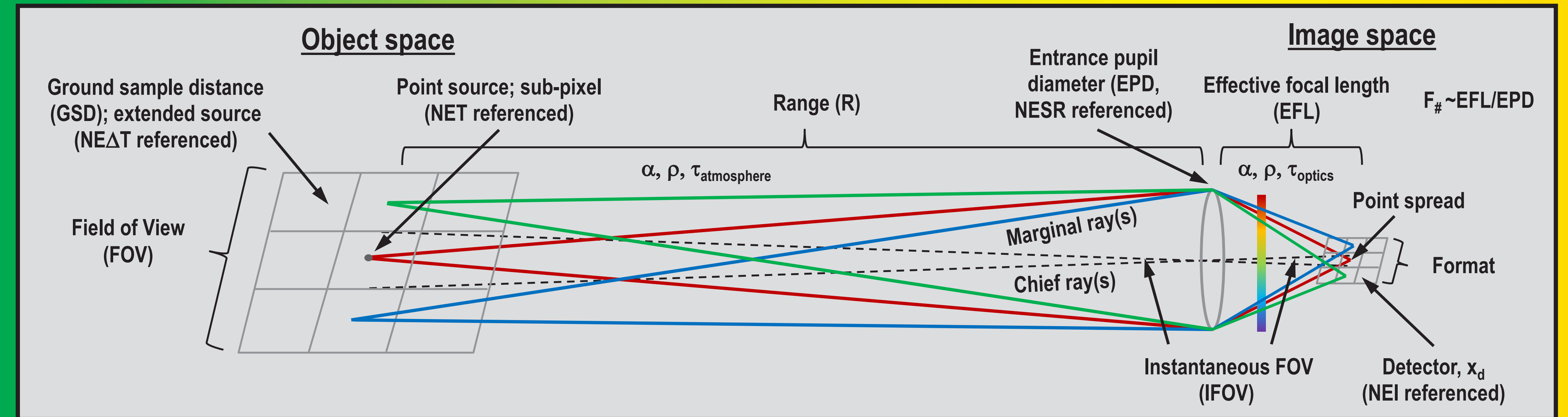
The Raytheon Infrared Wall Chart

TRANSMITTER/RECEIVER TERMINOLOGY

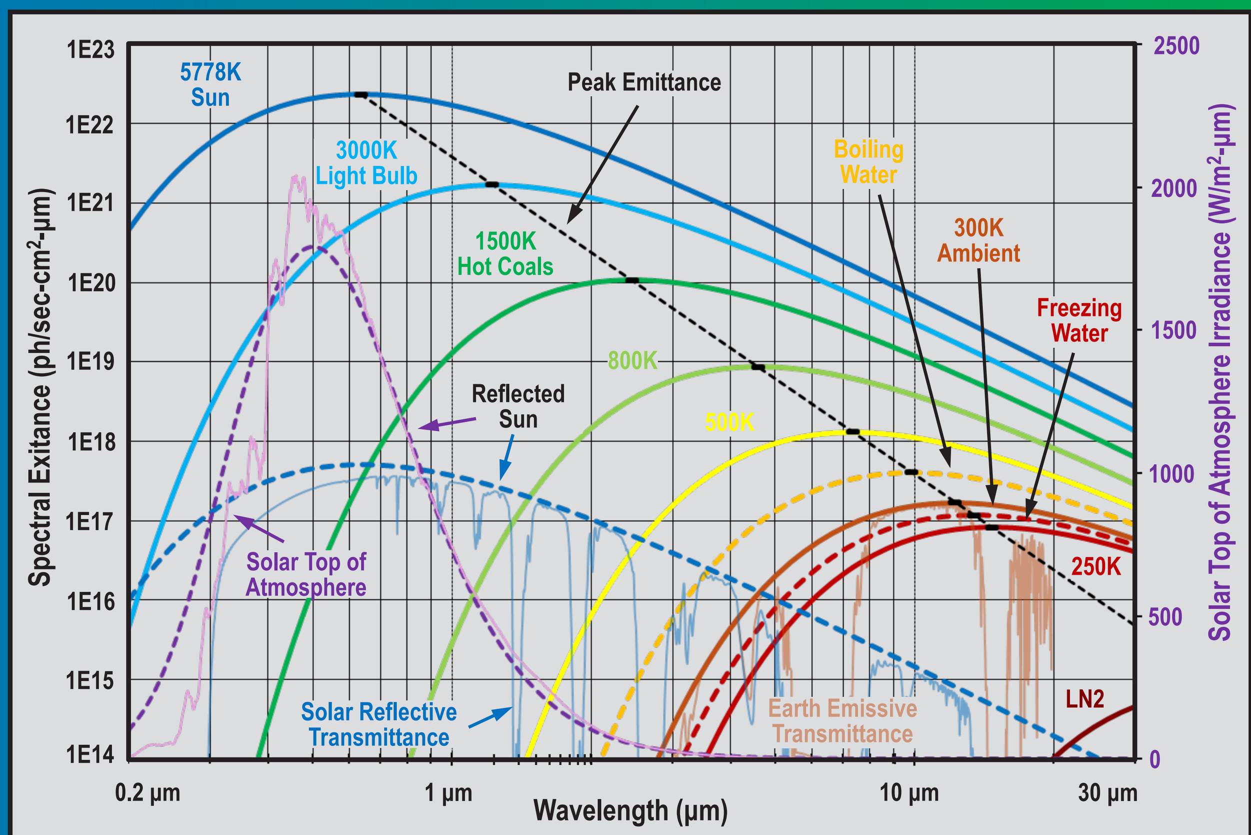
Term	Symbol	Energy Units	Quantum units	Definition
Energy	$Q_{e,q}$	J	ph	Basic unit of energy
Power (flux)	$\Phi_{e,q}$	W	ph/sec	Rate of energy transfer
Intensity	$I_{e,q}$	W/sr	ph/sec-sr	Point source transmitter (pointance)
Exitance	$M_{e,q}$	W/m^2	ph/sec-cm^2	Area transmitter (areance)
Radiance	$L_{e,q}$	W/m^2-sr	ph/sec-cm^2-sr	Area/angular transmitter (sterance)
Spectral radiance	L_λ	W/cm^2-sr-um	ph/sec-cm^2-sr-um	Generalized transmitter (flick)
Irradiance	$E_{e,q}$ (or Q)	W/m^2	ph/sec-cm^2	Incident flux surface receiver

Subscripts e denotes energy, q denotes quantum, λ denotes over spectral bandpass

GENERALIZED EOIR SYSTEM GEOMETRY



PHOTON SPECTRAL EXITANCE



SELECTED BLACKBODY FORMULAS

Planck's Law for photon spectral exitance

$$M_q(\lambda, T) = \frac{2\cdot\pi\cdot c}{\lambda^4\left(\exp\left(\frac{h\cdot c}{\lambda\cdot k\cdot T}\right)-1\right)} \qquad \text{ph/sec-cm}^2\text{-}\mu\text{m}$$

Spectral exitance W/cm^2-μm

$$M_e(\lambda, T) = M_q(\lambda, T)\,\frac{h\cdot c}{\lambda} = \frac{2\cdot\pi\cdot h\cdot c^2}{\lambda^5\left(\exp\left(\frac{h\cdot c}{\lambda\cdot k\cdot T}\right)-1\right)}$$

Photon irradiance (at image plane for a Lambertian source with a narrow, uniform spectral bandpass)

$$Q(\Delta\lambda, T) = \frac{\Omega_d\cdot\tau\cdot\Delta\lambda}{\pi}\,M_q(\bar{\lambda}, T) \qquad \text{ph/sec-cm}^2$$

Total blackbody exitance (Stefan-Boltzmann Law)

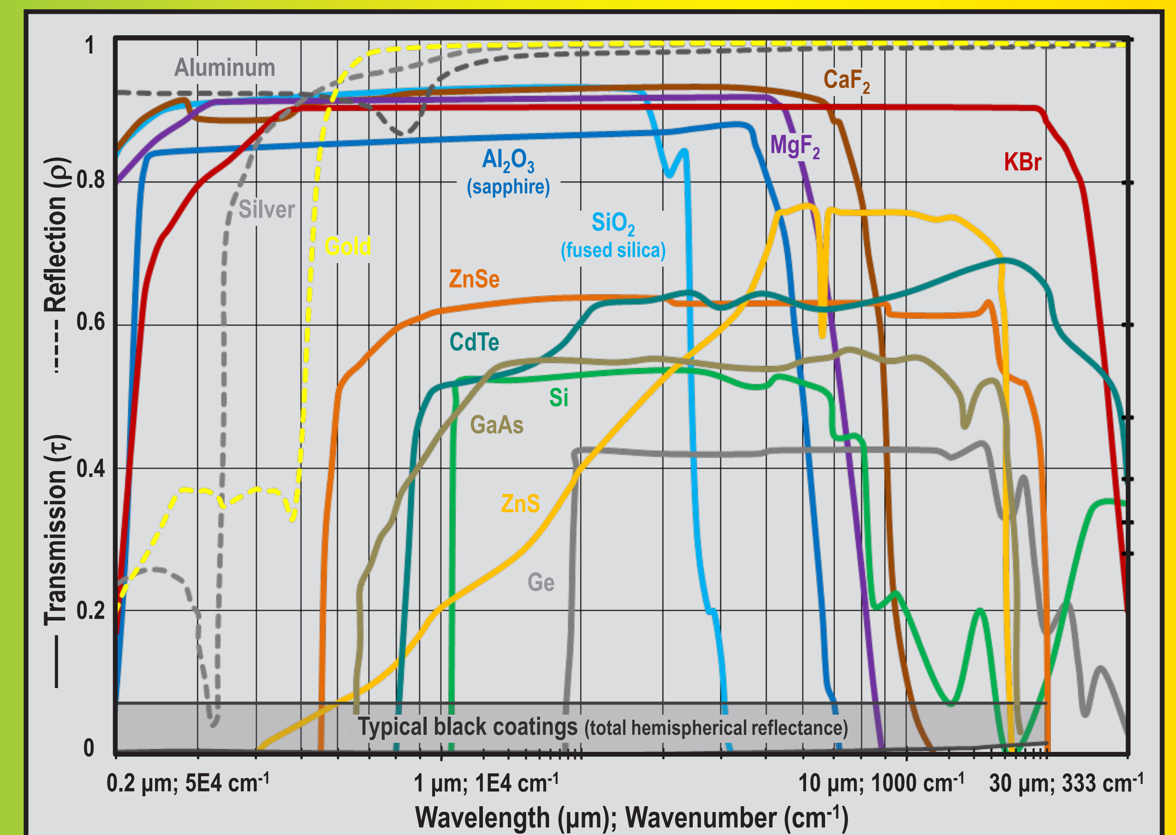
$$M_{total} = \int_0^\infty M(\lambda,T)\cdot d\lambda = \sigma_e T^4 \qquad \text{W/cm}^2$$
$$= \sigma_q T^3 \qquad \text{ph/sec-cm}^2$$

$\sigma_e = 5.6705 \times 10^{-12}$ W/cm^2-K^4 for spectral radiance
$\sigma_q = 1.5205 \times 10^{11}$ ph/sec-cm^2-K^3 for ph. spectral radiance

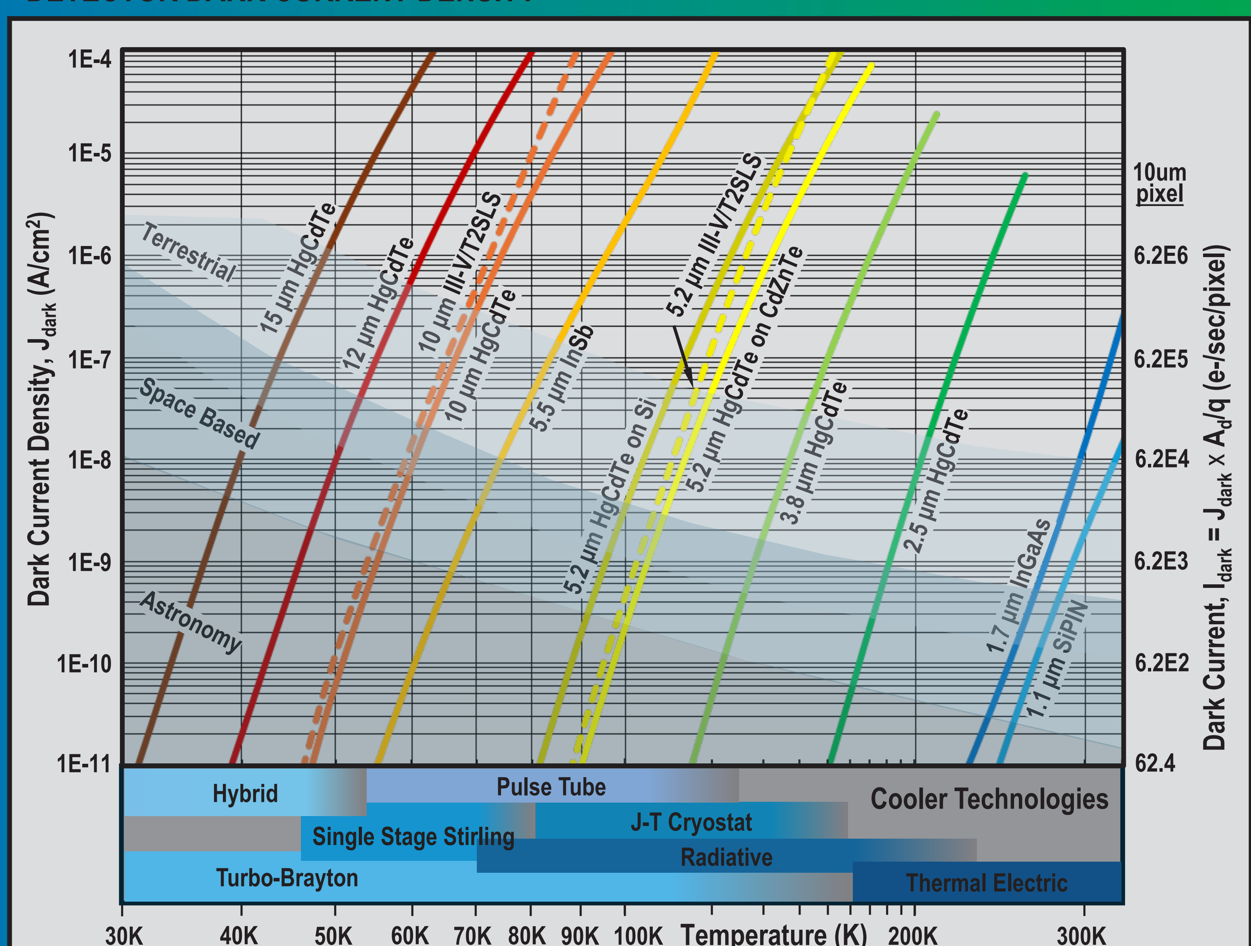
Wien's Displacement Law

$\lambda_m\cdot T = a_{e,q}$
λ_m = wavelength of maximum spectral radiance
a_e = 2891.8 um-K for spectral radiance
a_q = 3669.7 um-K for photon spectral radiance

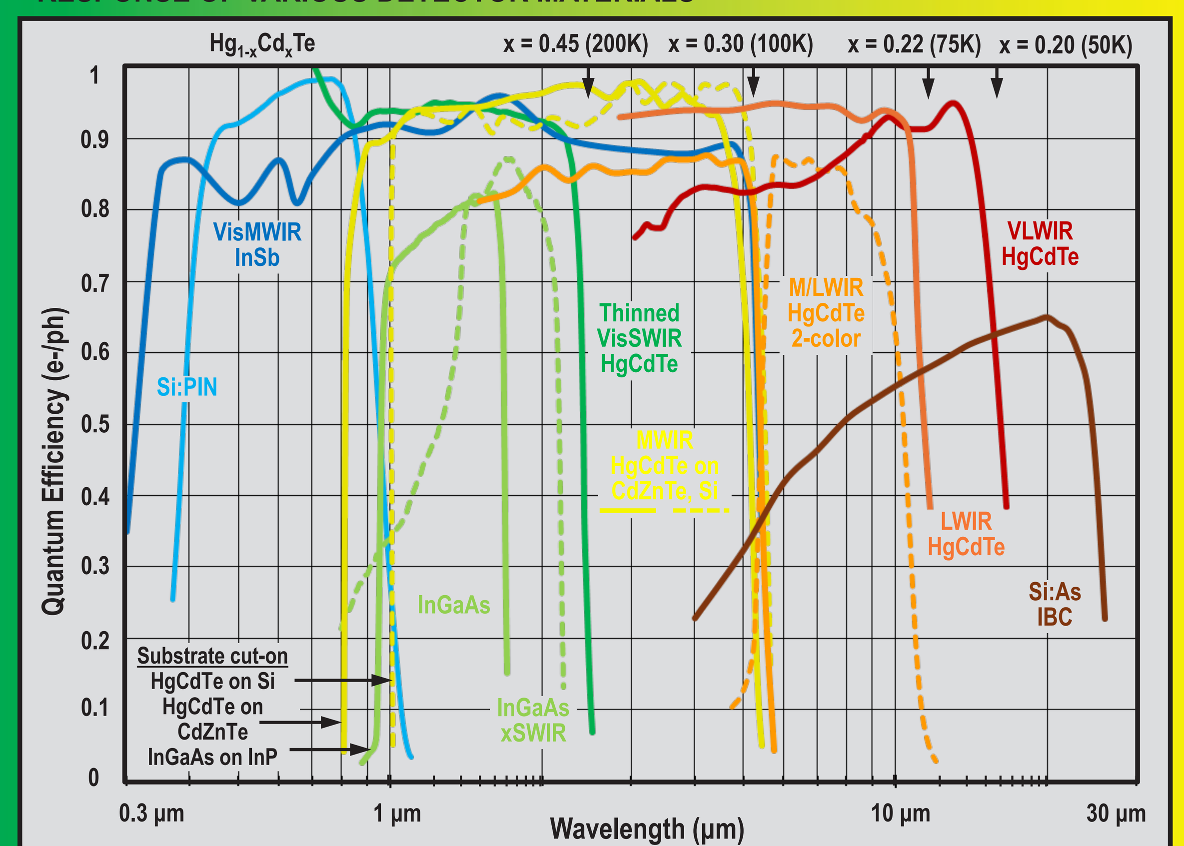
COMMON OPTICAL MATERIAL PROPERTIES



DETECTOR DARK CURRENT DENSITY



RESPONSE OF VARIOUS DETECTOR MATERIALS

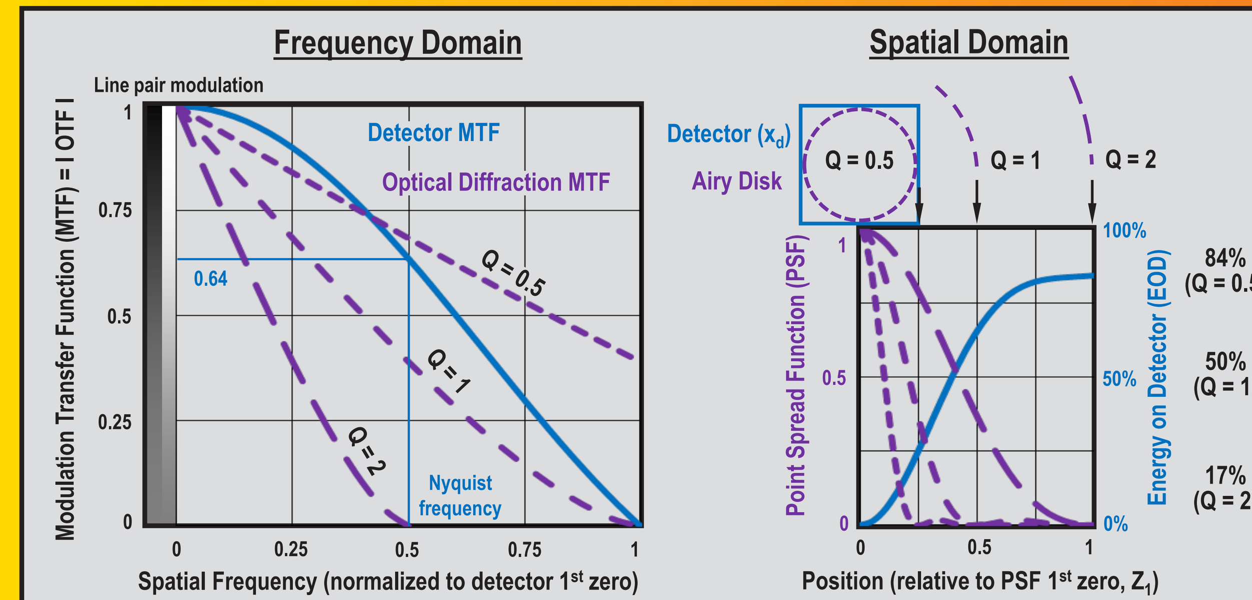


FIRST ORDER OPTICAL MEDIA PARAMETERS

For single surface, normal incidence in vacuum (n = 1) without absorption

Reflection	$\rho = \frac{(n-1)^2}{(n+1)^2}$
Transmission	$\tau = \frac{4\cdot n}{(n+1)^2}$
Critical angle	$\theta_C = \sin^{-1}\left(\frac{1}{n}\right)$
Brewster's angle	$\theta_B = \tan^{-1}(n)$
Total power	$1 = \alpha + \rho + \tau$
Emissivity	$\varepsilon = 1 - \rho$

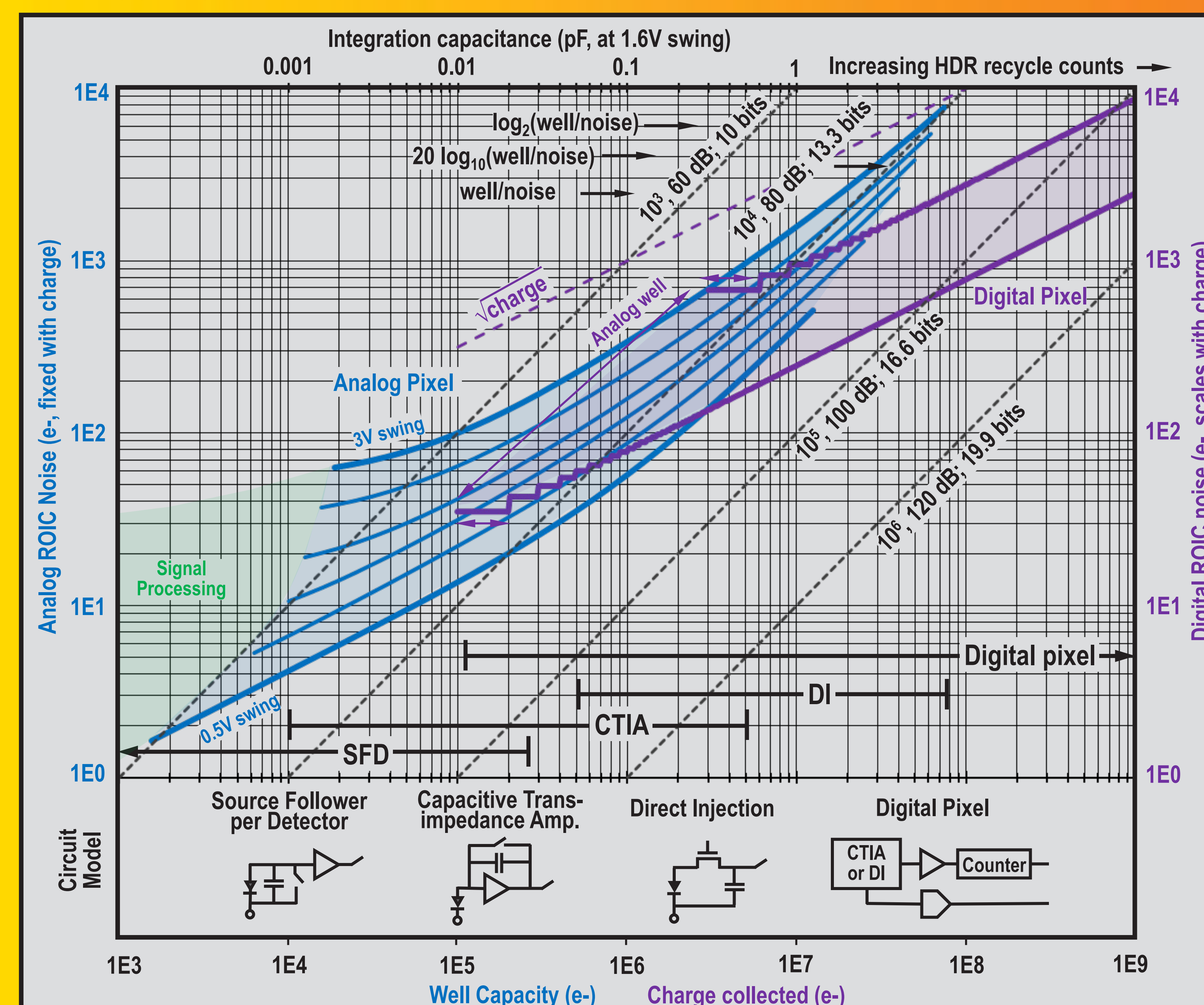
SPATIAL PERFORMANCE FIGURES OF MERIT



Geometric Detector MTF	$MTF_{detector}(f) = \text{sinc}(f\cdot x_d)$	where $\text{sinc}(x) = \frac{\sin(\pi\cdot x)}{\pi\cdot x}$; where f is in line pair/mm (lp/mm)
Optical Diffraction MTF	$MTF_{diffraction}(f) = \frac{2}{\pi}(\phi(f) - \cos\phi(f)\cdot\sin\phi(f))$	where $\phi(f) = \cos^{-1}(f\cdot F_\#)$
Total MTF	$MTF_{total}(f) = MTF_{detector}(f) \times MTF_{diffraction}(f) \times \ldots$	

Nyquist Frequency	$f_N = 1/(2\cdot x_d)$
Detector 1st zero	$f_d = 1/x_d$
Optical Cut-off	$f_{co} = 1/(\lambda\cdot F_\#)$
Diameter of Airy disk 1st zero	$2\cdot Z_1 = 2.44\cdot\lambda\cdot F_\#$
Quality Factor	$Q = \frac{\lambda\cdot F_\#}{x_d} = \frac{2\cdot f_N}{f_{co}}$

READOUT NOISE AND CHARGE CAPACITY



RADIOMETRIC SENSITIVITY FIGURES OF MERIT

Figure of Merit	Equation	Units
Instantaneous Field of View (IFOV)	$IFOV = \frac{GSD}{R} = \frac{x_d}{EFL}$	Radians (rad)
Projected Solid Angle	$\Omega_d = \pi\cdot\sin^{-1}\left(\tan^{-1}\frac{EPD}{2\cdot EFL}\right) \sim \frac{\pi}{4\cdot F_\#^2}$; $\Omega_{object} = \frac{\pi\cdot EPD^2}{4\cdot R^2}$; $\Omega_{optics} = IFOV^2$	Steradian (sr)
Etendue invariant (area x solid angle)	$A_{object}\cdot\Omega_{object} = A_{optics}\cdot\Omega_{optics} = A_d\cdot\Omega_d$	cm^2-sr
Source Signal	$S_{source}(\lambda) = \int L(\lambda)\cdot\frac{\lambda}{h\cdot c}\cdot A\cdot\Omega\cdot\tau(\lambda)\cdot\eta(\lambda)\cdot t_{int}\cdot n_{TDI}\cdot d\lambda$	Electrons
Responsivity	$R = \eta\cdot A_d\cdot t_{int}$	e-/ph/sec-cm^2
Background Limited Performance	$BLIP = \sqrt{Q_{source}\cdot\eta\cdot A_d\cdot t_{int}}$	Electrons
Photon Noise	$\sigma_{photon} = \sqrt{(Q_{source} + Q_{bkg})\cdot\eta\cdot A_d\cdot t_{int}}$	Electrons
Detector Noise	$\sigma_{dark} = \sqrt{\frac{J_{dark}}{q}\cdot A_d\cdot t_{int}}$ $\quad \sigma_{1/f.d} = \alpha_d\cdot\sigma_{dark}\sqrt{\ln\left(\frac{T_{cal}}{2\cdot t_{int}}\right)}$	Electrons
ROIC Noise	$\sigma_{ROIC} = \sqrt{N_{count}\cdot\sigma_{digital}^2 + \sigma_{analog}^2} + \sigma_{1/f.R}$	Electrons
FPA Noise (NEC or NEQ)	$\sigma_{total} = \sqrt{\sigma_{photon}^2 + \sigma_{dark}^2 + \sigma_{1/f.dark}^2 + \sigma_{ROIC}^2}$	Electrons
Noise Equivalent Irradiance	$NEI = \frac{\sigma_{total}}{\eta\cdot A_d\cdot t_{int}}$ $\quad \left(SNR = \frac{Q_{source}}{NEI\ (at\ Q_{source})}\right)$	ph/sec-cm^2
Noise Equivalent Spectral Radiance (for small bandwidths)	$NESR = \frac{NEI}{\Omega_d\cdot\tau_o\cdot\Delta\lambda\cdot\frac{\bar{\lambda}}{h\cdot c}}$	W/cm^2-sr-μm
Noise Equivalent Temp. Difference	$NE\Delta T = \frac{NEI}{\Omega_d\cdot\tau_a\cdot\tau_o\cdot\Delta\lambda\cdot\frac{\partial L}{\partial T}(T,\bar{\lambda})\cdot\frac{\bar{\lambda}}{h\cdot c}}$	mK
Noise Equivalent Target	$NET = \frac{A_d\cdot NEI}{\Omega_{object}\cdot\tau_o\cdot T_r\cdot\frac{\bar{\lambda}}{h\cdot c}}$	W/sr

A_d = Detector area, cm^2 (x_d^2)
A_{object} = Object area, cm^2 (GSD^2)
A_{optics} = Optics area, cm^2 ($\pi/4\ EPD^2\ (1-obs^2)$)
obs = Optical obscuration (if any)
τ_a, τ_o = Throughput of atmosphere, optics
η = Quantum efficiency, e-/ph
t_{int} = Integration time, sec
n_{TDI} = number in TDI (co-adds, from 1 to n)
TDI = Time delay integration (scanner/starer)
Q_{source} = Source signal, ph/sec-cm^2
Q_{bkg} = Extraneous signal, ph/sec-cm^2
α_d = 1/f noise (Tobin) co-efficient (unitless)
T_{cal} = Calibration interval, sec
N_{count} = Digital pixel counts (unitless)
$\sigma_{1/f.d}$ = Detector 1/f noise, e-
$\sigma_{1/f.R}$ = ROIC 1/f noise, e-
$\sigma_{digital}$ = Digital counter ROIC noise, e-
σ_{analog} = Native ROIC noise, e-
NEC, NEQ = Noise Equivalent Charge, e-
T = Temperature (K)
$\partial L/\partial T$ = Thm. derivative, W/cm^2-sr-um-K
$\Delta\lambda$ = Spectral band, um (for small values)
$\bar{\lambda}$ = Avg. wavelength, um (in band)
T_r = Target response ($\propto$EOD across FOV)

SELECTED CONSTANTS AND CONVERSIONS

Speed of light in vacuum	c	2.998×10^8 m/sec
Astronomical unit	AU	1.495×10^{11} m
Elementary charge (e-)	q	1.602×10^{-19} C
Electron rest mass	m	9.109×10^{-31} kg
Planck's constant	h	6.626×10^{-34} J-sec
Boltzmann constant	k	1.381×10^{-23} J/K
Boltzmann constant (k/q)	k	8.617×10^{-5} eV/K
Photon energy (hc/q)	E_{ph}	1.24 eV-um
Photometric power	lm	Lumen (eye weighted)
Photometric /area	lx	lux (lm/m^2)
Photometric /Ω	cd	candela (lm/sr)
Photometric /area-Ω	nit	nit (lm/m^2-sr = cd/m^2)

THE ELECTROMAGNETIC SPECTRUM

	Gamma Rays	X-Rays			Ultra-violet	Infrared			Microwaves			Radio waves					
Abbreviation	γ	HX	X	SX	UV	NIR	MIR	FIR	THZ	EHF	SHF	UHF	VHF	HF	MF	LF	VLF
Wavelength (λ)	0.1 Å	1 Å	1 nm	10 nm	100 nm	1 μm	10 μm	100 μm	1 mm	1 cm	10 cm	1 m	10 m	100 m	1 km	10 km	100 km
Frequency (v)	3×10^{19}	3×10^{18}	3×10^{17}	3×10^{16}	3×10^{15}	300THz	30 THz	3 THz	300 GHz	30 GHz	3 GHz	300 MHz	30 MHz	3 MHz	300 kHz	30 kHz	3 kHz
Energy	124 keV	12.4 keV	1.24 keV	124 eV	12.4 eV	1.24 eV	1.24×10^{-1}	1.24×10^{-2}	1.24×10^{-3}	1.24×10^{-4}	1.24×10^{-5}	1.24×10^{-6}	1.24×10^{-7}	1.24×10^{-8}	1.24×10^{-9}	1.24×10^{-10}	1.24×10^{-11}

ATMOSPHERIC TRANSMITTANCE

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