

Creating a Pulse Train using Custom Time Envelopes

Products: FullWAVE FDTD

Applications: Optical Communications, Photonic Sensors and Sensing Applications

Introduction

Mode-locked lasers, which generate a train of ultra-short pulses, have become an important tool in precision optical frequency measurement [1] and are useful for the design of future ultrahigh-speed optical communication systems [2]. This note will discuss how to use **FullWAVE's** custom time envelope feature to create this type of pulse train.

Simulation Background and Setups

The output of a mode-locked laser is a comb of equidistant lines in the frequency domain, separated by a bandwidth of f_{rep} . In the time domain, this corresponds to a train of pulses whose temporal separation is given by the cavity round-trip time $t_{rt} = 1/f_{rep}$. The offset of the comb, f_{ceo} is connected to the pulse-to-pulse phase slip $\Delta\phi = 2\pi(f_{ceo}/f_{rep})$. We are going to create a pulse train with $f_{ceo} = f_{rep}/4$, such that every fifth pulse is identical, as shown in Fig.1 [3].

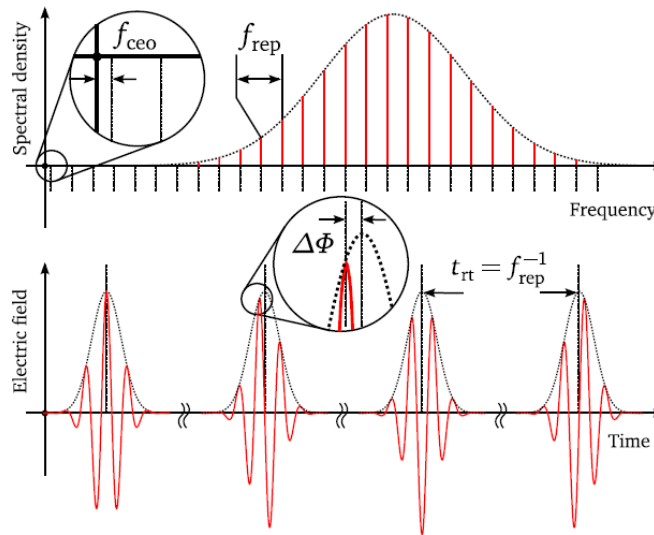


Figure 1. Pulse Train with $f_{ceo} = f_{rep}/4$, such that every fifth pulse is identical

The electric field of such a pulse train can be written as:

$$E_{train}(t) = A(t) \exp(i2\pi(f_c t + f_{ceo} t)) \cdot \sum_{m=-\infty}^{+\infty} \delta(t - m t_{rt}) \quad (1)$$

where $A(t)$ denotes the pulse envelope and $f_c = c/\lambda$ is the central frequency of the comb and the function $\delta(t - m t_{rt})$ function produces the pulse train. Note that the time envelope equation for FullWAVE's Pulse excitation type, as described in Section 4.D.2 of the FullWAVE manual, is:

$$g(t) = \exp\left[-\left(\frac{t}{\tau} - t_d\right)^2\right] \sin\left[\frac{2\pi}{\lambda}(t) + A t^2 + \phi_0\right] \quad (2)$$

The custom envelop in Eq. (1) can be written as

$$E_c(t) = \exp\left[-\left(\frac{t}{\tau} - t_d\right)^2\right] \cdot \sum_{m=-\infty}^{+\infty} \delta(t - mt_{rt}) \quad (3)$$

And the excitation wavelength will be modified by f_{ceo} term and become

$$\lambda_m = \frac{c}{f_c + f_{ceo}} = \frac{4\lambda_{trt}}{\lambda + 4 \cdot t_{rt}} \quad (4)$$

Using the above analysis, a simple model wabeguide model has been created as the design file Pulse_train.ind. We created the following symbols to help with the definition:

Symbol	Value	Description
DC	0.6	Duty Cycle, set as ratio of one time period
Lambda_c	0.5um	Initial Center Wavelength
Lambda_m	4*Lambda_c*Trt/(4*Trt+Lambda_c)	Modified Launch Wavelength
Trt	3	Pulse Repeating Time
Tp	Lambda_c/4	Pulse Time
Td	Lambda_c*6	Pulse Delay Time
free_space_wavelength	Lambda_c	The global wavelength setting
fddt_excitation_envelope	TIME_ENVELOPE_USER	Enables the use of a custome time envelope
fddt_user_envelope	$\exp(-(t/Trt - \text{floor}(t/Trt))/Tp - Td)^2) * \text{step2}((t/Trt - \text{floor}(t/Trt)), DC)$	Custom time envelope; the step2() function represents the repeating delta function and the floor() function is used to create the same envelope at each repeated time interval
t	1	The variable t must be in the symbol table so that we can use it in the envelope function; The value does not matter

The pulse simulation is set at center wavelength Lambda_c in global setting. But modified launch wavelength Lambda_m is set at Launch dialog.

Note that we have also enabled the **Excitation Time Waveform** option in the Output Options dialog so that we can view the time envelope used in the simulation.

Results

The animated results of the FullWAVE simulation are shown in Figure 2. Rsoft DataBrowser is used to creat animated pictures with 50 intermediate field slides set in Output dialog.

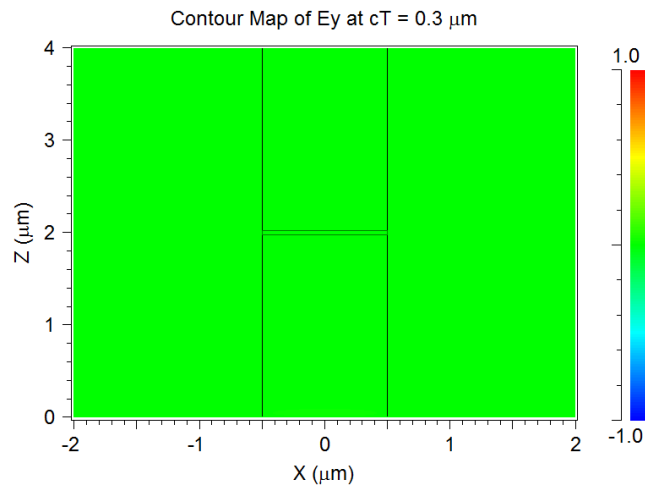


Figure 2. Pulse train propagating in a waveguide (Animated)

Here is a tip to obtain the envelope data file used in winplot. We can define a user profile with the `fdtd_user_envelope` function. By clicking on Test in the dialog below, a `tmpuser.dat` file will be created. That is the envelope data file based on equation(3). Please note that this is only used to create a reference data file. It is not used in simulation.

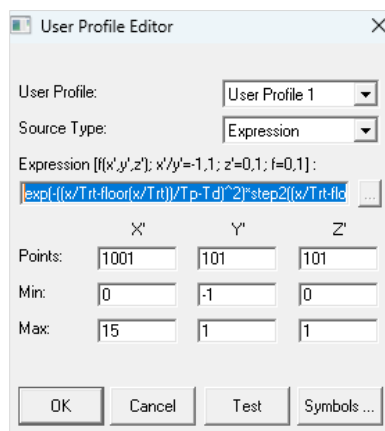


Figure 3. User profile Dialog for envelope function

Figure 4 shows the excitation pulse train envelope. The green curve is the envelope of each pulse with `fdtd_user_envelope` function.

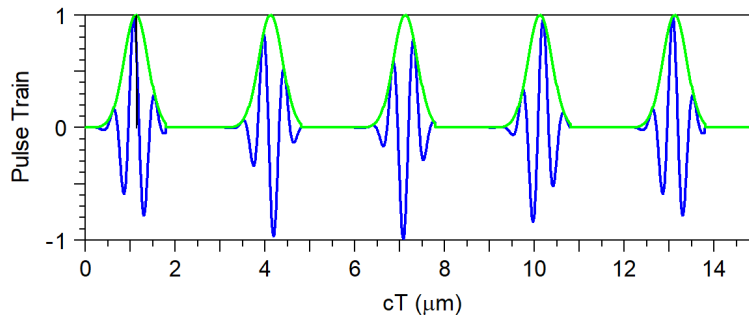


Figure 4. The pulse train recorded as time waveform(blue) and Envelope(green) based on envelope equation.

Example files

Supporting Files for RSoft Application Note "Creating a Pulse Train Using Custom Time Envelopes"

References

- [1] David J. Jones, Scott A. Diddams et al. "Carrier-Envelope Phase Control of Femtosecond Mode-Locked Lasers and Direct Optical Frequency Synthesis" SCIENCE VOL 288 28 APRIL 2000
- [2] M. Jacquety, S. Bonhommeau, and M. A. Bouchene, "Experimental demonstration of phase control of dispersion effects for an ultrashort pulse train propagating in a resonant medium" OPTICS LETTERS / Vol. 28, No. 14 / July 15, 2003
- [3] Fabian Lücking, Dissertation "Carrier-Envelope Phase Control for the Advancement of Attosecond Pulse Generation" 2014

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