SESAM modelocked lasers
Fast and slow saturable absorbers

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Loss modulation for a slow and fast saturable absorber

$$\frac{dq(t)}{dt} = -\frac{q(t)-q_0}{\tau_A} - \frac{q(t)P(t)}{E_{sat,A}}$$

slow saturable absorber: $\tau_p << \tau_A$

neglect recovery within pulse duration

$$\frac{dq(t)}{dt} \approx -\frac{q(t)P(t)}{E_{sat,A}}$$

$$P(t) = E_p f(t), \quad \text{where} \quad \int_0^{T_R} f(t)\,dt = 1$$

$$q(t) = q_0 \exp\left[-\frac{E_p}{E_{sat,A}} \int_0^t f(t')\,dt'\right]$$

fast saturable absorber: $\tau_p >> \tau_A$

follows "immediately" incoming power

$$0 = -\frac{q(t)-q_0}{\tau_A} - \frac{q(t)P(t)}{E_{sat,A}}$$

$$P_{sat,A} = \frac{E_{sat,A}}{\tau_A}, \quad \Rightarrow \quad \frac{P(t)}{P_{sat,A}} = \frac{I_A(t)}{I_{sat,A}}$$

$$q(t) = \frac{q_0}{1 + I_A(t)/I_{sat,A}}$$

Loss modulation for a slow saturable absorber

$$\frac{dq(t)}{dt} = -\frac{q(t)-q_0}{\tau_A} - \frac{q(t)P(t)}{E_{sat,A}}$$

slow saturable absorber: $\tau_p \ll \tau_A$

neglect recovery within pulse duration

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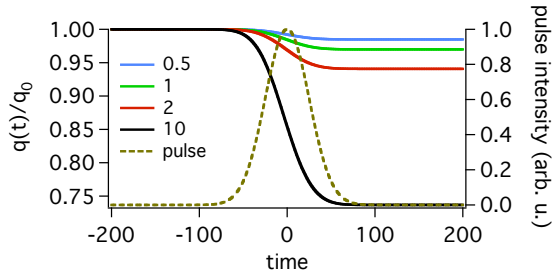

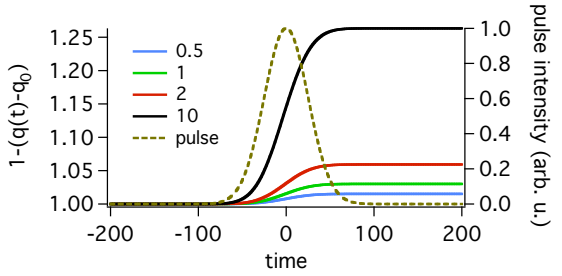

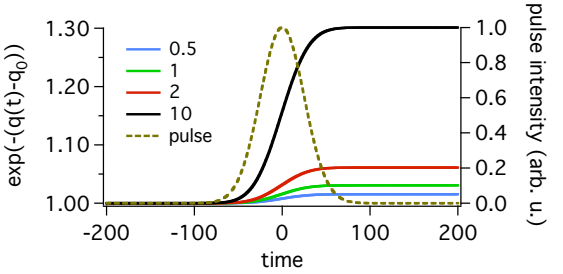

Loss modulation for a slow saturable absorber

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$$q(t) = q_0 \exp\left[-\frac{E_p}{E_{sat,A}} \int_0^t f(t')\,dt'\right]$$

loss a pulse experiences through this saturable absorber:

$$q_p(E_p) = \int_0^{T_R} q(t) f(t)\,dt$$

$$= q_0 \frac{F_{sat,A} A_A}{E_p}\left[1 - \exp\left(-\frac{E_p}{F_{sat,A} A_A}\right)\right]$$

does not depend on pulse shape because: $\tau_p \ll \tau_A$

absorbed energy:

$$E_{abs} = 2 q_p(E_p) E_p$$

Loss modulation for a fast saturable absorber

$$\frac{dq(t)}{dt} = -\frac{q(t)-q_0}{\tau_A} - \frac{q(t)P(t)}{E_{sat,A}}$$

fast saturable absorber: $\tau_p >> \tau_A$

follows "immediately" incoming power

$$0 = -\frac{q(t)-q_0}{\tau_A} - \frac{q(t)P(t)}{E_{sat,A}}$$

$$P_{sat,A} = \frac{E_{sat,A}}{\tau_A}, \quad \Rightarrow \quad \frac{P(t)}{P_{sat,A}} = \frac{I_A(t)}{I_{sat,A}}$$

$$q(t) = \frac{q_0}{1 + I_A(t)/I_{sat,A}}$$

loss a pulse experiences through this saturable absorber:

assuming **soliton pulse shape** and **fully saturated ideally fast absorber**

$$I(t) = I_p \operatorname{sech}^2(t/\tau)$$

$$q_p \approx \frac{q_0}{3}$$

loss now depends on pulse shape!

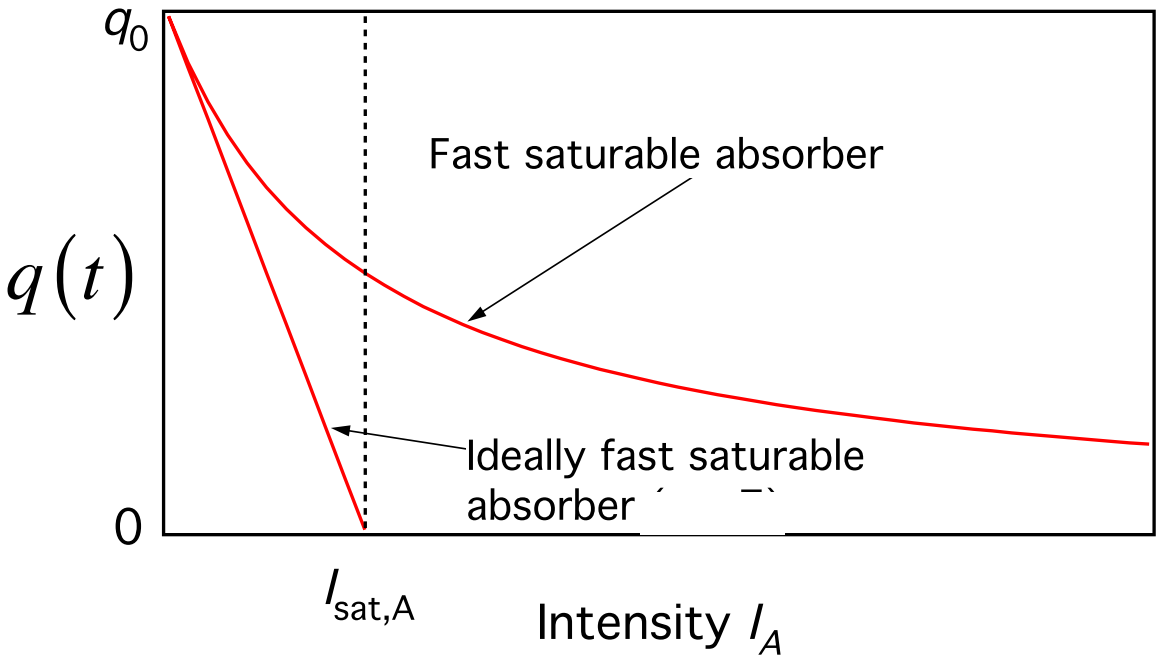
Ideally fast saturable absorber

$$q(t) = \frac{q_0}{1 + I_A(t)/I_{sat,A}} \approx q_0\left(1 - \frac{I_A(t)}{I_{sat,A}}\right) = q_0 - \gamma_A I_A(t)$$

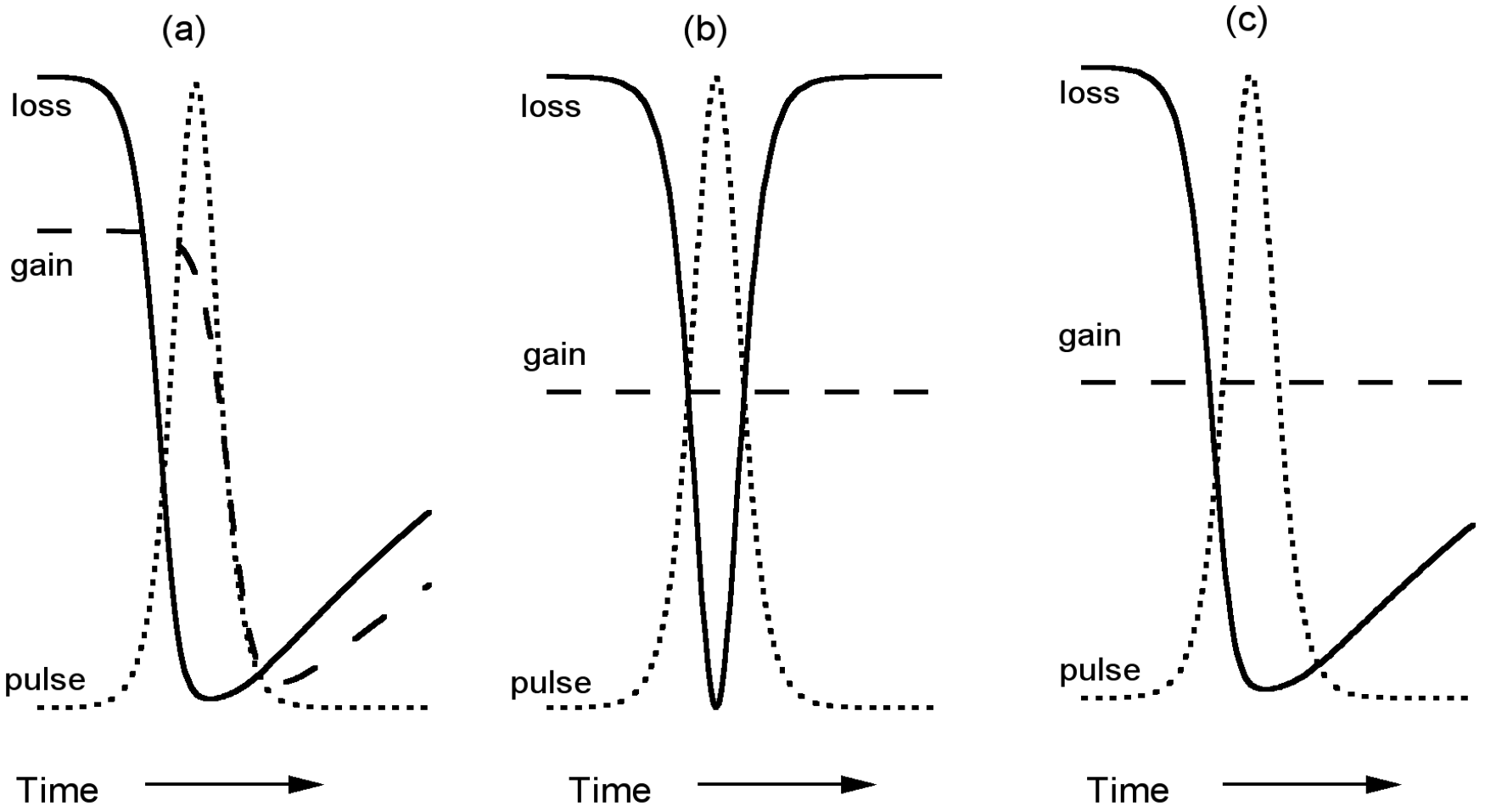
$$\gamma_A \equiv \frac{q_0}{I_{sat,A}}$$

fast saturable absorber

ideally fast saturable absorber



Pulse-shaping in passive modelocking



U. Keller, Ultrafast solid-state lasers, Landolt-Börnstein, Group VIII/1B1, edited by G. Herziger, H. Weber, R. Proprawe, pp. 33-167, 2007, ISBN 978-3-540-26033-2

Useful References

- **Fast and slow saturable absorber – What is the difference?**

[82] F. X. Kärtner, J. Aus der Au, U. Keller, **Invited Paper**, "Mode-locking with slow and fast saturable absorbers - What's the difference?", *IEEE J. Selected Topics in Quantum Electronics (JSTQE)*, vol. 4, pp. 159-168, 1998
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- **Slow saturable absorber**

[90] C. Hönninger, R. Paschotta, F. Morier-Genoud, M. Moser, U. Keller, "Q-switching stability limits of cw passive modelocking", *J. Opt. Soc. Am. B*, vol. 16, pp. 46-56, 1999
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[152] R. Paschotta and U. Keller, "Passive mode locking with slow saturable absorbers", *Appl. Phys. B*, vol. 73, pp. 653-662, 2001
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Overview book chapter for fast and slow saturable absorbers:

U. Keller, Ultrafast solid-state lasers, Landolt-Börnstein, Group VIII/1B1, edited by G. Herziger, H. Weber, R. Proprawe, pp. 33-167, 2007, ISBN 978-3-540-26033-2
http://www.ulp.ethz.ch/research/UltrafastSolidStateLasers

References can be downloaded on the webpage, organized by numbers quoted here.