Compact Spatial Triple-Band-Stop Filter for Cellular/PCS/IMT-2000 Systems

Dongho Kim, Junho Yeo, and Jaeick Choi

ABSTRACT— We propose a novel spatial multi-band-stop filter using modified multiple loop array elements to block electromagnetic waves or signals of mobile phones in public facilities. It operates at the following frequency bands: Korean cellular (824 MHz to 894 MHz), Personal Communication Service (PCS) (1.75 GHz to 1.87 GHz), and IMT-2000 (1.92 GHz to 2.17 GHz). Two frequency selective surfaces with modified multiple-loop elements are printed on the top and bottom of a pair-glass pane, which is a pair of glass panes with an air gap between them. A modified multiple-loop element with a meander line is used to make the size of the filter compact. The simulated and measured results show good agreement, which confirms the usefulness of the proposed tri-band spatial filter.

Keywords—Frequency selective surface (FSS), spatial filter, multi-band-stop filter.

I. Introduction

Frequency selective surfaces (FSSs) have been widely used in many areas of microwaves and optics, such as dichroic surfaces of reflector antennas in frequency reuse systems, spatial angular filters, antenna radomes, and so on [1], [2]. These surfaces are one- or multi-dimensional periodic structures of resonant elements and perform a filter operation depending on their unit cell geometry and constructing materials. For multi-band operation, multi-layered FSSs or a single FSS layer with multiple resonant elements have been used [3], [4].

In recent years, as the use of mobile phones has become widespread, the noise created by the use of mobile phones in public buildings, such as libraries or concert halls, has become a social issue in Korea. To solve this problem, electromagnetic waves or signals can be blocked between base stations and mobile phones in these facilities by installing an FSS-type spatial band-stop filter on the walls, windows, or other openings. As shown in Fig. 1, this type of spatial filter also can be used for houses or apartments near base stations or used as compartments inside offices to protect workers from excessive exposure to ambient electromagnetic energy.

In this letter, we present a compact multi-band-stop filter operating at the following bands: Korean cellular (824 MHz to 894 MHz), Personal Communication Service (PCS) (1.75 GHz to 1.87 GHz), and IMT-2000 (1.92 GHz to 2.17 GHz). It uses a novel FSS structure, which can be placed on the windows of public facilities, to block electromagnetic waves at these three bands.

One of the most important parameters in designing FSSs is the size of a unit cell because installation space for FSSs is usually limited. To increase the number and the effective length

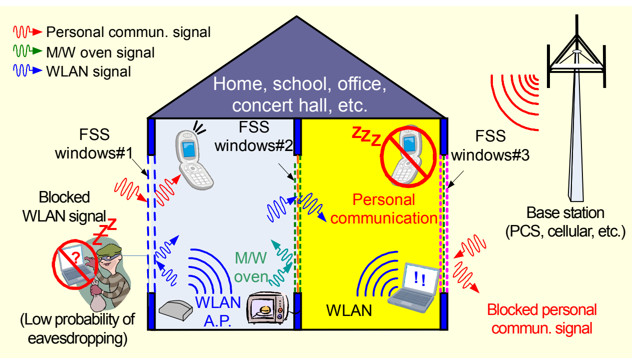

Fig. 1. Potential applications of the proposed spatial filters on building windows or walls.

Manuscript received May 28, 2008; revised June 30, 2008; accepted Aug. 5, 2008.

Dongho Kim (phone: + 82 42 860 6575, email: dhkim@etri.re.kr) and Jaeick Choi (email: jichoi@etri.re.kr) are with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

Junho Yeo (email: jyeo@daegu.ac.kr) is with the School of Computer & Communication Engineering, Daegu University, Daegu, Rep. of Korea.

of the FSS unit cell in a limited space, modified multiple loops with meander lines are used. This is based on the space-filling concept used in [5].

Commercial software of Ansoft HFSS is used to obtain all predicted data, and comparison between the measured and simulation data shows good agreement.

II. FSS Filter Design and Experiment

The structure of a unit cell of a proposed three-layer FSSs placed on a pair-glass pane is shown in Fig. 2. Most windows of modern buildings are made of large pair-glass panes, which comprise two glass panes with an air gap between them to reduce heat emission and to block environmental noise. In this regard, two FSSs with modified multiple-loop elements are printed on the top and bottom sides of the pair-glass pane. The optimized parameters to cover the three stop-bands, namely,

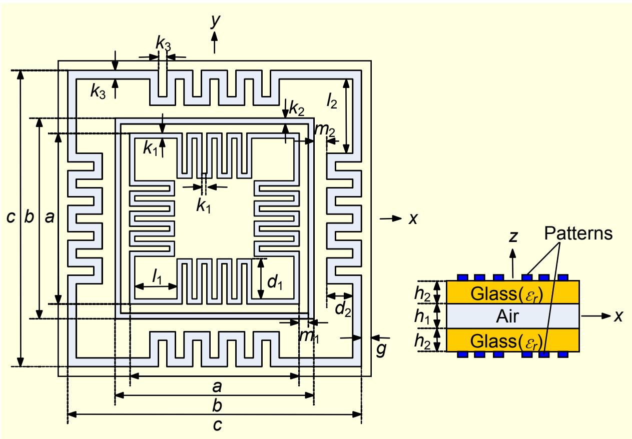

Fig. 2. Structure of the proposed FSS structure with a=18.82 mm, b=21.96 mm, c=32 mm, d_1=4.43 mm, d_2=2.82 mm, g=1 mm, k_1=0.55 mm, k_2=0.61 mm, k_3=0.94 mm, l_1=4.71 mm, l_2=8 mm, m_1=0.96 mm, m_2=1.26 mm, h_1=6 mm, and h_2=5 mm.

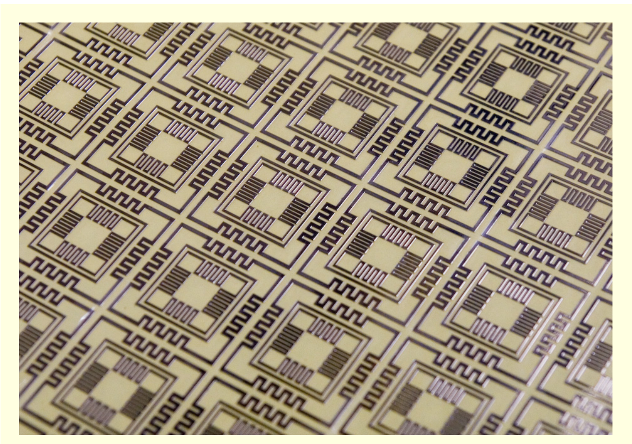

Fig. 3. Photograph of the fabricated FSS patterns.

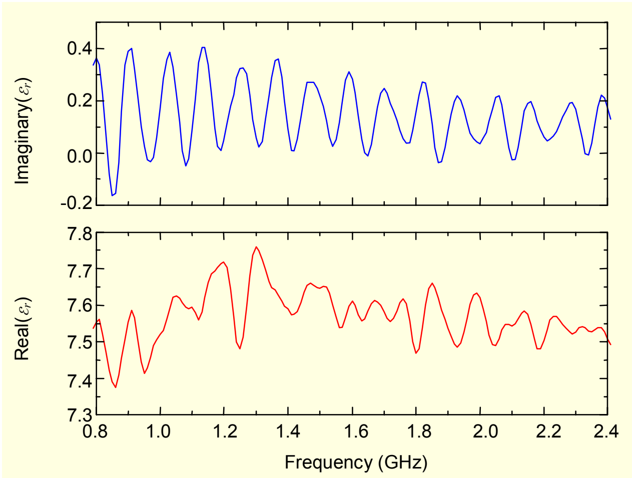

Fig. 4. Measured complex permittivity of glass used for a pair-glass pane.

cellular, PCS, and IMT-2000, are given in Fig. 2. The multiple-loop elements are realized with conductive aluminum patterns, and Fig. 3 shows a photograph of a fabricated FSS structure. The pair-glass pane consists of two 5 mm thick glass panes with an air gap of 6 mm; therefore, the total thickness of the pair-glass pane is 16 mm. This thickness was chosen because it is the thickness most commonly used in Korea for windows.

For simulation, the complex permittivity of the glass used for the pair-glass was measured by using the Agilent 85070D dielectric probe kit. The real and imaginary parts of the complex permittivity of the glass are presented in Fig. 4. Based on the measured results, the real and the imaginary parts of the permittivity used for the simulation were chosen to be 7.5 and 0.1, respectively, which correspond to average values over the frequency bands of interest. The unit cell of the FSS is a variation of multiple-loop elements consisting of three loops. Since the PCS and IMT-2000 bands are separated by just 50 MHz, these two bands are considered one wide band (1.75 GHz to 2.17 GHz) and we have tried to design a dual-band stop filter covering 824 MHz to 894 MHz and 1.75 GHz to 2.17 GHz. In this regard, a dual-band stop FSS with inner and outer square loop elements was first designed. The inner and the outer loop elements were modified by replacing straight lines with meander lines as shown in Fig. 2 to reduce the size of the unit cell. The simulated transmission characteristic of the FSS without the center square loops for normal incidence is shown in Fig. 5. It can cover the cellular band, but not the PCS and IMT-2000 bands. In fact, the second stopband is located in a lower frequency range than the PCS and IMT-2000 bands.

To shift the second stopband towards a higher frequency region and increase the bandwidth to fully cover the PCS and IMT-2000 bands, a center square loop, which has a little shorter

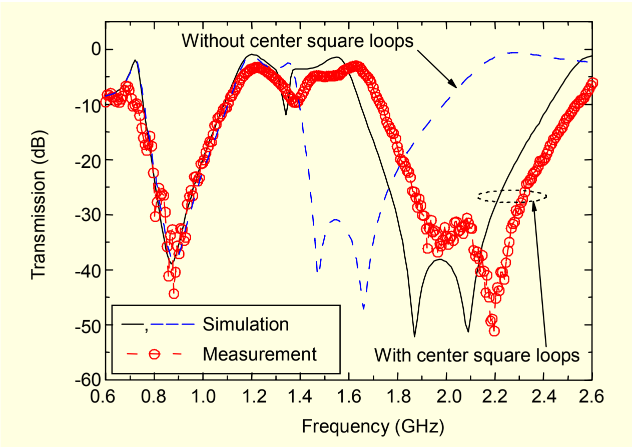

Fig. 5. Comparison of the simulated and measured transmission characteristics for normal incidence with or without center-square loops.

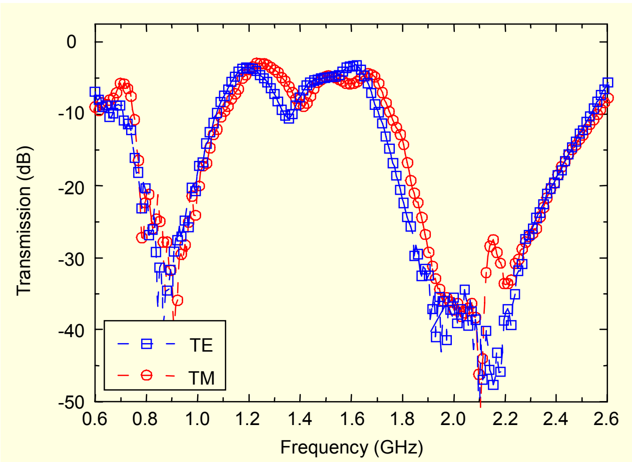

Fig. 6. Measured transmission behavior for 30°-inclined transverse electric (TE) mode and transverse magnetic (TM) mode incidences.

effective length than the inner meandered loop, is inserted between the inner and the outer meandered loops. The simulated and measured transmission characteristics of the FSS with center square loops are plotted together in Fig. 5 for comparison. The center square loop pushes up the second stopband towards a higher frequency region that can cover the PCS and IMT-2000 bands with about 1.5 times increased bandwidth, but it does not affect the first stopband. We can also see that the simulated and measured results for the FSS with center loops show some deviation in the second band. We conjecture that this is caused by the manual bonding between the FSS elements and the pair-glass. In fact, the FSS elements are fabricated as an aluminum sticker with some adhesive and these elements are cut element by element to be placed onto the pair-glass. In this process, misalignments between the two FSS layers, which are attached to the opposite surfaces of the pair-glass, might be produced. However, this can be eliminated by fabricating the FSS with an automatic manufacturing process.

Figure 6 shows the measured transmission responses for the inclined (φ=0°, θ=30°) transverse electric mode and transverse magnetic mode incidences, and the behavior is almost the same for normal and inclined incidences. This implies that the proposed spatial filter is insensitive to angular variation, which is a crucial property required for the spatial filter. The proposed multi-band-stop filter has two 20 dB attenuation bandwidths of 230 MHz and 560 MHz for normal and inclined incidences, respectively, which is easily wide enough to block all three bands.

III. Conclusion

We have proposed a novel spatial multi-band-stop filter using modified multiple-loop array elements operating at Korean cellular, PCS, and IMT-2000 frequency bands, which can be used to block electromagnetic waves of commercial mobile phones in public buildings.

Regarding the direct installation of FSSs onto pair-glass panes, our design can be considered a practical approach. Moreover, the patterns of the FSS element can be invisible if a transparent conductive material such as indium tin oxide is used. In this case, the existence of the proposed filter on the windows would not be visible and, thus would be preferable as it would not obstruct the window view.

References

[1] B.A. Munk, *Frequency Selective Surface: Theory and Design*, Wiley-Interscience, 2000.

[2] R. Mittra, C.H. Chan, and T. Cwik, "Technique for Analyzing Frequency Selective Surfaces: A Review," *IEEE Proceedings*, vol. 76, no. 12, 1988, pp. 1593-1615.

[3] D.H. Kim and J.I. Choi, "Design of a Multiband Frequency Selective Surface," *ETRI Journal*, vol. 28, no. 4, Aug. 2006, pp. 506-508.

[4] T.K. Wu, "Four-Band Frequency Selective Surface with Double-Square-Loop Patch Elements," *IEEE Trans. Antennas Propagat.*, vol. 42, no. 12, Dec. 1994, pp. 1659-1663.

[5] E.A. Parker and A.N.A. El Sheikh, "Convoluted Array Elements and Reduced Size Unit Cells for Frequency-Selective Surfaces," *IEE Proceedings*, vol. 138, no. 1, 1991, pp. 19-22.