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THE ANGLE DEPENDENT PROPAGATION CHARACTERISTICS OF A FREQUENCY SELECTIVE SURFACE APPLIED TO PLASTERBOARD

Grace H.H. SUNG, Kevin W. SOWERBY, and Allan G. WILLIAMSON
Department of Electrical and Computer Engineering, The University of Auckland
Private Bag 92019, Auckland, New Zealand
E-mail: hsun011@ec.auckland.ac.nz

Abstract

By attaching a bandstop Frequency Selective Surface (FSS) onto plasterboard, a common building wallboard is transformed into a filter which can effectively isolate an indoor wireless system from undesired external interference. An additional signal attenuation of 35 dB is obtained at the resonant frequency with 0° incidence. However, as the incident angle increases from 0° to 45°, a 1 GHz shift in resonant frequency is observed. Measurement results in the X-band show that with a correct choice of targeted stop band frequency, attenuation of at least 20dB can be maintained with incident angles ranging from 0° to 30°.

1. Introduction

The increasing use of wireless communications, especially in the unlicensed bands, can result in interference between coexisting systems. Signals propagating from one system to another both degrade service and compromise security. The problem of interference can be mitigated through the use of advanced radio hardware and signal processing, but these approaches can be very expensive. For indoor wireless systems, an alternative, or additional, technique to minimise interference is to modify the physical indoor propagation environment. A crude solution might be to surround an indoor wireless system with metallic shields. These would contain desired signals and exclude cochannel interfering signals, but would also exclude all other frequencies and their associated services e.g. broadcast radio and TV, and cellular telephone transmissions. A better solution would be to architecturally modify each building wall to create a filter (known as a *frequency selective surface* (FSS)) with a stop-band in the range of the service it is desired to contain. (See Figure 1.)

In indoor environments signals are incident on wall surfaces at various angles. Ideally the frequency selectivity of a wall will be independent of this angle. However, such independence cannot be achieved easily and is the ultimate objective of the research reported in this paper. In particular, this paper investigates the dependency of a FSS's response to angle of incidence, and concerns the development of techniques for modifying existing building materials so that they exhibit desirable frequency selective properties.

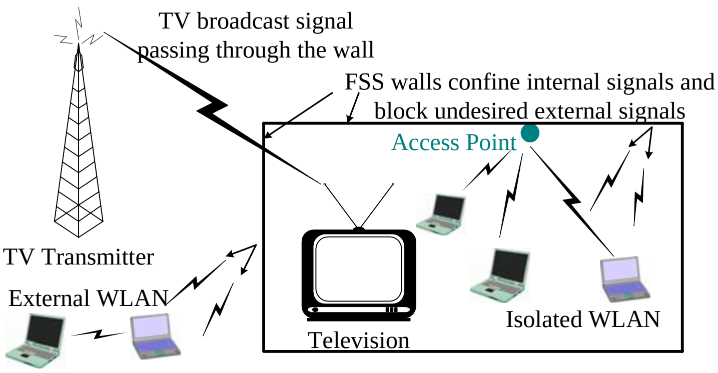

Figure1. An ideal frequency selective wall

A simple modification technique is to apply a frequency selective covering to existing building walls; therefore we are particularly interested in the combined frequency selective properties of standard building materials and specific FS coverings. In this research, a well known band-stop square loop FSS is applied to *Gib Board*, a common plasterboard building material. Signal transmission through the FSS alone and through the combined structure have been measured at X-band frequencies (8.2 GHz ~ 12.4 GHz) with different angles of incidence. Section II outlines the experimental measurements that generated the results presented in Section III. The effectiveness of a FS covering is observed and the sensitivity of the frequency response to incident illumination angle is quantified. Section IV concludes the study and suggests further research.

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2. Measurement Setup

The impact of applying a square loop FSS to one surface of Gib Board has been examined by measuring the attenuation of signals passing through it. The effect of different illumination angles on the FSS's performance has also been examined by rotating the pair of transmitting and receiving antennas. The X-band was chosen for initial investigation, however the measurement procedures can also be applied to other frequencies.

Frequency Selective Surfaces and construction materials

Frequency Selective Surfaces (FSSs) have been used in military applications, antennas, radar and satellite communications for many years [1]. FSSs behave like a filter, where the frequency response is dependent on the surface's element pattern. A well-studied element geometry is the *square loop* conducting pattern shown in Figure 2, which has a band-stop response with the resonant frequency dependent on the elements' dimensions and spacing. At normal incidence (angle of incidence = 0°), a frequency selective layer can be represented by an equivalent circuit model, with inductance and capacitance calculated from a simplified approximation [2, 3, 4]. With this equivalent circuit and using a transmission line analogy, the transmission and reflection coefficients of the FSS can be calculated easily. A square loop, band-stop FSS (60cm x 60 cm) with its resonant frequency at 11GHz was constructed using aluminium tape, with p = 16 mm, g = 4 mm, d = 12 mm, and s = 2 mm.

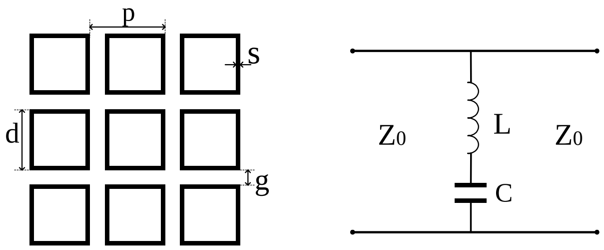
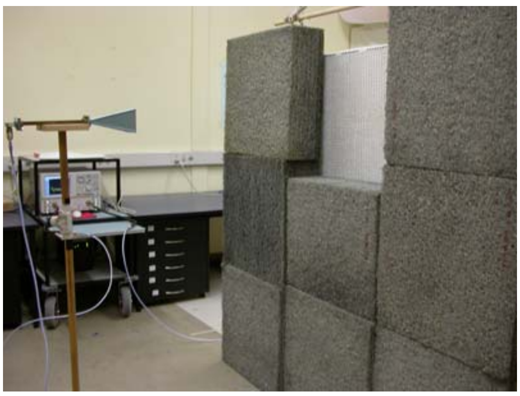


Figure 2. Square loop FSS and the approximate equivalent circuit

Experimental procedures

The freespace propagation approach [5] was used in this study with two X-band horn antennas connected to an Agilent E8374A PNA network analyser. (Measurements made with one open-ended waveguide and one horn antenna also yield the same result.) As shown in Figures 3 and 4, the sample under test was placed between the two horn antennas, while the network analyser measured the S_{21} parameter (i.e. the signal voltage received at the receiver relative to the signal voltage transmitted). The path gain due to the insertion of the sample can be determined by normalising the S_{21} value with the sample present to the S_{21} value with no material placed between the two antennas (i.e. Line Of Sight). This also yields the sample's transmission coefficient. Each antenna was placed 70 cm from the material to avoid near field effects. In order to eliminate unwanted diffraction and reflection, time-domain gating was applied to each measurement. In addition, the 60 cm square sample was surrounded by microwave absorbing material to prevent edge diffraction.



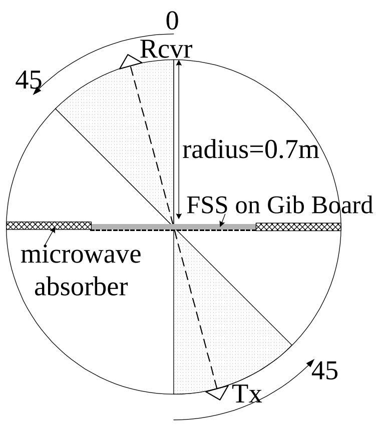


Figure 3. Laboratory measurement setup.

Figure 4. Plan-view of incident angle measurements

Three different samples were measured: (1) 13 mm thick Gib Board; (2) the square loop FSS in air; (3) the square loop FSS attached to the front surface of the Gib Board. For each sample, measurements were recorded for a range of incident angles. This was achieved by rotating the pair of antennas from 0° to 45°, in 15° steps, as shown in Figure 4. The effect of illumination angle on the frequency selective performance of the test material was observed.

3. Results and discussion

If one side of a FSS is backed by a dielectric substrate that is greater than 0.05 dielectric wavelengths (λ_{ε}) the dielectric slab will behave with an effective permittivity $\varepsilon_{eff} = (\varepsilon_r + 1)/2$, which affects the capacitive impedance value of the equivalent circuit shown in Figure 2 [1]. Measurements show that Gib Board's relative permittivity (ε_r) is approximately 2.26 - 0.03i, hence the ε_{eff} of the FSS on Gib Board is approximately 1.63 - 0.015i. Using this ε_{eff} value in an equivalent circuit analysis, the simulated frequency response for the FSS on Gib Board is plotted in Figure 5(a) along with the actual measured results. A clear band-stop response is observed with the resonant frequency around 9.2 GHz, as expected. At the resonant frequency, the frequency selective covering increases the attenuation of the Gib Board by about 35dB. Outside of the stop-band, the additional attenuation caused by the FSS is in the order of 10dB. These contrasting levels of attenuation would normally be sufficient to provide the isolation required for interference free indoor wireless operation without excluding external wireless services at other frequencies. Figure 5(a) shows good agreement between the theoretical model (based on a simplified equivalent circuit) and the actual measurements. However, this model is only valid for 0° incidence; for oblique angles of incidence, significant shifting of the resonant frequency was observed in measurements.

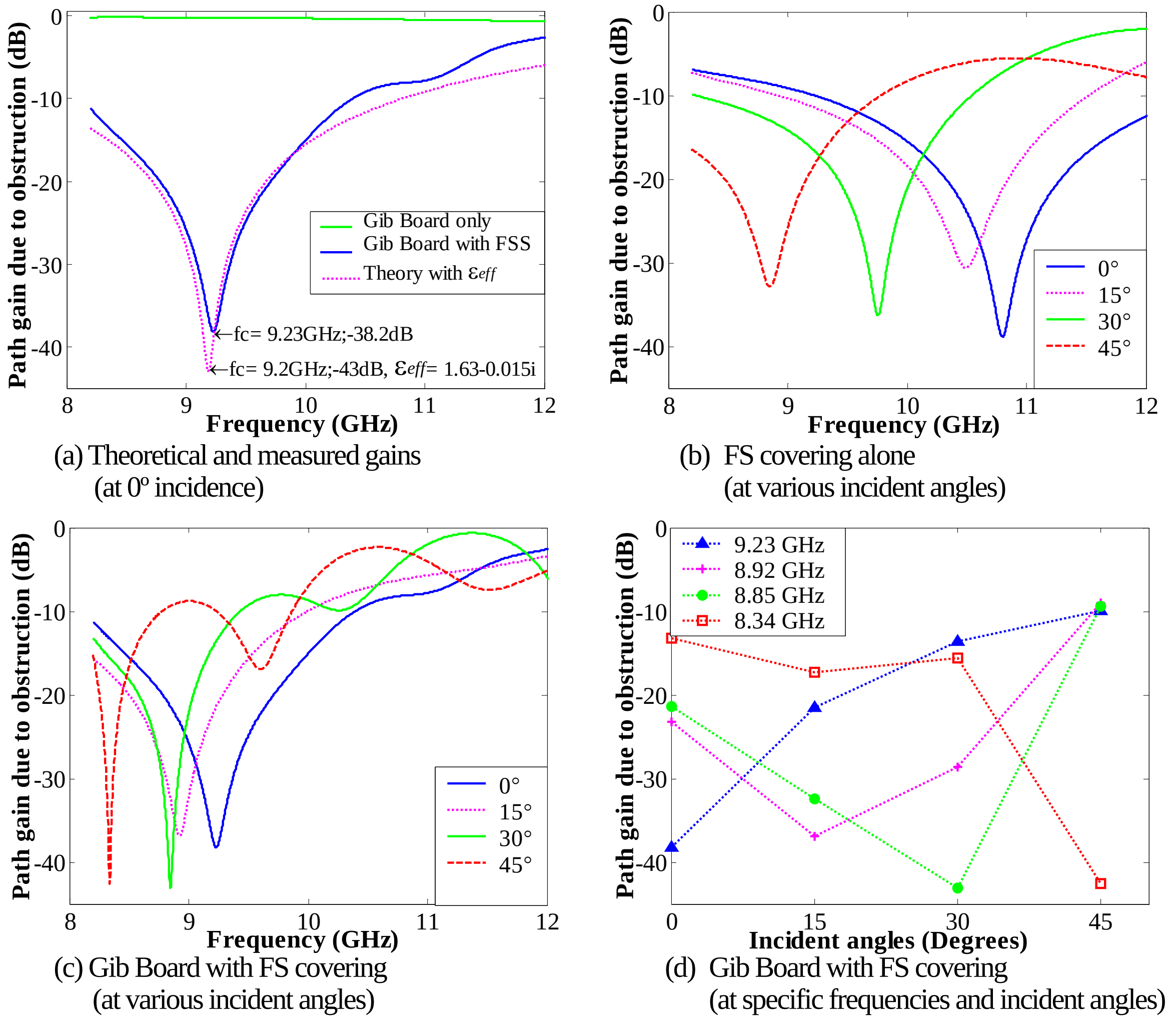


Figure 5. Path gain measurements

In real wireless systems, signals arrive at wall surfaces from various angles. Ideally a wall's frequency selectivity should be independent of the angle of the incident signal. The attenuation due to Gib Board alone (without a FS covering) increases with the angle of incidence and exhibits no frequency selectivity. The FSS alone, and the FSS applied to the Gib Board (Figures 5(b) and (c), respectively) have well defined frequency selective responses which depend on the angle of incidence. The resonant frequency varies noticeably as the incident angle increases from 0° to 45°. This kind of variation is undesirable if a frequency selective wall is required to function effectively and consistently regardless of the incident angle.

From Figure 5(b), for the FSS alone, the resonant frequency varies from 10.8 GHz (0°) to 8.9 GHz (45°); whereas, from Figure 5(c), for the FSS on the Gib Board substrate, the resonant frequency decreases from 9.2 GHz to

8.3 GHz as the incident angle increases from 0° to 45°. This suggests that the dielectric substrate influences the frequency selectivity with respect to angle of incidence. Despite the sensitivity to incident illumination angle, the FSS and the combined FS structure still act as good band-stop filters with at least 30 dB attenuation. The primary concern is that the shift in resonant frequency is in the order of 1 to 2 GHz, which is too large in comparison to the ~100 MHz bandwidth available to a WLAN application. When the resonant frequency shifts so does the band-stop region; so that the attenuation at any specific frequency will be dependent on the angle of incidence.

As shown in Figure 5(d), if the frequency to be blocked is 8.34 GHz, then the combined FSS and Gib Board structure can attenuate this frequency by 43 dB if the signal arrives on the wall surface at 45°. Unfortunately, at 30° incidence the attenuation is only 15 dB. However, if the desired resonant (stop-band) frequency is chosen to be 8.85 GHz, the structure may function effectively with incident angles ranging from 0° to 30°, since at least 20 dB attenuation is maintained. This implies that with a correctly targeted stop-band frequency, an optimised FSS response can be obtained. In other words, the surface may perform effectively and consistently over a range of incident angles. Nonetheless, deciding a suitable target resonant frequency requires knowledge of the angular distribution of the arriving signals. This is the subject of further investigation. Measurement results also show that the resonant frequency of the square loop patterned FSS shifts downwards as the incident angle increases. Therefore, given the expected incident angle distribution, it may be necessary to design a FSS with a higher theoretical resonant frequency at 0°, so that the average band-stop response falls at the (lower) targeted frequency.

Ultimately, a frequency selective wall that is insensitive to angle of incidence is desired. This might be achieved using multiple FSS layers, or employing more than one element shape. Theoretically, with the use of multiple FSS layers, the frequency response of the surface can be shaped to exhibit a sharper roll off, or a broader stop/pass band. A broader stop-band response makes the attenuation at a particular frequency less dependent on angle of incidence (and the consequent variation in the centre frequency).

4. Conclusions

X-band measurement results indicate that an effective frequency selective wall can be created by attaching a custom designed band-stop FSS to a common homogeneous building material such as plasterboard. A FS covering can provide an additional band-stop attenuation of at least 30 dB, which would be effective in mitigating the interference and security concerns in wireless communication systems. However the resonant frequency shifts as the incident angle changes, which presents a challenge to the design of an ideal frequency selective wall for an indoor wireless system. The results presented in this paper suggest that the 0° resonant frequency can be designed so as to produce the required stop-band over a range of incident angles. Knowledge of the expected range of incident angles would assist this design process.

The performance of a frequency selective surface is tightly related to the FSS element geometry, dielectric substrate, incident angles and the operating frequency. Unwanted angle sensitivity may be ameliorated by the careful selection of resonant frequency; but multiple layers of frequency selective surfaces might be required to remove the problem altogether. This is an area of ongoing investigation.

Although this paper has presented measurements made at X-band, with appropriate scaling of geometries, similar results can be anticipated in other radio bands used for indoor wireless communications. However, experimental confirmation is required.

REFERENCES:

[1] B. A. Munk, *Frequency Selective Surfaces Theory and Design*. New York: John Wiley & Sons, 2000.

[2] C. Mias, C.Tsakonas, C.Oswald, "An investigation into the feasibility of designing Frequency Selective Windows employing periodic structures." Final report for The Radiocommunications Agency. The Nottingham Trent University, Nottingham, U.K. Ref. AY3922, 2001.

[3] R. J. Langley, E.A. Parker, "Equivalent circuit model for arrays of square loops," *Electron. Letters*, vol. 18, pp. 294-296, Feb., 1982.

[4] N. Marcuvitz, *Waveguide Handbook*, vol.21: Peter Peregrinus Ltd. on behalf of the IEE, 1986.

[5] D. K. Ghodgaonkar, Varadan,V.V., and Varadan, V.K., "Free-space measurement of complex permittivity and complex permeability of magnetic materials at microwave frequencies," *IEEE Transactions on Instrumentation and Measurement*, vol. 39, April, 1990.