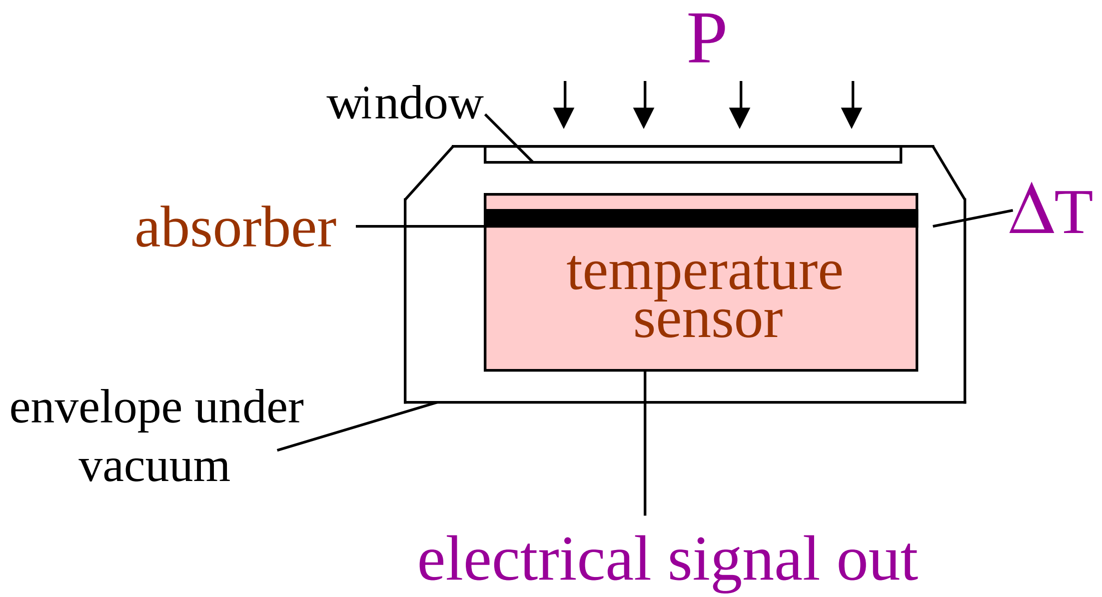
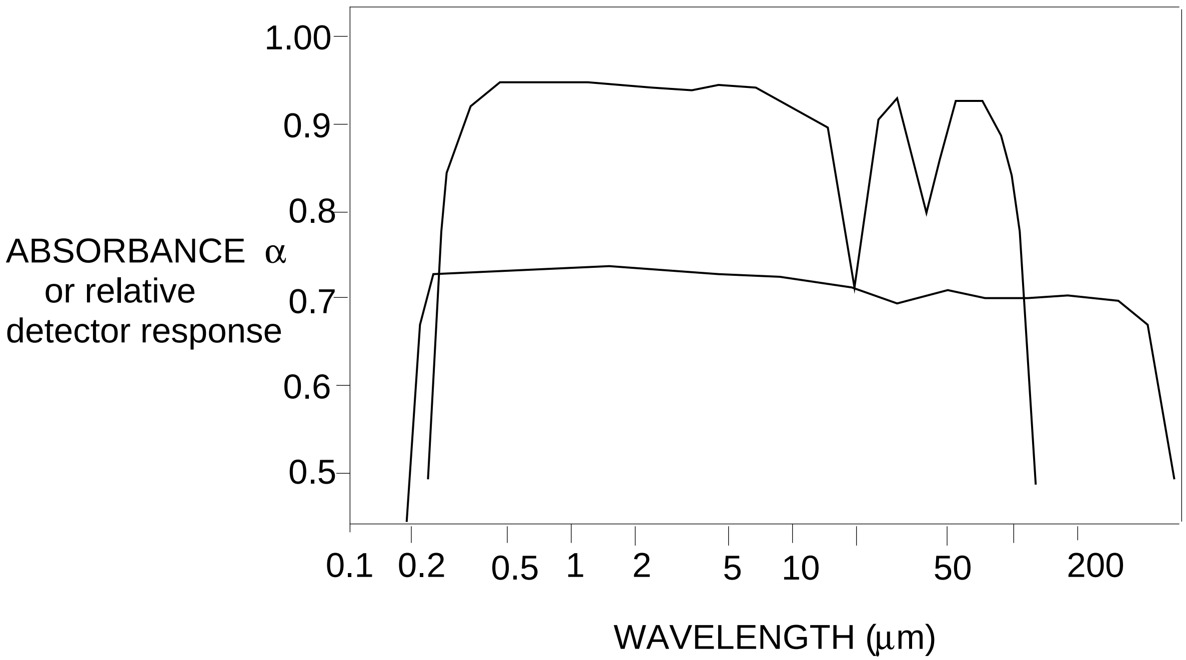
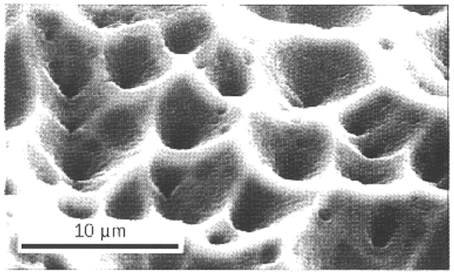
Basics

A thermal detector combines an absorber and a temperature sensor



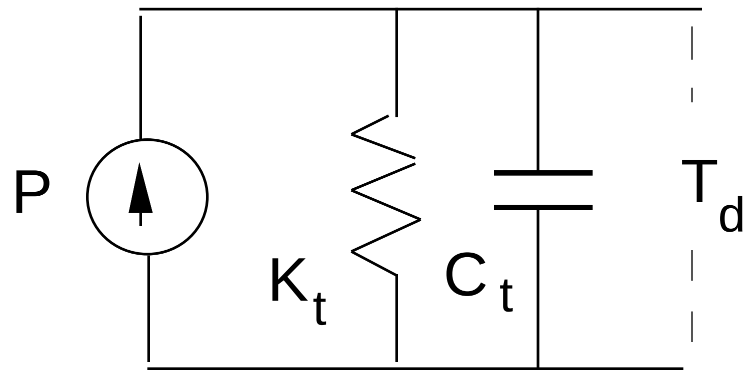
Absorber spectral response





Black coating reflects only 0.2% at 630 nm. p9

Absorber thermal circuit



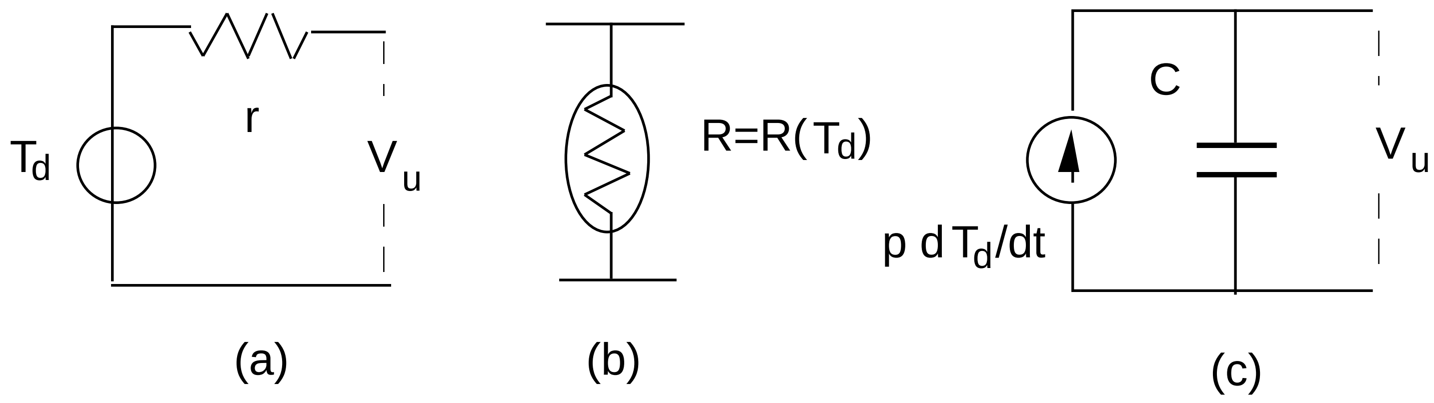
thermal balance equation: $C_t\, dT_d/dt + (1/K_t)\, T_d = P$

(as an RC parallel circuit) or, $\tau\, dT_d/dt + T_d = K_t\, P$

whence $f_2 = 1/2\pi\tau = 1/2\pi K_t C_t$

from:"Photodetectors", by S.Donati, Prentice Hall 2000

Temperature-sensing section



responsivity:

thermopile:

$R = V_u/P = \gamma K_t$

bolometer

$R = \Delta R/P = \alpha R_0 K_t$

pyroelectric

$R = Q/P = pK_t$

Pole-zero cancellation in pyroelectrics

in electrical circuit, derivative operator $p dT_d/dt$ (pyroelectric) cancels out integration of thermal circuit ($f >> 1/\tau$)

$$T_d = (1/C_t) \int P dt$$

then

$$I = p\, dT_d/dt = (p/C_t) P$$

short-circuit current is proportional to P (even at $f >> 1/\tau$)

or, responsivity is

$$\mathcal{R} = I/P = p/C_t$$

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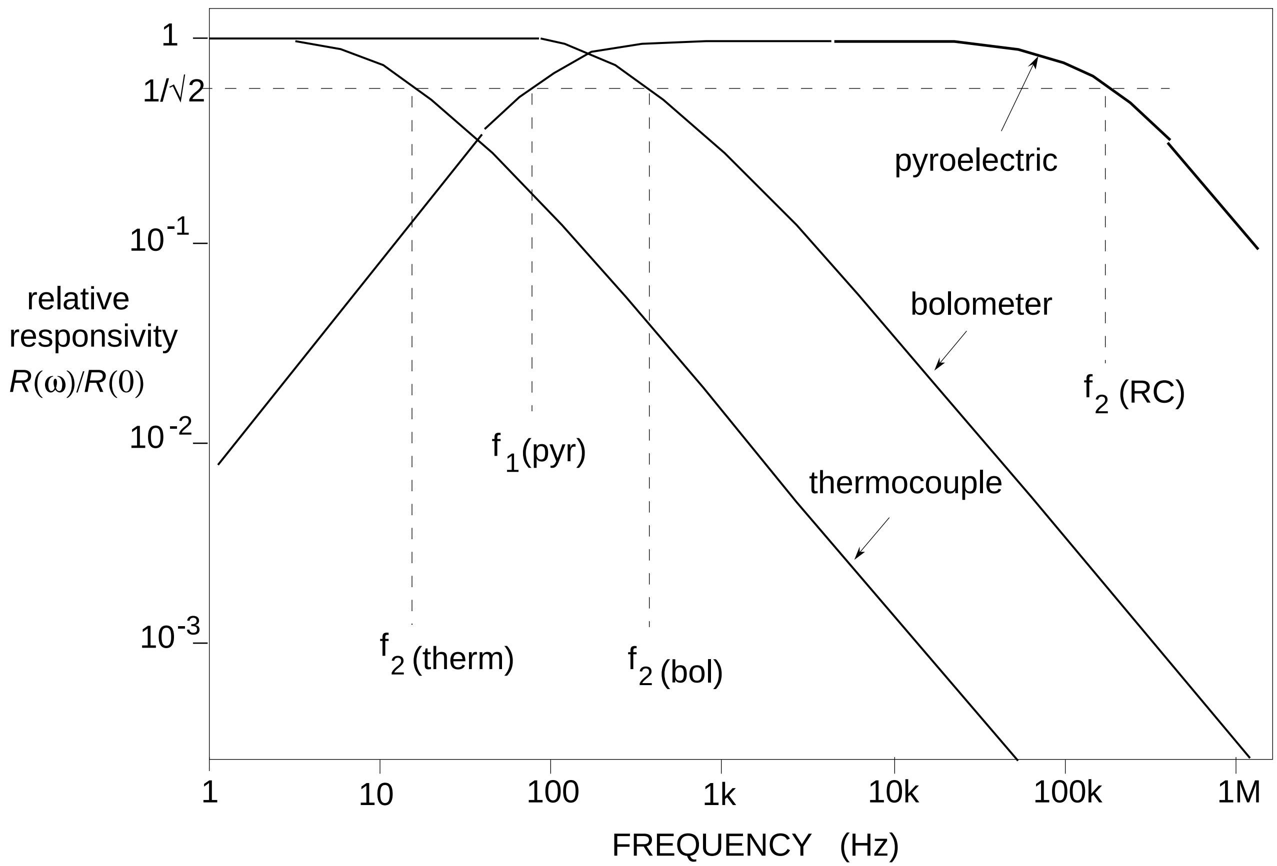
Frequency response



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Detectivity of thermal detectors

$$K_t = dT/dP = 1/(4A\sigma T^3)$$

$$\Delta T_n = [kT^2/C]^{1/2}$$

$$NEP = \Delta T_n / K_t = [kT^2/C]^{1/2} / K_t$$
$$= [kT^2 2\pi B]^{1/2} \sqrt{(4A\sigma T^3)}$$

$$D^* = \sqrt{AB} / NEP = 1/ [8\pi\sigma k T^5]^{1/2}$$

typical values: $D^*=1.8.10^{10}$ W^{-1} cm $Hz^{1/2}$ at T=300K, and $D^*=5.2.10^{11}$ W^{-1} cm $Hz^{1/2}$ at T=77 K,

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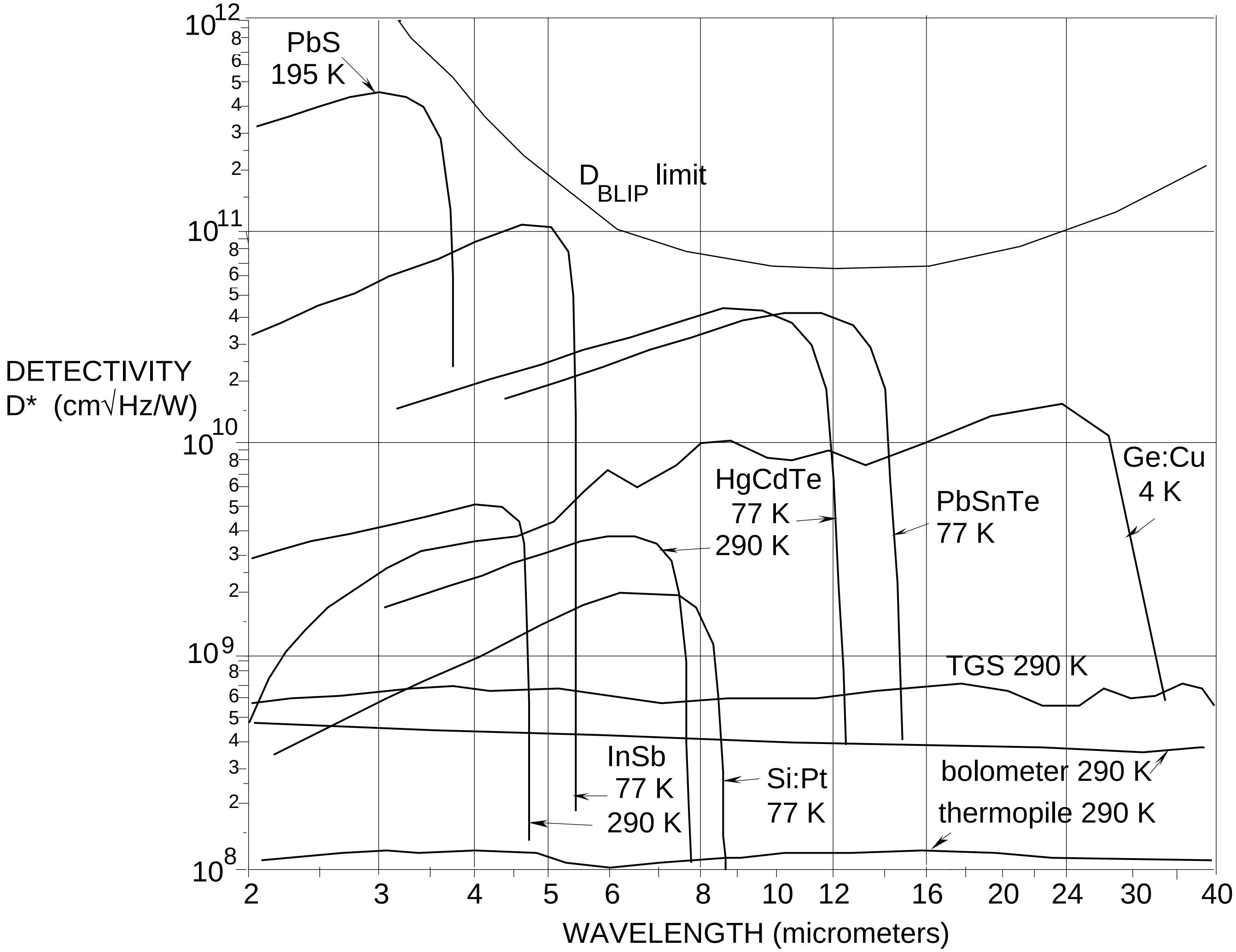
Detectivity vs λ



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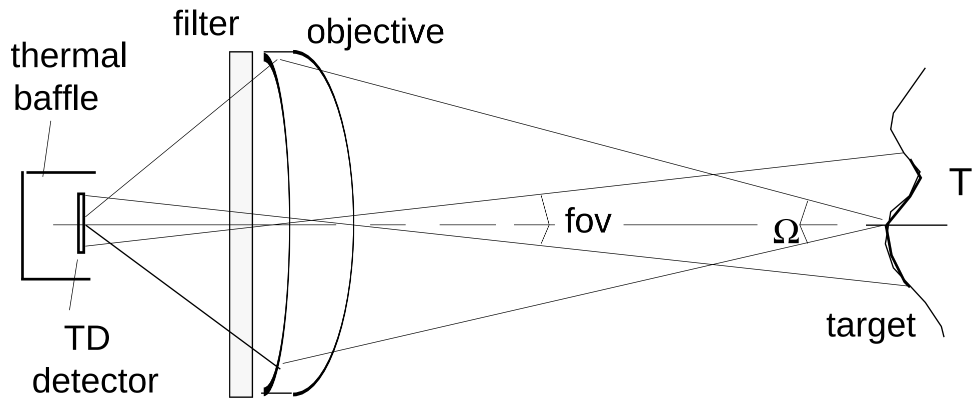
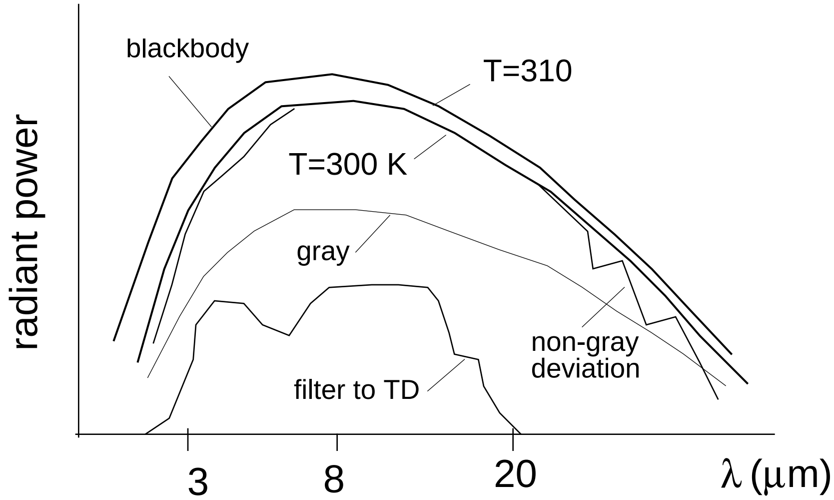
Temperature measurements





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Temperature signal

received power: $p = r(\lambda,T)\ \pi NA^2\ A\ \Delta\lambda$

r is blackbody radiance: $r(\lambda,T) = 2hc^2/\pi\ \lambda^5\ (\exp h\nu/kT-1)$

$$\Delta p = (dp/dT)\ \Delta T = [dr(\lambda)/\Delta T\ dT]\ \pi\ NA^2\ A\ \Delta\lambda =$$
$$= \pi\ NA^2\ A\ \Delta\lambda\ \ \kappa\ r(\lambda)\ \Delta T/T$$

where $\kappa = (h\nu/kT)\ [\exp h\nu/kT\ /(\exp h\nu/kT-1)]$

$$\approx\ hc/\lambda kT = 47.88(\mu m)\ /\lambda \qquad \text{for}\ \ h\nu > kT$$

(or, $\lambda < 48\mu m$, the break-point between thermal and quantum)

Noise

In a BLIP-limited detector:

$$i_{n(bg)} = \sigma\, NEP = \sigma\, NA\sqrt{AB}/D_{BLIP}$$
$$= NA\sqrt{[2\pi e\sigma\, r(\lambda)\Delta\lambda AB]}$$

but signal is $i = \sigma\,\Delta p = \sigma\,\pi\, NA^2\, A\,\Delta\lambda\;\; \kappa\, r(\lambda)\;\Delta T/T$

then $S/N = \kappa\,(\Delta T/T)\; NA\;\sqrt{[\pi\sigma\, Ar(\lambda)\Delta\lambda/2eB]}$

and the NEDT - noise equivalent differential temperature - ΔT @ S/N=1:

$$NEDT = (T/\kappa NA)\,\sqrt{[2eB/\sigma\pi\, r(\lambda)\Delta\lambda A]}$$
$$= 2kT^2\, D_{BLIP}\,(1/\eta NA)\sqrt{(B/A)}$$

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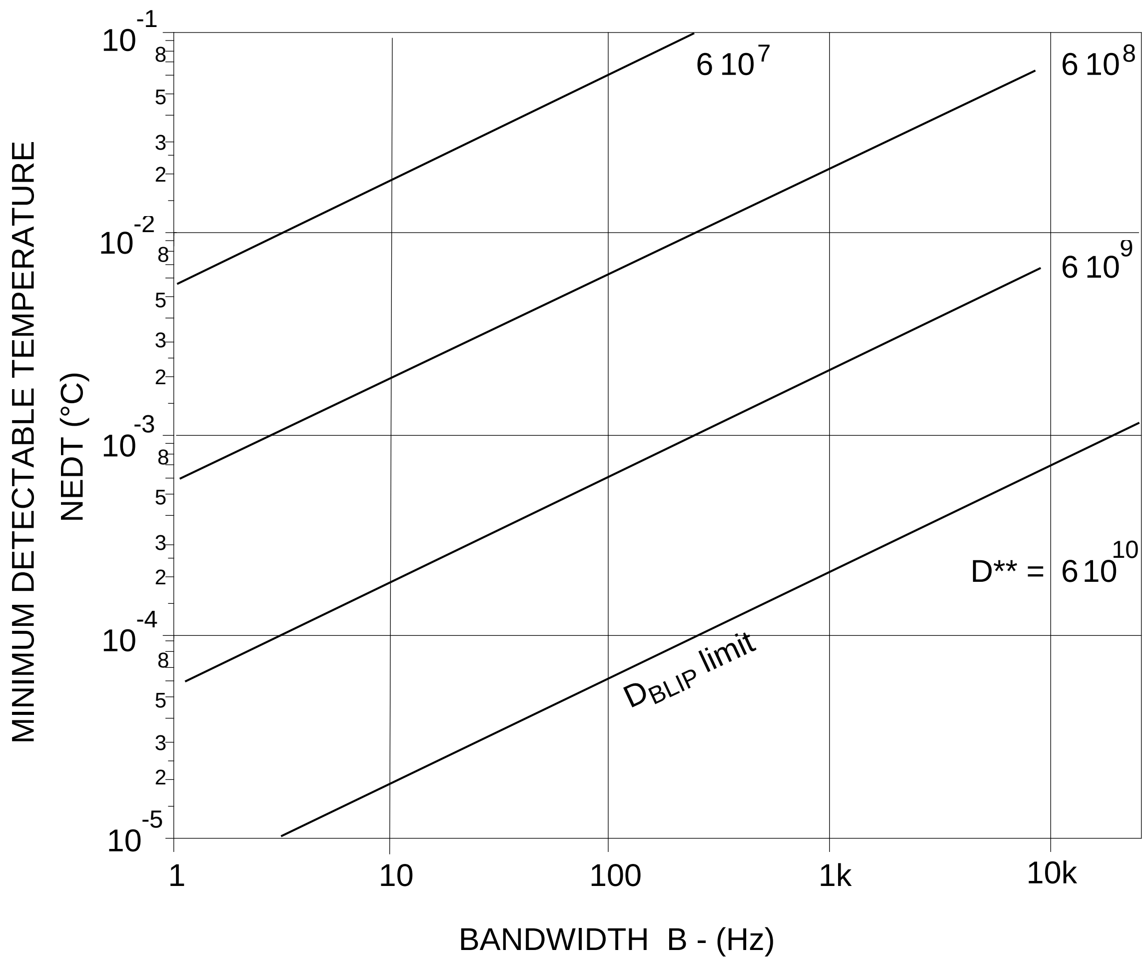
Theoretical NEDT



η=0.5, NA=0.5
A=0.01 cm^2
D_{BLIP} =6·10^{10}
(W^{-1}cm√Hz)

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NED in real detectors

If detector is real (not BLIP-limited):

$$i_{n(bg)} = \sigma \, NEP = \sigma \, NA\sqrt{AB}/D^{**}$$, signal is the same

$$S/N = \Delta i/i_{n(bg)} = \pi \, NA \sqrt{(A/B)} \, \kappa \, r(\lambda) \, \Delta\lambda \, (\Delta T/T) \, D^{**}$$

and

$$NEDT = T \, [\pi \, NA \, \kappa \, r(\lambda) \, \Delta\lambda \, D^{**}]^{-1} \sqrt{(B/A)}$$

$$= 2kT^2 \, (D^2_{BLIP}/D^{**}) \, (1/\eta NA) \sqrt{(B/A)}$$

Effect of non-unity emissivity

If emissivity is $\varepsilon < 1$, total radiance is sum of:

- blackbody term scaled by ε, and
- ambient re-diffused contribution $(1-\varepsilon)$:

$$r_{tot}(\lambda,T) = \varepsilon\, r(\lambda,T+\Delta T)+(1-\varepsilon)\, r(\lambda,T) \approx r(\lambda,T)$$

thus, background noise is about the same, and radiant measurement of temperature supplies a signal $\varepsilon\Delta T$.

CORRECTIONS:

- by a separate conventional thermometric calibration

(typ. accuracy:1% or of 0.05°C for $\Delta T<50°C$)

- by estimate f ε from proprieties of surface under test

(typ. accuracy:$\approx$ 10%for $\Delta T<50°C$)

An infrared thermometer

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Correcting against non-unity emissivity

If temperature $T = T_{amb} + \Delta T$ is large enough to make the ambient contribution negligible, i.e.

$$r_{tot}(\lambda,T) = \varepsilon\, r(\lambda,T_{amb}+\Delta T) + (1-\varepsilon)\, r(\lambda,T_{amb})$$

$$\approx r(\lambda,T_{amb}) + \varepsilon\, [dr(\lambda,T_{amb})/dT]\, \Delta T$$

$$\approx \varepsilon\, [dr(\lambda,T_{amb})/dT]\, \Delta T$$

then we can correct against ε by looking at the current

$J = \sigma\, r_{tot}(\lambda,T)$ found at two wavelengths λ_1 and λ_2.

This is called two-color pyrometry.

Two-color pyrometry

using 2–λ channels:

$$J_{bg}(\lambda_1) = \varepsilon_1\, \sigma_1\, \Delta\lambda_1\, \pi NA^2\, 2hc^2/\lambda_1^5(\exp hc/\lambda_1 kT -1)$$
$$J_{bg}(\lambda_2) = \varepsilon_2\, \sigma_2\, \Delta\lambda_2\, \pi NA^2\, 2hc^2/\lambda_2^5(\exp hc/\lambda_2 kT -1)$$

ratio of the detected signals

$$R = J_{bg}(\lambda_2)/J_{bg}(\lambda_1)$$
$$= (\varepsilon_1/\varepsilon_2)(\lambda_1/\lambda_2)^5(\sigma_2\Delta\lambda_2/\sigma_1\Delta\lambda_1)\ \exp[hc(1/\lambda_2-1/\lambda_1)/kT]$$

taking the logarithm of R, $\ln R = \ln C_1 + C_2/T$, T is solved as:

$$T = C_2/[\ln R - \ln C_1] = \frac{(\varepsilon_1/\varepsilon_2)(hc(1/\lambda_2-1/\lambda_1)/k}{\log [J_{bg}(\lambda_2)/J_{bg}(\lambda_1)]+5\log(\lambda_2/\lambda_1)+\log(\sigma_1\Delta\lambda_1/\sigma_2\Delta\lambda_2)}$$

independent from emissivity (if $\varepsilon \approx$ const. in $\lambda_1 - \lambda_2$)

and is self-calibrated (in absolute temperature)

Thermovisions

Spectral range of operation: MIR, λ=3-5μm or FIR, λ=8-14μm

GENERATIONS:

0-th: pioneer's work: Spectracon (oil -film camera), 1950

1st: LN-cooled InSb scan camera (AGA, Huges, etc.) 1970 -
- general purpose

2nd: LN-cooled CMT and LTT FPA, 1980 - military

3rd: TEC-cooled Bolometer, 1985 - portable

4th: uncooled Pt-Si and VO_x bolometer 1990 - camcorder

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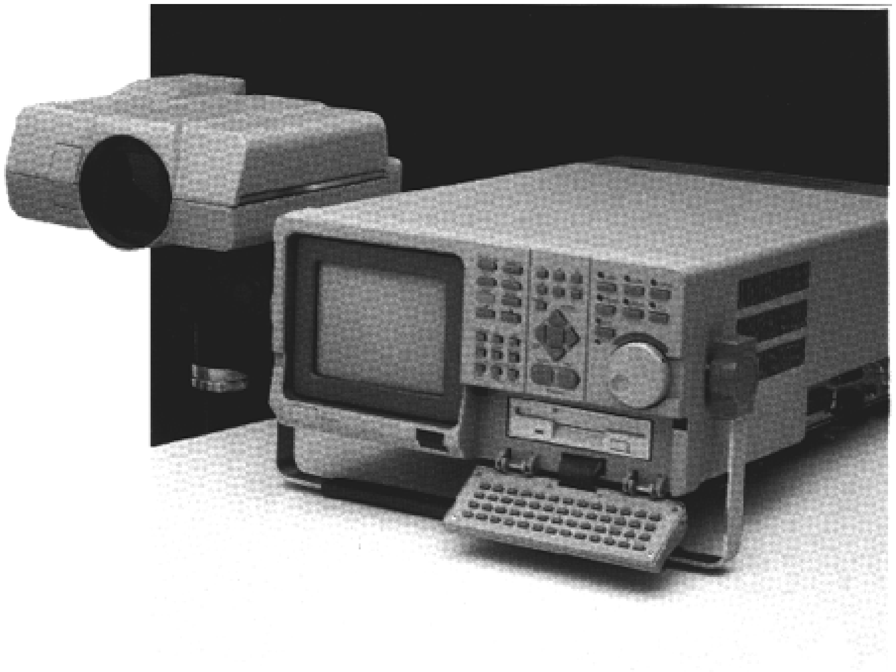
Equipment



Avio LN-cooled
InSb-FPA
high-performance
thermovision

Inframetrics
uncooled CAM corder

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Fields of application

- *industrial applications*: visualization of temperature pattern for application in: electronics, power engineering air-conditioning, automotive, construction
- *medical applications*: early diagnosis of breast cancer, spotting necrotized areas after severe burning, reveal circulatory diseases
- *remote sensing*: several earth resource satellites carry aboard multispectral sensors (12 channels in VIS and 1-2 in MIR/FIR) to reveal pollution, crops, etc.
- *Military:* the most important driving force of IR techniques, as THV is a passive vision system, working at night or in the dark with no need for illumination, revealing thermal signatures