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Research Article

Dual-band Frequency Selective Surface Design for GSM Shielding Applications

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Abstract

Global Mobile Communications (GSMs) systems have been developed very rapidly over the past decades. Mobile phone base stations are located almost everywhere nowadays. However, there is a deep concern about the health associated risks of electromagnetic radiation of GSM signals. Unwanted interference between GSM systems and electronic devices is another important issue to be considered. Transforming building surfaces to frequency selective filters is an efficient solution approach to decrease RF exposure levels inside the buildings and to prevent unwanted interference. As a solution approach, single-layer frequency selective surface (FSS) geometry is proposed in this work, which reflects 900 MHz, 1800 MHz and 2100 MHz GSM frequency bands. 1800 MHz and 2100 MHz GSM bands are considered as a single frequency band in this work since they are very close to each other. Ansoft HFSS software is used for simulation, design, and optimization purposes. The equivalent circuit model is also utilized at the design and optimization stages. Achieved results show that proposed FSS element geometry has a stable frequency response up to 60 degrees of incidence angle with minimum of 10 dB attenuation.

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Öz

Global Mobil İletişim (GSM) sistemleri son yıllarda çok hızlı bir şekilde gelişmiştir. Baz istasyonları günümüzde hemen hemen her yerde bulunmaktadır. Cep telefonları ve baz istasyonlarından yayılan elektromanyetik radyasyonun sağlığa olan olumsuz etkileri önemli bir tartışma konusudur. GSM sistemlerinden kaynaklanan istenmeyen girişim dikkate alınması gereken bir diğer önemli konudur. Bina yüzeylerinin frekans seçici filtrelere dönüştürülmesi, bina içindeki GSM sinyal seviyelerini azaltmak ve istenmeyen girişim etkilerinden korunmak açısından önemli bir çözüm yaklaşımıdır. Bu çalışmada, 900 MHz, 1800 MHz ve 2100 MHz GSM frekans bantlarını yansıtan tek katmanlı frekans seçici yüzey (FSS) tasarımı anlatılmaktadır. 1800 MHz ve 2100 MHz GSM bantları birbirlerine çok yakın olmaları sebebi ile tek bir frekans bandı olarak ele alınmıştır. Ansoft HFSS programı ve eşdeğer devre modelinden tasarımların benzetim ve eniyileme aşamalarında yararlanılmıştır. Elde edilen sonuçlar, önerilen FSS geometrisinin minimum 10 dB zayıflama ile 60 derecelik bir geliş açısına kadar kararlı bir frekans cevabına sahip olduğunu göstermektedir.

1. INTRODUCTION

Global Mobile Communication (GSM) systems have been developed very rapidly over the past decades and their usage has become quite widespread. However, there is a deep concern about health-associated risks of electromagnetic radiation of GSM signals [1, 2]. Besides, electromagnetic interference (EMI) which is radiated from GSM systems has become a serious threat to electronic devices, especially in hospitals [3]. Faraday cage or metal foil can be used for reflective shielding against electromagnetic radiation from GSM cell base stations and phones. However, complete opaqueness for broadcast frequencies and obligatory grounding measures are two main disadvantage issues. The usage of frequency selective surfaces (FSS) which blocks the transmission of undesirable GSM signals can be utilized as a good solution to prevent interference and decrease the health associated risks [4]–[10]. FSSs are periodic conducting surfaces that are designed to reflect, transmit, or absorb electromagnetic waves upon them [11, 12, 13]. They have been used in many applications such as interference mitigation between adjacent wireless systems and devices, in microwave absorbers, in radomes and antennas for performance increments, as artificial magnetic conductors etc. [11].

The aim of this work is to design a novel FSS that reflects the downlink 900 MHz (923 - 960 MHz), 1800 MHz (1808 - 1880 MHz) and 2100 MHz (2110 - 2170 MHz) GSM frequency bands and allows the transmission of other frequencies. 1800 MHz and 2100 MHz GSM bands are considered as a single frequency band in this work since they are very close to each other. Simulation and optimization processes are performed by Ansoft HFSS v.19.2 software. The equivalent circuit model (EC) is utilized efficiently in design and optimization stages to obtain the relationship between the FSS parameters and their frequency responses [14, 15, 16].
Although multi stop-band FSSs are heavily investigated, there are not too much work that stops all the 900 MHz, 1800 MHz, and 2100 MHz GSM frequency bands. Modified square loops in a 3-layered cascaded structure in [4] and a synthetic resonator in a single-layer structure in [5] are used to achieve tri-band frequency response for GSM shielding. Penta-band stop FSS, which stops GSM, GPS, Bluetooth/Wi-Fi, Wi-MAX, and WLAN frequency bands is proposed in [9]. The penta-band FSS unit cell consists of a square patch surrounded by five thin modified rectangular rings. An FSS design which have circular holes on its substrate for ventilation is described for shielding the GSM 1800 MHz downlink band in [17]. Double square loop and double ring FSS geometries are used in [18], nested square-loop geometries are used in [19] to shield 900 MHz and 1800 MHz GSM bands. A compact tunable metasurface for dual-band electromagnetic interference shielding is proposed for the 900 MHz and 1.8 GHz GSM bands in [20].
In order to achieve a small unit cell dimension, meandering of the excited metal patch of FSS is considered in this work [21]. Proposed FSS performs a miniaturization characteristic with a unit cell size of $0.17\lambda_0 \times 0.17\lambda_0$, where the λ_0 represents the free space wavelength of the lower resonance frequency. More important, the proposed FSS exhibits a stable frequency response up to 60^0 for TE and TM polarization. In the proposed design, the 1800-2100 MHz frequency band is considered as a single frequency band to stop. There is no similar work in the literature that stops 1800 MHz, 2100 MHz GSM bands as a single wide frequency band while stopping the 900 MHz GSM band.
The inner geometry of nested geometries stops the higher frequency band and generally has smaller dimensions. Therefore, achieved attenuation levels in the higher frequency bands are generally less than the lower frequency bands. The main challenge encountered during the design and optimization phases of the proposed FSS geometry is to stop the entire second frequency band (1800-2100 MHz). The contribution of this work is a dual-band FSS geometry design whish stops 900 MHz and 1800-2100 MHz GSM bands. There is no similar dual-band FSS design in literature which stops all the 900 MHz, 1800 MHz and 2100 MHz GSM bands.
This paper is organized as follows. Section II describes the design steps and presents the simulation and measurement results. Section III discusses the results.

2. DESIGN & MEASUREMENT

As concluded from Singh, Najim, Agarwala & Varma's studies [10], square loop FSS geometries provide better control over the resonant frequency among other common FSS geometries such as hexagonal and circular. This study [10] focuses on aperture structures, however, the information gained from this study can also be used on patch geometries since they are complementary to each other both physically and electromagnetically. Therefore, at the initial stage of the proposed design, two nested square loop geometries are used to control 900 MHz and 1800-2100 MHz GSM frequency bands by using outer and inner geometries, respectively.

In this work, EC model is utilized to find out the relationship between FSS geometries and their frequency responses. An EC model of a dual stop-band FSS structure having two different periodic element geometries is shown in Figure 1. Each geometry of the FSS structure acts as a reflector for the desired GSM frequency bands and can be modeled by a serial LC circuit. M is a mutual inductance between geometries and Z_o is the free space characteristic impedance. As shown in Figure 2 equivalent capacitance ($C \propto \frac{w}{g}$) is defined by the width of the gap (w) and the gap (g) between periodic element geometries, while equivalent inductance ($L \propto \frac{d}{w}$) is defined by the length (*d*) and the width (*w*) of the current path. Resonance bandwidth (*BW*) of series LC circuits is proportional to $BW \propto \frac{C}{L}$.

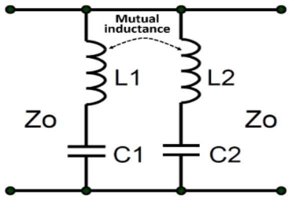


Figure 1. EC model of a dual stop-band FSS

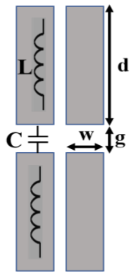


Figure 2. A sample FSS and its EC parameters

Equivalent impedance of FSS can be derived from the circuit model given in Figure 1 as,

$$Z = \frac{(1 - w^2 L_1' C_1)(1 - w^2 L_2' C_2)}{jw(C_1 + C_2 - w^2 C_1 C_2 (L_1' + L_2'))} \quad (1)$$

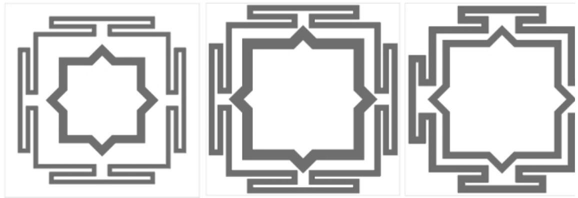
$$L_1' = L_1 - M,\ L_2' = L_2 + M.$$

It is obvious that FSS behaves as a metal wall when the impedance Z approaches to zero and as a result, the resonance frequencies of the FSS are derived as:

$$f_{01} = \frac{1}{2\pi\sqrt{L_1' C_1}}\ , f_{02} = \frac{1}{2\pi\sqrt{L_2' C_2}}. \quad (2)$$

Unit cell sizes of FSS geometries should be kept minimum to have stable angular frequency response [11]. This purpose can be achieved by bending the edges of square loop geometries in ways that would increase the circumference greatly while not increasing its area too much. The distance between neighboring inner geometries (square loop) should also be kept minimum for stable frequency response. Therefore, outer geometry should be bent more than the inner geometry so that the gap between the inner and outer geometries would be less which in turn would prevent the inner geometries of two neighboring unit cells from being too far from each other.

In conclusion, at the first design stage (Figure 3(a)), rectangular shapes are added to each of the edges of the outer structure which increases the outer structure's circumference greatly while not affecting its area too much. The middle of the edges of the inner structure are bent into "V" shapes which doesn't increase the circumference too much. The simplest way of achieving the minimal circumference with maximum area would be having the inner structure as just a regular square, however the "V" shape's perpendicular length provides us with an extra parameter which is useful while optimizing our design. Simulations are performed by Ansoft HFSS v.19.2 software and the results are shown in Figure 4 for TE (Transverse Electric) polarization.



(a) Stage 1 (b) Stage 2 (c) Stage 3

Figure 3. Design stages

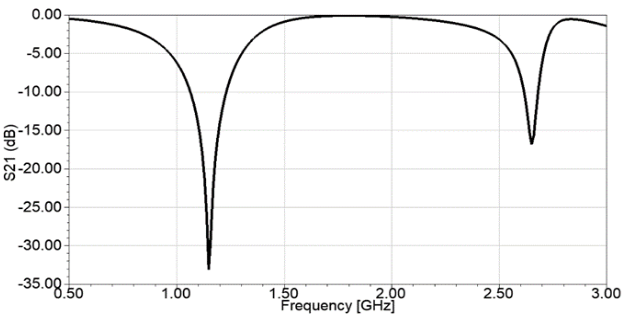


Figure 4. S_{21} frequency curve of the 1st design stage (TE polarization, $\theta=0^0$)

When the results in Figure 4 are analyzed, it is seen that both resonance frequencies are higher than the targeted resonance frequencies and should be lowered. Besides, achieved attenuation (S_{21}) and bandwidth of the second stop-band are quite low since it is supposed to attenuate signals between 1805 to 2170 MHz by at least -10 dB. At the second design stage, in order to decrease the second resonance frequency, outer geometry circumference is increased in a controlled manner. Equivalent inductance is increased with the increase of outer geometry circumference ($L \propto \frac{\mathbf{d}}{w} : \boldsymbol{d}\ is\ increased$) and resonance frequency decreases according to the Eqn. 2. Meanwhile, the thickness of the inner conductor is increased to increase both the achieved bandwidth and the attenuation level. Equivalent inductance is decreased with the increase of thickness ($L \propto \frac{\mathrm{d}}{\boldsymbol{w}} : \boldsymbol{w}\ is\ increased$) and as a result bandwidth of the higher stop-band increases ($BW \propto \frac{C}{L}$). Increasing the thickness also increases the resonance frequency of the second stop-band. Therefore, the circumference of the inner conductor is also increased as much as possible without intersecting with the outer conductor, as can be seen in Figure 3(b).

According to the simulation results shown in Figure 5, the increase of path thickness (Figure 6: *t2*) of the inner geometry both increases the bandwidth and attenuation level of the second stop-band to the desired levels. However, it can also be observed that the 1st resonance frequency is decreased too much while 2nd resonance frequency is not decreased at the desired level.

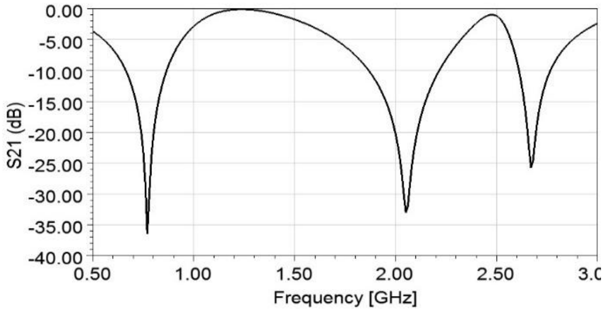


Figure 5. S_{21} frequency curve of the 2nd design stage (TE polarization, θ=0^0)

At the third design stage (Figure 3(c)), in order to decrease the 2nd resonance frequency, inner geometry thickness can be decreased or its circumference can be increased even more. If the path thickness (*th2*) is decreased too much, its bandwidth would again fall under the desired level. The circumference of the inner geometry should also be increased. However, increasing the circumference, even more, would cause overlapping with the outer conductor. However, the outer conductor's circumference should be decreased since the resonance frequency was decreased more than desired.

In order to fit a bigger inner conductor inside the outer conductor and decrease the outer conductor's circumference at the same time, parameters of outer conductor parameter values should be adjusted. Decreasing the '*c*' parameter (Figure 6) by a small amount causes a big decrease in the total circumference of the outer conductor since it is used 16 times in outer geometry. As a result, the '*e*' parameter can be freely increased now. Once the '*e*' parameter is increased, '*f*' can also be increased, which will increase the circumference of the inner conductor. Also increasing the path thickness of outer geometry will also be ideal since it would increase 1st resonance frequency.
Proposed final FSS geometry and its dimensions are depicted in Figure 6. The thickness of the FR4 substrate (*h*) is 1mm. Other dimensions (in mm) are *a* = 3, *b* = 5, *c* = 7, *e* = 41, *f* = 33, *g* = 4, *p* = 57, *th1* = 2, *th2* = 2 and *gap* = 1.

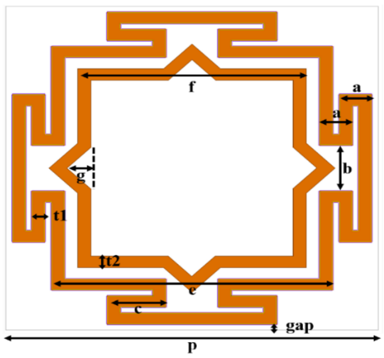


Figure 6. Proposed FSS geometry and its parameters

Figure 7-8 shows the obtained transmission (S_{21}) coefficient results for 0^0, 30^0, and 45^0 of incidence angles with respect to FSS surface normal (θ) for both TE (Transverse Electric) and TM (Transverse Magnetic) polarizations respectively. The percentages of achieved stop-bandwidths ($S_{21} < -10$dB) are shown in Table 1 for the desired GSM frequency bands. As the incident angle increases at TM polarization, achieved stop-bandwidths decreases due to the less induction of current on the conducting geometries of FSS [11]. According to the achieved results, the desired frequency response is almost obtained for oblique incidence angles from normal to 60^0 for all polarizations. Performance comparison of the proposed design with some of the existing designs is shown in Table 2.

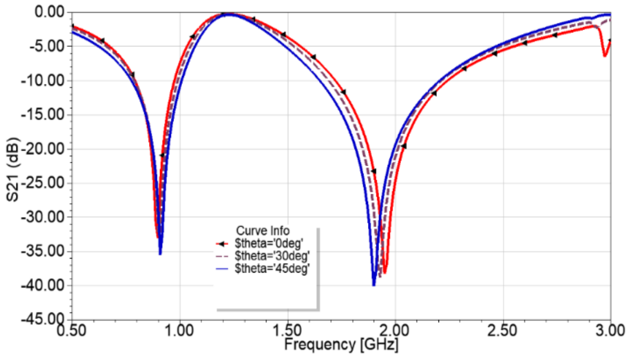


Figure 7. S_{21} frequency curves of the proposed FSS design (TE polarization, θ=0^0, 30^0 and 45^0)

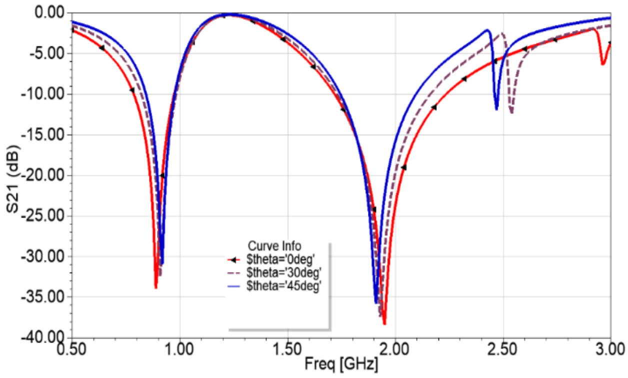


Figure 8. S_{21} frequency curves of the proposed FSS design (TM polarization, θ=0^0, 30^0 and 45^0)

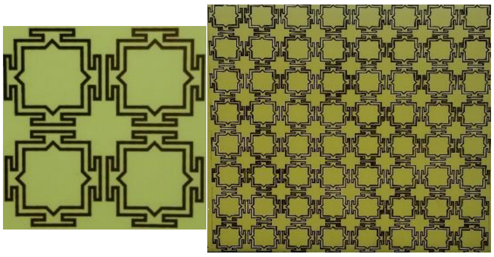
Table 1. The percentages of obtained stop-bandwidths of FSS (θ =Incidence angle (degrees), BW= Bandwidth (S_{21}<-10dB), P: Polarization

P	θ	900MHz	1800 - 2100MHz	P	900MHz	1800 - 2100MHz
TE	0	100%	100%	TM	100%	100%
TE	15	100%	100%	TM	100%	100%
TE	30	100%	100%	TM	100%	%98
TE	45	100%	100%	TM	100%	%80
TE	60	100%	100%	TM	100%	%62
TE	70	100%	100%	TM	100%	%48

Table 2. Performance comparison of the proposed design with some of the existing designs. θ = Angular stability (incidence angle: degrees), P= Periodicity (mm), L= Number of layers, ND= No data

Reff.	L	Mobile Bands	P	θ
Curr.	1	900 and 1800-2100 MHz	57	45
[4]	1	900, 1800, and 2100 MHz	46	45
[5]	3	900, 1800, and 2100 MHz	32.57	60
[22]	1	900, 1800, and 2100 MHz	50	45
[19]	1	900 and 1800 MHz	45	ND

The measurements for the fabricated prototype (Figure 9) were performed by Rohde & Schwarz R&S®FSH8 model network analyzer and with two Vivaldi antennas. A thru calibration was performed to calibrate the network analyzer in the absence of the FSS. Both antennas were at the same height and located on the line-of-sight direction. Measurement results are shown in Figure 10 and 11.



(a) (b)

Figure 9. (a) 4 × 4 array from the prototype of FSS. (b) Prototype of FSS

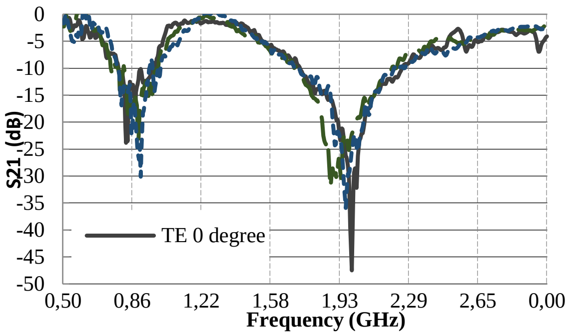


Figure 10 S_{21} frequency curves of the proposed FSS design (TE polarization, θ=0^0, 30^0 and 45^0)

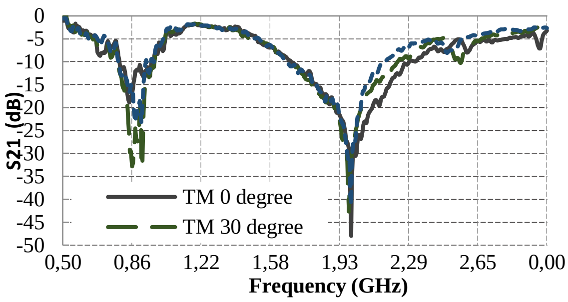


Figure 11. S_{21} frequency curves of the proposed FSS design (TE polarization, θ=0^0, 30^0 and 45^0)

It is observed that measured results are below -10 dB for the desired frequency band. Some ripples and frequency shifts are also observed between measurement and simulation results. Fabrication errors of the prototype, the finite size of the prototype (456 x 456 mm), and existing GSM signals in the measurement environment should be attributed to the frequency shift and ripples. Furthermore, the finite size of the prototype allows diffraction at the edges, especially at the low frequency signals. Therefore, achieved measurement attenuations (S_{21}) in the 900 MHz GSM band are generally less than simulation results, unlike the 1800-2100 MHz GSM band.

3. CONCLUSION

In this work a novel dual-band FSS geometry design is introduced to stop the 900 MHz, 1800-2100 MHz GSM frequency bands. The 1800-2100 MHz GSM frequency band which is quite wide compared to 900 MHz GSM band is successfully stopped with the use of closely placed nested geometries. There is no similar dual-band FSS design in literature which stops all the 900 MHz, 1800 MHz and 2100 MHz GSM bands. Desired attenuation values (S_{21}<-10 dB) are obtained in a range of oblique incidence angles from normal to 60^0 (expect TM 45^0 and 60^0) for all polarizations. Thickness of the proposed FSS is only 1mm which gives us a compact design.

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VITAE

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