Measurement of Electromagnetic Surface Waves Using an Optically Modulated Scatterer

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1 Abstract

This paper describes a recent collaborative project designed to study electromagnetic surface wave propagation. Measurements are presented of the surface wave standing wave at 10 GHz in a closed waveguide structure. The design of the waveguide enables inference of the properties of Zenneck surface waves from waveguide data. Surface wave data are recorded using an OMS (optically modulated scatterer).

2 Introduction

Electromagnetic surface waves, like all surface waves, are a guided wave phenomenon; their influence decays exponentially away from the guiding surface. However, surface waves contribute to far-field scattering when energy is re-radiated from a guiding surface, typically at a surface impedance discontinuity. Examples of the re-radiation of surface waves may be found in a companion paper [6]. Where it is necessary to control far-field scattering caused by surface waves, the guiding surface may be treated with an absorbing material whose properties are chosen to reduce the magnitude of the surface wave field [1]. Converting energy into a surface wave mode can minimize the effects of other more problematic scattering phenomena.

The measurement of electromagnetic surface waves has changed little since the 1950s and early 60s, when pioneering work on surface waves was carried out at University College, London [2, 3]. Most surface wave measurement techniques rely on a free field probe that is scanned over the guiding surface. Free field measurement techniques are, however, inevitably subject to interference from fields other than surface wave fields, and steps have to be taken to minimize their impact. In 1997, a fully enclosed waveguide measurement method was proposed [4] that exploited the quasi-surface wave nature of the fields within a partially-filled rectangular waveguide. Using this method, investigation of surface wave phenomena on lossy and lossless layered media can be undertaken free from interference from other scattering sources (the broadband launching efficiency is close to unity). Moreover, only modest sample dimensions are required.

Originally, experiments on the waveguide cell used a vector network analyzer to infer indirectly the properties of the enclosed surface wave [4]. More recently, surface waves propagating in the waveguide cell have been viewed directly using an OMS (optically modulated scatterer) measurement system at NPL [5].

3 The Optically Modulated Scatterer (OMS) Measurement System

The modulated scatterer is a device designed for measuring the magnitude and phase of microwaves in a minimally invasive way. The scatterers used in this study were small dipole antennas, either 5 mm or 10 mm from tip to tip, with a gallium arsenide optical microwave switch at their centre. A portion of the microwave radiation incident upon such a dipole is scattered by it. By modulating the microwave impedance of the optical switch, usually at a 10-kHz rate, the magnitude of the scattered microwave radiation is itself modulated and it is possible to pick out this scattered wave from all other ambient radiation in the vicinity. If the modulated scattered radiation is received by a nearby antenna, it is possible to compute the magnitude and phase of co-polarised electric field component at the dipole [5]. By scanning the scatterer through space on a regular grid, it becomes possible to map this field component. The NPL modulated scatterer is referred to as an <u>optically</u> modulated scatterer (OMS) because the impedance of the optical microwave switch is modulated by pulsed laser light incident upon it from an optical fibre. Compared with other field mapping techniques, e.g. the use of metal horn antennas for near-field-scanning, the OMS normally disturbs the fields that it is measuring very little because the optical fibre and the supports for the OMS are small and are made of dielectric material; only the dipole itself is metal.

The OMS is normally used to measure electromagnetic fields in free-space or dose to open surfaces, as described in our companion paper [6]. In such a case it is normally used in conjunction with a measurement antenna (typically a horn antenna) operated monostatically, i.e. it is stationary – only the OMS itself is scanned – and it is used both to launch the fields which are to be scanned and also to receive the modulated scattered signals. The antenna is typically fitted with a circulator to separate the incoming from the outgoing signals. The received signal, which contains both modulated and unmodulated components, then passes into a two-channel homodyne detector. The final stage of detection makes use a phase sensitive detector (PSD) to pick out the modulated signal. The PSD is synchronised to the light pulses from the laser that is modulating the OMS impedance. With such a coherent detection system the dynamic range of the OMS can be as high as 60 dB at 10 GHz. Full details can be found in earlier papers on the NPL OMS systems [e.g. 5].

The measurements described in this paper were performed in a specially constructed waveguide cell and the 10 GHz source signal was fed directly into the cell, making the monostatic antenna redundant. The final stages of detection were, however, as described above, but with minor changes to the balance of the detection system to allow for the higher coupling to the OMS that is possible in a waveguide cell. For this work the OMS was mounted on a narrow balsa-wood support, this material being chosen for its low permittivity, typically less than 1.5. Its position was scanned in the waveguide cell using the same *x*-, *y*-, *z*-scanner that is normally employed for free-field OMS work.

4 Description of the Waveguide Cell

Figure 1 shows a schematic representation of the surface wave cell. A description of the cell's design is contained in [1]. A qualitative description of the cell's behaviour is as follows. To the left of point A, the waveguide mode is the conventional rectangular waveguide mode TE_{10}. Between points A and B, the mode is transformed into a quasi-surface-wave mode; the fields decay above the surface of the material, but the decay is halted by the upper horizontal wall of the waveguide. Higher order modes are prevented from propagating by the presence of a short uniform section between B and C. The height of the upper horizontal wall between C and D is increased linearly to allow the quasi-surface wave mode to transform into a conventional infinite plane surface wave mode, modified only by the waveguide's width. A simple procedure for subtracting the effects of the waveguide's width is described in [1]. The electromagnetic field in the waveguide section following D should be a single mode surface wave. The exponential decay in the field magnitude above the sample surface allows removal of the horizontal metal wall in this region. With the upper horizontal wall removed, the OMS dipole can access the region of the cell in which the surface wave propagates. The surface wave cell has the dimensions of conventional X-band waveguide at the A transition. The height of the cell at D is 30mm; the waveguide taper is 200mm in length.

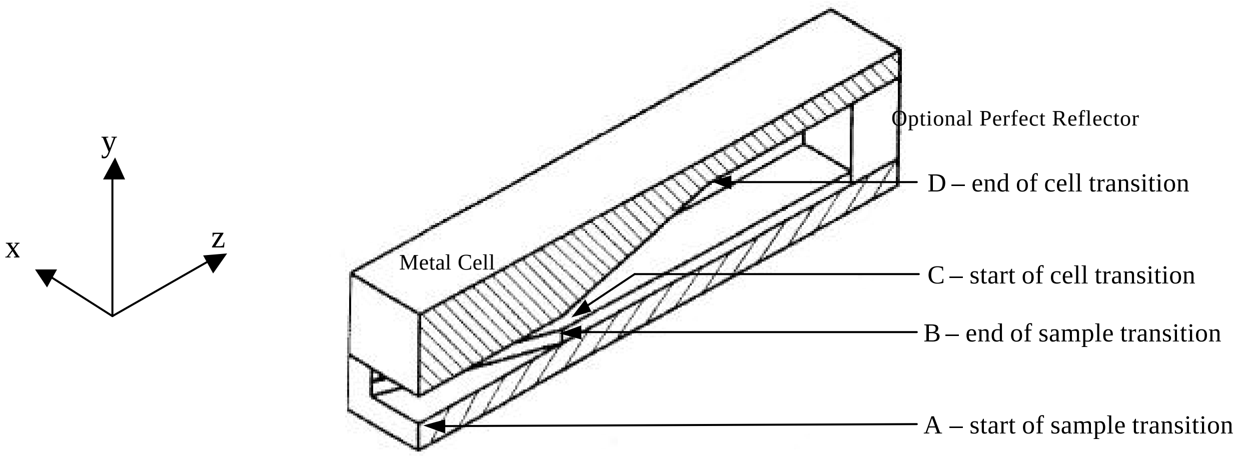
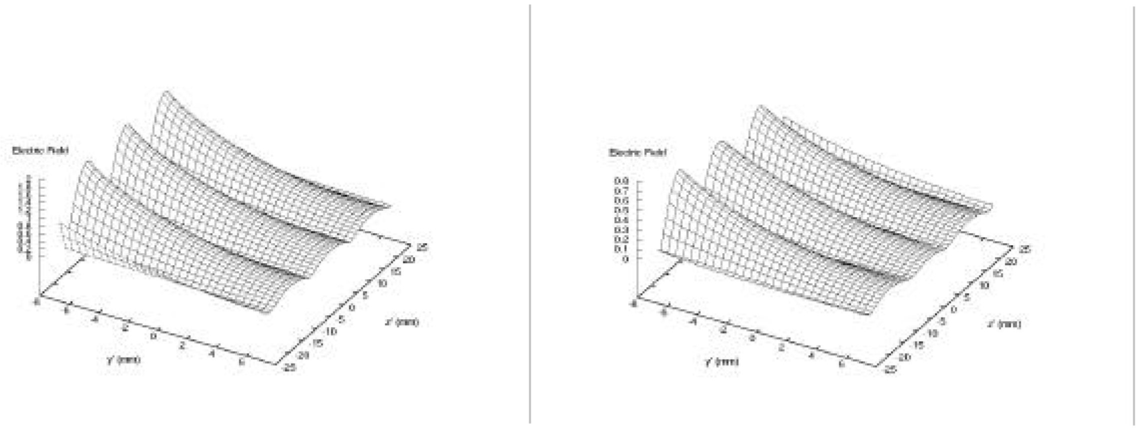


Figure 1 Schematic diagram of a section through the electromagnetic surface wave cell

While it may have been possible to monitor some features of the surface wave standing waves in the cell using a simpler detection system, e.g. a simple monopole probe as in slotted-waveguide VSWR measurements, the OMS offered much more flexibility, allowing field strength to be measured as a function of height above the dielectric, and allowing measurements to be made with *z*-polarisation (i.e. with E-field polarisation along the waveguide axis). In free-field measurements OMS detection may with some justification be referred to as low perturbation detection. In the closed confines of the waveguide cell the OMS is much more invasive and it certainly significantly perturbed the fields it was measuring. However, the introduction of a 5-mm OMS dipole for the first time in this project, as opposed to the 10-mm dipole that had been used for all previous NPL OMS measurements, helped to minimise this effect. Given the high coupling coefficient into the OMS in this cell, one can envisage the use of smaller scatterers in future work, mounted on a minimal support structure.

5 Measured Surface Wave Data



(a) (b)

Figure 2 3D plots of the magnitude of field strength: (a) E_y , (b) E_z. The scans are centred on *z* positions 35 mm and 38 mm in front of the conducting waveguide termination respectively. Local scanning axes are used, giving the position of the centre of the OMS: *z*' = 0 corresponds to *z* = -35 mm in (a) and *z* = –38 mm in (b). The polyethylene surface is at *y*' = -11.5 mm in (a) and -9 mm in (b). The scan is laterally positioned at the centre of the waveguide at *x* = 0. The vertical scale shows the measured electric field strength in arbitrary units.

Figures 2(a) and 2(b) show respectively the measured values of E_y and E_z for *y/z* scans above a 6-mm layer of high density polyethylene. The standing wave arises from the reflection at the conducting plane that terminates the waveguide. The *y*-variation in both figures exhibits the attenuation characteristic of a Zenneck surface wave. The comparison between E_y and E_z in Figure 3 shows that the two components are offset a quarter of wavelength and have a ratio of E_y/E_z = 2.58 on average. The measurements in Figure 3 were performed at a height of 3.5 mm above the surface of the polyethylene strip and approached to within 3.5 mm of the conducting waveguide termination at *z* = 0. Table 1 shows a comparison between the measured and predicted values for the surface wave propagation constant within the guide, ß, for two polyethylene layers with a measured permittivity of 2.35. The propagation constant, β_Z , of the corresponding Zenneck surface wave, i.e. of the surface wave which would propagate on a full conducting plane covered by the polyethylene layer, is given [1] by:

$$\beta_Z = \sqrt{\beta^2 + \left(\frac{\pi}{a}\right)^2} \tag{1}$$

where *a* is the width of the waveguide cell.

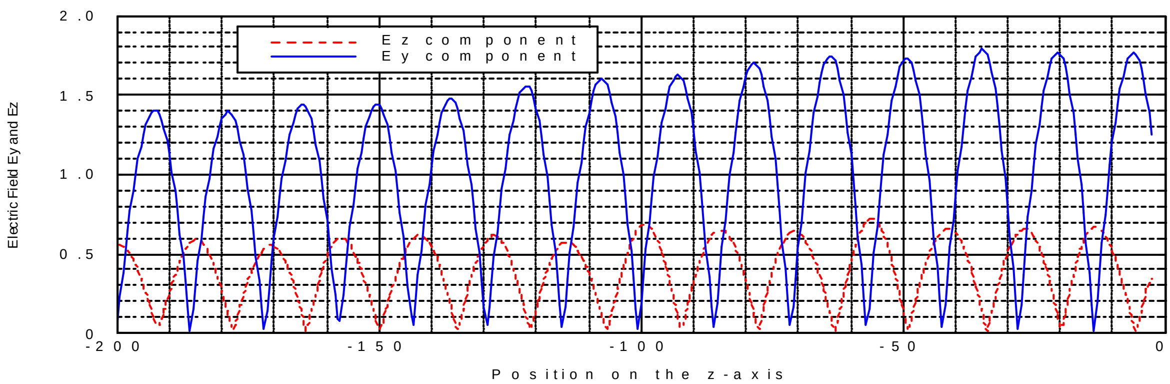


Figure 3 Comparison between E_y and E_z for a *z*-scan. *z* = 0 corresponds to the position of the conducting waveguide termination, see Figure 1. The vertical scale is in arbitrary units but E_y and E_z are correctly scaled with respect to each other.

Dielectric	ß computed, rads/metre	ß measured, rads/metre
Polyethylene, P1 3.14 mm thick	179.25	179.1
Polyethylene, P2 6.00 mm thick	223.63	223.2

Table 1 A comparison between measured and predicted surface-wave propagation constant within the guide, ß.

6 Conclusions

Data related to the propagation of a surface wave over a low loss dielectric layer have been presented. These data exhibit the characteristics of a conventional surface wave. From a comparison between the measured and predicted propagation constants, it can be concluded that the surface wave cell supports a very pure surface wave mode. The cell can therefore be used as a tool to investigate the effects of surface wave propagation over materials.

7 Acknowledgements

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8 References

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