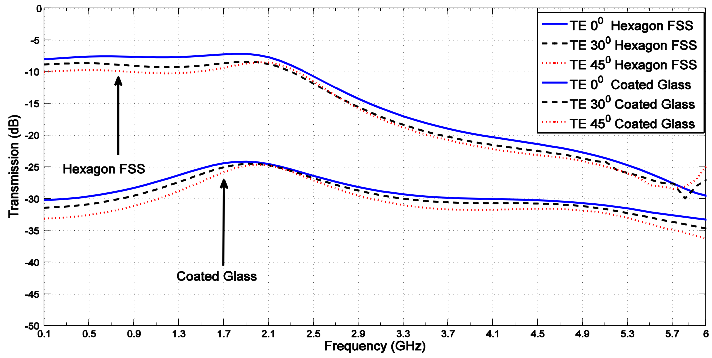

Fig. 3 Simulation transmission results of dual-layer coated ESG with full coating and with hexagon FSS for TE polarization.

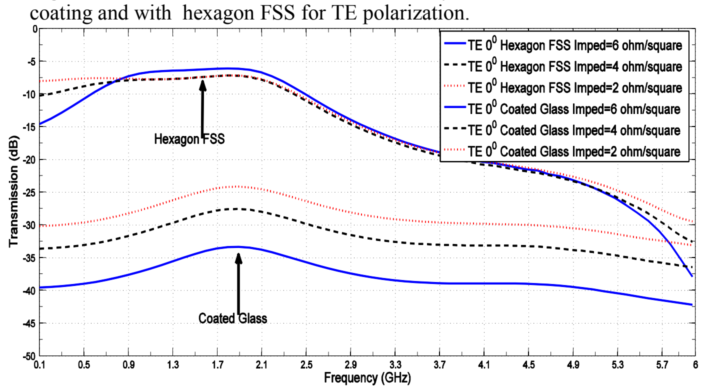

Fig. 4 Simulation transmission results with full coating and with hexagon FSS for TE polarization with varied surface impedance at normal incidence.

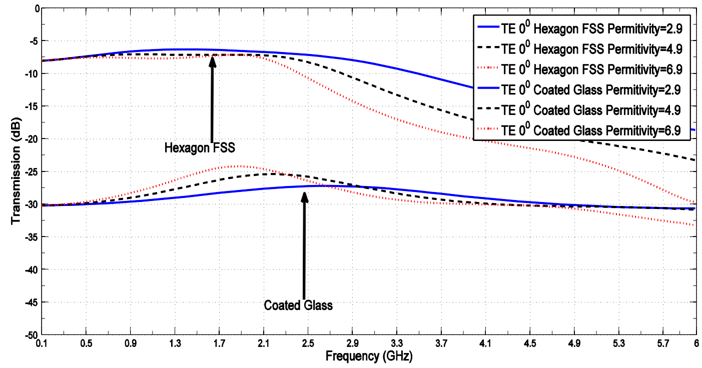

Fig. 5 Simulation transmission results with full coating and with hexagon FSS for TE polarization with varied glass permittivity at normal incidence

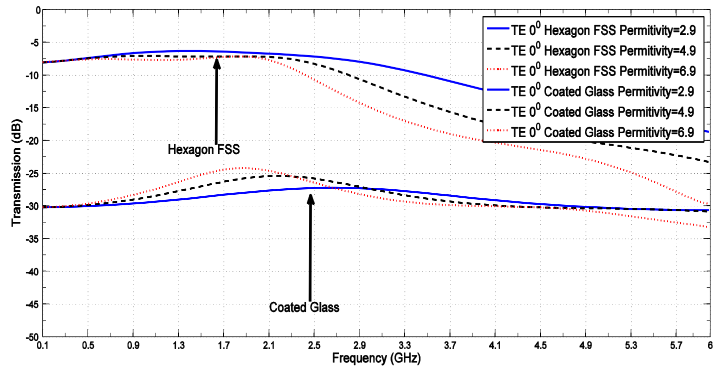

Fig.6 Simulation transmission results with hexagon FSS for TE polarization with variable aperture width at normal incidence

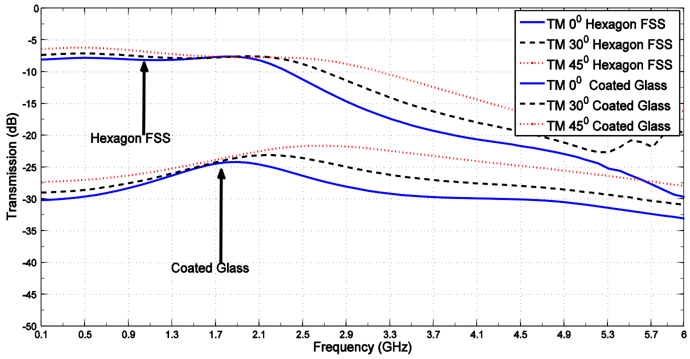

Fig. 7 Simulation transmission results of dual-layer coated ESG with full coating and with hexagon FSS for TM polarization.

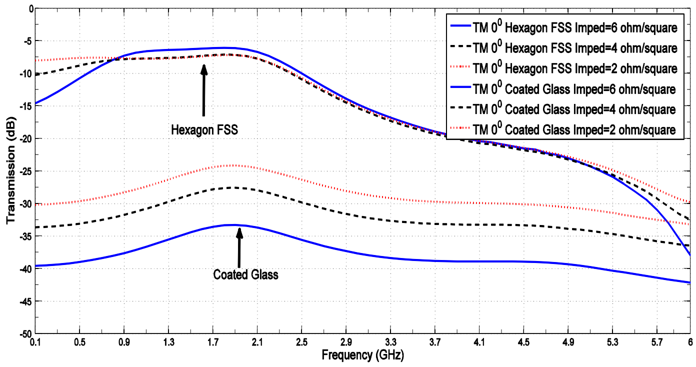

Fig. 8 Simulation transmission results with full coating and with hexagon FSS for TM polarization with varied surface impedance at normal incidence.

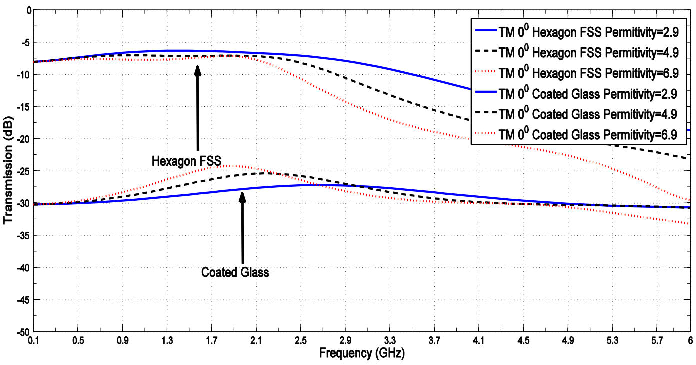

Fig. 9 Simulation trasmission results with full coating and with hexagon FSS for TM polarization with varied glass permittivity at normal incidence.

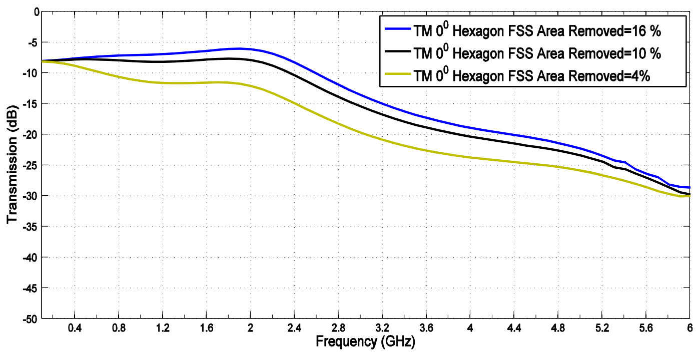

Fig. 10 Simulation transmission results with hexagon FSS for TM polarization with variable aperture width at normal incidence

advantage of this configuration over [5]is the distance between two glass layers which is 12 mm and the number of layers (2 compared to 3) making it low profile and easy to fabricate and implement. Moreover, WLAN security at 2.45 GHz and 5.25 GHz bands has also been achieved. The attenuation in both bands is less than 10 dB which is acceptable.

C. Variable Surface Impedence (TE Polarization)

Simulation transmission results with full coating and with hexagon FSS for TE polarization with varied surface impedance at normal incidence are presented in Fig 4.It can be observed that there is a significant difference in transmission for varying impedance values. Greater the impedance value the lesser is the transmission loss and vice versa (for both with and without hexagon FSS).

D. Variable Permittivity (TE Polarization)

Frequency response for different permittivity values of glass layers is shown in Fig 5. It is interesting to notethatfor ESG with full coating, the transmission attenuation is lesser when permittivity is 6.9 while greater transmission loss is observed when permittivity is 2.9. In the case when the FSS is etched in the coating, the results are different.Here, the transmission improvement is lesser when permittivity is 6.9 and it increases when permittivity of the glass is 2.9.

E. Variable Width of Hexagon FSS (TE Polarization)

Variable width of hexagon FSS has been taken to optimize the frequency response over the important set of frequencies. Lesser the aperture width greater is the transmissionloss andvice versa as shown in Fig 6 (normal incidence). Hence an optimized width of aperture is taken which is 0.8mmwhich gives an acceptable transmission bandwidth from 0.1MHz to 2.3 MHz with an average transmission improvement of 20dB by removing only 10 % coating to ensure the maximum IR attenuation to maintain the inside temperature of a building.

F. With Full Coating (TM Polarization)

Simulation transmission results of dual-layer coated ESG with full coating for TM polarization are shown in Fig. 7. As in previous case, the transmission through double glazedESG has been analyzed with full coating (without FSS etched in it).An average transmission loss of about 25 dB is observed at normal incidence in the band of interest. Some of the important observations are:

1. Transmission loss is decreasing significantly by increasing the angle of incident.
2. Large vertical shift in the transmission curve is observed for normal and oblique angle of incident compared to TE polarization.
3. Resonances are found for 19 GHz, 21 GHz and 25 GHz at 0^0, 30^0 and 45^0 even when there is no FSS etched in the coating.

G. FSS etched in the coating (TM Polarization)

Simulation transmission results of double glazed coated ESG with hexagon FSS etched in the coating for TMpolarization are also shown in Fig.7. Frequency stability for

0.1 GHz to 2.3GHz is shown to be highly stable which is required for this band of interest whereas for the rest of the band vertical shift in transmission curve is larger as compared to the transmission curve of TE polarization. For all angle of incidences, a transmission loss of less than 10 dB is observed making an average transmission improvement of more than 20 dB as in TE case. Moreover,WLAN security has been achieved as in case of TE polarization.

H. Variable Surface Impedence (TM Polarization)

Transmission response for TM polarization at normal incidencefor variable surface impedancesis shown in Fig 8.The results follow a pattern as in case of TE polarization. It is observed that there is a significant difference in transmission when the impedance value is varied. Greater the impedance value the lesser is the transmission loss and vice versa for bothcases(with and without hexagonal FSS).

I. Variable Surface Impedence (TM Polarization)

Frequency response of different permittivity values for TM polarization at normal incidence are shown in Fig 9. The result is the same for normal incidence for both TE and TM polarizations, however for oblique incidence, the transmission loss decreases as opposed to TE polarization.

J. Variable Width of Hexagon FSS(TM Polarization)

Variable width of hexagonal FSS has also been taken into account to optimize the frequency response over the important set of frequencies for TM polarization. Lesser the aperture width greater is the transmission loss and vice verse as shown in Fig 10 for normal angle of incidence. However, the results for oblique incidences are opposite to what was observed in TE case.

IV. CONCLUSION

Besides energy saving property of ESG, it also blocks transmission of MW/RF signals which is a disadvantage. An aperture type hexagonal FSS is presented which has an average improved RF/MW transmission ofabout 20 dB. Optimal results have been achieved using parametric analysis of FSS and glass electrical properties. Only 10 % coating has been removed from the unit cell which in turn will reduce thermal efficiency by the same percentage. It has a stable frequency response for both TE and TM polarizations at normal and oblique incidences. Acceptable WLAN security has also been achieved at 2.45 and 5.25 GHz.Moreover, its wideband response, angular stability and percentage transmission improvementshave clear advantage over some of the recently published research.

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