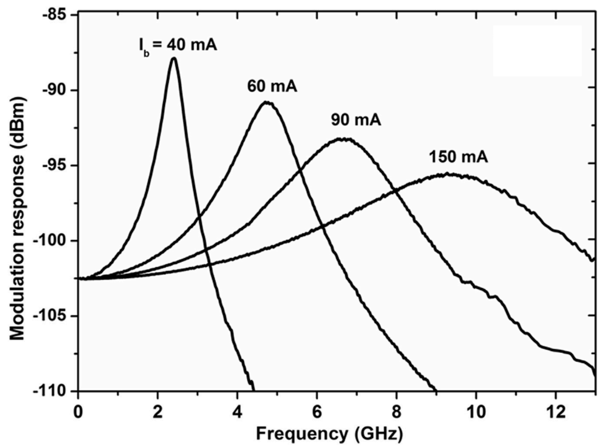
Exercise 1 **(10 pts)**
The figure below displays the electro-optical response of a semiconductor laser at several bias currents.

1) Give the oscillation frequency f_r at 40, 60, 90, and 150 mA.
2) Why the response falls down at high biases? Explain.
3) Determine the 3-dB bandwidth frequency using $f_{3dB} = f_r\sqrt{1+\sqrt{2}} \cong 1.55\, f_r$ at 40, 60, and 90 mA. Use a graphical check to confirm your calculated values.
4) Cite at least two effects limiting the modulation capabilities of directly modulated semiconductor lasers.



Exercise 2 **(10 pts)**
We consider the dimensionless rate equations of a semiconductor laser

$$\frac{dP}{dt} = P(D-1)$$
$$\frac{dD}{dt} = \gamma(A - D(P+1))$$

with *P* the photon number, *D* the carrier number, A > 0 the pump parameter, and $\gamma \ll 1$ the ratio of the photon lifetime to carrier lifetime. We note P_s and D_s the steady state.

1) Determine the zero-intensity steady states (A < 1).
2) Determine the non-zero intensity steady state (A > 1).
3) Plot P=f(A) and D=f(A). Explain.
4) Assume a small perturbation of the steady states such as $P(t) = P_s + u(t)$ and $D(t) = D_s + v(t)$, show that the evolution matrix $\boldsymbol{J_L}$ of the laser is given by

$$\boldsymbol{J_L} = \begin{bmatrix} D_s - 1 & P_s \\ -\gamma D_s & -\gamma(1+P_s) \end{bmatrix}$$

Hint: neglect the second order terms ($u \times v \ll 1$).

5) Find the characteristic polynomial for the non-zero steady state. Considering small γ values show that the relevant eigenvalue can be expressed such as

$$\lambda = -\gamma\frac{A}{2} + i\sqrt{\gamma(A-1)}$$

Assuming $u(t) = e^{-\frac{\gamma A}{2}t}\sin\left[\sqrt{\gamma(A-1)}t + \phi\right]$, plot $u(t)$ and link the observed behavior with the eigenvalue in particular by stressing the roles of the damping and oscillation frequency.