4.3. Receiver Design

A digital receiver consists of three main components: the front-end, the linear channel, and the data recovery unit. The front-end serves as the interface between the optical and electrical domains, and contains the photodiode and a pre-amplifier. The linear channel handles high-gain amplification and has a special low-pass filter. Finally, the data recovery unit performs clock recovery and samples the incoming waveform to produce a clean digital output.

4.3.1. Receiver front end

We have already talked about photodiodes in some detail. The purpose of the photodiode is to convert the incoming optical signal from the fiber into an electrical signal. The role of the preamplifier is to amplify the converted signal for additional processing. There are two main choices of front-end circuits, the high-impedance front end and the transimpedence front-end.

The high-impedence front-end has the basic schematic shown in the figure. At high incident optical power, the voltage drop across the diode approaches the bias voltage, and the voltage response is no longer linear with optical power. The maximum current is

\[ I_p \leq \frac{V_B}{R_L} \]

The maximum light power is therefore

\[ P_{\text{inc}} \leq \frac{V_B}{R_L} \cdot R_L. \]

The linear range can be increased by reducing \( R_L \), but the sensitivity decreases. This circuit provides high sensitivity due to the large load resistance \( R_L \), but this large resistance reduces bandwidth

\[ \Delta f = \frac{1}{2\pi R_L C_T} \]

where \( R_s \) is the series resistance of the photodiode. The total capacitance is written

\[ C_T = C_{\text{photodiode}} + C_{\text{transistor}} \]

The frequency response of the front-end should be at least the bit-rate. Transimpedence front-ends provide high sensitivity, large bandwidth, and large dynamic range. Negative feedback reduces the effective input impedance by the factor \( G \), which is the amplifier gain. Therefore, the bandwidth is given by

\[ \Delta f = \frac{G}{2\pi R_L C_T} \]

Transimpedence front-ends are the most common for optical receivers.

4.3.2. Linear channel

The linear channel consists of a high gain amplifier and a low-pass filter. An equalizer is sometimes used to compensate for limited bandwidth of the front end by attenuating low-frequencies such that linear amplification over the entire frequency range will result in increased effective bandwidth. The high gain amplifier uses automatic gain control (AGC) to limit the average output voltage to a fixed level no matter what the average incident optical power. The low-pass filter shapes the voltage pulse and reduces noise with the intent of not introducing intersymbol interference.

Receiver noise is proportional to overall receiver bandwidth \( \Delta f \), and can be reduced by using \( \Delta f \) somewhat smaller than the bit rate \( B \). Note that it may not be beneficial to low-pass at the front-end, so bandwidth reduction typically occurs at the filter. For \( \Delta f < B \), the electrical pulse spreads beyond the bit slot such that intersymbol interference, or ISI, occurs. ISI is minimized by using a low-pass filter with a specific, raised-cosine, transfer function.

By treating the front end and linear channel as a linear system, we can write the output voltage (after the filter) as

\[ V_{\text{out}}(t) = \int_{-\infty}^{\infty} z(t-\tau)I_p(\tau)d\tau. \]

The photocurrent \( I_p \) is generated in response to the incident optical power, i.e. \( I_p = RP_{\text{inc}} \). In the
frequency domain,
\[ V_{\text{out}}(\omega) = \frac{Z_T(\omega)}{Z_T(0)} I_p(\omega), \]
where \( Z_T \) represents the total complex impedance. We can normalize the input output relationship by defining a total transfer function
\[ H_T(\omega) = \frac{Z_T(\omega)}{Z_T(0)} I_p(\omega), \]
such that
\[ V_{\text{out}}(\omega) = Z_T(0) H_T(\omega) I_p(\omega). \]
Dividing by \( Z_T(0) \), we obtain
\[ \frac{V_{\text{out}}(\omega)}{Z_T(0)} = H_T(\omega) I_p(\omega), \]
which relates an input current to an output current, or
\[ \tilde{H}_{\text{out}}(\omega) = H_T(\omega) \tilde{H}_p(\omega) \]
in normalized form.

ISI is minimized when the output signal takes the form
\[ \tilde{H}_{\text{out}}(f) = \begin{cases} \frac{1}{\sqrt{2}} [1 + \cos(\pi f/B)] & f < B \\ 0 & f \geq B \end{cases}, \]
which is the raised cosine filter. Here, \( f = \omega/2\pi \). The raised cosine filter is plotted in the figure, and cuts off sharply at the bit rate \( B \). Taking the inverse transform of \( H_{\text{out}} \) gives the impulse response function
\[ h_{\text{out}}(t) = \frac{\sin(2\pi B t)}{2\pi B t} \frac{1}{1 - (2Bt)^2}. \]