Noises in Photodetectors

Shot Noise: current is carried by discrete quanta (electron). Random fluctuation in the number of electrons arriving in a time interval.

$$\langle \bar{i}_s^2(f) \rangle = 2q\langle I \rangle \Delta f$$

$\langle I \rangle$: Average current

Δf: bandwidth, freq = $f \to f+\Delta f$

Generation-recombination noise (in photoconductors)

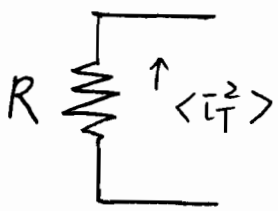
Recombination time is a random variable

$$\langle \bar{i}_{GR}^2 \rangle = \frac{4qI_p}{1+(2\pi f \tau_n)^2} \cdot \frac{\tau_n}{\tau_t} \Delta f$$

Thermal Noise (or called Johnson noise, Nyquist noise)

Random thermal motion of charged particles

$$\langle \bar{i}_T^2 \rangle = \frac{4k_B T}{R} \Delta f$$



1/f Noise (Flicker Noise)

$$\langle \bar{i}_{1/f}^2 \rangle = C \cdot \frac{1}{f^B} \quad , \quad B \approx 1$$

Physical origin not exactly known

Signal to Noise Ratio (SNR)

$$SNR = \frac{\bar{i}_p^2}{\sum_{\bar{i}} \langle \bar{i}_i^2 \rangle} = \frac{\bar{i}_p^2}{\langle \bar{i}_S^2 \rangle + \langle \bar{i}_T^2 \rangle + \langle \bar{i}_{GR}^2 \rangle}$$

↑ all noise sources

Noise-Equivalent Power (NEP)

Optical power at which SNR = 1 with $\Delta f = 1$ Hz (Noise bandwidth)

Detectivity (D^*)

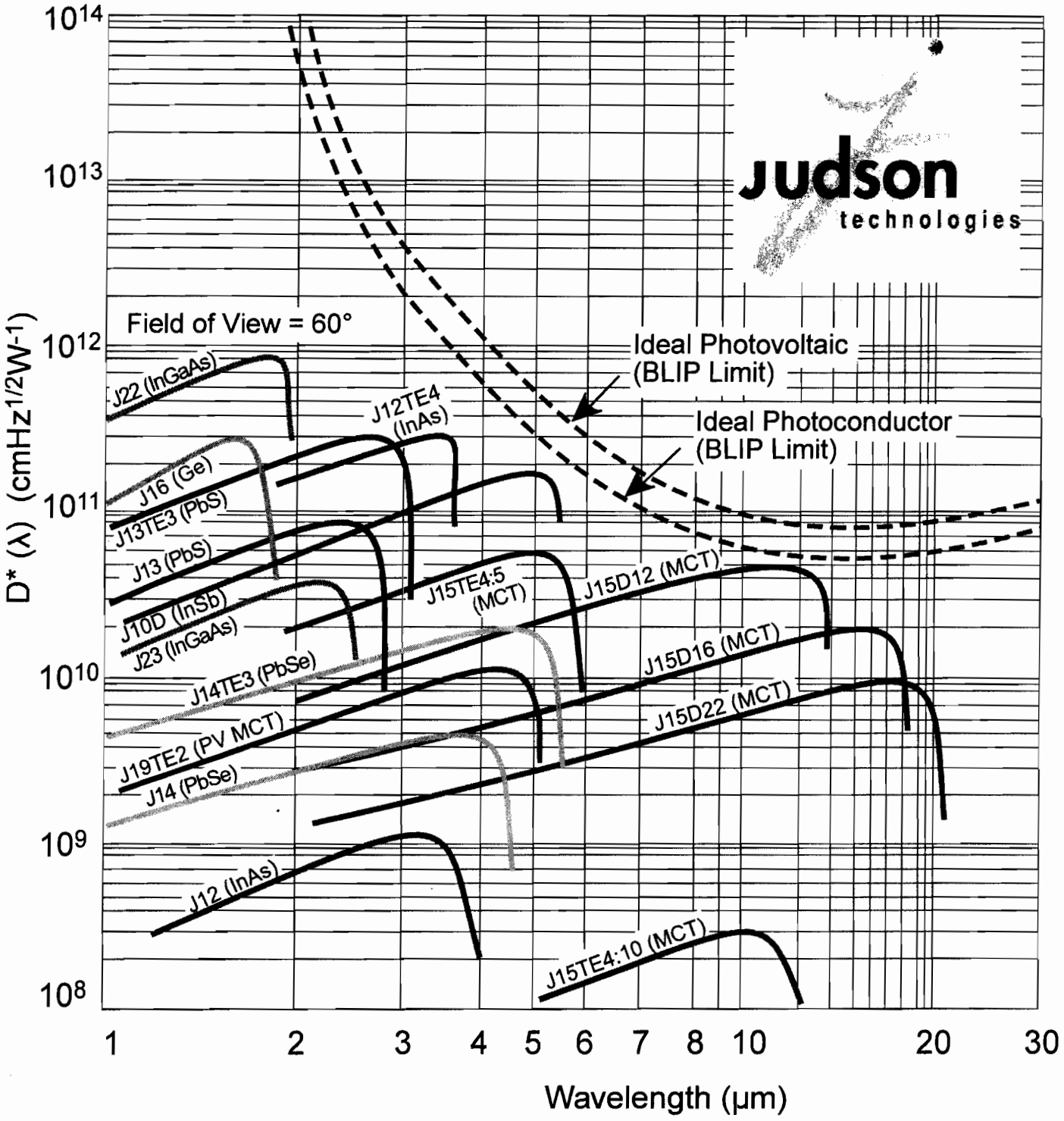
$$D^* = \frac{\sqrt{A \cdot \Delta f}}{NEP} \quad \left(\frac{cm\sqrt{Hz}}{W} \right)$$: a figure of merit

A: area
Δf: noise bandwidth

Note: $NEP \propto \sqrt{\Delta f}$, $\sqrt{A}$

$\therefore D^*$ is a figure of merit (larger is better)

JUDSON TECHNOLOGIES DETECTOR OFFERINGS:



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Photoconductor

$$\bar{i}_p = \eta \frac{q}{\hbar\omega} \left(\frac{\tau_n}{\tau_t}\right) \cdot P_{opt}$$

$$\langle i^2 \rangle = \left(2q + 4q \frac{\tau_n}{\tau_t}\right) \cdot \bar{i}_p \cdot \Delta f + \frac{4k_B T}{R} \Delta f$$

Recomb. noise > shot noise

At low power (small $\bar{i}_p$), thermal noise dominant.

$$SNR = \frac{\bar{i}_p^2}{\frac{4k_B T}{R} \Delta f} = \frac{\eta^2 \left(\frac{q}{\hbar\omega}\right)^2 \cdot \left(\frac{\tau_n}{\tau_t}\right)^2 \cdot P_{opt}}{\frac{4k_B T}{R} \Delta f}$$

At high power, GR noise dominant

$$SNR = \frac{\bar{i}_p^2}{4q \frac{\tau_n}{\tau_t} \bar{i}_p \Delta f} = \frac{\eta \left(\frac{q}{\hbar\omega}\right) \left(\frac{\tau_n}{\tau_t}\right) \cdot P_{opt}}{4q \left(\frac{\tau_n}{\tau_t}\right) \cdot \Delta f} = \frac{\eta P_{opt}}{4 \Delta f \hbar\omega}$$