Progress In Electromagnetics Research Letters, Vol. 52, 11–16, 2015

Dual Frequency Selective Transparent Front Doors for Microwave Oven with Different Opening Areas

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Abstract—Microwave oven generates a harmful electromagnetic wave at 2.45 GHz of 1000 Watts. The generated microwave is confined within the cavity of the oven for efficient heating and secured operation. To prevent microwave leakage through the front glass door, a special construction of Faraday Cage is involved. In this paper, Faraday Cage is replaced with Transparent Frequency Selective Surface Front Door, which provides better visibility and avoids microwave energy to escape from the oven. Two works are proposed in this paper. The first one is band pass response which has been achieved for 10 GHz by printing array of Greek cross aperture (FSS) on the front glass door, and the second work is band stop response which has been achieved for 2.45 GHz frequency by printing the array of circular ring patch (FSS) on the front glass door. Design of two different FSS arrays and the simulation results were discussed.

1. INTRODUCTION

A microwave oven is a microwave generator used for heating food, which works by passing non-ionizing microwave radiation, at a frequency of 2.45 GHz through the food. Microwave is generated by magnetron and fed to the metal cavity (cooking compartment) through waveguide. The metal cavity (size $\approx 33.6 \times 22.5 \times 34.9\,\text{cm}^3$) is closed with solid metal plates on five sides and Faraday Cage incorporated glass plate on the sixth side. Since all the six faces are reflecting the microwave, the energy is confined inside the oven for heating.

The front glass window design is important, because it will see through and not allow the microwave to pass through. To achieve this, Faraday Cage is placed inside the glass plate. Faraday Cage is conducting mesh screen which blocks out external static and non-static electric fields. Its operation depends on the fact that an external static electrical field will cause the electrical charges within the cage's conducting material to redistribute themselves in order to cancel the field's effects in the cage's interior. The hole size in the mesh should smaller than the wavelength of the microwave signal so that it cannot penetrate. In this paper, Faraday Cage is replaced with Frequency Selective Surface to provide improved visibility and microwave radiation blocking capability.

2. FREQUENCY SELECTIVE SURFACE (FSS)

FSS is a periodic structure of conductive elements or apertures in either one or two dimensions that provide a filter operation when they are illuminated with EM wave. When illuminated by an electromagnetic wave, FSS exhibits total transmission/reflection around the resonance frequency. This spatial filter behavior of FSS is used in designing the FSS shield. The filter behavior (low-pass, high-pass, band-pass and band-stop) of the FSS depends on the shape of the element [1]. In this paper, Greek

Received 18 December 2014, Accepted 15 February 2015, Scheduled 4 March 2015

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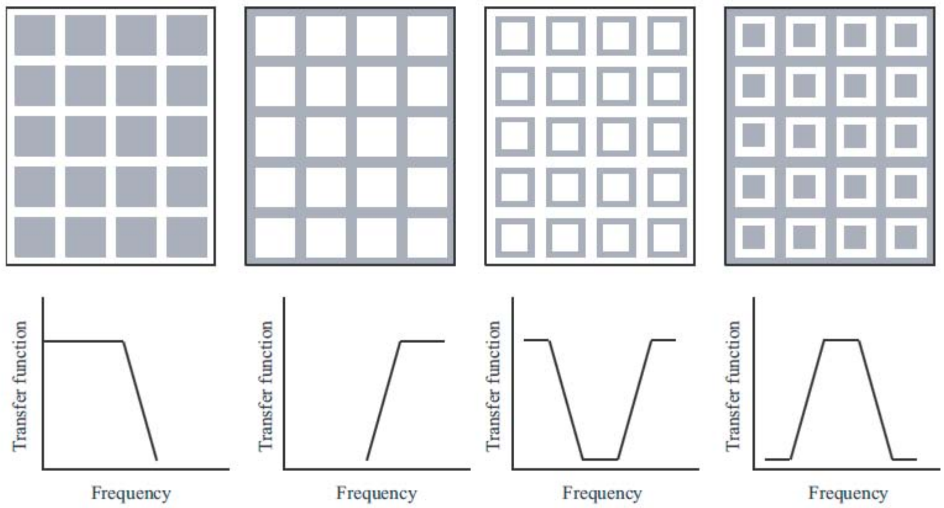


Figure 1. FSS types and response, (a) solid patch array — low pass, (b) slot array — high pass, (c) patch looped array — band stop and (d) slot looped array — band pass.

Cross element is considered for FSS design. Figure 1 shows various arrays of FSS and the frequency response.

The major application of FSS is selective shielding. By carefully choosing the element shape and size, desired frequency response can be obtained. FSS has already been applied to block/allow Wi-Fi band 2.4 GHz.

In [2] Band pass Shielding Enclosure has been designed to allow the 2.4 GHz band and block the remaining frequencies. Here the size of the enclosure considered in $10 \times 16 \times 2.1\,\text{cm}^3$, and array of Jerusalem cross apertures has been made. The design objectives of a practical BPSE are — high transmittance in the specified wireless-signal band and high shielding outside that band. Also several works have been proposed to block the Wi-Fi inside the building.

In [3] a frequency selective surface (FSS) of square loops printed on both sides of a dielectric substrate is used to allow/block 2.4 GHz band inside a room. This FSS structure is printed on the walls to control the Wi-Fi band.

In [4], FSS wall has been designed to stop penetration of Wi-Fi inside the building. Here square loop patch is printed on the walls to achieve the band stop response. In [5], transparent FSS box has been designed to place microwave oven. The microwave oven measurements in the presence of the FSS box demonstrate that there is satisfactory attenuation, around 20 dB. In all the above literatures, FSS is printed on a substrate which is either transparent or non-transparent for blocking or allowing the Wi-Fi signal. But so far FSS design approach has not been applied to design the front doors of microwave oven.

3. DESIGN OF FSS FRONT WINDOW

The aim of designing a Frequency Selective Surface is (i) block the radiation of 2.4 GHz and (ii) provide the transparency in FSS wall, so that light passes through the window, and user can see through the oven. So FSS has to be designed to block 2.45 GHz, i.e., a band stop response at 2.45 GHz. But for safety reasons, in this paper FSS has been designed to allow 10 GHz band. This design will block till 5 GHz strongly. Array of Greek cross apertures will be made on the conductor, and this FSS will be placed above the glass. The model is simulated with Feko 5.5 Lite Version. Microwave oven with see through FSS window is shown in Figure 2.

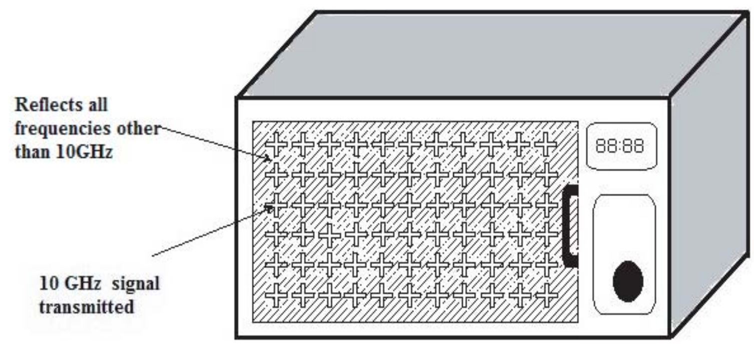


Figure 2. Microwave oven with FSS Wall (FSS slots are embedded on the front door).

3.1. Design of FSS Unit Element (Greek Cross Slot)

First the single unit cell of the FSS array should be decided. The length of the Greek cross aperture should be of approximately $\lambda/2$ with the resonance length of the aperture pole. Since band pass response is expected at $f = 10\,\mathrm{GHz}$ ($\lambda = 3\,\mathrm{cm}$), the half wavelength is 1.5 cm. The single element is shown in Figure 3.

For Simulation Feko 5.5 Lite version is used. As the FSS is an infinite periodic array, periodic boundary condition is applied. Unit cell meshed view is shown in Figure 4. This Greek cross aperture shaped unit cell is placed above the glass. The white part of the cross will be the transparent part, and the remaining is metal. As the array is baked by glass, the resonance frequency curve is shifted to a few hundred megahertz.

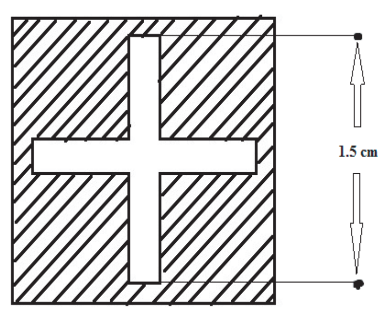


Figure 3. FSS unit element.

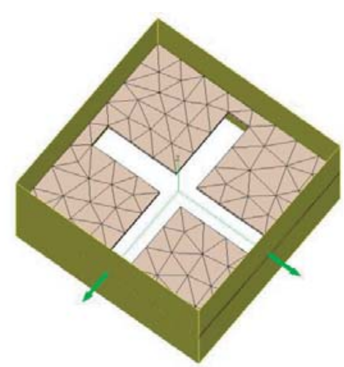


Figure 4. Unit cell meshed view.

3.2. Design of FSS Unit Element (Circular Ring Patch)

Then the second work is the implementation of a new FSS structure called ring patch structure. This structure possess the inner radius of 1.4 cm, distance between two layers of 0.6 cm, thickness of patch 1 mm made up of copper, width of the patch 0.6 cm and the dimension of whole box $36 \times 34 \times 20\,\mathrm{cm}$. The schematic of the unit structure of the ring patched FSS is drawn below.

The major reason for the implementation of the second structure in FSS is the generation of more open surface in the case of circular ring construction rather than the Greek cross structure. In the case of the first construction, the design prompts to create 19×12 arrays of Greek cross structure, which leads to 228 individual crosses. The opening of a single slot generates $58\,\mathrm{mm}^2$. In total of 228 slots, it creates a large opening area which is approximately $13{,}224\,\mathrm{mm}^2$. Double-layer FSS can also be preferred for improving the shielding efficiency.

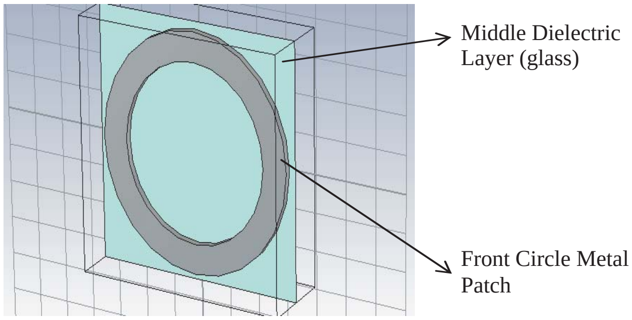


Figure 5. FSS unit element.

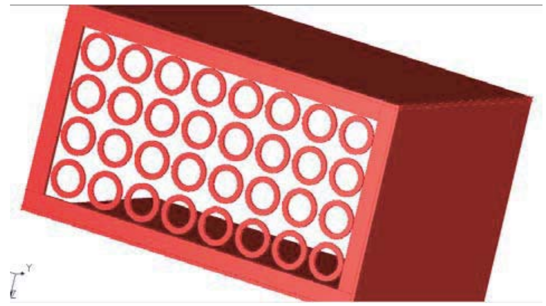
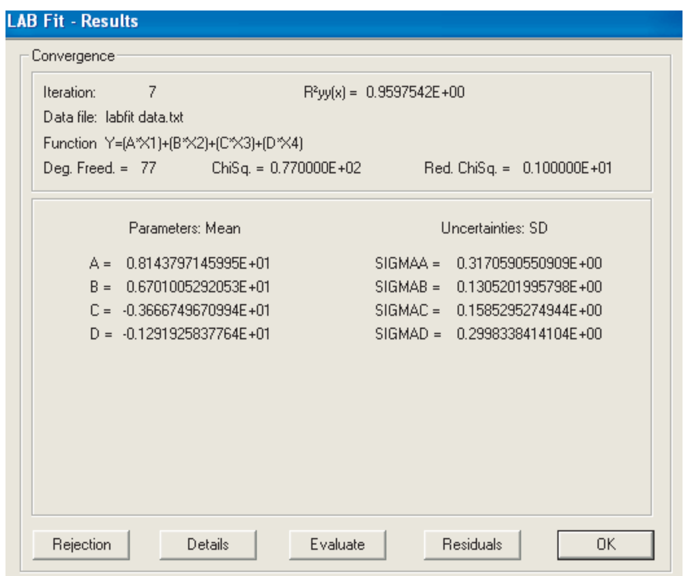


Figure 6. Microwave enclosures with ring cross FSS wall.

The complete structure of the oven is depicted, and its enclosure is shown above for simulation and analysis purpose. This clearly shows that there is more opening area compared to the previous case of Greek cross structure.

In general, the front surface of the oven glass coverage holds the total opening area of $75600\,\mathrm{mm}^2$ for the total dimension of $336 \times 225\,\mathrm{mm}$ with no shielding provided or printed on the glass surface.

In the case of the proposed work 2, there is only 4×8. So totally there are 32 ring structures used for shielding the desired range of frequency 2.45 GHz. This ring structure possesses an outer diameter of 20 mm and inner diameter of 14 mm with 6 mm thickness patch. Each unit blocks an area of $160.14\,\mathrm{mm}^2$ of the total opening or visible area on the front glass door. 32 unit cells totally block the area of $5125\,\mathrm{mm}^2$. Hence subtracting this with the total opening area gives the opening visible region for the proposed work 2. Thus $70475\,\mathrm{mm}^2$ should be visible, and it is more than 5 times larger than the visible area obtained from the case 1 proposal. The analytical equation is generated by solving all the known parameters.



$$\lambda_r = 8.1d + 6.7\,ir - 3.6\,p - 1.29\,w$$

Figure 7. Analytical information which relates wavelength with patch distance, inner radius, periodicity and width of the patch, $\mathbf{Y} = (\mathbf{A} * \mathbf{X1}) + (\mathbf{B} * \mathbf{X2}) + (\mathbf{C} * \mathbf{X3}) + (\mathbf{D} * \mathbf{X4})$.

where,

Y — wavelength lambda.

A — Distance between 2 patches (d).
B — Inner radius (ir).
C — Periodicity of patches (p).
D — Width of the patch (w).
$\mathbf{X1} = \mathbf{8.1}$, $\mathbf{X2} = \mathbf{6.7}$, $\mathbf{X3} = \mathbf{-3.6}$, $\mathbf{X4} = \mathbf{-1.29}$ — Constants.

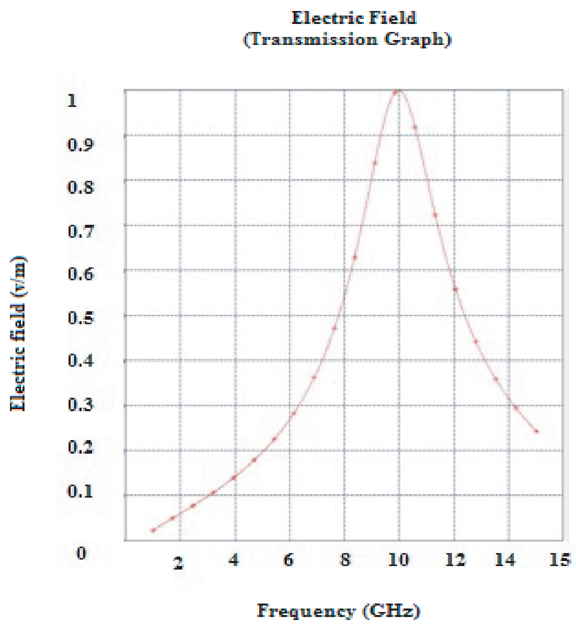


Figure 8. Response curve between electric field vs. frequency.

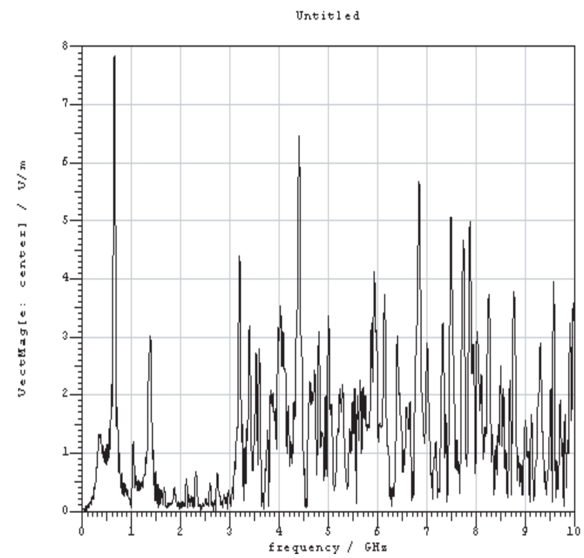


Figure 9. Result obtained in CST (signal transmission vs. frequency).

4. RESULT AND CONCLUSION

From the simulation of the first work, the FSS screen possesses band-pass response at 10 GHz and high attenuation at 2.45 GHz band. In this paper, Frequency Selective Surface is designed to block the microwave energy from the microwave oven front glass window. For this purpose, a FSS layer which consists of array of Greek cross shaped apertures is made on the conducting surface and printed on the glass front window of the microwave oven and also a FSS layer which consists of array of circular ring patch made up of copper conduction plate and is printed on the front glass window.

To provide further attenuation, one more layer of FSS has been inserted. This provides improved transparent area over the conventional Faraday Cage based oven door. So simultaneously transparency and electromagnetic shielding was achieved.

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