Electric circuits to support a laser diode

Electric property of a laser diode is just like a conventional diode, and has operate in the forwarded region:

Because the current-voltage relation of laser diode is exponential, while optical power versus current is linear (above threshold), a current source has to be used to bias the laser.

The danger of using a constant voltage source is the thermal run-away: For example, if a 1.5V constant voltage bias is applied on the laser, when temperature increases from 17°C to 47°C, the current will be increased from 200mA to 800mA, so that the laser will be destroyed.
Electric circuits to support a photodiode

- Reverse biasing is required to increase carrier transient velocity.
- Photocurrent is linearly proportional to the received signal optical power.
- Photocurrent needs to be amplified by an electric amplifier.
- Voltage amplifier is usually used for low speed signals and high gain (for sensors). Trans-impedance amplifier is usually used for high speed signals (typically for communications).
Example of a trans-conductance amplifier (voltage input and current output)

\[ I_D = V_{cc} \frac{1 - R_4 / (R_3 + R_4)}{R_e} + \frac{v_s R_2 / R_1}{R_e} \]

- DC bias is determined by \( R_3 \) and \( R_4 \)
- AC signal trans-conductance gain is determined by \( R_1, R_2 \) and \( R_e \)

For DC biasing current:

\[ I_D = \frac{V_{cc} - V_1}{R_e} \]

\[ V_1 = V_{cc} R_4 (R_3 + R_4) \]
Using a voltage amplifier

![Equivalent Circuit Diagram]

- **Output voltage**
- **Bias**
- **Optical signal**
- **Amp**
- **RL**

### PD equivalent circuit

- **Rp** is usually negligible

\[ V_{in} = I_d \left( \frac{R_L}{R_s + R_L} \right) \left( \frac{R_s + R_L}{R_s + R_L + \frac{1}{j\omega C_d}} + \frac{1}{j\omega C_d} \right) = \frac{I_d (R_s + R_L) R_L}{[1 + j\omega C_d (R_s + R_L)](R_s + R_L)} \]

**Trans-impedance gain:** \( G_v(\omega) = \frac{V_0}{I_d} = \frac{A (R_s + R_L) R_L}{[1 + j\omega C_d (R_s + R_L)](R_s + R_L)} \approx \frac{AR_L}{1 + j\omega C_d R_L} \)

**3dB bandwidth:**

\[ f_{3dB} = \frac{1}{2\pi R_L C_d} \]

- \( R_L \uparrow \rightarrow G_v(0) \uparrow \) (increases the gain at low-frequency), as DC gain \( G_v(0) = AR_L \)
- \( R_L \uparrow \rightarrow f_{3dB} \downarrow \) (reduces bandwidth)
Using a trans-impedance amplifier (TIA)

Trans-impedance gain:

\[ V_0 = \left[ V_z + \frac{V_0 - V_{in}}{R_F} R_z \right](-A) = \frac{V_z A / (1 + A)}{R_z / R_F + 1 / (1 + A)} \]

with \[ V_z = \frac{I_d}{j \omega C_d} \quad \text{and} \quad R_z = R_s + \frac{1}{j \omega C_d} \]

\[ G_{TIA}(\omega) = \frac{V_0}{I_p} = \frac{-R_F}{1 + j \omega C_d} \]

3dB bandwidth:

- \[ |G_{TIA}(0)| = R_F \], independent of amplifier gain \( A \)
- \( f_{3dB} \) only depends on the PD parameters \( R_s \) and \( C_d \)
- TIA usually has higher bandwidth (than voltage amplifier) as \( R_s \ll R_L \)

\[ f_{3dB} = \frac{1}{2\pi R_s C_d} \]