Theory and Applications of Temporal Reflection in a Dispersive Medium

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Space-time duality

- Analogy between beam diffraction and pulse propagation

$$\begin{cases} \dfrac{\partial U}{\partial z} = \dfrac{i}{2k}\dfrac{\partial^2 U}{\partial x^2} & \text{Paraxial beam diffraction equation} \\ \dfrac{\partial A}{\partial z} = -\dfrac{i\beta_2}{2}\dfrac{\partial^2 A}{\partial \tau^2} & \text{Narrow band pulse propagation equation} \end{cases}$$

Kolner B. H. Space-time duality and the theory of temporal imaging. IEEE Journal of Quantum Electronics, 1994, 30(8): 1951-1963.

Temporal Reflection

Boundary of refractive index change is caused by optical Kerr effect or electro-optical effect. Boundary is moving with some speed V_B:

$$\Delta n(z,t) = \Delta n\left(t - \frac{z}{V_B}\right)$$

Work in a moving frame: $\tau = t - z/V_B$

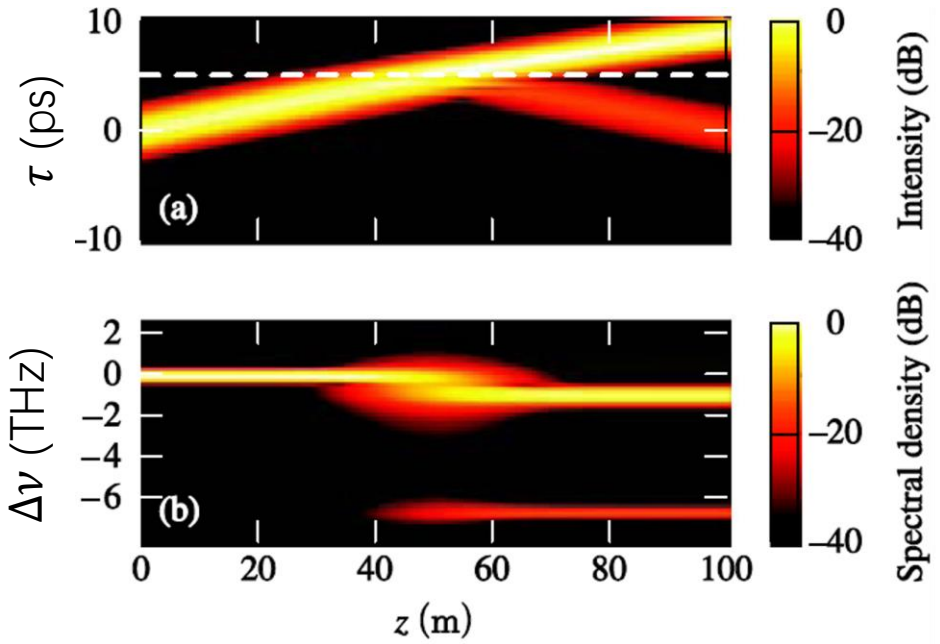
Theoretical Modeling:

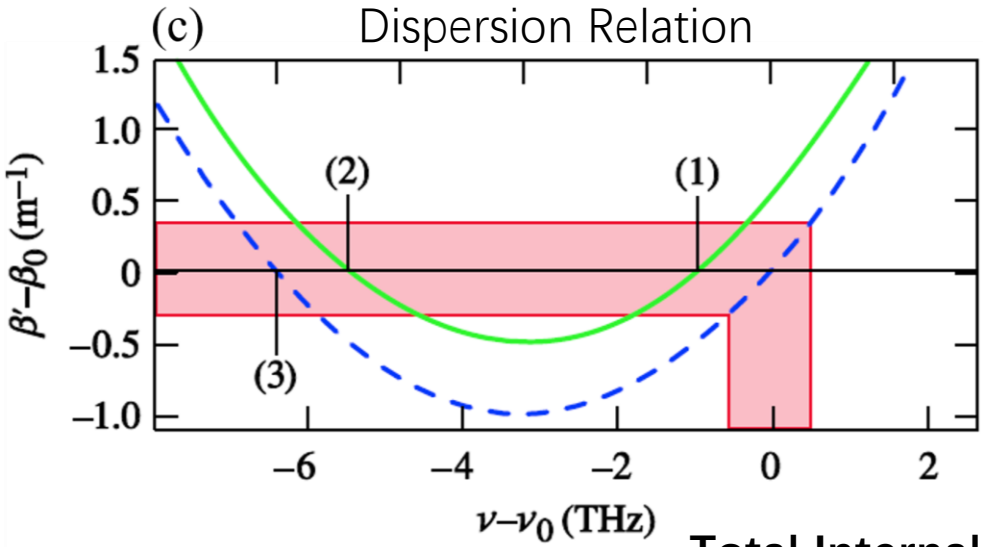
$$\frac{\partial A}{\partial z} + \Delta\beta_1 \frac{\partial A}{\partial \tau} + i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial \tau^2} = ik_0 \Delta n(\tau) A$$

$$\Delta\beta_1 = \frac{1}{v_g} - \frac{1}{V_B} \quad \text{(Group velocity mismatch)}$$

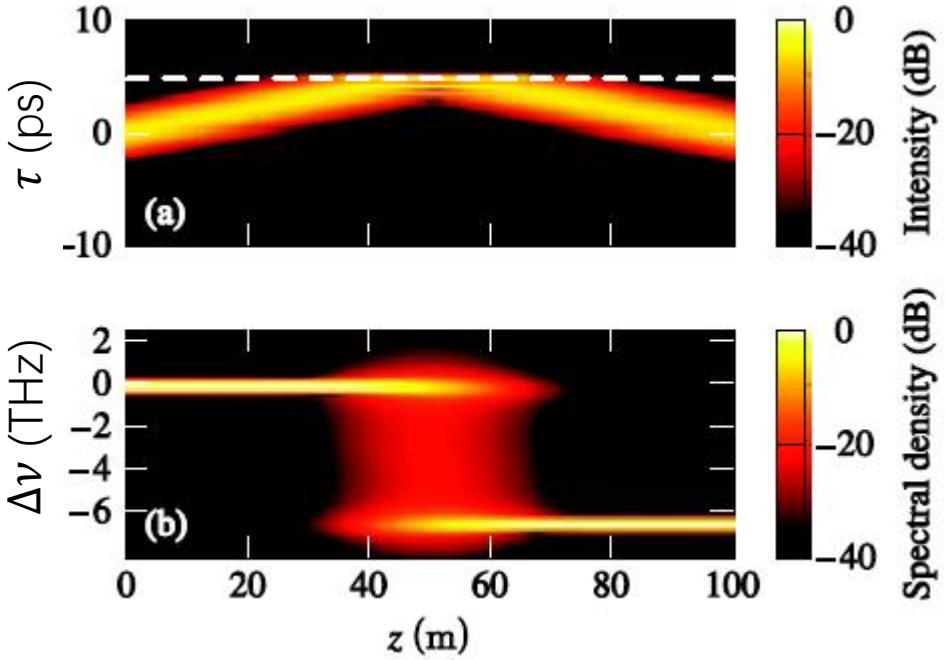
Plansinis, B. W., Donaldson, W. R., and Agrawal, G. P. (2015). What is the temporal analog of reflection and refraction of optical beams? Physical review letters, 115(18), 183901.

Simulation





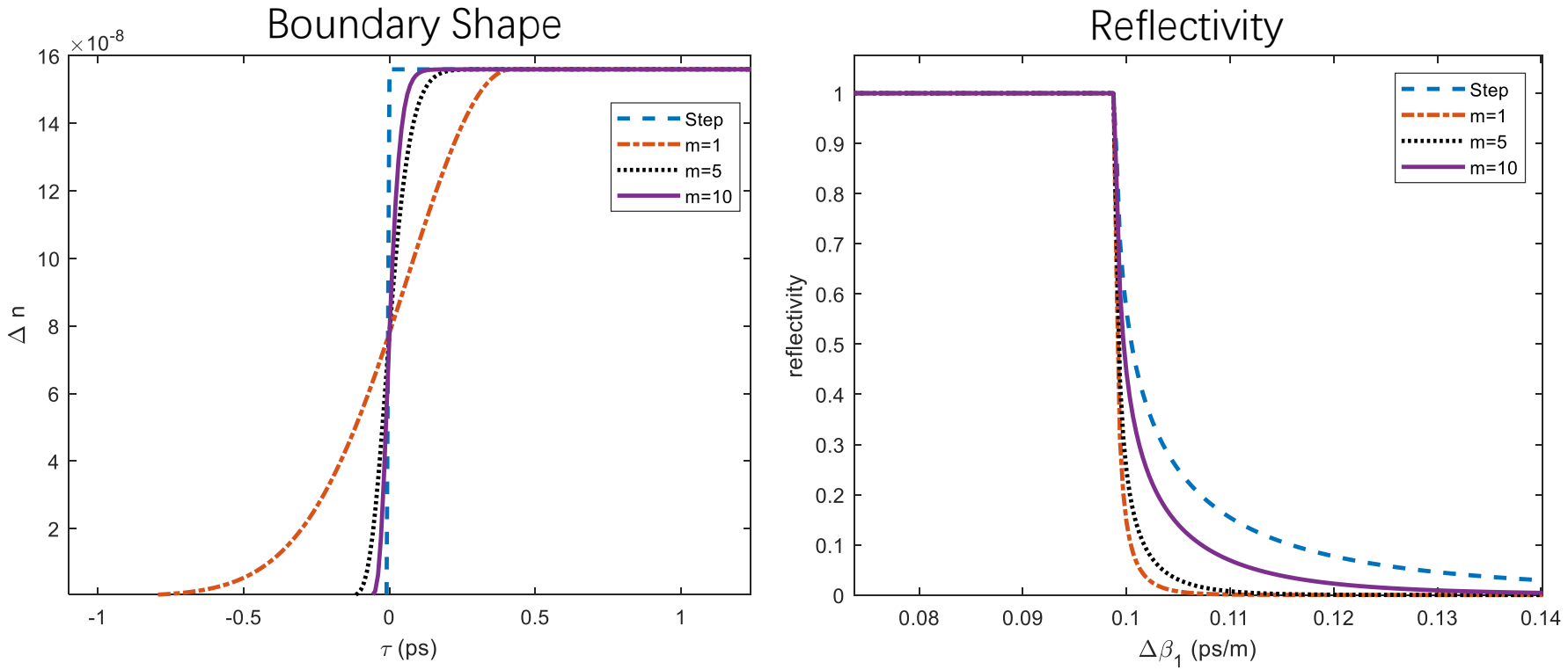
Total Internal Reflection



Plansinis, B. W., Donaldson, W. R., and Agrawal, G. P. (2015). What is the temporal analog of reflection and refraction of optical beams? Physical review letters, 115(18), 183901.

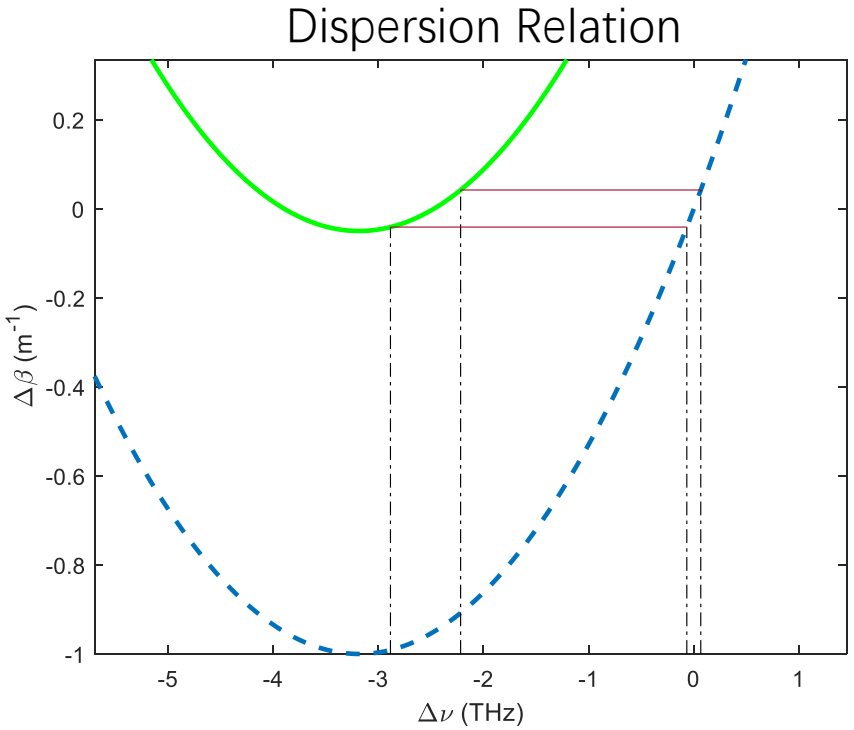
Reflectivity

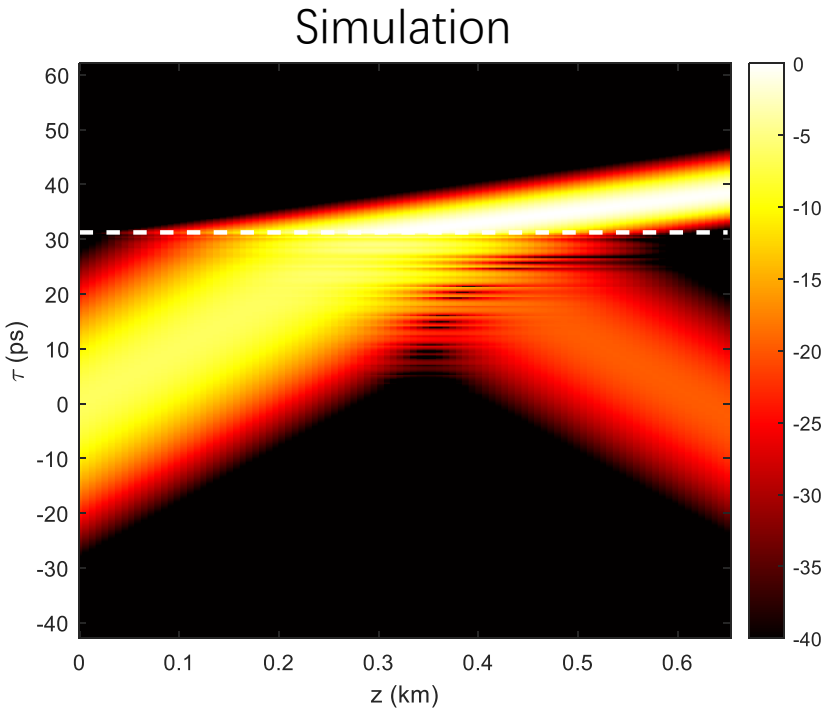
- Reflectivity of a temporal boundary is calculated as a function of group velocity difference:

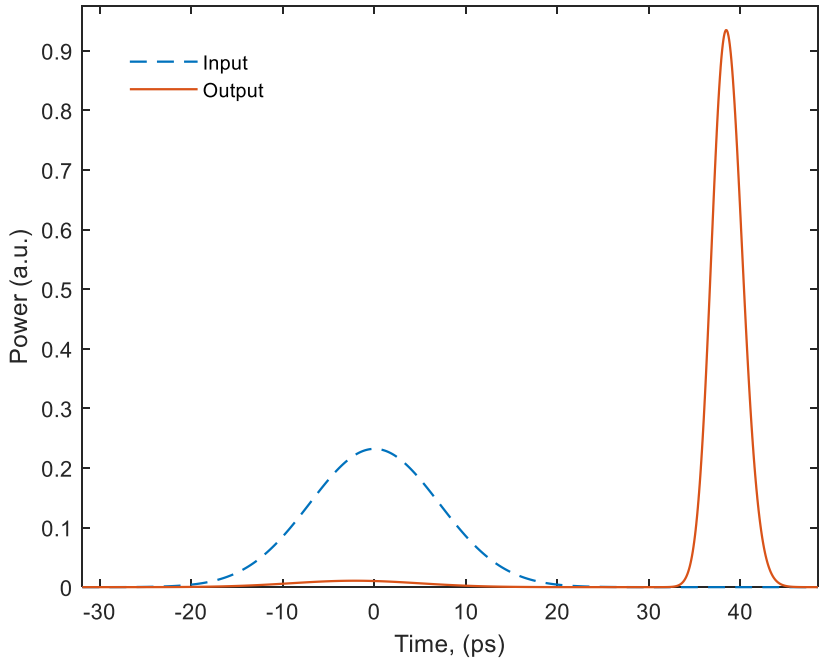


Zhang, W. Donaldson, and G. P. Agrawal, "Impact of the boundary's sharpness on temporal reflection in dispersive media," Opt. Lett. 46, 4053–4056 (2021)

Pulse compression







Conclusion

- Temporal analog of reflection can happen between an optical pulse with a moving index boundary.
- Frequency of pulse changes, governed by momentum conservation.
- Frequency conversion or pulse compression can be achieved.