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Design of a Tri-band Double Wire Square Loop Frequency Selective Surface for Mobile Signal Shielding

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Abstract— This paper presents the design of a novel frequency selective surface (FSS) structure. The proposed FSS structure here is constructed of square loops of copper wires interconnected together using iron wires and thus forming a wire net. It is designed to shield the mobile signals of different networks: GSM 900, GSM 1800 and 3G and hence operating as an electromagnetic bandstop filter. A single cell consists of double square copper loops with outer loop tuned at GSM 900 and the inner loop tuned at GSM 1800 and 3G frequency bands. The structure can be easily manufactured and installed in outdoor areas. The simulation results of transmission coefficients show stable frequency response for both the TE and TM polarizations for angle of incidence from 0^0 to 30^0.

Index Terms—Frequency Selective Surface (FSS), GSM signal shielding, wire square loop.

I INTRODUCTION

There has been extensive research on frequency selective surfaces (FSS) in the last few decades. FSS structures are two dimensional arrays formed of metallic patch elements or their complementary having apertures and they act like band-stop filter in case of patch elements and as band-pass filters in case of aperture elements. The most commonly used shapes in design of FSS are straight dipole, circular loop, cross dipole, three-legged dipole, square loop and Jerusalem cross as shown in Figure 1[1]. The frequencies of transmitted or reflected signals strongly depend on the resonant frequencies of the shapes of conductive elements in the FSS structure. The applications of FSSs are various and several designs have been reported in literature for different purposes including microwave ovens, radome antennas, electromagnetic signal shielding ,...etc. In [2], a transparent FSS is proposed for microwave oven front door to prevent leakage of high power electromagnetic waves. Large structures of FSSs with curved geometries are used in antenna radomes [3-4]. Some designs of FSSs are proposed to improve radio frequency (RF) transmission through energy saving glass in green buildings to overcome the glass attenuation of electromagnetic signals [5-6]. In some places such as hospitals, airports and places of worship such as mosques it is desired to maintain the environment free from mobile signals. For this purpose frequency selective surfaces can be used to shield the building from electromagnetic radiation from GSM sources. The FSS structures can be mounted on walls or designed on glass to achieve spatial filtering for the desired frequency. Several FSS structures have been reported in literature for the purpose of GSM shielding [7-11]. In [7] the authors proposed an FSS structure on FR-4 substrate that shields the 900, 1800 and 2100 MHz bands with minimum attenuation of 20 dB. In [8] the authors presented an FSS with double squared loop elements etched on FR-4 to block GSM 900 and 1800 bands. Similarly, dual band GSM 900 and GSM 1800 FSS structures are proposed in [9-10] but realized as wallpaper on walls for signal shielding. In [11] a FSS structure on FR-4 substrate with circular apertures is proposed for shielding of GSM 1800 downlink signals.

Furthermore, reconfigurable FSS designs have been presented for shielding where PIN diodes are added to the structures to control the FSS filtering behavior [12-13]. Other broadband shielding FSS structures have been proposed to filter out wide frequency range (i.e. 6.5-14 GHz) [14].

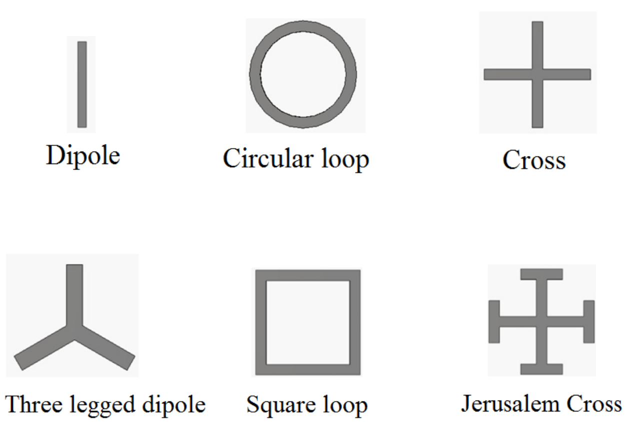

Figure 1 Unit cells of common FSS elements

The previously reported structures are for indoor use and the majoritites are designed with microstrip patches on dielectric substrates which would be impractical to shield the entire building. In this paper, we propose a novel frequency FSS structure made from copper wire cells attached together using iron metal to form the periodic structure and it does not need a dielectric substrate as the conventional structures. Each cell is fomed of double square loops and the whole periodic FSS structure is supported by iron wires that connect the loops together. To the best of the authors' knowledge, it is the first proposed FSS made of wires that can be installed outdoor to shield mobile signals at different frequency bands: GSM-900, GSM-1800 and UMTS (3G). A single cell consists of two square loops interconnected together using iron wires. The proposed FSS structure as well as simulation results will be presented next sections.

II. Structure of the FSS

The frequency selective service is designed using wire net that can be built in open areas. The signal of interest here to be blocked is the downlink frequency bands for multi cellular networks including GSM 900 downlink (925-960 MHz), GSM 1800 downlink (1805-1880 MHz) and the UMTS downlink (2110-2170 MHz).

The novel proposed single cell structure is shown in Figure 2. It is formed of double square copper loops interconnected by iron wires. The copper wires have cylindrical shape with radius r_2 with soft square corners. The iron metal is used in the design to connect the copper square cells with each other and thus supporting the whole periodic structure. The iron elements are of cylindrical shape with radius r_1. The surrounding environment of the FSS is air with dielectric constant of ε_r = 1.00059. The main feature of this design is ease of formation and convenience in installation and use in open areas. The dimensions of the FSS cell structure are given in Table 1.

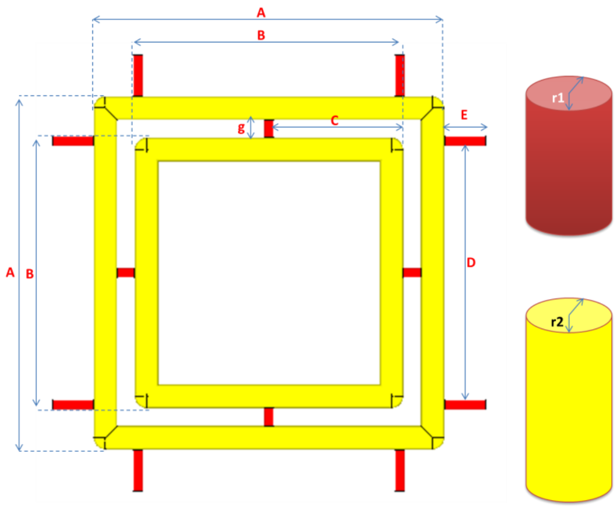

Figure 2 Single cell structure of the FSS

TABLE 1
Dimensions of the design

Parameter	A	B	C	D
Value (mm)	75.21	54.6	26.31	54.17
Parameter	E	G	r1	r2
Value (mm)	8.7	5.19	1	2.5

The whole FSS cell structure is shown in Figure 3. It is constructed of the double square loops joined together using the iron wires to form the shown periodic structure. The bandstop characteristics are achieved by optimizing the strucutre using CST simulation software [15]. The periodicity of unit cell is 92.7×92.7 mm^2. The outer square loop is tuned to 900 MHz while the inner square loop is tuned to 1800 MHz and 3G band. The diameter of the wire used to form the elements is 5 mm.

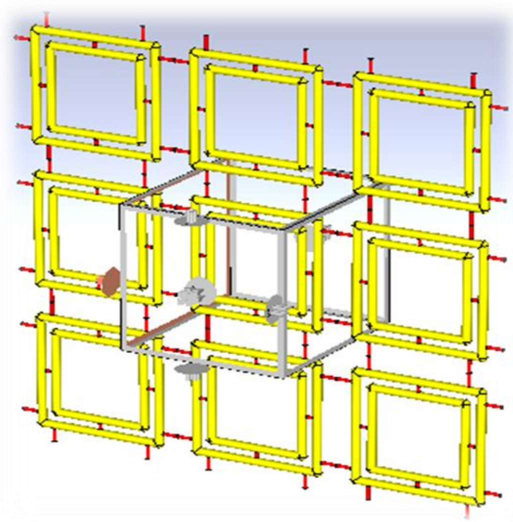

Figure 3 periodic square cells

III. Simulation Results

The transmission coefficients are obtained within the frequency range from 500 MHz to 2600 MHz for both TE and TM polarizations using CST simulation software.

In Figure 4, the transmission coefficients are presented for TE polarization for 0^0 and 30^0 angle of incidence. The resonant frequencies at 0^0 are 972.4 MHz and 1994.8 MHz, while at 30^0 the frequencies are 965.2 MHz and 1973.2 MHz respectively. The corresponding transmission coefficients are -55.4 dB, -58.1 dB at 0^0, and -54 dB, -59.7 dB at 30^0. The shift in resonant frequency from 0^0 to 30^0 is about -7.2 MHz at 900 MHz. and -21.6 MHz at 1800 MHz/3G bands. This shows that the proposed FSS has a stable frequency response as the angle of incidence varies from 0^0 to 30^0.

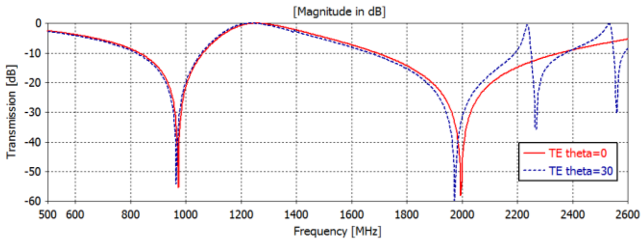

Figure 4 Simulation results of tri-bandstop FSS for TE polarization

In Figure 5, the transmission coefficients are presented for TM polarization for 0^0 and 30^0 angle of incidence. The resonant frequencies at 0^0 are 972.4 MHz, 1994.8 MHz, while at 30^0, these are 990.4 MHz, 1926.4 MHz. The corresponding transmission coefficients are -52.5 dB, -58.7 dB at 0^0, and -52.4 dB, -57.5 dB at 30^0, respectively. The shift in resonant frequency from 0^0 to 30^0 is about 18 MHz at 900 MHz, and -68.4 MHz at 1800 MHz/3G bands. This shows fair stability in frequency for the TM polarization as the angle of incident is varied from 0^0 to 30^0. Therefore, it can be seen that the FSS response is sufficiently stable for both TE and TM polarizations as the angle of incidence is varied from 0^0 to 30^0.

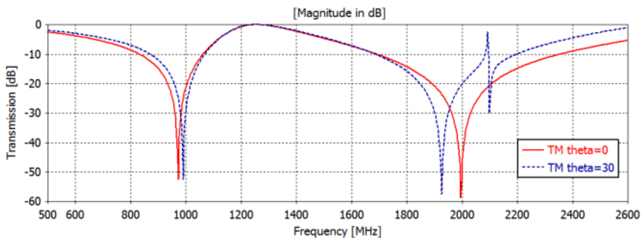

Figure 5 Simulation results of tri-bandstop FSS for TM polarization

Figure 6 shows that the resonant frequencies are stable over TE and TM polarizations when the angle of incidence is 0^0. However, when the angle increases to 30^0 the resonant frequencies shift by 25.2 MHz at band 900MHz, and shift by 46.8 MHz at band 1800/3G, as depicted in Figure 7. Tables 2 and 3 summarize the simulation results for both TE and TM polarizations, respectively, and show the -10 dB transmission bandwidth at each frequency band.

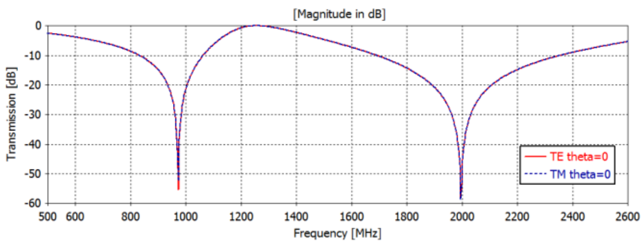

Figure 6 TE and TM polarization at theta=0

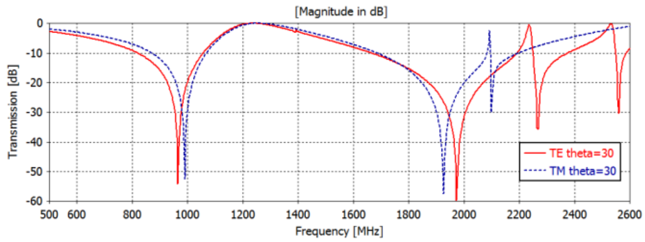

Figure 7 TE and TM polarization at theta=30.

Table 2 summarizes the simulation results for TE polarization and presents the -10 dB bandwidth for each particular frequency band. Similarly, Table 3 presents the results for the TM polarization. It can be shown that the achieved -10 dB bandwidth is satisfies the system rquirements and thus blocking the signals of interest can be achieved.

TABLE 2

-10 dB transmission bandwidths at 900/1800 MHz and 3G Band for TE polarization

	900 MHz	
Angle	Resonant frequency fr1 (MHz)	Bandwidth BW (MHz)
TE 0^0	972.4	225.3
TE 30^0	965.2	226.4
	1800 MHz/3G	
Angle	Resonant frequency fr2 (MHz)	Bandwidth BW (MHz)
TE 0^0	1994.8	639.8
TE 30^0	1973.2	503

TABLE 3

-10 dB transmission bandwidths at 900/1800 MHz and LTE Band for TM polarization

	900 MHz	
Angle	Resonant frequency fr1 (MHz)	Bandwidth BW (MHz)
TM 0^0	972.4	221
TM 30^0	990.4	186
	1800 MHz/3G	
Angle	Resonant frequency fr2 (MHz)	Bandwidth BW (MHz)
TM 0^0	1994.8	626
TM 30^0	1926.4	478

IV. Conclusion

A frequency selective surface is presented in this paper to shield mobile signals: GSM 900, GSM 1800 and UMTS (3G) in outdoor areas. The FSS structure is formed of double square wire loops connected together using iron wires. The simulation results for both TE and TM polarizations showed stable frequency response as angle of incidence is changed from 0^0 to 30^0.

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