Solution:

At the noise-equivalent power level, the shot noise for this photodetector is contributed only by the dark current because the background current is negligible. Thus, the shot noise is

$$\overline{i^2_{\mathrm{n,sh}}} = 2eB\overline{i_\mathrm{d}} = 2 \times 1.6 \times 10^{-19} \times 15 \times 10^{-6} B\ \mathrm{A}^2\ \mathrm{Hz}^{-1} = 4.8 \times 10^{-24} B\ \mathrm{A}^2\ \mathrm{Hz}^{-1}.$$

With $R = 2\ \mathrm{k}\Omega$, the thermal noise at $T = 300$ K, for which $k_\mathrm{B}T = 25.9$ meV, is

$$\overline{i^2_{\mathrm{n,th}}} = \frac{4k_\mathrm{B}TB}{R} = \frac{4 \times 25.9 \times 10^{-3} \times 1.6 \times 10^{-19}}{2 \times 10^3} B\ \mathrm{A}^2\ \mathrm{Hz}^{-1} = 8.3 \times 10^{-24}\ B\ \mathrm{A}^2\ \mathrm{Hz}^{-1}.$$

The total noise is

$$\begin{aligned}\overline{i^2_\mathrm{n}} &= \overline{i^2_{\mathrm{n,sh}}} + \overline{i^2_{\mathrm{n,th}}} = 4.8 \times 10^{-24} B\ \mathrm{A}^2\ \mathrm{Hz}^{-1} + 8.3 \times 10^{-24}\ B\ \mathrm{A}^2\ \mathrm{Hz}^{-1} \\ &= 1.31 \times 10^{-23}\ B\ \mathrm{A}^2\ \mathrm{Hz}^{-1}.\end{aligned}$$

Therefore,

$$\frac{\mathrm{NEP}}{B^{1/2}} = \frac{\overline{i^2_\mathrm{n}}^{1/2}}{\mathcal{R}B^{1/2}} = \left(\frac{1.31 \times 10^{-23}}{0.8^2}\right)^{1/2}\ \mathrm{W\ Hz}^{-1/2} = 4.52\ \mathrm{pW\ Hz}^{-1/2}.$$

With $B = 5$ kHz, the total NEP over the entire bandwidth is

$$\mathrm{NEP} = \frac{\mathrm{NEP}}{B^{1/2}} \times B^{1/2} = 4.52 \times 10^{-12} \times \left(5 \times 10^3\right)^{1/2}\ \mathrm{W} = 320\ \mathrm{pW}.$$

11.3.5 Detectivity

The detectivity characterizes the ability of a photodetector to detect a small optical signal. It is defined as the inverse of the NEP of the photodetector:

$$D = \frac{1}{\mathrm{NEP}}, \tag{11.58}$$

which has the unit of W^{-1}.

As discussed above, $\mathrm{NEP} \propto B^{1/2}$. The shot noise from the input optical signal at the NEP level is negligible compared to the shot noise from the background radiation current, i_b, and that from the dark current, i_d, both of which are often proportional to the surface area, $\mathcal{A}$, of a photodetector. Therefore, when i_b and i_d are the dominant sources of noise for a photodetector, the intrinsic noise characteristics of the photodetector can be better quantified by normalizing NEP to $(\mathcal{A}B)^{1/2}$. A useful intrinsic parameter of a photodetector is the *specific detectivity*, D^*, defined as

$$D^* = \frac{(\mathcal{A}B)^{1/2}}{\mathrm{NEP}}, \tag{11.59}$$