

# Photonics at Space–Time Interfaces for Advanced THz-Wave Manipulations

A. Contestabile<sup>1</sup>, C. Rizza<sup>1</sup>, M.A. Vincenti<sup>2</sup>, G. Castaldi<sup>3</sup>, M. Scalora<sup>2</sup>, M. Ferrera<sup>4</sup>,  
V. Galdi<sup>3</sup>

<sup>1</sup>Department of Physical and Chemical Sciences, University of L'Aquila, I-67100, Italy

<sup>2</sup>Department of Information Engineering, University of Brescia, Brescia, I-25123, Italy

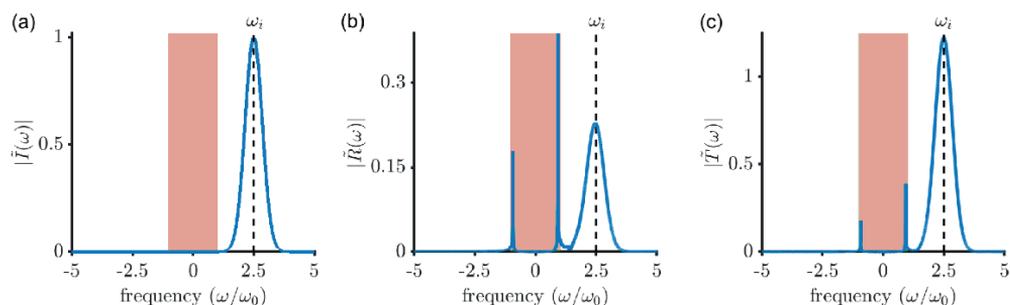
<sup>3</sup>Fields & Waves Lab, Department of Engineering, University of Sannio, I-82100, Italy

<sup>4</sup>Institute of Photonics and Quantum Sciences, Heriot-Watt University SUPA Edinburgh, EH14 4AS  
United Kingdom

**Abstract:** We present a theoretical study of electromagnetic wave scattering at a space–time interface, a subwavelength slab with Lorentz-type dispersion whose plasma frequency experiences an abrupt temporal change. Our analysis uncovers several unconventional photonic effects induced by this spatiotemporal discontinuity, highlighting new opportunities for compact and ultrafast THz photonic devices.

We investigate wave scattering at a space-time interface. i.e., a thin dielectric slab characterized by Lorentz-type dispersion, whose plasma frequency undergoes an abrupt temporal change. Remarkably, the temporal discontinuity in plasma frequency triggers unusual phenomena. We have developed a semi-analytical theory demonstrating that a space–time interface enables linear frequency generation at all wave modes supported by the medium [1]. The temporal discontinuity can excite waves at the system's intrinsic resonance frequencies  $\omega_0$ , and at the epsilon-near-zero (ENZ) crossing points, corresponding to Ferrell–Berreman modes. Furthermore, unlike conventional approaches that rely on spatial structuring (such as gratings or prisms), our method shows that incident propagating waves can directly excite evanescent modes triggered by a sudden temporal boundary. In Fig. 1, we report the incident, reflected and transmitted wave-packet spectra, normalized with respect to the peak value of the incident one, in the Transverse-Electric (TE) case with an angle of incidence  $\theta_{in} \approx 24^\circ$  and center frequency  $\omega_{in} = 2.5 \omega_0$ . The arrival of the wave-packet is synchronized with the occurrence of the plasma frequency switching. The peaks associated with the excited modes  $\pm\omega_0$  lay inside the area highlighted with red shading, which represents the evanescent spectral range. Conversely, in absence of the time-switch, such modes would not be excited. We also investigate spin-dependent effects occurring at a space–time interface [2]. A purely temporal interface induces phase-conjugated backward waves and leads to anomalous spin conversion. When both spatial and temporal boundaries are present, the scattered field results from their combined action, forming a superposition of the incident wave's polarization and its phase-conjugated counterpart. Remarkably, this mechanism enables polarization conversion without the need for bi-anisotropy, chirality, or nonlinear effects. It is now worth mentioning that all our results are supported and validated by full-wave simulations. Finally, we discuss potential implementations in realistic

material systems, emphasizing that the investigated parameters are compatible with standard semiconductor platforms operating at terahertz frequencies [3-5].



**Fig.1** | Normalized spectra of the incident (a), reflected (b), and transmitted (c) wave packets; the dashed vertical lines represent the carrier frequency of the incident field. All spectra are normalized with respect to the peak value of the incident one. The area highlighted with red shading represents the evanescent spectral range.

## Contacts:

Alessandra Contestabile ([alessandra.contestabile@graduate.univaq.it](mailto:alessandra.contestabile@graduate.univaq.it))

Carlo Rizza ([carlo.rizza@univaq.it](mailto:carlo.rizza@univaq.it))

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