Convoluted Frequency Selective Surface Wallpaper to Block the Industrial, Scientific, and Medical Radio Bands Inside Buildings

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Abstract. This paper reports some of the findings in a project done at Al-Ahliyya Amman University in Jordan. The project was to create a band-stop square loop and convoluted frequency selective surface (FSS) wallpaper. FSS wallpaper as a state of the art that may be applicable on wall to block Wi-Fi frequency working on the 2.4GHz frequency inside buildings by blocking all unwanted outdoor transmissions, regardless their origin (Taylor et al., 2011). The convoluted FSS differs from the designed square loop FSS, by getting a better performance in presence of different incident angles of the propagating wave (0^o-60^o) and to reach a stable resonance frequency for both a transverse electric (TE) and a transverse magnetic (TM) incident waves. The designed FSS is used to modify the indoor wireless physical propagation environment and reducing the interference level which enhancing the network security with in the buldings in the unlicensed 2.4GHz, as industrial, scientific, and medical (ISM) radio bands (Sung et al., 2006).

Keywords: Band-Stop, Convoluted, Frequency Selective Surface, Indoor Propagation, Simulation, Square Loop.

1 INTRODUCTION

Radio signals generally propagate through reflections, refractions, diffractions, and scattering. Transmitted signal components arrive at the point of interest with various amplitude and phases values and these combine together to produce the received signal.

Interference between neighboring systems is an important issue because of the rapid growth in the use of wireless communications systems, especially, in unlicensed bands such as the ISM band. This interference is not only degrading the system's performance (Kartal, 2011), but also compromising the transmitting system's security (Batchelor et al., 2009) & (Mais et al., 2001). From this point of view, it is essentially to create techniques that put a boundary between two frequencies used by neighboring systems which is reducing the interference in order to let the systems to work effectively.

The problem is how to make a screening on 2.4GHz frequency and give the other bands the maximum transparency. Researchers and scientists were working on developing FSS by using many shapes: loaded dipole, Jerusalem cross, tripole, cross dipole, dipole, and square loop (Mais et al., 2001).

Pervious researches showed that the square loop FSS has the best response and stability to work within the angular insensitivity, cross polarization TE or TM modes, and small band separation (Mais et al., 2001). Square loop FSS is used in an increasing way with different structures and convoluted shapes in order to enhance the figure of merit of FSS for band blocking filters (Qasem & Seager, 2012).

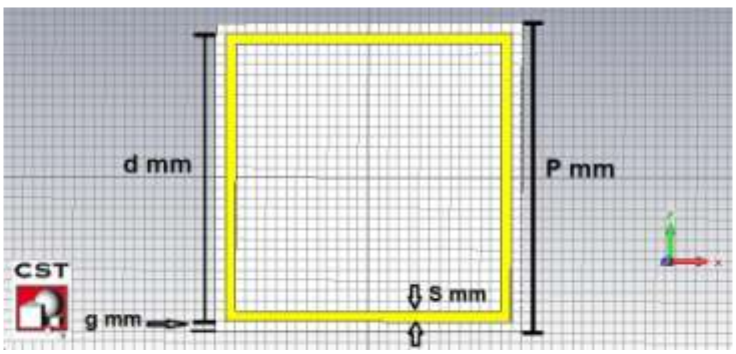
In general case, the performance of FSS structures for different incidence angles of the propagating wave must exhibits stable band-stop filter. In addition, the FSS must show good frequency stability for both TE and TM polarized waves for angles from (0^o-60^o) (Qasem & Seager, 2010), where the signals are most likely to arrive at the surface between (0^o-60^o) with significant strength (Sung et al., 2006).

To improve the efficiency of communication systems in an indoor environment by blocking the outdoor 2.4GHz, an FSS was designed and simulated. To block the received signal from outdoor environments, the FSS wallpaper placed in front of the brick wall. Mobile telephone, TV, radio, and the majority of communication systems generally use frequency ranges lower than 2GHz. These frequencies can still penetrate the investigated area via the designed FSS wallpaper (Qasem & Seager, 2009).

2 FREQUENCY SELECTIVE SURFACES (FSS's)

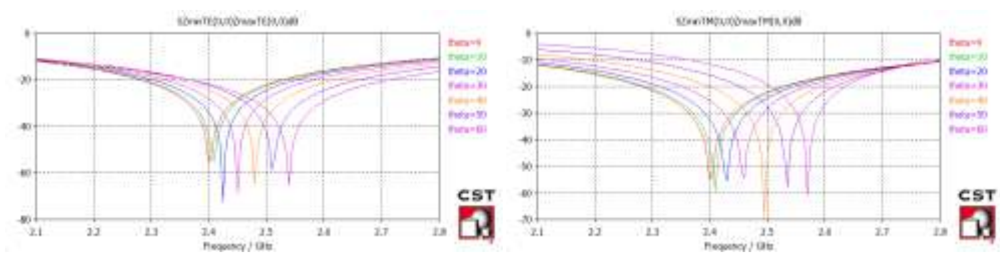
A Frequency Selective Surface (FSS) is a surface, which exhibits reflection and/or transmission properties as a function of frequency, in other word the band-stop FSS at the resonant frequency behaves like a metal sheet to radio signals (Sung et al., 2006).

Square loop FSS, as shown in Fig.1, had been designed and tested by using Computer Simulation Technology-Microwave Studio (CST-MWS) for different incidents angles ranging from (0°-60°) (C.S.T.M.Studio, 2012). Square loop response for changing of incident angles is shown in Fig.2.



P =30 mm, g = 0.1 mm, d =28 mm, S=0.1 mm, thickness=0.3 mm

Fig. 1. The simple square loop FSS dimensions.



(a) TE. (b) TM.

Fig. 2. Response of the square loop FSS.

The response of the square loop FSS is not stable for different incident angles, as shown in Fig.2. The necessity of such a stability improvement in angular response needs to be justified. As some papers are using a cascade of grids in order to improve the angular stability (Mais et al., 2001). This paper goes with other mind who suggests that FSS could be made complicated element pattern which is called the convoluted FSS yielding less angle sensitive (Batchelor et al., 2009) & (Qasem & Seager, 2012).

One of the benefits of convoluted FSS over square loop FSS structure is size reduction, which leads to improve stability of transmission or reflection frequency response with angle of incidence of existing wave. In addition, the interactions between the FSS and the wall surface could be minimized with an appropriate convoluted FSS design, as FSS must be separated with distance $\lambda/10$ from the brick wall in order to cancel the coupling effect with wall response that may affect the resonance frequency of the FSS (Qasem & Seager, 2010) & (Qasem & Seager, 2012).

From these points of view, the convoluted FSS was chosen in order to reach a good performance comparing with the designed square loop FSS. Decreasing the element sizes will ensure an improved frequency response over a wide range of incident angles (Qasem & Seager, 2012).

The physical area taken up by an individual element can be significantly reduced, while maintaining its electrical length by the use of convoluted shapes (Batcher et al., 2009). Therefore, a new convoluted FSS shape has been designed under CST-MWS, as show in Fig.3. Response for different incident angles is shown in Fig.4.

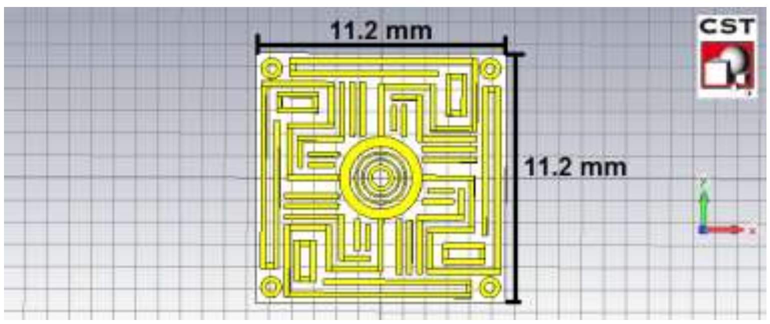
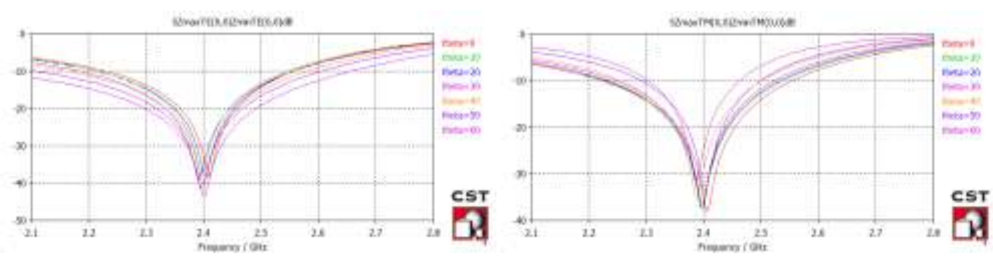


Fig. 3. The designed convoluted FSS.



(a) TE. (b) TM.

Fig. 4. Response of the convoluted FSS.

The thickness of copper in the FSS is 0.1mm and the rogger thickness is 0.2mm with permittivity equal to 3F/m. Table 1 shows some differences between the two elements. The average bandwidth at -10dB value has become smaller which means the blocking area is smaller and hitting the resonant frequency without affecting the others frequencies. In addition, the figure of merit is becoming larger.

Table1. Comparisons for a selection of array elements (figure of merit λ/p).

Element	f_r GHz	P mm	Unit Cell Area mm^2	λ/p	Average Bandwidth -10dB (θ =0) GHz
Square Loop FSS	2.45	30	900	4.16	0.2224

Convoluted FSS	2.4	11.2	125.7	11.3	0.1023

3 IVESTIGATED SCENARIOS AND SIMULATION RESULTS

A common office partition wall was the main propagation path (6.5m wide and 3m height). This wall is transformed into a frequency selective wall (FSW) by attaching the designed convoluted band-stop FSS as a cover on the wall surface with a space 1.2cm from the wall. Remcom 'Wireless InSite' will simulate the propagation paths from transmitter (Tx) to receivers (Rx's) at any location inside the interest area and how the designed convoluted FSS structure will block the propagation of 2.4GHz inside the interested area. Three scenarios were investigated.

In all of these scenarios, the study area is two rooms and omni directional antennas were used with a sensitivity of -71dBm (Cisco, 2009). All the receiving antennas are mounted at 1.5m above floor and the transmitter antenna mounted at 2m above the floor of the room, the spaces between the grid antennas of receiver is 1.5m. The transmitter input power was 17dBm as suggested by Cisco routers (Cisco,2009), and the two rooms materials details are presented in Table 2.

Table 2. Electrical parameters used for building interfaces.

Interface Type	Material	Relative Electrical Permittivity, ε_r	Conductivity σ	Thickness (meter)
External wall, Internal wall	Brick	4.44	0.001	0.125
Floor & Ceiling	Concrete	7	0.015	0.30
Door	Wood	5	0	0.03
Window	Glass	2.4	0	0.003

3.1 First Scenario

As illustrated from the room layout considered in this paper, which consists of two rooms with a common dividing wall. Only the separation brick wall between two rooms will be the propagation path for radio signal, as shown in Fig.5. After simulation, the result of the received power was ranging between -50dBm and -67dBm which is depending on the receiver location. All the telecommunications equipment using 2.4GHz will work.

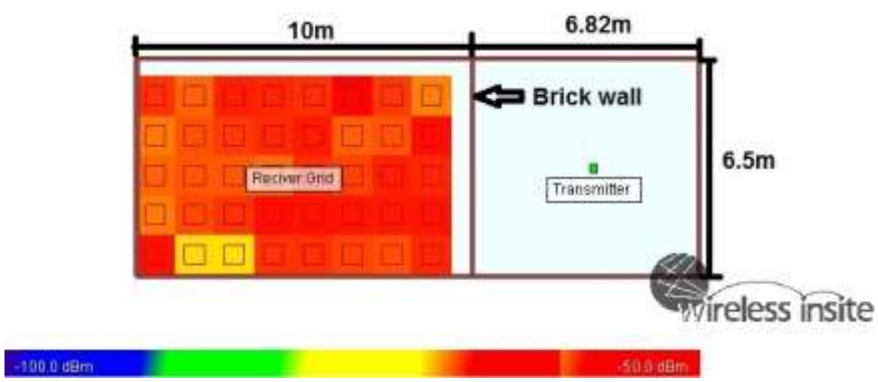


Fig. 5. The first scenario layout.

3.2 Second Scenario

The convoluted FSS coating the separation wall is shown in Fig.6. The received power is ranging between -68dBm and -84dBm by an additional attenuation of 18-20dB compared to unmodified wall. The gained attenuation of 18-20dB is considered to be significant and beneficial in interference reduction (Sung et al., 2006). Equipments that work in the frequency of 2.4GHz will not work if it has an ordinary antenna's sensitivity.

Signals may travel from one room to another via diffractions around windows and doorways, or reflections from the corridor wall. These diffractions or reflections are inevitable unless other shielding strategies could be applied to windows or doorways. The performance of the FSS could be maximized if shielding are used on the others walls, windows even door to eliminate the signal to enter the room from other entry point. As particular shielding by using foils on walls may be the cheapest way to do such shielding.

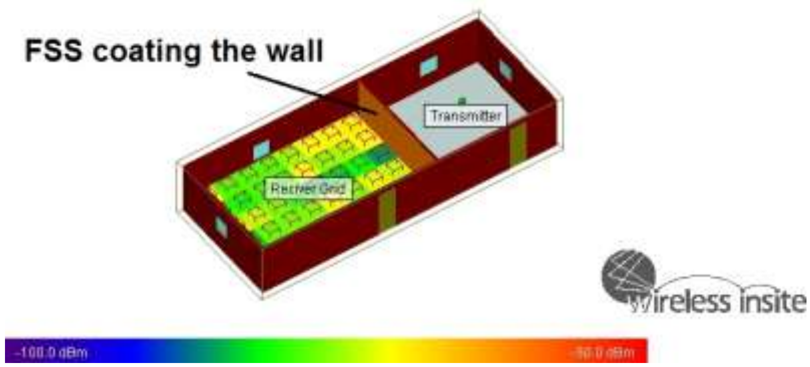


Fig. 6. The second scenario layout.

3.3 Third Scenario

In this scenario, foils and FSS were used on the separated wall, as shown in Fig.7. FSS (1m wide with 3m height) is placed at the center of the wall and the foil is used to complete the remaining part of the wall. After simulation was conducted, the received power was ranging between -75dBm and -120dBm. An additional attenuation of 7-36dB is achieved comparing to the second scenario and 25-53dB comparing to the first scenario.

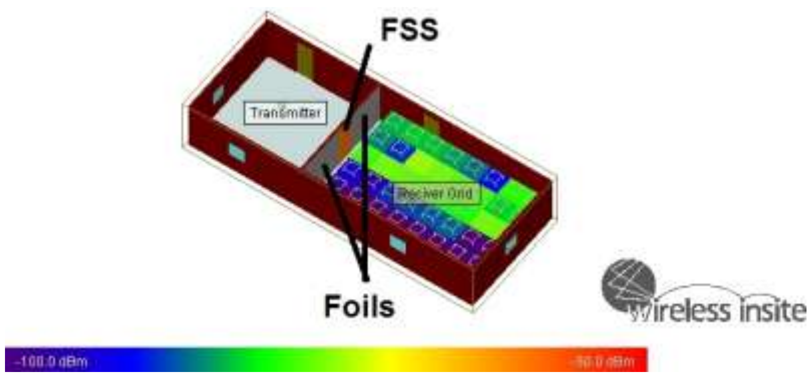


Fig. 7. The third scenario layout.

3.4 Comparison between the Three Scenarios

The best performance was when the FSS becomes smaller and combined with foils, as shown in Fig.8. The advantages of cost minimization and better performance have been achieved, but attenuation problem is raised for other frequencies because the foil does not pass any signal according to its specifications.

When using the FSS along the wall, the blocking performance will be on the 2.4GHz with minimum attenuation effect on other frequencies. This scenario is costly more than the third scenario because of FSS fabrication that needs time and specific machines.

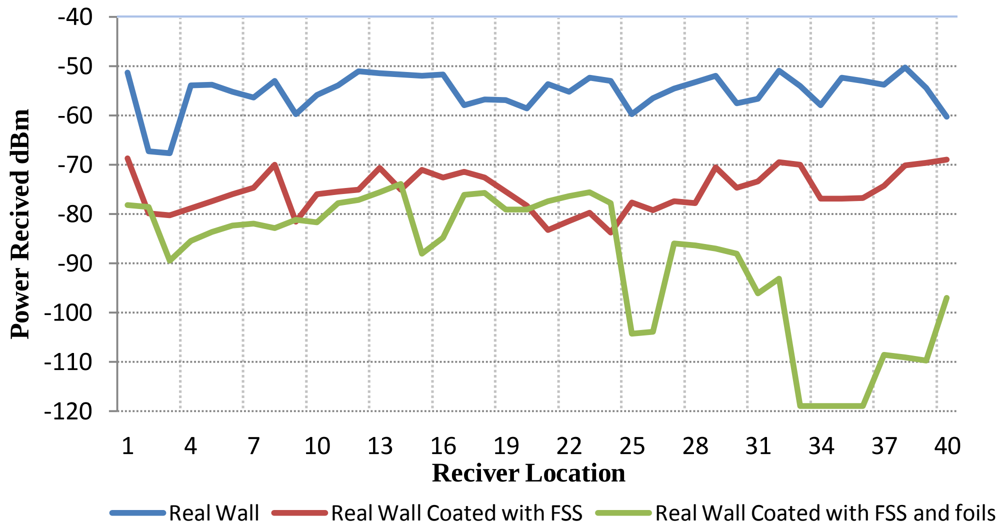


Fig. 8. Comparison between the three scenarios using the received power versus the receiver locations.

4 CONCLUSION

Enhancing the blocking performance of the indoor wireless physical propagation environment to reduce the interference level at 2.4GHz were investigated and demonstrated in this paper.

The frequency response of the frequency selective wall developed in this paper was relatively insensitive to varying incidence angles; FSS also showed a good capability to deal with TE and TM waves. Three scenarios were conducting to simulate the FSS action and how it affects the signal propagation.

The best action was when the foil attached with FSS wallpaper because the FSS surface is smaller and no signal can enter the investigated area from any way than the FSS window.

Using foil to cover walls instead of the full FSS would greatly reduce the time and labor requiring for mass production but there will be attenuation to other frequencies.

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