5.1:

There are a number of clues that lead to conclusions about the value of the current relative to its threshold value:

1) There is significant stimulated emission output, which implies that the laser is operating above threshold.

2) The stimulated emission rate, R_{21}, is significantly more than the absorption rate, R_{12}. This implies that there is a large population inversion, which implies a large gain. This implies that the laser is operating near or above threshold.

3) The best clue, however, is the relative rates of carrier flow from the carrier reservoir:

$$R_{st} = R_{21} \approx R_{sp} + R_{nr}$$

Since this implies $\frac{1}{\tau_{st}} \approx \frac{1}{\tau_{sp}} + \frac{1}{\tau_{nr}}$ as mentioned at the end of section 5.2.2.3 on p. 193. We can deduce that

$$I \approx 2I_{th}$$

5.2:

Eq. 5.37 can be rewritten as directed in the text:

$$\frac{d}{dt}\begin{bmatrix} dN \\ dN_P \end{bmatrix} = \begin{bmatrix} -\gamma_{NN} & -\gamma_{NP} \\ \gamma_{PN} & -\gamma_{PP} \end{bmatrix} \begin{bmatrix} dN \\ dN_P \end{bmatrix} + v_g N_P \begin{bmatrix} 0 \\ -d\alpha_m \end{bmatrix}$$

Making substitutions as in Eq. 5.39, we get an equation similar to Eq. 5.40:

$$\begin{bmatrix} j\omega + \gamma_{NN} & \gamma_{NP} \\ -\gamma_{PN} & j\omega + \gamma_{PP} \end{bmatrix} \begin{bmatrix} N_1 \\ N_{P1} \end{bmatrix} = -v_g N_P \alpha_{m1} \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

Let Δ be defined as in Eq. 5.41. Then

$$N_1 = (-v_g N_P \alpha_{m1}) \frac{1}{\Delta} \begin{vmatrix} 0 & \gamma_{NP} \\ 1 & \gamma_{PP} + j\omega \end{vmatrix} = (-v_g N_P \alpha_{m1}) \frac{-\gamma_{NP}}{\Delta}$$

$$N_{P1} = (-v_g N_P \alpha_{m1}) \frac{1}{\Delta} \begin{vmatrix} \gamma_{NN} + j\omega & 0 \\ -\gamma_{PN} & 1 \end{vmatrix} = (-v_g N_P \alpha_{m1}) \frac{-\gamma_{NN} + j\omega}{\Delta}$$

with

$$H(\omega) = \frac{\omega_R^2}{\Delta}$$

So, we have

$$N_1 = (v_g N_P \alpha_{m1}) \frac{\gamma_{NP}}{\omega_R^2} H(\omega)$$

$$N_{P1} = (-v_g N_P \alpha_{m1}) \frac{\gamma_{NN} + j\omega}{\omega_R^2} H(\omega)$$

The output power is proportional to the photon population, N_P, and the mirror loss, α_m. So, to first order, P_1 will have two terms. Combining Eqs. 5.5, 5.6, and 5.7,

$$P_0 = F v_g h\nu V_P \alpha_m N_P$$

$$P_1 = F v_g h\nu V_P (\alpha_{m0} N_{P1} + \alpha_{m1} N_{P0})$$

The main distinction between modulating mirror loss instead of current is the phase of the carrier population oscillation relative to the photon population oscillation. Current modulation directly modulates the carrier population, which is coupled to the photon population. Mirror loss modulation directly modulates the photon population, which is coupled to the carrier population. In each case, the phase (of modulation) for the directly modulated population preceeds the phase of the coupled population.

Also, the photon density displays a low frequency pole in the response such that it drops off at 20 dB/decade rather than at 40 dB/decade.

5.4:

First, find $H_{RC}(\omega)$:

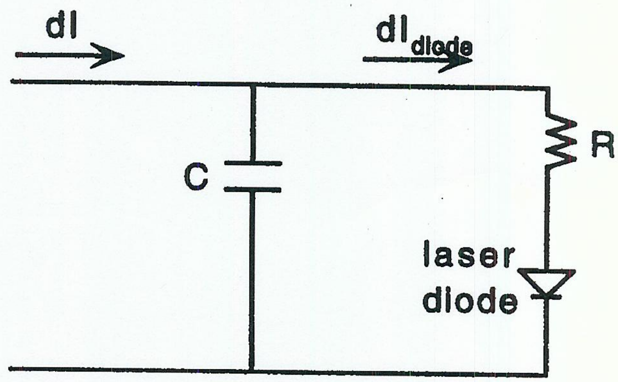

Figure 5.4. Equivalent circuit diagram for laser.

The diode has an impedance of R in its "ON" state.

$$dI_{diode} = dI\frac{(R||C)}{R} = dI\frac{\frac{1}{\frac{1}{R}+j\omega C}}{R} = dI\frac{1}{1+j\omega RC}$$

$$H_{RC}(\omega) = \frac{1}{1+j\omega RC}$$

$H(\omega)$ for the laser diode is given by Eq. 5.46:

$$H(\omega) = \frac{\omega_R^2}{\omega_R^2 - \omega^2 + j\omega\gamma} \tag{5.46}$$

From the problem statement, we know that

$R = 10\ \Omega$

$\omega_R = (20\ \text{GHz})2\pi = 1.257 \times 10^{10}\text{rad/s}$

$\gamma \approx 0$

$\omega_{3dB} = 1.55(20\ \text{GHz})2\pi * 90\% = 1.75 \times 10^{11}\text{rad/s}$ (using Eq. 5.54)

Use the limitation on bandwidth to solve for capacitance:

$$\frac{1}{\sqrt{2}} = |H_{RC}(\omega_{3dB})\ H(\omega_{3dB})|$$

$$\frac{1}{\sqrt{2}} = \left|\frac{1}{1+j\omega_{3dB}RC}\ \frac{\omega_R^2}{\omega_R^2 - \omega_{3dB}^2}\right|$$

$$= \frac{1}{\sqrt{1+(\omega_{3dB}RC)^2}}\ \frac{\omega_R^2}{\omega_R^2 - \omega_{3dB}^2}$$

$$C = \sqrt{\frac{\frac{2\omega_R^4}{(\omega_R^2-\omega_{3dB}^2)^2} - 1}{\omega_{3dB}^2 R^2}}$$

$$C = 0.634pF$$

5.5:

Find the poles of the denominator of Eq. 5.59:

$$\omega_R^2 - \omega^2 + j\omega\gamma = 0$$

$$(j\omega)^2 + (j\omega)\gamma + \omega_R^2 = 0$$

$$j\omega = \frac{-\gamma \pm \sqrt{\gamma^2 - 4\omega_R^2}}{2}$$

Thus, we see the poles occur for

$$0 = j\omega + \frac{\gamma}{2} \pm j\omega_R \sqrt{1 - \left(\frac{\gamma}{2\omega_R}\right)^2}$$

or

$$0 = j\omega + s_{1,2}$$

where $s_{1,2}$ are defined by Eq. 5.60.