Angular independent frequency selective surfaces for interference control in indoor wireless environments

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A study of electromagnetic wave propagation in buildings using a finite-difference time-domain algorithm has demonstrated that waves are incident on walls over a wide range of angles. If wall mounted frequency selective shielding is desired, it is argued that this behaviour requires shielding solutions that are angle insensitive. A simple single-layer annular ring frequency selective surface (which is relatively economic to fabricate) is shown to offer adequate angular stability of the transmission response, and is thus suitable for electromagnetic interference control in indoor wireless environments.

Propagation modelling and energy flow visualisation:

A comprehensive study of propagation in multi-storey steel-reinforced buildings has been undertaken to identify the major propagation mechanisms which dominate received signal strengths. Details have been reported elsewhere [1, 2], but a particular observation made in the study is relevant to the design of frequency selective surfaces (FSS) intended for incorporation into wireless friendly buildings [3]. In [2], a parallel 3D finite-difference time-domain (FDTD) algorithm was implemented and used to analyse electromagnetic wave propagation at 1 GHz over three floors of the School of Engineering Tower at The University of Auckland. The salient features of this building include a centrally located steel reinforced services core (containing a stairwell and lifts), and peripheral offices which are separated from the core by a corridor (further details are described in [4]). The simulation domain (containing the three floors) is 18.5 × 18.5 × 9m and was discretised to a resolution of $\lambda/30$ = 1 cm, resulting in approximately 3 billion mesh cells. A single E_z element of the FDTD lattice (equivalent to a short dipole) was excited at a frequency of 1GHz. A timestep of 18.3ps was used for a total of 15000 iterations to approximate steady state. The resulting interleaved electric and magnetic field components were then co-located (via spatial averaging) and used to estimate the time-averaged Poynting vector throughout the lattice [2]. The Poynting vector quantifies the magnitude and direction of the net energy flow at each point in the lattice. Energy flow streamlines can then be projected through this vector field by applying principles developed in fluid dynamics for studying steady flows [5]. (A similar analysis using Poynting's vector streamlines to visualise energy flow escaping backwards around a pyramidal horn antenna was shown in [6].) Energy flow streamline results for the Engineering School Tower are shown in Fig. 1. These results clearly demonstrate that the propagating fields are incident on walls at a range of angles from near normal (as can been seen at location A) to almost glancing (location B). This behaviour clearly shows that if an FSS is to be applied to walls for use in interference control, it must possess a frequency/transmission response that is stable over a wide range of angles of incidence.

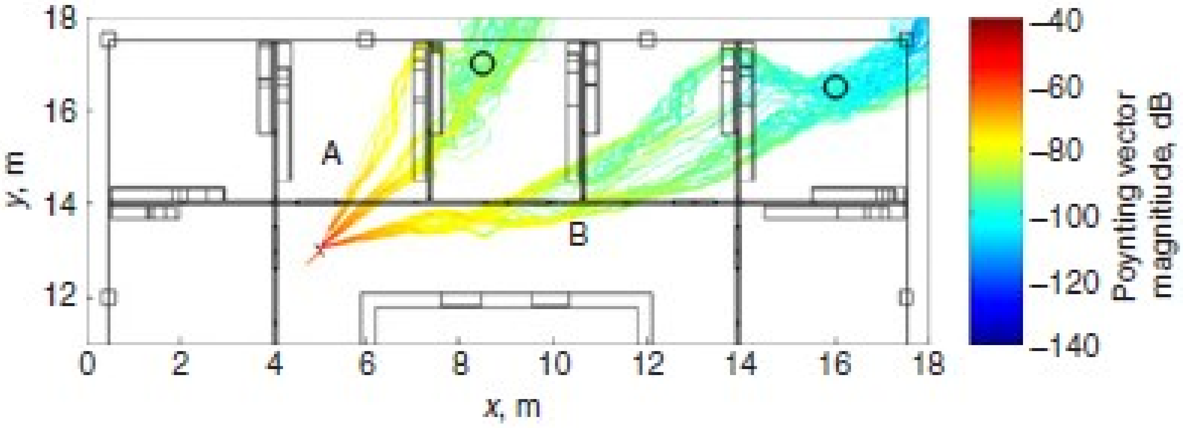

Fig.1 Computed energy flow streamlines for School of Engineering Tower, The University of Auckland.

FSS design and performance:
The requirement for FSSs with both angle and polarisation independence rules out the use of linearly polarised elements (such as dipoles) for the FSS array, as well as widely spaced arrays, the performance of which tends to suffer at oblique angles owing to the onset of grating responses. The loop family of elements with rotationally symmetrical geometries have been shown to offer good angle of incidence stability – in particular the annular ring [7, 8] – suggesting they might be a suitable choice for applications in the built environment.

Using CST Microwave Studio$^{\text{TM}}$ (CST MWS$^{\text{TM}}$) an empirical method was adopted to achieve the required physical dimensions for an annular ring FSS resonant at $f_r \sim$ 10GHz. Although actual indoor systems operate at lower frequencies, 10GHz was chosen simply for expediency as it is easier to carry out transmission characterisation measurements at 3cm wavelength than at 30cm, where factors such as the physical size of the FSS required to adequately assess performance becomes impractical. The dimensions of the specific FSS unit cell considered are shown as an inset in Fig. 2, the array being etched on a copper clad 0.17mm-thick polyester substrate with $\varepsilon_r = 3$ and $\tan\delta = 0.04$. These unit cells repeat over a regular square lattice. The FSS was modelled using CST MWS$^{\text{TM}}$ at angles of incidence of 0°, 40° and 80°, respectively, for both TE and TM excitation. The simulated results showed a well-defined stopband at approximately 10.2 with good centre frequency and bandwidth stability with respect to incident angle. For TE incidence f_r drifted from about 10.2 to 10.5GHz for angles from 0° to 80° and 10.2 to 10.9GHz for TM incidence, corresponding to drifts of 3 and 6.8%, respectively.

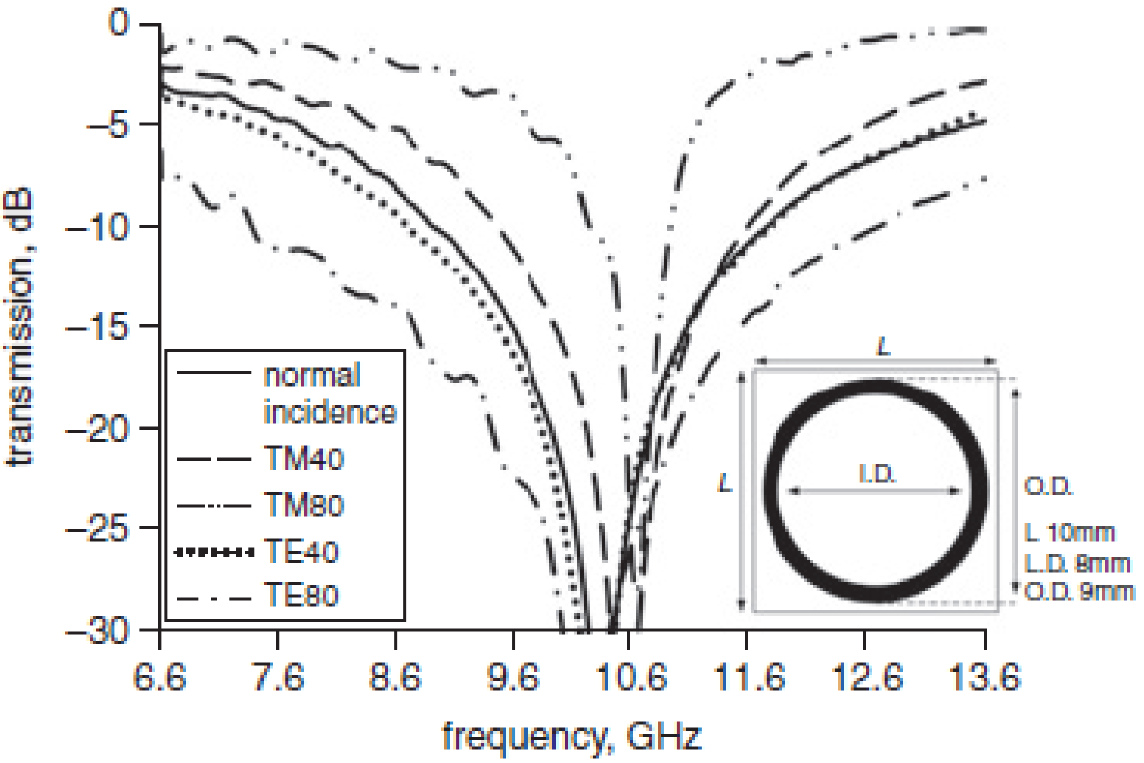

Fig.2 Measured transmission response for annular ring FSS. Element dimensions in inset diagram. L is array periodicity.

Having established its performance via numerical modelling, a prototype test FSS was fabricated as a 160 × 29 element array on the 0.17mm polyester substrate, corresponding to a surface 1560 × 280mm containing a total of 4640 unit cells. Owing to the size constraints of the etching system, the FSS was made as a series of eight panels that were accurately joined after etching. The measurement setup consisted of an anechoic chamber with an aluminium supporting screen of peripheral dimensions 3.5 × 1.8 m, with a centrally located aperture to accept the FSS under test. A metal screen was used (rather than an absorber loaded structure) as it is more representative of what might be used in an actual in-building deployment. An Agilent E8364A vector network analyser connected to a pair of X-band horns (located on opposite sides of the FSS supporting screen) was used to measure path gains with the FSS present. Results were obtained for incident angles 0°, 40° and 80° and are shown in Fig. 2. For TM incidence fr drifts from about 10.3 to 10.6GHz for angles from 0° to 80° resulting in centre frequency drift of approximately 3%. For TE incidence the drift is negligible although a general broadening of the stop-band is observed.

Measurement and simulations are summarised and compared in Fig. 3, which shows the variation of resonance frequency fr against angle of incidence on a magnified frequency scale. Overall, the modelled and measured results are in good agreement, although the apparent sharp rise in fr in the simulations might point to a need for finer meshing at the highest angles. This drift in frequency might be compensated for by operating the surface at the frequency of the centre of the oblique angle (TM808) response, i.e. at 10.6GHz in this case (Fig. 2). At this frequency and at lower angles of incidence the isolation provided by the FSS is still at least 20 dB.

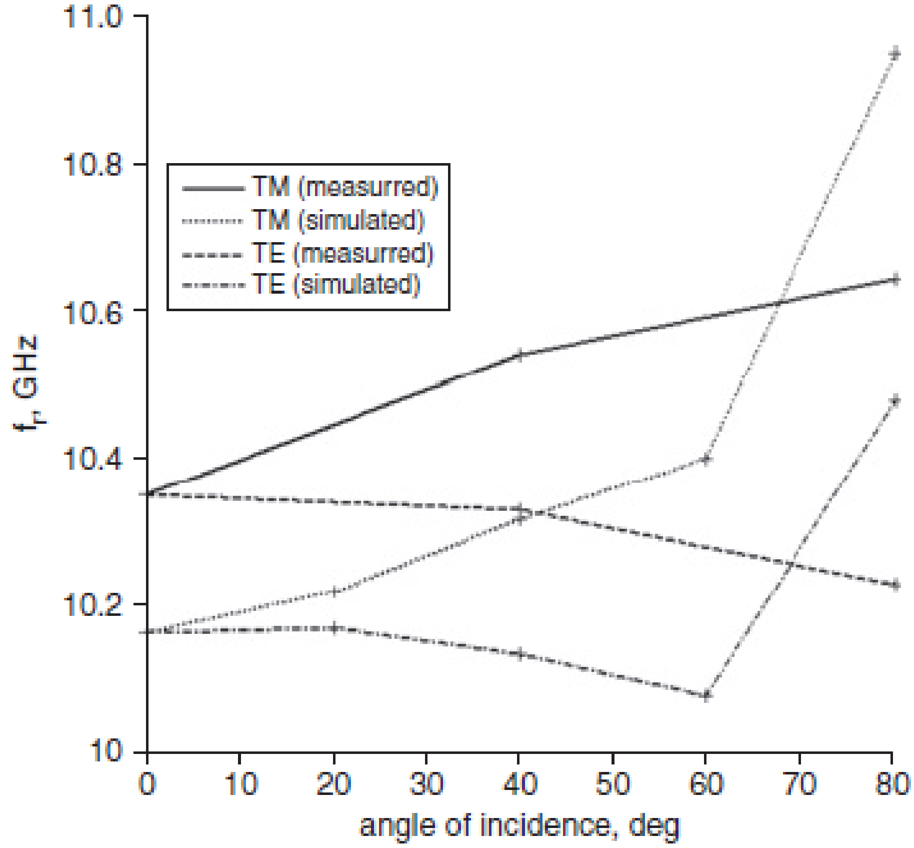

Fig. 3 Measured and simulated values of resonance frequency f_r against angle of incidence

Conclusions: A simple single-layer FSS using annular rings has been shown to offer adequate angle of incidence stability of the transmission response for potential shielding applications in the built environment. Notably, this performance can be achieved without employing additional sub- or superstrate dielectric materials to improve the performance. Furthermore, their simplicity makes them mechanically flexible and economic to fabricate – both important requirements if such shielding solutions are to be adopted either in new installations or as retrofits to existing building structures.

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