Optical Communication Components

Notes & Tutorials

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29th April, 2022

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Introduction

I wrote this document for the students studying Optical Communication Networks to have a nice set of notes, and correct reference code and graphs for the module. I hope that it is sufficient for this task and it helps all of your studies.
I spent have spent a lot of time developing the template used to make this LaTeX document, I want others to benefit from this work so the source code for this template is available on GitHub [1].

1 Introduction

1.1 Introduction

The main goal of this class is the investigation of the evolution of the optical pulses which propagate in an optical fibre.

We will consider the propagation of pulses from two perspectives:

1. Theoretically
2. Via numerical simulation, using software such as MATLAB, Python, or C/C++

We will analyse and understand a number of different optical effects and regimes / models. These include:

- Group Velocity Dispersion (GVD, this is a linear effect)
- Self-Phase Modulation (this is a non-linear effect)
- Optical, Self-Trapped Waves (Solitons)
- Abnormal, Extreme Waves
- Optical Shocks

The assessment for the course will consist of a piece of coursework on the numerical dynamics of optical pulses propagating under different linear and non-linear regimes. After this coursework is handed in, a type of oral examination will be performed with each student about their coursework.
Each of you is invited to work in groups of 2-3 persons, each with different jobs.

Finally, should the lectures leave you with any confusion, or you wish to study further, the suggested textbook for this course to aid in study (if this is needed) is Non-linear Fibre Optics by Govind P. Agrawal [2].

1.2 The Non Linear Schrödinger Equation (3+3D)

The first step to considering the propagation of optical pules in a fibre is to know that an optical fibre is a non-linear and dispersive medium and that any propagation with this waveguide is governed by the fundamental and universal modal of optical wave dynamics; the Non Linear Schrödinger Equation (NLSE).

In Optical Communication Components Prof. Constantino De Angelis will analytically study the properties of the NLSE. This course, however, will consider different regimes from theoretical viewpoints, as well as numerical simulation of each of these regimes to understand the linear and non-liner effects and their uses.

So, without further ado, the Non Linear Schrödinger Equation (NLSE) (3+3D) is given by Equation 1:

$$j\frac{\partial A(r,t)}{\partial z} + \frac{1}{2\beta}\frac{\partial^2 A(r,t)}{\partial x^2} + \frac{1}{2\beta}\frac{\partial^2 A(r,t)}{\partial y^2} - \frac{\beta''}{2}\frac{\partial^2 A(r,t)}{\partial t^2} + \chi^{(3)}|A(r,t)|^2 A(r,t) = 0 \tag{1}$$

Where:

$r = (x, y, z)$, this is the 3-dimensional spatial coordinates

t, is the time coordinate

$A(r,t)$, is the slowly varying (compared to the carrier signal) envelope of the signal

$E(r,t) = Re[A(r,t)e^{i(\omega_0 t + \beta_0 z)}]$, is the electrical field of the pulse and the carrier signal

$e^{i(\omega_0 t + \beta_0 z)}$, is the optical carrier signal at the angular frequency ω_0 and 'wavenumber' β_0

1.2.1 A Quick Detour - The Gaussian Pulse

The type of communication signal model that we will deal with most often initially in the course is that of the Pulsed Gaussian or Gaussian Pulse. This signal is the combination of a lower frequency Gaussian (this is where the information is really communicated) and a higher frequency carrier sine/cosine component, these individual signals are shown separately in Figure 1.

Please note that we will give the Gaussian as a function most simply described by Equation 2:

$$f(t) = Ie^{-\frac{t^2}{2t_0^2}} \tag{2}$$

Please note t_0 is expressed here as the half-waist duration at an intensity of $\frac{1}{e}$, there are other definitions which are useful for other purposes

If one has a linear system (or one that can be approximated as such a type of system) these two signals can be super-positioned to create a Gaussian pulse, which is shown in Figure 2

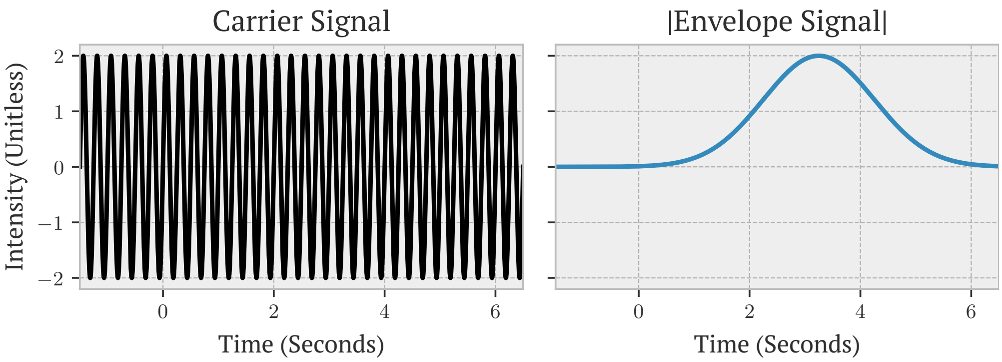

Figure 1: An example graph demonstrating the de-constructed elements of a Gaussian pulse, the carrier signal is on the left and the Gaussian on the right

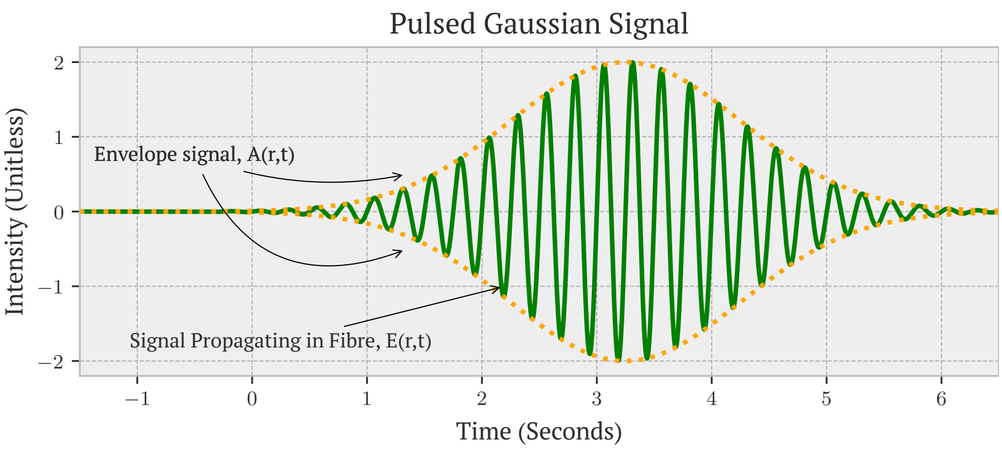

Figure 2: An example graph of the Gaussian Pulse, the envelope signal is shown as a dotted line, the signal propagated in the medium is the solid line.

It is also important to note here that the envelope signal is itself comprised of two components, a positive and a negative portion, this is easily displayed in the frequency domain, observe the spectrum (Figure 3) of the propagating signal (displayed before in Figure 2), there are a positive and negative frequency components:

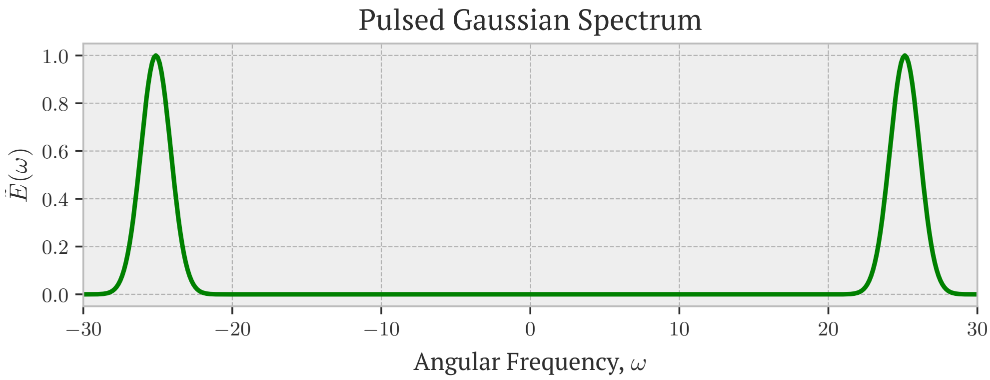

Figure 3: The Gaussian Pulse spectrum

Note that the two Gaussians are centred at the carrier frequency and that the waist frequency interval at 1/e intensity ($\Delta\omega$) must be significantly smaller than the carrier frequency of the signal (ω_0), i.e. $\Delta\omega \ll \omega_0$. This is shown in the normalised frequency spectrum graph, Figure 4:

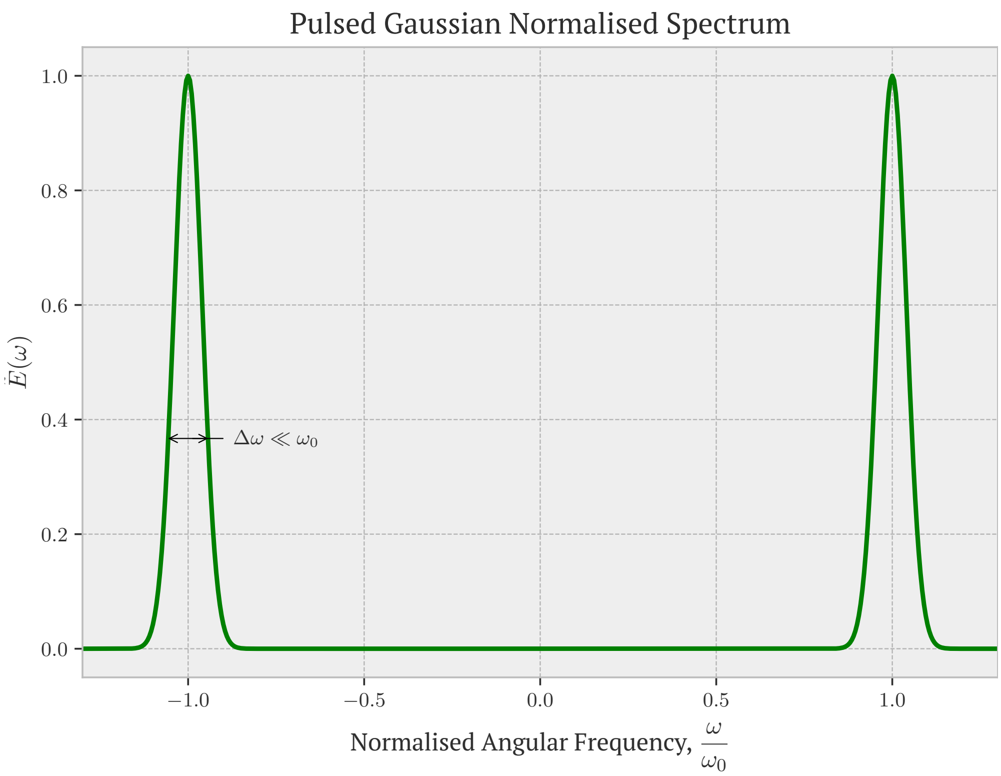

Figure 4: The Gaussian Pulse on the normalised frequency spectrum

References

[1] A. Wilson. (2021, Apr.) Academic report template. GitHub. (accessed: 16.07.2021). [Online]. Available: https://github.com/AS-Wilson/Academic-Report-Template/tree/dev-AS-Wilson

[2] G. P. Agrawal, *Nonlinear Fiber Optics*, 5th ed. The boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK: Academic Press, 2013.