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FREQUENCY SELECTIVE SURFACE FOR RF/MICROWAVE SIGNAL TRANSMISSION IN ENERGY-SAVING GLASS

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ABSTRACT

Presented here, the measured transmission of RF/Microwave signals in Energy-Saving Glass (ESG) using a dual-layer bandpass Frequency Selective Surface (FSS). The results demonstrate a wider 1.5 GHz bandwidth, confinement of Wi-Fi 2.45 GHz signals and less loss of heat due to only 9% removed coating. The unit-cell consists of two co-centric rings etched over the glass panels, placed close to each other.

Key words: Energy-Saving Glass・Perfect Electric Conductor・Wi-Fi・

INTRODUCTION

ESG is extensively used in modern buildings in the regions where climate remains very hot or cold throughout the year. This glass prevents the penetration of Infrared (IR) heat waves through its surface and thus the thermal effects inside those buildings remain at ease. This results in a less-load on the heating and cooling systems, and hence a useful amount of energy is saved and the glass is termed as energy-saving glass or simply ESG. Basically ESG is made out of an ordinary glass, generally used in the windows for light and visibility. However to obtain the energy-saving property, thin coatings of metal-oxide (0.2-0.4 microns) are deposited over one of its surfaces, which actually block heat penetration through glass surface.

Unfortunately this coating also attenuates the transmission of RF/Microwave signals such as GSM 0.8/0.9, 1.8/1.9 GHz, UMTS, 3G, GPS etc. (< 2 GHz) signals with an average 35-40 dB attenuation, ultimately affecting the wireless communication between inside and outside those buildings. To overcome this problem, Frequency Selective Surfaces FSSs, as bandpass filters, have been proposed in the past (Kiani 2010), (Sohail 2011). FSSs are one- or two-dimensional arrays of conducting elements, usually designed to act as bandpass or bandstop filters at the resonant frequencies. The inherent capacitive and inductive nature of periodic elements is optimized to obtain the desired filtering characteristics (Ben 2000) in FSS.

In past, many bandpass FSSs designs have shown improved transmission for (< 2 GHz) signals in ESG. For example, a fully coated ESG panel in (Sohail 2011) exhibits 40 dB attenuation for these signals, but when an FSS was etched, the same panel exhibits only 10 dB attenuation, providing a significant transmission improvement. Similarly FSSs (Sanz 2008), (Kiani 2007), Widenberg 2002), (Mias 2001) and (Philippakis 2004) were designed to improve the signal transmission and to control the indoor wireless radio propagation as well. As an example, FSS in (Kiani 2006) transmits GSM cellular phone 900/1800/1900 MHz signals while attenuates WLAN signals. A bandpass FSS in (Kiani 2011) also showed transmission improvement but exhibited a narrow (0.5 GHz) bandwidth. Recently a dual-band FSS in (Ullah 2011) was also designed for 887 and 2112 MHz frequency. Although it transmits the two bands, but it attenuates the vital GSM 1.8 GHz signals and is also unable to confine Wi-Fi 2.45 GHz signals. Moreover in this design (Ullah 2011), more FSS apertures would be required for multi-band transmission which will cause more loss of heat. In one of our previously published work (Sohail 2012), an FSS with its simulated results for RF/Microwave signals (< 2 GHz) transmission in ESG was presented earlier.

In this current paper, we have practically measured the transmission response of (Sohail 2012) FSS and have also carried out a detailed parametric study to further analyze its performance. The measured and simulated analytical results of this FSS are not published before and are presented here for the first time. As per measured results, FSS successfully transmits the RF/Microwave signals with a low acceptable attenuation. It exhibits 1.5 GHz bandwidth and also transmits the vital 1.8 GHz signals. It also confines the important Wi-Fi 2.45 GHz signals, a benefit for defense units, who intend to secure their Wi-Fi signals, but allow mobile phone signals to be received and transmitted. Figure-1 shows inward view of one ESG panel with etched FSS. A complete design of unit-cell, measured results and simulated results are described.

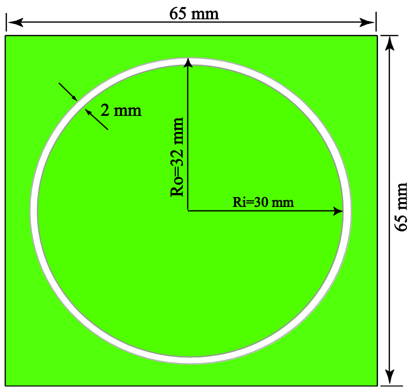

Figure1: A view of one surface of ESG panel with FSS ring

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Unit-cell Design

Figure 2 shows the perspective view of bandpass FSS unit-cell. It consists of two rings etched in the inward coatings of two ESG panels facing each other.

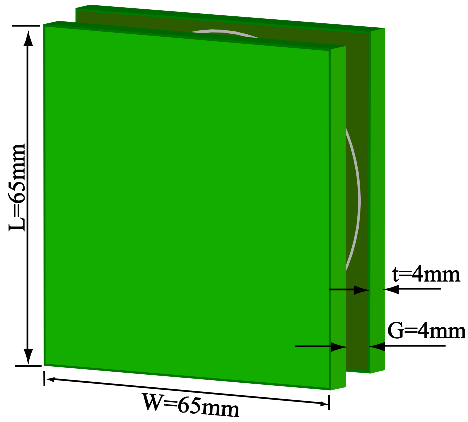

Figure 2: FSS unit-cell schematics; perspective view showing two ESG panels with FSS etched ring

The outer radius of ring is 32 mm and inner one is 30 mm, creating an aperture of 2 mm. The size of unit-cell is 65 by 65 mm, dielectric constant of glass is 6.9, its conductivity is $5e^{-4}$ S/m, its thickness is 4 mm and the panels are kept at 4 mm gap (Figure-2). The hard coating is modeled as Perfect Electric Conductor (PEC) and CST Microwave Studio is used for simulations.

FSS prototype

Figure 3 shows the FSS prototype glass panels, stacked firmly together, in such a way that the ring patterns are exactly aligned to each other. These etched FSS rings can be clearly seen on glass surface (etched in the inward surface of glass panels).

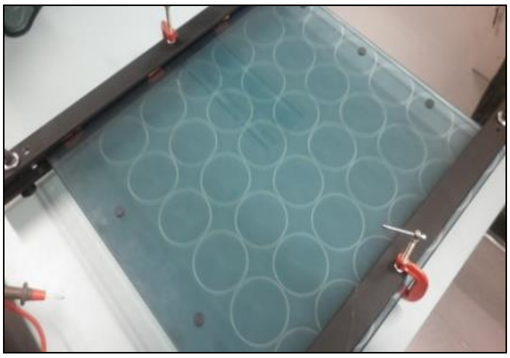

Figure 3: FSS prototype; the ring patterns can be seen on the glass surfaces

Here, LASER technique was used to remove the coating from galss surface. Since the coating is diffused into the molten glass and becomes hard after its cooling, it is not possible to remove it completely from the surface. Moreover, a high power beam could damage or even burn the glass sheets and hence a low power beam was used to remove the coating, as far possible, avoidng any damage to the prototype.

Measurement setup

The measuring setup is shown in Figure 4. It can be seen that two Log periodic antennas, are connected to HP Network Analyzer via SMA cable and are palced over the wooden stands at either sides of the glass panel.

Figure 4. Measurement setup; Glass panels, antenna and wooden stands holding the panels

MEASURED RESULTS AND ANALYSIS

Figure 5 shows a comparison between the measured and predicted transmission response of FSS.

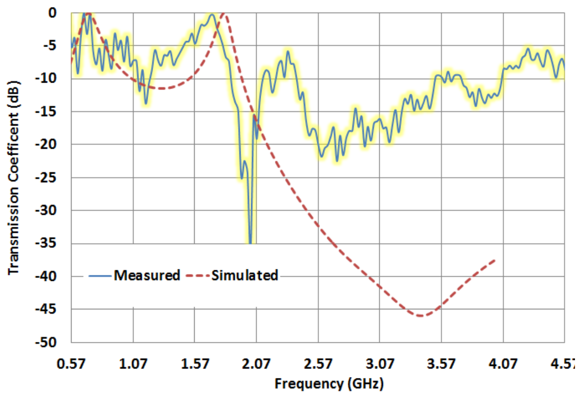

Figure 5: Measured and predicted transmission response of FSS

It can be seen that the two results match each other to some extent in the 0.5-1.9 GHz band. It means that FSS transmits the desired RF/Microwave signals and exhibits a wide 1.5 GHz bandwidth. The difference in simulated and measured results is due to the fact that hard-coating was not fully removed from the glass surface as it was diffused into the glass and LASER technique was used to remove it due to lack of etching facilities. Moreover, after 1.9 GHz frequency point in the Figure 5 the two results are not similar which may be due to smaller size of prototype, that might have casued the reflections. This FSS is also transmitting the important GSM 1.8 GHz signals, whereas FSS in (Ullah 2011) has a transmission null at this frequency. Moreover, as per measured result (green curve in Figure 5), the FSS practically confines the Wi-Fi 2.45 GHz signals with 18 dB attenuation, while theoretically (red curve in Figure 5), it shows 30 dB attenuation for those wireless signals. The non-uniform nature of measured curve may be due to the reflections and signal scattering around the edges of the glass panels, as the size of the prototype is as small as 2 by 2 feet

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and is not sealed or enclosed like industry manufactured Integrated Glass Units (IGUs) which consist of two or more sealed panels, similar to the panel shown in Figure 2. If properly sealed and enclosed with insulating material like Argon gas, suc type of prototype panels can be useful for some commercial applications where it is required to prevent the Wi-Fi signals from transmission, but allowing the GSM mobile phone and other low-frequency signals to be received and transmitted.

The other interesting feature of this FSS is that only 9% coating is removed, which means a small amount of heat loss will occur, which is negligible as compared to the amount retained. This panel also provides protection from the external climates due to two glass sheets.

PREDICTED ANALYTICAL RESULTS

As stated earlier, the FSS performance was also analyzed in a detailed parametric study by considering different situations and varying the design parameters. The subsequent results obtained for each study case are described here in detail.

Gap "G" variation

We started with, the gap "G"; varied periodically to observer its effect on the signal's transmission and the response is shown in Figure-6.

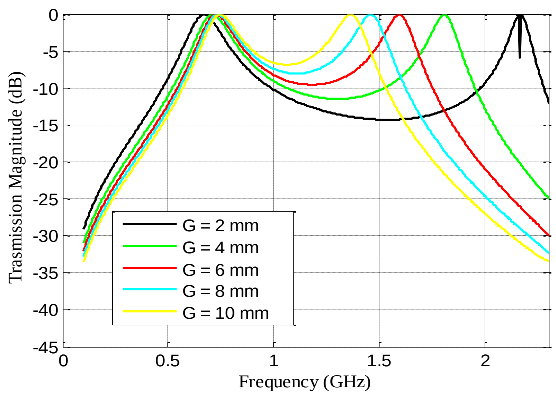

Figure 6: FSS Transmission with varied gap "G" between the glass panels

It can be seen that initial peaks (0.6 GHz) remain almost stationary, but the other peaks shifts from 1.3 to 2.5 GHz, exhibiting larger bandwidths at narrow gaps (2, 4 mm) and smaller bandwidths at the wider gaps (6, 8, 10 mm). This could be due to the interference of waves reflected from the two-layered cascaded transmitting boundaries of ring conductors. It can also be seen that narrow gaps lead to high in-band attenuation such as 14 dB at 2 mm, and hence the 4 mm gap was considered optimal as compromise between the wider bandwidths and less in-band attenuations exhibited by the FSS.

Varying inner radius R_i

In second stage, the inner radius R_i was varied, keeping outer radius R_o constant (32 mm) and the respnse obtained is shown in Figure-7.

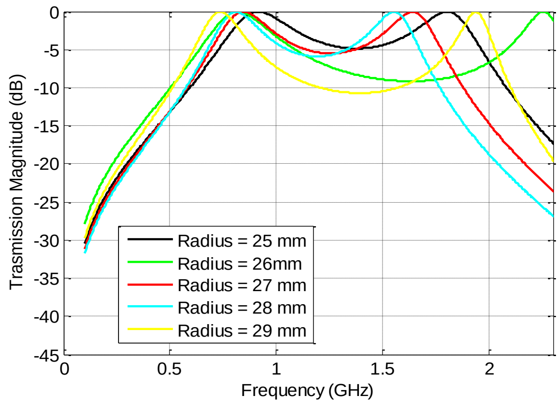

Figure 7: FSS Transmission with varied inner radius of FSS ring

The tranmission curves in Figure 7, fairly resemble to curves in Figure 3. However it can be said that irregular shifts in the second transmission peaks were seen which can be readily identified at 1.5, 1.65, 1.8, 1.9 and 2.2 GHz (Figure 7). These shifts in the peaks can be due to the two cascaded boundaries, their spacings and glass permitivity which may affect the transmission response.

FSS on soft-coated panels

In third stage, an FSS on soft-coated dual-layer panel was considered, and the gap was varied accordingly, to see the tranmission of RF/Microwave signals through it. The response obtained is presented in Figure 8.

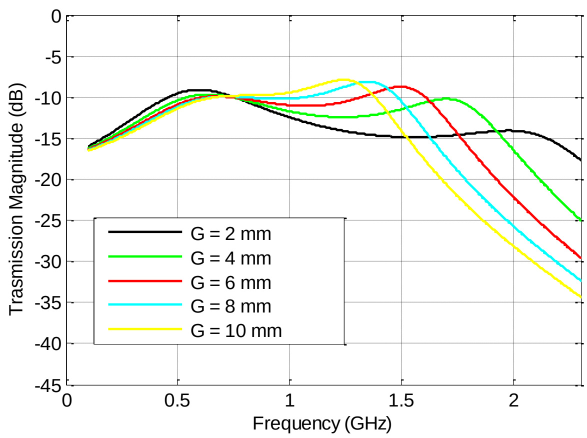

Figure 8: FSS Transmission with varied gap "G" between the glass panels (soft-coated)

It can be noted that FSS exhibits 8 dB attenuation at the first transmission peak (0.65 GHz) at 2 mm gap and 15 dB at the second peak (1.5 GHz) at10 mm gap in the entire 0-2 GHz band. This trend shows that FSS on soft-coated panels attenuate these signals more than the FSS with hard-coated panels and this difference of attenuation is due to ohmic loss in soft-coating. However, FSS on the soft-coated panel exhibits less sharper transmisison response as compared to FSS on hard-coated panels. Also second transmission peaks between 1.2 to 2 GHz are lower than the first transmission peaks (0.5 to 0.58 GHz), as can be seen in Figure 8.

Single-layer FSS; hard- and soft-coated panels

In our final analysis, a comparison was carried out between transmission response of single-layer FSS (soft-coated panel) and single-layer FSS (hard-coated panel) and the trends obtained for both FSSs are shown in Figure 9.

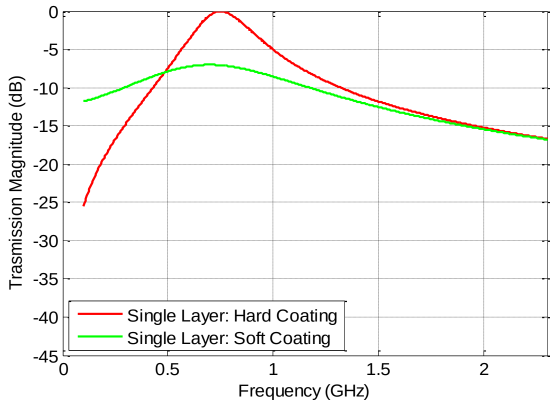

Figure 9: Transmission response of single-layer FSS with soft-coated and hard-coated panels

It can be seen that the soft-coated panel showed maximum attenauation 7 dB at 0.6 GHz with a relatively flat respnse. On the other hand, the hard-coated panel exhibited near perfect transmission at 0.7 GHz with narrow band. Although the hard-coated FSS can be useful due to its high transmsission but its bandwidth is narrow. However both of these FSSs do not fulfill the desired RF/Microwave signal transmision requirement in the band of interest (< 2 GHz).

CONCLUSION

A bandpass FSS with its measured transmission response and predicted analytical results was presented. It has several key advantages over the other designs such as; it has wider 1.5 GHz transmission bandwidth, it confines the vital Wi-Fi 2.45 GHz signals and it shows less heat loss due to only 9% removed coating. Moreover, it will require fewer apertures, if designed for multi-band transmission. Finally, due to double-glass, it can provide extra thermal protection from extreme outer climates, in addition to the protection, provided by the coating over glass surface.

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