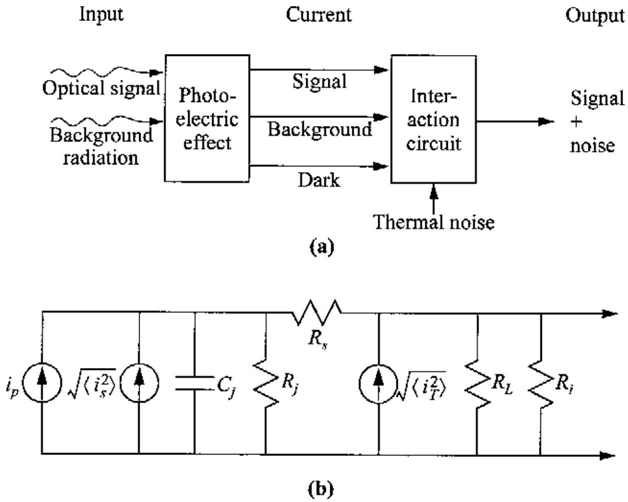

Fig. 5 Noise analysis of photodiode. (a) Photodetection process. (b) Equivalent circuit. (After Ref. 8.)

I_D. Because of the random generation of all these currents, they contribute to shot noise given by

$$\langle i_s^2 \rangle = 2q(I_P + I_B + I_D)B \tag{18}$$

where B is the bandwidth. The thermal noise is given by

$$\langle i_T^2 \rangle = \frac{4kTB}{R_{eq}} \tag{19}$$

where

$$\frac{1}{R_{eq}} = \frac{1}{R_j} + \frac{1}{R_L} + \frac{1}{R_i}. \tag{20}$$

The equivalent circuit of a photodiode is shown in Fig. 5b. The component C_j is the junction capacitance, R_j the junction resistance, and R_s the series resistance. The variable R_L is an external load resistor and R_i is the input resistance of the following amplifier.[9] All the resistances contribute additional thermal noise to the system. The series resistance R_s is usually much smaller than the other resistances and can be neglected.

For a 100% modulated signal ($m = 1$) with average power P_{opt}, the signal-to-noise ratio can be written as

$$\left.\frac{S}{N}\right|_{power} = \frac{i_p^2}{\langle i_s^2 \rangle + \langle i_T^2 \rangle} = \frac{(1/2)(q\eta P_{opt}/h\nu)^2}{2q(I_P + I_B + I_D)B + 4kTB/R_{eq}}. \tag{21}$$

From this equation, the minimum optical power required to obtain a given signal-to-noise ratio is (setting $I_P = 0$)