PERFORMANCE EQUATION FOR THERMAL IMAGER

A SYSTEM WHOSE FUNCTION IS TO PRODUCE A THERMAL IMAGE OF A SCENE HAS A VERY DIFFERENT FUNCTION FROM THAT OF A SEARCH SYSTEM

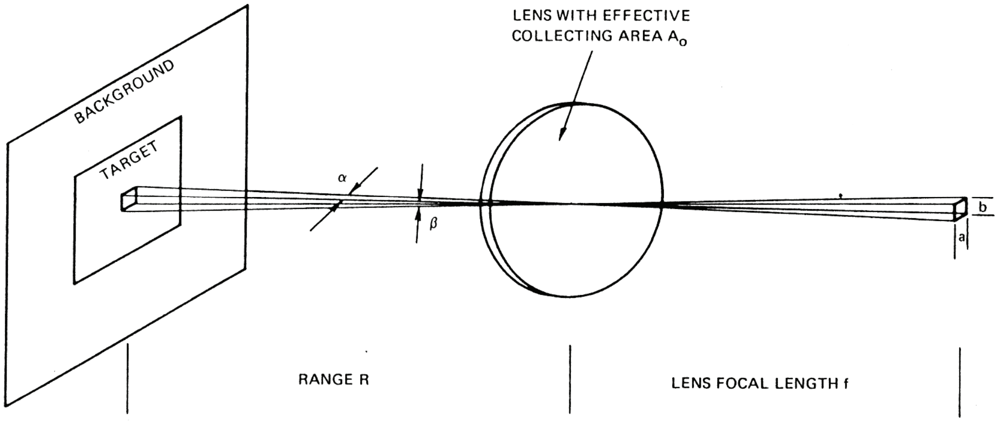
AN EXTENDED SOURCE IS TO BE IMAGED - RADIANCE (NOT INTENSITY) IS VARIABLE OF INTEREST

E_{det} IS INDEPENDENT OF RANGE R IF EXTENDED SOURCE FILLS FOV

TARGET FILLS FOV CONTINUOUSLY, FUNCTION IS NOT TO DETECT, BUT TO MAP ACCURATELY - WANT PICTURE, NOT PULSE

MAP DIFFERENCES IN TEMPERATURE BY DIFFERENCES IN RADIANT FLUX EMITTED

1) FLUX IS A NONLINEAR FUNCTION OF TEMPERATURE
2) THE FUNCTIONAL DEPENDENCE OF FLUX EMITTED ON TEMPERATURE IS ALSO DEPENDENT ON λ

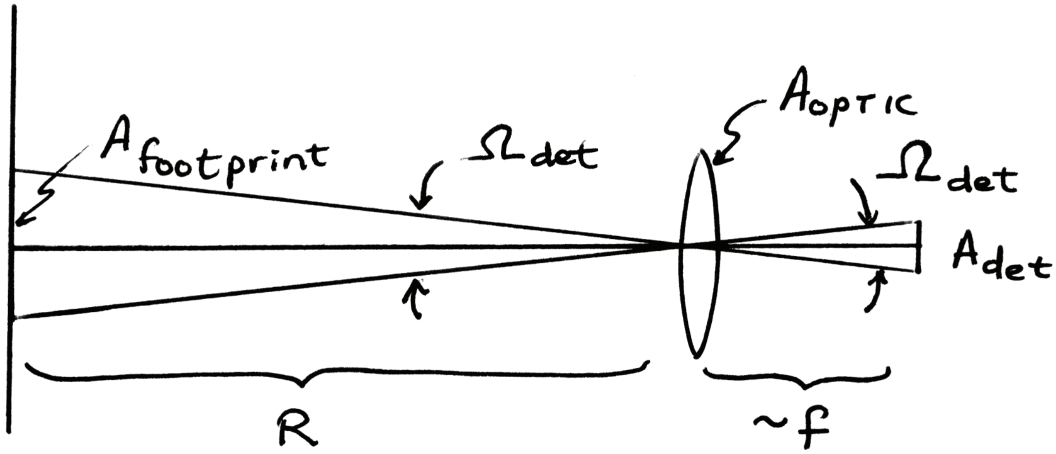


From Lloyd, "Thermal Imaging Systems"

NETD DERIVATION

THE THERMAL-IMAGER SYSTEM PRODUCES A MAP OF RADIATED FLUX DIFFERENCES OVER AN EXTENDED TARGET

THUS, RADIANCE [watt/cm^2 ster] OF THE SOURCE IS THE FUNDAMENTAL QUANTITY, NOT INTENSITY [watt/steradian]



$$\phi_{det} = L \times A_{optic} \times \Omega_{det}$$

$$\Omega_{det} = \frac{A_{det}}{f^2} = \frac{A_{footprint}}{R^2}$$

$$\phi_{det} = L \times \frac{\pi}{4} D_o^2 \times \frac{A_{det}}{f^2}$$

$$\phi_{det} = \frac{\pi}{4} L \times \frac{A_{det}}{(F/\#)^2}$$

RELATING THIS FLUX REACHING THE DETECTOR TO A SIGNAL VOLTAGE IS THE RESPONSIVITY $\mathcal{R}$

$$V_s = \mathcal{R} \times \phi_{det} = \mathcal{R} \times \frac{\pi}{4} L \times \frac{A_{det}}{(F/\#)^2}$$

SINCE WE ARE INTERESTED IN A THERMAL MAPPING OF THE OBJECT, THE CHANGE OF THIS SIGNAL VOLTAGE FOR A CHANGE IN TEMPERATURE, $\frac{\Delta V_s}{\Delta T}$ IS OF INTEREST

$$\frac{\Delta V_s}{\Delta T} = \frac{\partial L}{\partial T} \times \mathcal{R} \times \frac{\pi}{4} \times \frac{A_{det}}{(F/\#)^2}$$

WE RECAST THE RESPONSIVITY AS $\mathcal{R} = \frac{V_n \quad D^*}{\sqrt{A_d} \ \sqrt{\Delta f}}$

$$\frac{\Delta V_s}{\Delta T} = \frac{\partial L}{\partial T} \times \frac{\pi}{4} \times \frac{A_d}{(F/\#)^2} \times \frac{V_n \quad D^*}{\sqrt{A_d} \ \sqrt{\Delta f}}$$

REARRANGING IN TERMS OF A SIGNAL TO NOISE RATIO:

$$\frac{\Delta V_s}{V_n} = \Delta T \times \frac{\partial L}{\partial T} \times \frac{\pi}{4} \times \frac{A_d}{(F/\#)^2} \times \frac{D^*}{\sqrt{A_d} \ \sqrt{\Delta f}}$$

THE NETD, THE NOISE EQUIVALENT TEMOPERATURE DIFFERENCE, IS THAT ΔT FOR WHICH THE SIGNAL TO NOISE RATIO EQUALS 1

$$\text{NETD} = \frac{4 \ (F/\#)^2 \quad \sqrt{\Delta f}}{\pi \frac{\partial L}{\partial T} \quad D^* \quad \sqrt{A_d}}$$

INTERPRETATION OF NETD = $\dfrac{4\,(F/\#)^2\,\sqrt{\Delta f}}{\pi\,\dfrac{\partial L}{\partial T}\,D^*\,\sqrt{A_d}}$

A SMALLER NETD INDICATES BETTER THERMAL SENSITIVITY

ACTUALLY, THE QUANTITY $\dfrac{\partial L}{\partial T} \times D^*$ IS AN AVERAGE VALUE, HAVING BEEN INTEGRATED OVER SOME PASSBAND

FOR BEST (SMALLEST) NETD, THE $D^*(\lambda)$ OF THE DETECTOR SHOULD BE PEAKED NEAR THE λ OF MAXIMUM EXITANCE CONTRAST OF THE SOURCE (λ OF MAX $\partial L/\partial T$)

NETD $\propto (F/\#)^2$

A SMALLER F/# COLLECTS MORE FLUX, YIELDING A MORE ACCURATE ESTIMATE OF ΔT

A LARGER APERTURE DIAMETER GIVES SMALLER F/#

A SHORTER f GIVES A LARGER FOOTPRINT IN OBJECT SPACE (LARGER IFOV FOR CONSTANT DETECTOR AREA), AGAIN COLLECTING MORE FLUX

NETD $\propto \sqrt{\Delta f}$

SMALLER BANDWIDTH (LARGER DWELLTIME) YIELDS A SMALLER NOISE VOLTAGE

NETD $\propto \dfrac{1}{\sqrt{A_d}}$

A LARGER DETECTOR GIVES A LARGER IFOV, AND THUS COLLECTS MORE FLUX

NETD EQUATION FOR THERMAL IMAGER SYSTEMS - BLIP

FOR NON-BLIP OPERATING CONDITIONS

$$\text{NETD} \propto \frac{(F/\#)^2}{D^*}$$

THIS CHANGES UNDER BLIP CONDITIONS, SINCE AGAIN, $D^* \propto F/\#$

THE ABOVE DEPENDENCE OF NETD WILL GO TO A TERM $\propto F/\#$, WHEN BLIP CONDITIONS OBTAIN

NETD Example

- Given a staring uncooled IR imager operating in 8-12 μm band, with 50 μm detectors, F/1 optics, 30 Hz bandwidth.

- Let us say the NETD spec is 50 mK – what D* does this correspond to?

- Starting with

$$NETD = \left(\frac{4}{\pi}\right)\frac{(F/\#)^2\sqrt{\Delta f}}{\frac{\partial L}{\partial T}\; D^*\;\sqrt{A_d}}$$

- Evaluate change in radiance per unit temperature, integrated over passband

$$\frac{\partial L}{\partial T} = \int_{8\,\mu m}^{12\,\mu m}\frac{\partial L(\lambda, T = 300K)}{\partial T}\,\mathrm{d}\lambda \approx 7.6\times 10^{-5}\,\frac{Watt}{cm^2\,Sr\,K}$$

- Find integrated in-band D* is ≈ 4 × 10^8 cm $\mathrm{Hz}^{1/2}$ Watt^{-1}.

Performance Specification
of
Thermal Imaging Systems

There are two main ways that the performance of thermal imaging systems is specified:

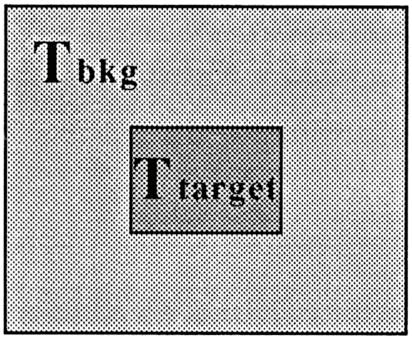
Noise equivalent temperature difference: **NETD**
NETD only measures system's thermal sensitivity.

Mimimum resolvable temperature difference: **MRTD**
MRTD combines thermal sensitivity & resolution.

NETD only measures the system's thermal sensitivity.

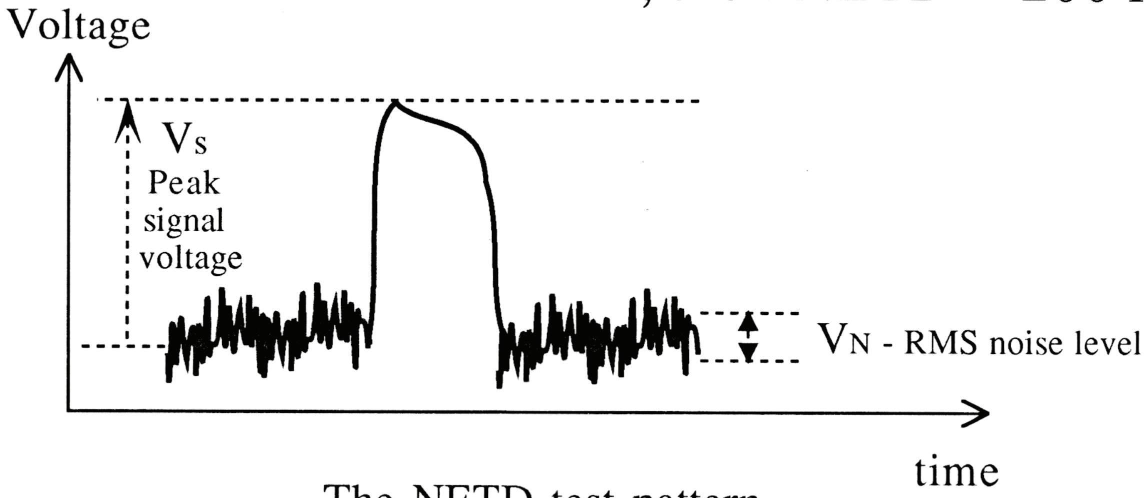
What temperature difference gives S/N=1?

$$\mathbf{T_{target} - T_{bkg} = \Delta T}$$



$$\text{NETD} = \frac{\Delta T}{V_S/V_N}$$

If S/N=5 is obtained for a ΔT = 1 K, then NETD = 200 mK



The NETD test pattern
and the
resulting voltage waveform output from the system.

NETD is a good diagnostic test on a day-to-day basis for a given system, since it does measure thermal sensitivity and the test is easy to set up.

It is not a good summary measure of performance or a good design criterion since it ignores the image quality (resolution).

MRTD combines thermal sensitivity and resolution.

It is a good summary measure of performance and a good design criterion.

What temperature difference is required for various bar targets to be visible on the display?

Smaller bar targets will require larger temperature differences in order to be visible, since finer detail is harder to see.

Infrared Systems Design – References

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