Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

6.977 Ultrafast Optics

Spring 2005

Problem Set 6

Issued: March 17, 2005. **Due:** 11am, March 31, 2005.
Note: Please keep the due exactly. From Problem Set 6, a late penalty will be applied.

Problem 6.1: Passive Q-Switching

A microchip laser with the following parameters:

parameter	value
$2\ g_0$	0.7
$2\ l$	0.14
T_R	2.7 ps
τ_L	0.87 μs
E_L	0.2 μJ

is passively Q-switched with two different absorbers: (i) a fast saturable absorber with an absorption depth of $2q_0 = 0.03$, a saturation energy of $E_A^{FSA} = 0.77$ pJ, and an absorber recovery time of $\tau_A^{FSA} = 1$ ps; and (ii) a slow saturable absorber with the same modulation depth but with a saturation energy of $E_A^{SSA} = 77$ pJ and a recovery time of $\tau_A^{SSA} = 100$ ps.

(a) Is the laser with the fast saturable absorber Q-switching?

(b) Formulate the rate equations for case (i) and (ii).

(c) Write a short MATLAB routine that numerically solves these rate equations using the routine ode45 (of course, also any other numerical ode solver can be used). It helps to add spontaneous emission for numerical stability: for example, add $10^{-8}g$ term in your power rate equation.

(d) Integrate the rate equations over many cavity round-trip times, and plot the corresponding solutions versus time (similar to Fig. 4.22 in the class note) and in a phase space (similar to Fig. 4.21 in the class note). Normalize the corresponding quantities properly.

(e) For the slow saturable absorber case, extract the characteristic pulse properties of the Q-switched pulse trains (pulse energy, pulse width and repetition rate) from the numerical simulations, and compare these values with the analytical results derived in Section 4.5.2 of the class note.

Problem 6.2: Active Mode-Locking and Gaussian Pulse Analysis

In this Problem, the steady-state pulse width in an actively mode-locked laser using Gaussian pulse analysis will be obtained.

The master equation for active mode locking by pure loss modulation is given by the following expression

$$T_R \frac{\partial A}{\partial T} = \left[g - l + D_g \frac{\partial^2}{\partial t^2} - M_s t^2 \right] A \tag{1}$$

where the loss modulator is already described in parabolic approximation. In the same way as the Split-Step Fourier transform method to simulate the NSE, we can use it to simulate the dynamics of the actively mode-locked laser. We start from a Gaussian pulse

$$A_1(t) = e^{-\Gamma_1 t^2/2}, \tag{2}$$

with the complex $\Gamma-$parameter, $\Gamma_1 = a + jb$. Propagation through the gain and loss parts of the system within one round trip can be described in the frequency domain by the operation

$$\hat{A}_2(\omega) = e^{\left(g - l - D_g \omega^2\right)} \hat{A}_1(\omega), \tag{3}$$

which is again a Gaussian pulse in the frequency and time domain

$$A_2(t) = e^{-\Gamma_2 t^2/2}. \tag{4}$$

Propagation through the modulator is most simply described in the time domain by

$$A_3(t) = e^{-M_s t^2} A_2(t) = e^{-\Gamma_3 t^2/2} \tag{5}$$

(a) Calculate the complex Gamma coefficients Γ_2 and Γ_3 as a function of Γ_1, D_g and M_s. Assume $D_g \Gamma_1 \ll 1$.

(b) What is the condition for steady-state pulse after one round-trip?

(c) Derive the Γ-parameter for the steady-state pulse. How do the stationary pulse width and chirp depend on the system parameters?

Enjoy your spring break!