P_0 is the laser output power measured in mW. The laser has a threshold current of $I_{\text{th}} = 12$ mA. It is biased at a DC injection current of $I_0 = 28$ mA and is modulated with a modulation current at a modulation frequency of $f = 10$ GHz and a modulation index of $m = 10\%$. (a) Find the output power of the laser at the DC bias point. (b) What is the amplitude of the modulation current? (c) Find the relaxation resonance frequency f_{r} and the total carrier relaxation rate γ_{r} of this laser at this operating point. What is the value of the K factor? (d) What are the amplitude of the modulated output power and the phase delay of the response to the current modulation? (e) Find the 3-dB modulation bandwidth of this laser at this operating point in terms of its modulation response in the electrical power spectrum of the photodetector output. (f) At this modulation frequency, what is the modulation response in the electrical power spectrum of the photodetector used to measure the laser output? What is the normalized modulation response in dB?

Solution:

A laser has a threshold. Therefore, the DC output power is not proportional to its DC bias current but is proportional to $I_0 - I_{\text{th}}$, and the modulation index is defined as the ratio of the amplitude I_{m} of the modulation current to $I_0 - I_{\text{th}}$.

(a) The photon energy at $\lambda = 850$ nm is

$$h\nu = \frac{1239.8}{850}\ \text{eV} = 1.46\ \text{eV}.$$

The DC output power of the laser is found using (10.35):

$$P_0 = \eta_{\text{inj}} \frac{\gamma_{\text{out}}}{\gamma_{\text{c}}} \frac{h\nu}{e} (I_0 - I_{\text{th}}) = 0.6 \times \frac{5.7 \times 10^{10}}{2 \times 10^{11}} \times 1.46 \times (28 - 12)\ \text{mW} = 4.0\ \text{mW}.$$

(b) The amplitude of the modulation current for $m = 10\%$ is

$$I_{\text{m}} = m(I_0 - I_{\text{th}}) = 10\% \times (28 - 12)\ \text{mA} = 1.6\ \text{mA}.$$

(c) With $\tau_{\text{s}} = 6.67$ ns, $\gamma_{\text{c}} = 2 \times 10^{11}\ \text{s}^{-1}$, $\gamma_{\text{n}} = 4.9P_0 \times 10^9\ \text{s}^{-1}$, and $\gamma_{\text{p}} = 6.1P_0 \times 10^9\ \text{s}^{-1}$ given, and $P_0 = 4.0$ mW found in (a), we have

$$\gamma_{\text{s}} = \tau_{\text{s}}^{-1} = 1.5 \times 10^9\ \text{s}^{-1}, \gamma_{\text{c}} = 2 \times 10^{11}\ \text{s}^{-1}, \gamma_{\text{n}} = 1.96 \times 10^{10}\ \text{s}^{-1}, \gamma_{\text{p}} = 2.44 \times 10^{10}\ \text{s}^{-1}.$$

Therefore, using (10.41) and (10.42), we find

$$f_{\text{r}} = \frac{1}{2\pi}\sqrt{\gamma_{\text{c}}\gamma_{\text{n}} + \gamma_{\text{s}}\gamma_{\text{p}}} = 10\ \text{GHz},$$

$$\gamma_{\text{r}} = \gamma_{\text{s}} + \gamma_{\text{n}} + \gamma_{\text{p}} = 4.42 \times 10^{10}\ \text{s}^{-1}.$$

The K factor is found using (10.43):

$$K = \frac{\gamma_{\text{r}} - \gamma_{\text{s}}}{f_{\text{r}}^2} = \frac{\cancel{4.55} \times 10^{10} - 1.5 \times 10^9}{(10 \times 10^9)^2}\ \text{s} = 440\ \text{ps}.$$

(d) For a modulation frequency of $f = 10$ GHz, we find that $f = f_{\text{r}}$, thus $\Omega = \Omega_{\text{r}}$, because $f_{\text{r}} =$ 10 GHz as found in (c). Therefore, from (10.40), we find