Linear propagation of optical pulses with high-order dispersion

Antoine F. J. Runge[a], Y. Long Qiang[a], Tristram J. Alexander[a], and C. Martijn de Sterke[a,b]

[a] *Institute of Photonics and Optical Science (IPOS), School of Physics, The University of Sydney, NSW 2006, Australia.*

[b] *The University of Sydney Nano Institute (Sydney Nano), The University of Sydney, NSW 2006, Australia*

Chromatic dispersion is one of the most important phenomena in optics. It affects many optical processes and systems including telecommunication, frequency conversion and ultrashort pulse generation. Dispersion is also central in the formation of optical solitons, pulses that balance negative quadratic dispersion ($\beta_2 < 0$) and self-phase modulation (SPM). Recent experiments have shown that optical solitons can in fact arise from the balance between SPM and negative dispersion of any even order [1,2]. However, in that work high-order dispersion is only considered through its interaction with SPM [1,2]. The effect of high-order dispersion acting by itself was rigorously investigated in telecommunications [3], but this work is highly mathematical which impedes physical understanding. Here, we study theoretically and numerically the linear propagation of optical pulses in the presence of high orders of dispersion m. Through an intuitive approach we show that, provided that m is sufficiently large, all pulses evolve following a universal evolution as a function of a dimensionless length ℓ, weakly depending on the initial condition, but not on m. This is illustrated in Fig. 1a, which shows that the pulse full-width at half maximum versus ℓ for different m follows a universal curve. Eventually, all pulses evolve to a temporal sinc-function (see Figs. 1b & c). Thus, perhaps counterintuitively, the effect of high-dispersion orders is easier to understand that that of the well-understood quadratic dispersion ($m = 2$). Our work also allows us to define characteristic lengths for any dispersion order.

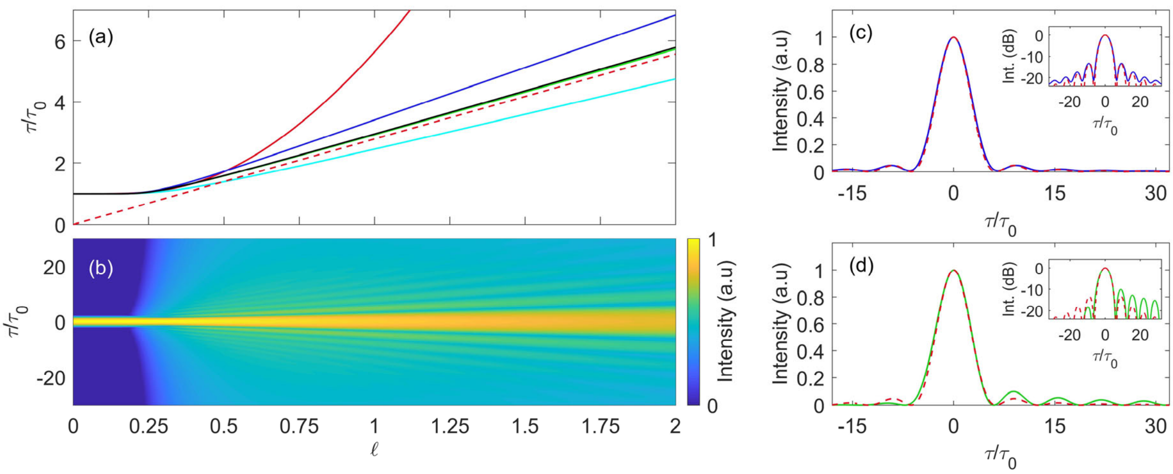

Fig. 1. (a) Evolution of the temporal width versus the dimensionless parameter ℓ for $m = 2$ (solid red), $m = 3$ (cyan), $m = 4$ (blue), $m = 15$ (green) and $m = 18$ (black). (b) Corresponding calculated temporal intensity for $m = 18$. Normalized calculated temporal intensity profile at $l = 2$ for (c) $m = 18$ (blue) and (d) $m = 15$ (green). The red-dashed line is the predicted asymptotic pulse shape.

[1] A. F.J. Runge, et al, Nature Photonics **14**, 492 (2020).
[2] A. F. J. Runge, et al., Phys. Rev. Res. **3**, 013166 (2021).
[3] M. Amemiya, J. Lightwave Technol. **20**, 591 (2002).