# Modes and Pseudo-modes in TE Extraordinary THz Transmission

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***Abstract*—Transverse electric (TE) transmission through dielectric-baked subwavelength slit arrays is inextricably linked to the grounded-dielectric slab $TE_1$ mode, and thus, it depends highly on the electrical thickness of the substrate. We track the influence of the $TE_1$ mode using both TDS measurements and the Method of Moments. For electrically thick dielectric samples, the $TE_1$ mode is in propagation, and hence total transmission occurs (in excess of 0 dB, attributed to collimation), whereas in electrically thin samples, the $TE_1$ mode is in cutoff. In this regime, the mode still contributes to transmission, and hence is referred to as a pseudo-mode.**

## I. INTRODUCTION

EXTRAORDINARY optical transmission (EOT) through metallic periodic structures baked with dielectric slabs rely largely on the formation of grounded dielectric slab modes [1]-[3]. For transverse magnetic (TM) modes, for any given dielectric slab thickness ($t_d$), at least one propagating mode always exists ($TM_0$) [4]. With increasing thickness, an increasing number of modes can be supported by the structure. For transverse electric (TE) modes, however, a cutoff frequency exists, for which below this frequency, no modes can be supported by the dielectric [4]. This frequency depends on the thickness of the dielectric slab, such that the occurrence of EOT relies on the slab to be thick enough to support at least the first mode ($TE_1$) [4]. Until recently, research into TE EOT has been somewhat neglected relative to TM EOT.

## II. RESULTS

Two samples were characterised using an all fibre-coupled THz time-domain spectrometer TERA K15 in a scatterometer setup. The excitation pulses had temporal lengths of 261 ps, giving a spectral resolution of 4.8 GHz. Each sample had a thin aluminum plate with varying number of slits patterned in to form a periodic structure and a polypropylene (PP) ($\varepsilon_r$ = 2.25 [5]) slab of with thicknesses 102 µm and 188 µm, below and above the threshold thickness, respectively. The width and periodicity of the slits were 0.2 mm and 0.6 mm.

Time-resolved normal transmission is observed in the form of spectrograms in Fig. 1 for each of the 107 slit samples. The full development of the mode responsible for EOT is evident for the thicker dielectric, indicated by the longer ringing of energy within the sample. This indicates that the incident radiation couples to the mode efficiently, remaining in the structure for some time before reradiating, comparable to that observed in Bull's Eye antennas [6]. The transmission appears to be reduced in the sample with dielectric thickness below threshold, confirming the incomplete development of the mode. EOT is still present, and so it is referred to as a pseudo-mode.

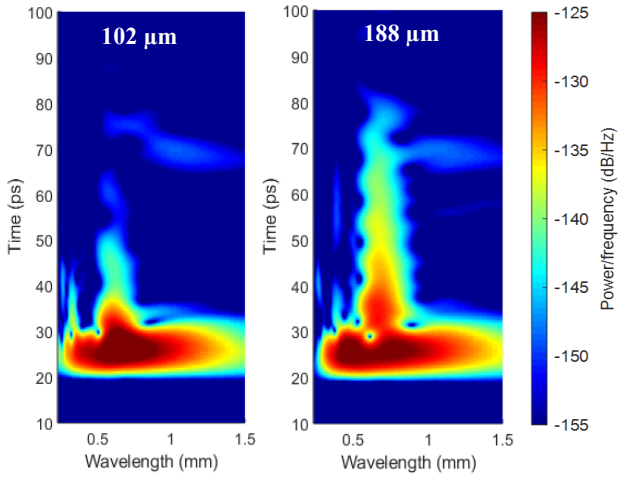



**Fig. 1.** Spectrograms for samples with dielectric thicknesses 102 µm (left) and 188 µm (right).

The dispersion relation of the samples calculated from the Method of Moments (MoM) [7] are presented in Fig 2. The modes can be obtained from the zeros in the determinant of the system matrix (indicated by the colour bar) and are presented as a black dashed line. The cutoff wavelength for each sample is presented as a white dashed line. From the results for the sample with dielectric thickness below threshold, true zeros do not exit, indicating the presence of the pseudo-mode. This supports the occurrence of the frustrated EOT, observed in the spectrograms in Fig. 1, despite the thickness being below threshold. For the thicker sample, however, zeros exist in the determinant of the matrix and hence the modes are fully developed.

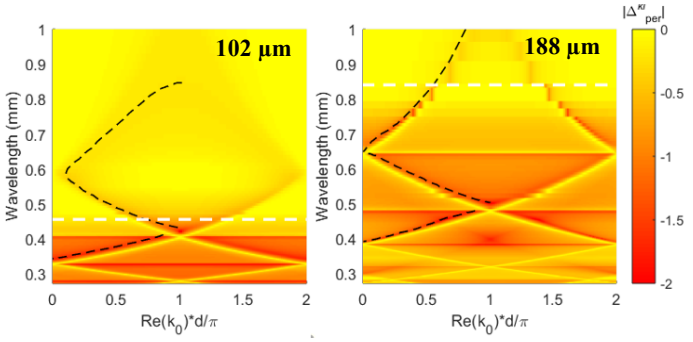



**Fig. 2.** MoM dispersion diagrams. The colour indicates the determinant of the matrix, plotted in log form. The modes calculated from the zeros or minima in the matrix are presented as black dashed lines and cutoff wavelengths as white dashed lines.

## III. CONCLUSION

A grounded dielectric slab of defined minimum thickness is a necessity for total TE EOT through periodic slit arrays, in contrast with TM EOT, for which at least one surface mode always exists. The development of the first grounded dielectric slab mode $TE_1$ has been demonstrated through time domain spectroscopy measurements and MoM analysis. For structures with dielectric slabs of thickness less than the threshold, the existence of a pseudo mode has been presented, for which frustrated EOT has been observed.

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