Eye opening by saturable absorber

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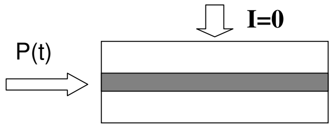
I. PROBLEM DESCRIPTION

A short ($L \approx 100\mu$m) unpumped SOA (open circuit) is considered.



A pulse train $P(t)$ with a bad extinction ratio is injected. How does this device perform as an "eye opener"? Which are the optimum operation point and design rules? I try to find formulae helping to answer these questions and to understand simulation and measurement.

As a measure for the effects I consider the

$$\boxed{\textbf{suppression} \qquad s(t) = -10\lg\left(\frac{P_{\mathrm{out}}(t)}{T_0 P_{\mathrm{in}}(t-t_{\mathrm{travel}})}\right)} \tag{1}$$

$T_0 = \exp(-\alpha_0 L)$: CW transmittivity of the completely saturated device, α_0: back ground absorption coefficient, $t_{\mathrm{travel}} = L/c$: time of travel through the device, c: group velocity of light.

This quantitiy give the actual suppression in dB of the transmittivity due to incomplete saturation of the absorber. Its temporal behaviour is a direct measure for the influence of the device on the vertical opening of the eye.

II. EQUATION OF MOTION

Some assumptions:
bit rate $f \ll 1/t_{\mathrm{travel}} \approx$ THz,
spatially constant carrier density $N(t)$.

The suppression is determined by the actual carrier density as follows:

$$s = g(N)L = \Gamma g' L \cdot (N - N_t). \tag{2}$$

$\Gamma = 0.4$: confinement factor, $N_t = 10^{24}\mathrm{m}^{-3}$: transparency density, $g' = 5\cdot 10^{-20}\mathrm{m}^2$: differential gain. Thus, its evolution is governed by the carrier rate equation:

$$\partial_t N = \frac{I}{eAL} - \frac{N}{\tau} - cg(N)S(t). \tag{3}$$

$I = 0$: injection current (set to zero, but here I keep it general because perhaps better performance with $I \neq 0$), $A = 5\cdot 10^{-13}\mathrm{m}^2$: cross section area of AZ, $\tau = 1$ns: carrier life time,

$$S(t) = \frac{\bar{P}(t)}{cA\hbar\omega} \qquad \text{photon density} \tag{4}$$

$\bar{P}(t)$: spatailly averaged power in the cavity, $\hbar\omega = 0.8$eV: photon energy.

The resulting equation of motion for the suppression is

$$\boxed{\tau\partial_t s = s_0 - (1+p)s} \tag{5}$$

$$s_0 = 10\lg(e)\Gamma g' L N_t (1 - \frac{I}{I_t}) = 8.7\mathrm{dB} \tag{6}$$

$$p = \frac{\bar{P}}{P_s}, \quad P_s = \frac{A\hbar\omega}{\tau\Gamma g'} = 3.2\mathrm{mW} \text{ saturation power} \tag{7}$$

s_0 is the maximum possible suppression, i.e., an upper limit for the improvement of the eye opening.

III. GENERAL SOLUTION

The general solution of the equation of motion is

$$s(t) = s_0 \int_{-\infty}^{t} \frac{dt'}{\tau} \exp\left(-\int_{t'}^{t} \frac{dt''}{\tau}(1+p(t''))\right) \tag{8}$$

$$= s_0 \int_{0}^{\infty} \frac{dt'}{\tau} \exp\left(-\int_{0}^{t'} \frac{dt''}{\tau}(1+p(t-t''))\right) \tag{9}$$

Qualitative discussion: the integral is always ≤ 1. It becomes $= 1$ only in the limit $p(t) \to 0$ (maximum suppression for very small signals). The bigger p becomes, the faster decays the integrand (the exp-function) to zero, reducing s. $s(t)$ does not depend on the actual power $p(t)$ only, but it also remembers earlier powers. The memory time is of the order of that t' for which the exponent becomes -1, i.e. roughly

$$\text{memory time:} \quad t_{\mathrm{mem}} \approx \frac{\tau}{1+\langle p\rangle}, \tag{10}$$

$\langle p\rangle$: average of p over the memory time. Signals weaker than $P_s = 3$mW: $t_{\mathrm{mem}} \approx \tau = 1$ns, i.e. s averages over about 40 periods of a 40 GHz signal and shows only a small modulation at this frequency. It responds much more to slower changes of the pulse train as accumulations of many 1-bits or many 0-bits, which causes the unwanted pattern effects.

To get the variations of s due to patterns smaller than those at the operation frequency $f = 40$ GHz, one must achieve $ft_{mem} \leq 1$, independent of the value of s_0.

Thus, t_{mem} has to be decreased to the order of 25ps or less. One possibility is using true saturable absorbers with a short τ. The same effect is achieved with increasing $\langle P\rangle/P_s$ up to about 40. With our parameters this required mean powers of about $40\cdot 3\mathrm{mW} \approx 100$ mW. In order to find out which parameters have to be changed to reduce this very high value, I rewrite the memory time in the high power limit:

$$t_{\mathrm{mem}} \approx \frac{\hbar\omega}{\langle P\rangle}\,\frac{A}{\Gamma g'} \qquad \text{if } \langle P\rangle \gg P_s. \tag{11}$$

Note: τ has canceled out in this limit. The only possibility to reduce the memory time is to increase the effective differential gain $\Gamma g'/A$.
In the following I support this discussion by considering some special cases.

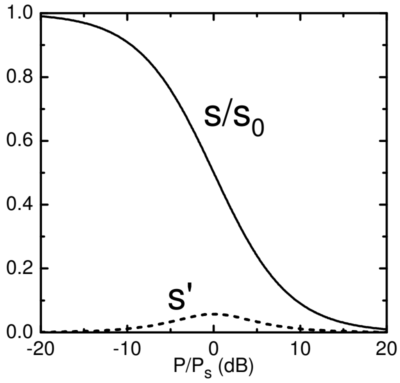
IV. SPECIAL CASES

A. CW injection ($p(t)$ =const.)

Integral (9) is easily calculated:

$$s = \frac{s_0}{1+p}. \tag{12}$$

This gives the CW characterisitics



Additionally I have plotted here the derivative parameter

$$s' = \frac{d(s/s_0)}{d(10\lg(P/P_s))} = \frac{1}{10\lg e}\,\frac{p}{(1+p)^2}. \tag{13}$$

It shows the differential change of the relative suppression s/s_0 per dB change of the input power. Its maximum at $p = P/P_s = 1$ is here about 0.06, i.e., the maximum differential change of s is about $0.06 s_0 = 0.5$dB per dB change of the input power.

If e.g. we have an extinction of 5dB at input, the static extinction at output is about $5 + 0.5 * 5 = 7.5$dB.

B. Periodic pulse sequence

Hier muss ich erst mal aufgeben. Keine Zeit mehr.