PhD PROJECT PROPOSAL

PhD Project Title

Terahertz surface scattering for communication and remote sensing

PhD Supervisory Team

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Project Abstract

This PhD research programme will focus on the characterization of Terahertz scattering from random surfaces and frequency selective surface (metasurface) wallpapers. In particular, the PhD student will carry out (i) experimental work using a Terahertz time-domain spectrometer and a PNA network analyser; and (ii) development of surface-topology-dependent models for Terahertz surface scattering. This is underpinning research for future THz communication and sensing systems.

How does the project utilise topology or topological design?

Coherent and incoherent surface scattering depends on the surface topology.
The strength of wireless THz signals in highly-dense indoor scenarios is largely influenced by the dielectric properties and topology of the walls and objects. It is well understood at RF and microwaves that wireless THz signal propagation can be enhanced (and supressed) by a wise topological design of wallpapers based on metasurfaces. Besides, the outputs of the project will inform radio network planning engineers on the most suitable wireless network topology for THz indoor comms and sensing systems.

Detailed Project Description

Research background, intended outcomes and methodology;

(Adapted from 2019-20 A. Vernon's MEng thesis)

The existence of a huge, unallocated frequency band between 100 GHz and 10 THz frequencies has piqued the interest of researchers in recent decades; the capacity to provide enormous data rates beyond the command of 5G [1], manufacture tiny, high gain antennas [2] and alleviate the pressures of ever-increasing mobile traffic has tipped the full adoption of the terahertz (THz) frequency band to be a major leap forward in commercial communications technology. Although communication links employing frequencies over 100 GHz are demonstrably feasible [4], it is important to appreciate their reliability when operating in different environments and under different atmospheric conditions. Some studies have examined the performance of THz links in adverse weather [5] – [7] but, particularly for gauging the non-LOS performance of a communications link, THz waves' manner of reflection from common indoor and outdoor surfaces demands just as much research. While this too has been addressed in some instances [8], it is clearly not as well understood as for radio and microwave frequency waves.

Typically, longer-wavelength light is not scattered when reflected by ordinary surfaces, such as concrete which, as far as this light is concerned, is perfectly smooth. This means that reflected rays travel in the same plane and with the same angle (with respect to the surface normal) as those which are incident on the surface.

Conversely, (sub-)millimetre waves are of a similar scale to the roughness of these kind of surfaces, and as such, the path difference between an incident ray reflected by a valley and a ray reflected by a peak is a significant proportion of a wavelength. Producing a large difference in phase, two rays both incident and reflected in parallel might interfere destructively, indicating that energy flow has been steered in other directions: scattered [9, pp. 9-10]. The result is a total reflected field with two constituents: a coherent field propagating in the specular direction, and an incoherent field created by rough surface scattering.

Mathematical models of the rough surface scatter problem have been formulated since Rayleigh and developed further by numerous authors such as Rice [10]. These models tend to perform well for slightly rough surfaces but decline in accuracy as roughness becomes more extreme. This is due to difficulties in evaluating the fields on the surface boundary. Another challenge derives from the need to emulate the characteristics of real rough surfaces mathematically.

The student will undertake extensive measurement campaigns using VNA and THz-TDS to characterise dielectric properties, roughness and inhomogeneity properties of typical material boundaries. The measurement will be extensive to characterise sample variability and their post-processing will unify the two sets of results (VNA and THz-TDS) into a comprehensive library of scattering measurements. Subsequently, the student will implement a detailed set of coherent and incoherent surface scattering models and will perform a model validation against the measurements. The PhD project will result into a frequency-dependent library of coherent and incoherent scattering models, capable of predicting field strength/power, its angular, spatial and temporal (delay) distribution, and its depolarisation characteristics as a function of the surface topology.

[1] China Communications; 2019; 16 (2): 1-35.
[2] IEEE Trans. Terahertz Sci. Technol; 2011; 1 (1): 256-263.
[3] IEEE Trans. Microw. Theory Tech; 1984; 32 (9): 1118-1127.
[4] Transmission trial of television broadcast materials using 120-GHz-band wireless link.
[5] Low-THz wave snow attenuation. Paper presented at: 2018 International Conference on Radar (RADAR); 2018; Brisbane (Australia).
[6] IET Radar Sonar Nav; 2019; 13 (9): 1421-1427.
[7] Comparison of terahertz versus infrared free-space communications under identical weather conditions. Paper presented at: 2014 39th International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz); 2014; Tucson (Arizona).

[8] Wideband terahertz band reflection and diffuse scattering measurements for beyond 5G indoor wireless networks. Paper presented at: European Wireless 2016; 22th European Wireless Conference; 2016; Oulu (Finland).
[9] The scattering of electromagnetic waves from rough surfaces. London: Pergamon Press Limited; 1963
[10] Reflection of electromagnetic waves from slightly rough surfaces. Comm. Pure Appl. Math; 1951; 4 (2-3): 351-378

Training and skills to be developed over the PhD;

This PhD project offers training in diverse areas of research in computational and applied electromagnetics. The student will develop critical thinking and analysis capability through strong linkage between the computational/theory and experimental outcomes. S/he will be supported in developing project management and leadership skills, and be active in the direction of the research. S/he will develop her/his communication skills through reporting, and disseminating the research outputs through publication and conferences.

Explanation of why the project is suitable for the CDT in Topological Design;

The project focuses on the impact of surface topology on THz scattering. This activity will require a strong collaboration between the School of Engineering and School of Physics and Astronomy, centred around the training and development of the student. As such, the multidisciplinary nature of the CDT in Topological Design provides an ideal environment for this project to develop successfully.

Links with research in the research groups of the supervising team;

This project will benefit from close synergy with other projects successfully completed in the Department of Electronic Electrical Engineering (the EPSRC funded projects "TRAVEL: TeraHertz Technology for Future Road Vehicles" and "PATRICIAN: New Paradigms for Body Centric Wireless Communications at mm Wavelengths") as well as current projects in the School of Physics and Astronomy (the Royal Society funded projects "THz propagation models for complex medical environments" and "Experimental demonstration of transmissive-type terahertz digital metamaterials based on microfluidic system").

Also, the Metamaterials Research Group (Dr Navarro-Cia) is a partner in the EU funded H2020 Rise "Non-Conventional Wave Propagation for Future Sensing & Actuating Technologies" project and is involved in the EPSRC UK Metamaterials network led by the University of Exeter - the proposed PhD project falls within the remit of both of them.

Links with research strategies, possibly including UoB, EPSRC, partner organisations;

The project falls within two of the UoB strategic priority areas within the overarching themes 'Science Frontiers' and 'Advanced Manufacturing Research'; namely, metamaterials and radar, respectively.

The project will make full use of a recent investment in the School of Engineering in a new anechoic chamber and associated facilities for antenna characterisation (£2.5M) and the THz testing equipment (£1.2M EPSRC investment).

The proposed research is a foundational topic situated at the intersection of the ICT and Physical Sciences EPSRC thematic portfolio areas, specifically the RF & Microwave Communications area. This in turn, underpins much of the strategic priority themes of Digital Economy, Healthcare Technologies, Engineering (e.g. Sensors and Instrumentation) and Living with Environmental Change (e.g. Information Infrastructure).

An ideal/acceptable undergraduate background and interests;
First degree in Physics, Electronic Engineering or closely related subject, with background in basic electromagnetics, and advanced mathematics and preferably some experience or interest in microwave communications systems.