Spectral and Radiometric Design of a 3-line CCD Camera for Mars Observation

Spectral Design

Requirements: spectral range
bandwidth
spectral characteristics

Design:

1. first approach by filter selection from catalogues
2. modelling of the spectral system response
   (contains spectral characteristics of the sensor and optical systems)
3. fine tuning of bandwidth, centre wavelength and spectral system characteristics

Filter selection:

wide spectral bandwidth - glass filters
narrow bandwidth - interference filters

Spectral Design

Glass Filters

Advantages:

- low impact of inclined entrance ray
- robustness and long-term stability
- high transmission in a large bandwidth

Disadvantages:

- limited filter assortments
- very limited bandpass characteristics feasible
- fine tuning not possible

Interference Filters

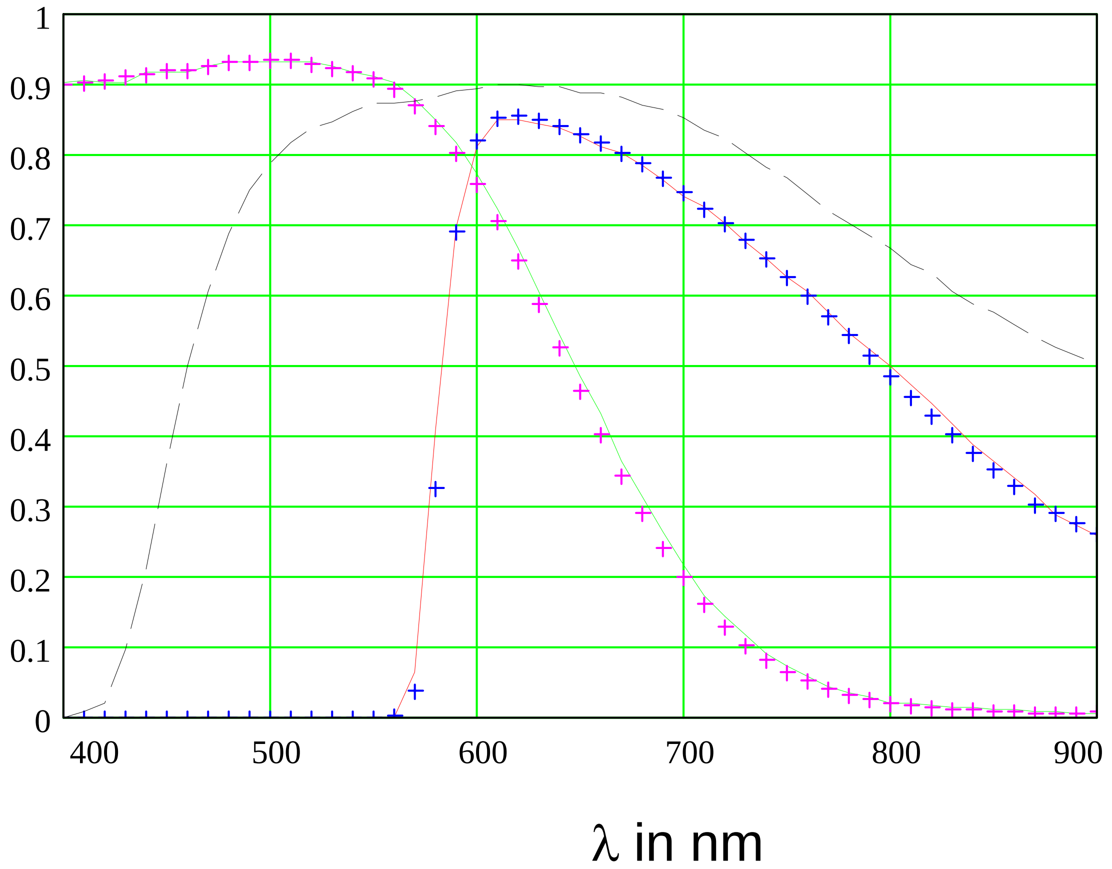
Advantages:

- any narrow bandwidth feasible
- spectral fine tuning feasible
- low mass
- steep edges in the spectral characteristics feasible

Disadvantages:

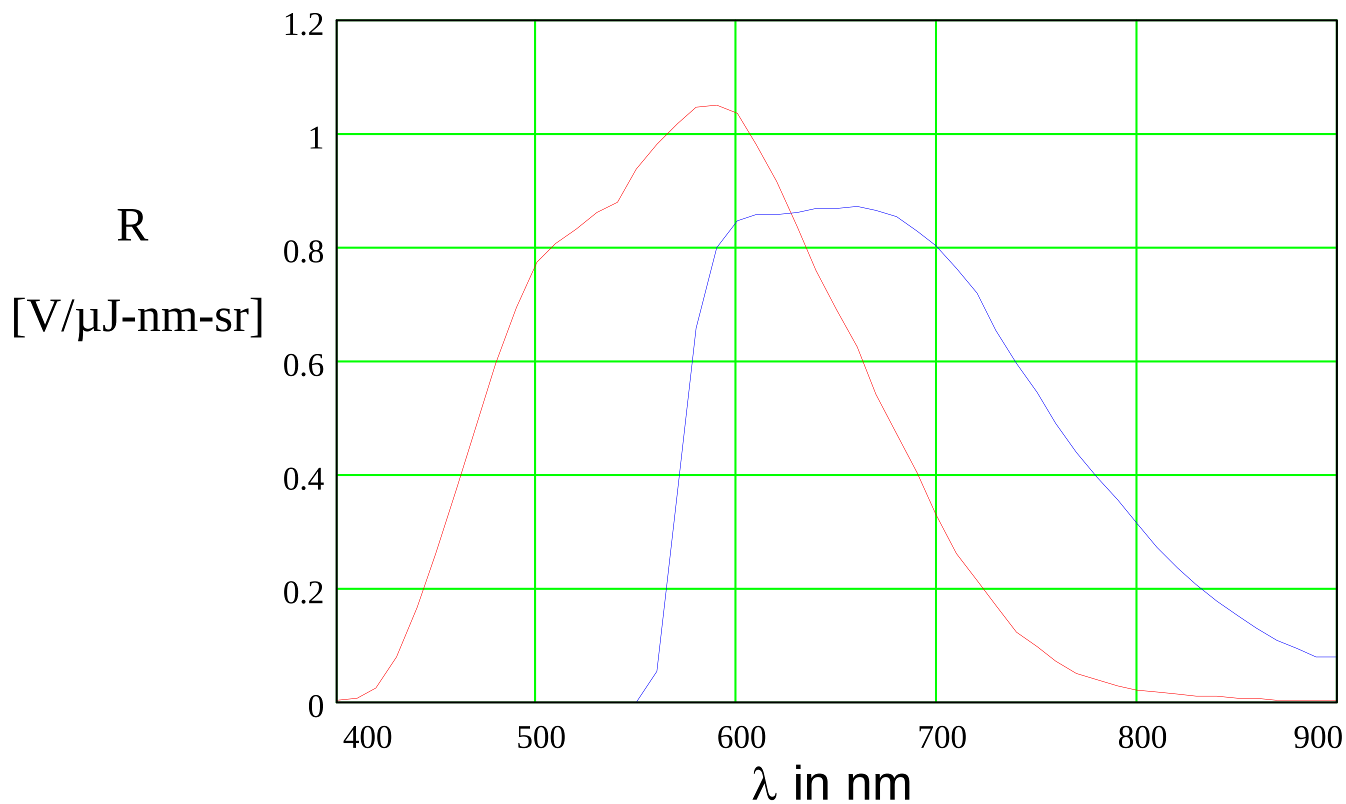
- near parallel incidence of light required
- sensitive against environmental impacts
- additional glass blocking filters necessary

Theoretical (line) and measured (+) transmission of WAOSS filters



Nadir line filter combination: 1mm KG1 + 1mm BG38

Spectral System Response of WAOSS Nadir and Stereo Channels



Stereo line filter combination: 1mmKG1 + 1mm OG570

Radiometric Design

Basic Requirements:

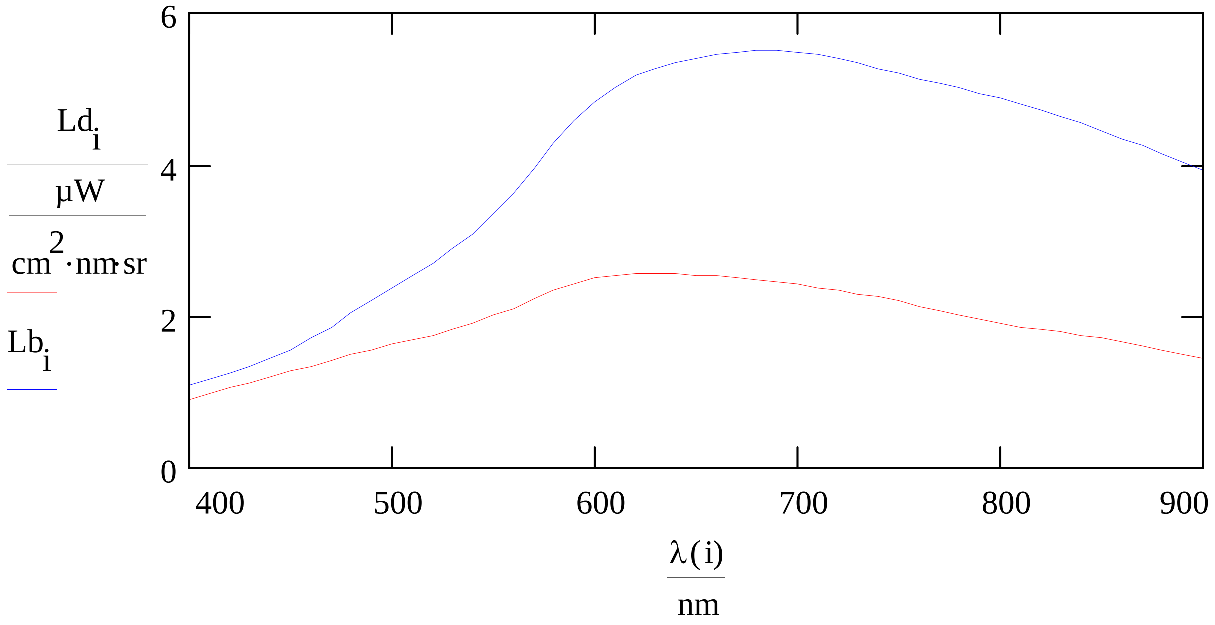
- signal-to-noise-ratio
- dynamic range and
- the image quality

Radiometric design is supported by models:

- a target model (for instance of the Martian surface and atmosphere),
- a sensor model
- a model of distortions

Radiometric Design

Signal Estimation



Model of spectral radiances of bright (Arabia) and dark (Syrtes Major) Mars regions

Radiometric Design

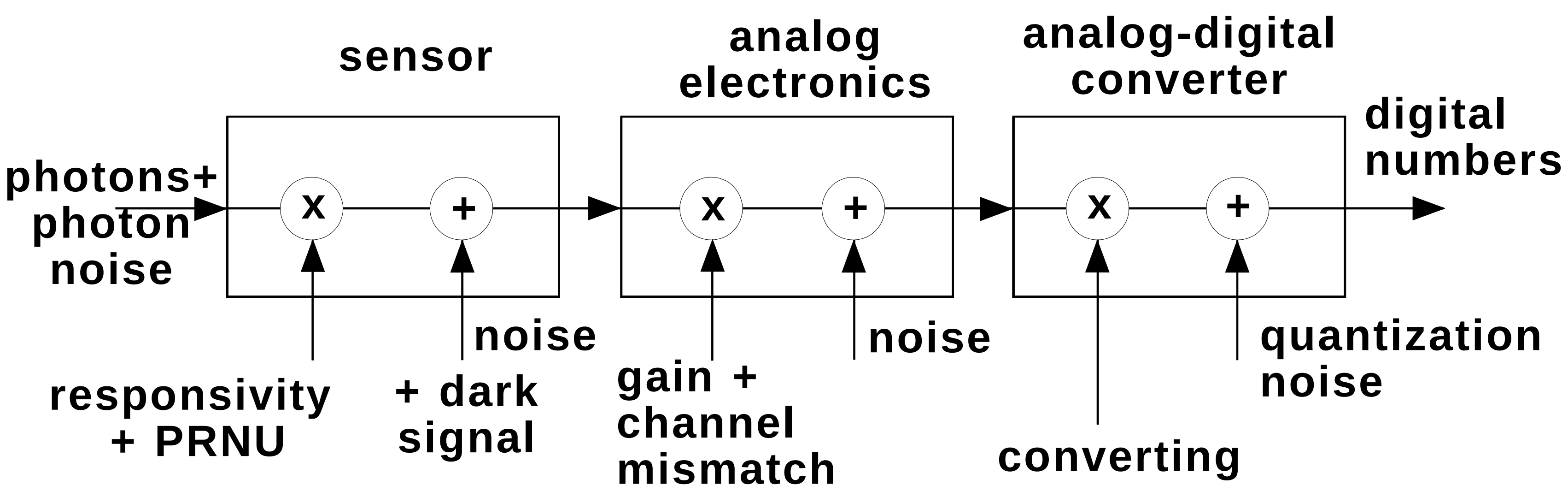
Sensor Model and Signal Estimation

$$s_i = t_{\text{int}} \frac{\pi}{4k^2} \frac{\cos(\varepsilon)^{ld}}{K(1+M^2)} \int_{\lambda 1}^{\lambda 2} T_{opt}(\lambda) R_i(\lambda) L_i(\lambda) d\lambda + \sigma_{signal} + \sigma_{system}$$

with		
	k	= 4.5 (F-number, f/aperture)
	K	= 1.44µV/el (conversion factor)
	M	= f/H (scale factor)
	ε	= view angle of pixel i
	ld	= 3.82 (limb darkening of lens)
	Topt(λ)	= Transmission of lens and filters
	R(λ)	= Responsivity of the CCD
	L(λ)	= input radiance

Radiometric Design

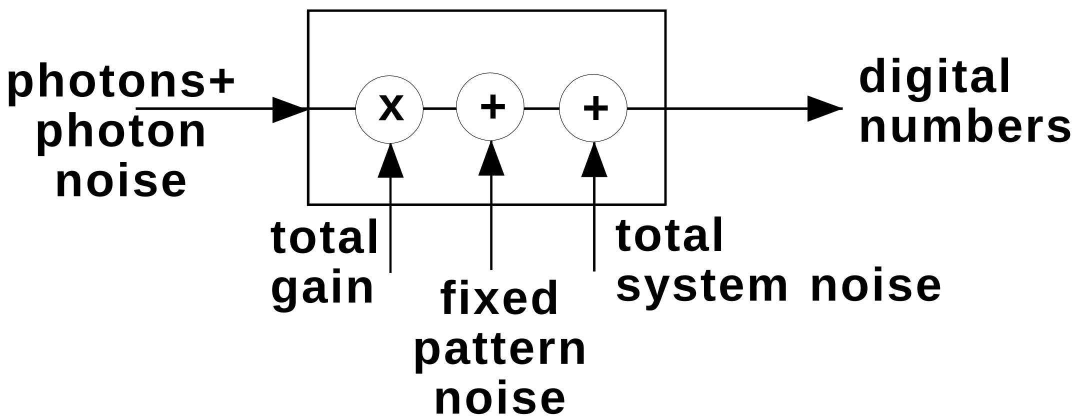
Noise sources



Model of the main noise sources of the CCD sensor system

Radiometric Design

Simplified noise model of a CCD sensor system



Main system noise sources:

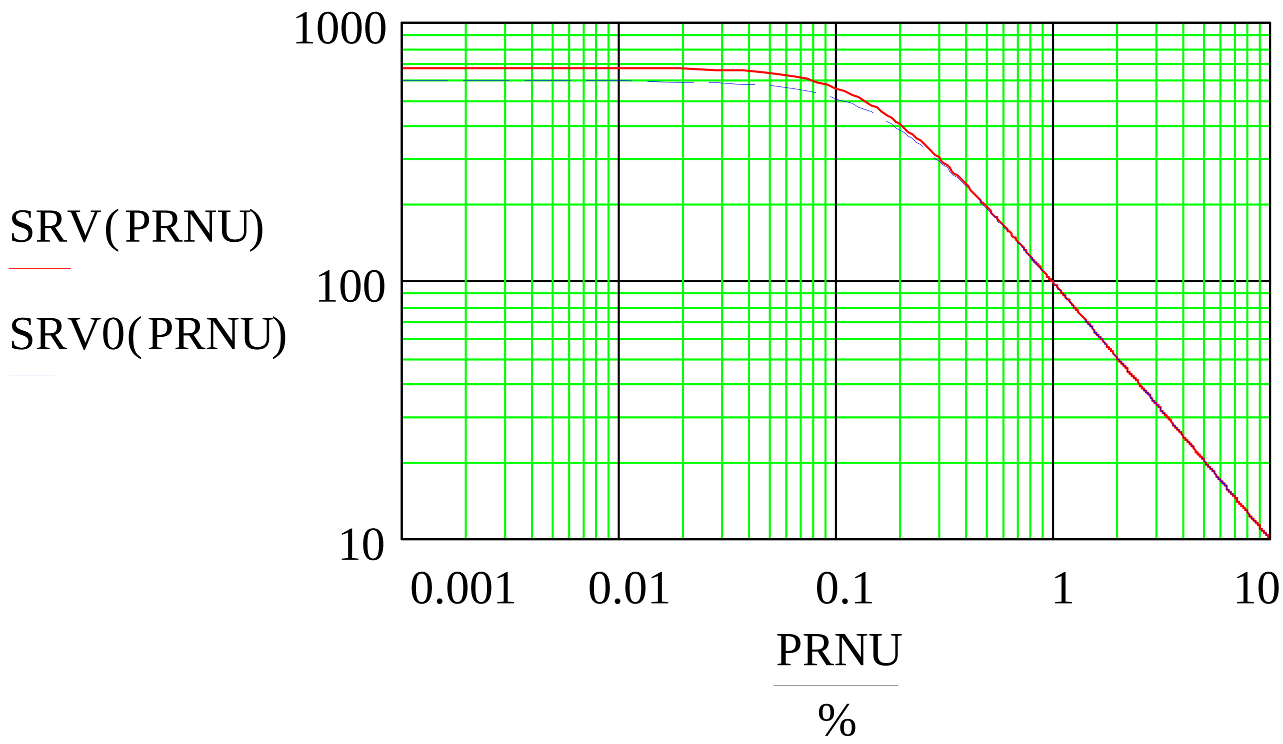
- a pixel-related multiplication factor (gain or relative photo response of the pixel i)
- the signal dependent photon noise
- the fixed pattern noise of the CCD
- the temporary total system noise (r.m.s. noise)

Radiometric Design
Signal to Noise Ratio SNR

$$\mathrm{SNR} = \frac{s_i}{\sqrt{s_i + \sigma_{system}^2}} \cdot \sqrt{ma}$$

with s_i = sensor signal
ma = macro pixel factor
σ_{system} = total system noise, transformed at sensor input

Radiometric Design
Signal to Noise Ratio SNR



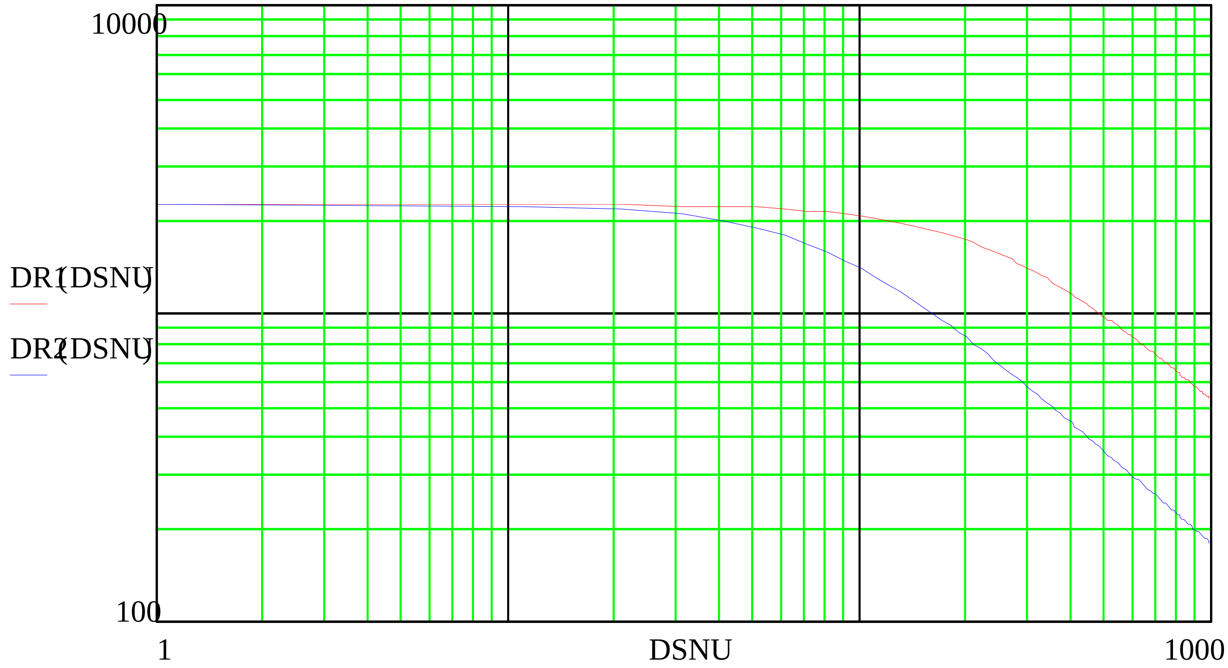
SNR in dependance of PRNU at a system noise of 235e- for two full-well options: FW=400000e- and 500000e-

RADIOMETRIC DESIGN
Dynamic Range

$$DR = \frac{FW - ADS \cdot t_{\text{int}}}{\sqrt{\sigma_{fp}^2 + \sigma_{system}^2}}$$

with	FW	= full well of sensor pixel
	ADS	= average dark signal
	σ_{fp}	= fixed pattern noise of dark signal
	σ_{system}	= total system noise, transformed at sensor input

Dynamic Range



DSNU in %

Dynamic Range in dependance of DSNU at t_{int} = 10ms and 30ms and at a system noise of 235e-

RADIOMETRIC DESIGN
Image Quality

Evaluation by MTF: MTF = |OTF| OTF = F{PSF}

System MTF: $MTF_{sys} = MTF_{opt} \cdot MTF_{CCD} \cdot MTF_{blu} \cdot MTF_{el}$

with

MTF_{opt} = MTF optics and filters

MTF_{CCD} = MTF of CCD

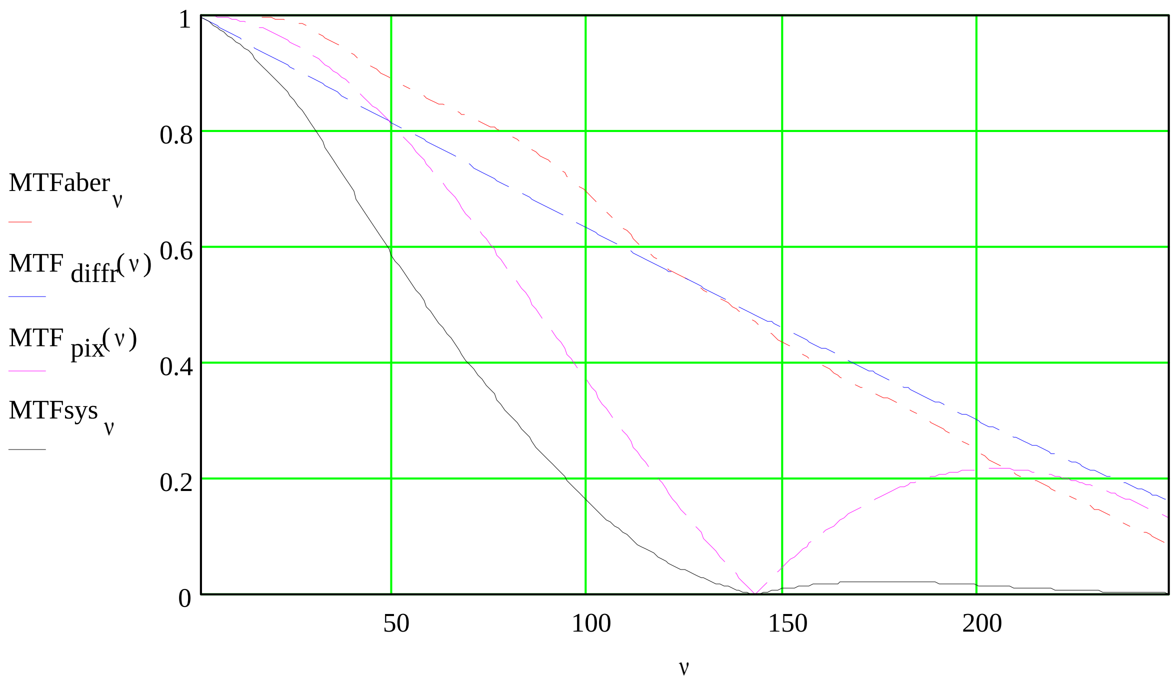
MTF_{blu} = MTF of blurring

MTF_{el} = MTF of electronics

for WAOSS optics 21.7mm f/4.5 within 450-800nm:

$$MTF_{sys} \cong MTF_{diffr} \cdot MTF_{aber} \cdot MTF_{pix}$$

RADIOMETRIC DESIGN
Image Quality



at λ= 650nm:
νcut= 342 lp/mm (diffraction limit)
νpix= 71.4 lp/mm

Summary

1. The geometric design starts with computing of all non-given geometric parameters from the requirements.

2. The spectral design is characterized by an iteration process with consideration of all spectral components (optics, filters, sensors). Glass filters are used for the determination of wide spectral bands and at wide filed of view requirements.

3. The radiometric design includes
   - a parametric sensor model
   - model signals from the target objects
   - noise models for signals and instrument
   - the conversion into digital numbers
   - the estimation of the signal-noise-ratio
   - the estimation of the dynamic range
   - a MTF system evaluation.