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**First analysis and results of the SNR**

# Abstract

This report presents the initial analysis and application of a method for calculating the Signal-to-Noise Ratio (SNR) of an infrared detection system using the MODTRAN atmospheric transmission model. By leveraging the methodology outlined in the paper *"Calculation of signal-to-noise ratio (SNR) of infrared detection system based on MODTRAN Model"*, we aim to estimate the SNR for the FLIR BOSON 640 thermal camera selected for the IGNIS mission. This approach enables a more accurate performance prediction by incorporating environmental and atmospheric conditions into the radiometric evaluation. The goal is to validate the suitability of the chosen camera and lens configuration under realistic observational scenarios, thereby supporting better-informed decisions in sensor selection and mission design.

# 1. Contextualization

The original paper *“Calculation of signal-to-noise ratio (SNR) of infrared detection system based on MODTRAN Model”* analyzes a setup where the **target is located in the atmosphere** and the **detector is positioned on the ground**. In contrast, our project reverses this configuration: the **detector is placed in the atmosphere (on a CubeSat in LEO)**, and the **target is on the Earth’s surface**. This inversion affects the MODTRAN modeling, especially in terms of the atmospheric path and spectral radiance behavior.

Moreover, since the FLIR BOSON 640 camera used in our project is **uncooled**, **detector noise is considered negligible** and is excluded from the SNR calculation. The camera's **narrow Ground Sample Distance (GSD)** also limits the observable background, allowing us to **neglect background radiance noise**.

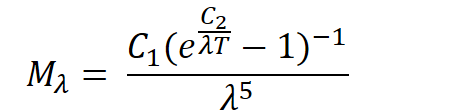
Finally, because the system operates in the **Long-Wave Infrared (LWIR)** range, we **do not need to calculate the term** *. As a result, the radiometric energy simplifies to* , which streamlines the computational model for our specific use case.

# 2. Calculation of the Formulas

In this section, we derive the SNR calculation for our infrared detection system, beginning with the blackbody radiation model and proceeding through the necessary radiometric and atmospheric components. The methodology follows the framework presented in the referenced MODTRAN-based paper but is adapted to the parameters of our CubeSat mission.

### 1.1 Spectral Exitance — Planck’s Law Form (in μm)

We use the following equation:



Where:

* is the **spectral exitance** in W·m⁻²·μm⁻¹
* λ: wavelength (μm)
* T: temperature of the target (K)
* =3.7418×108
* =14388 μmK

Given:

λ=8μm  
 T=433.15 K  
 =   
 =14388 μm⋅K

Then:

Mλ ​= () / ( ⋅ ( - 1) ​≈ 182.3

Mλ ​≈ 182.3

### 1.2 Spectral Emissive Power of the Target

The spectral **emissive power** Eλ​ of a real (non-ideal) surface is obtained by multiplying the blackbody spectral exitance Mλ by the surface spectral emissivity ελ​:



Where:

* ελ​ is the spectral emissivity of the target surface (unitless),
* Mλ​ is the spectral exitance of a blackbody at the same temperature.

In our case, the target is **solid ground**, such as soil or land surface, which in the **LWIR region (8–14 μm)** typically has a high emissivity. A representative value is:

ελ≈0.95

This value provides a realistic estimate for most terrestrial targets and is consistent with empirical data from thermal remote sensing studies.

Given:

Mλ​=182.3   
 ελ=0.95

Then:

Eλ ​= ελ​ ⋅ Mλ​ = 0.95 ⋅ 182.3 = 173.185

### Justification for Radiometric Simplification

The methodology we follow is based on the paper *“Calculation of signal-to-noise ratio (SNR) of infrared detection system based on MODTRAN Model,”* which provides a framework for both **3–5 μm (MWIR)** and **8–12 μm (LWIR)** spectral bands.

However, our system uses the **FLIR Boson 640**, which operates strictly in the **LWIR region (8–14 μm)**. This means we are **not capable of detecting thermal emissions in the 3–5 μm band**, where reflected solar irradiance plays a significant role.

As a result:

* The term Eλ′​, which accounts for **reflected solar radiation** in the MWIR range, can be **neglected** in our application.
* The total spectral irradiance simplifies to:

This assumption aligns with standard practice for **pure thermal sensing in LWIR**, where surface emission dominates and external reflection is minimal or absent.

### 1.3 Optical Geometry and System Parameters

Before calculating the total signal received by the detector, it is necessary to define the optical parameters of the system.

Our infrared camera system is equipped with a **lens of focal length f=72.8 mm** and a **focal ratio (f-number) of F#=1.05**. The **focal ratio** is defined as:

Where:

* f is the focal length,
* D is the entrance pupil diameter (aperture).

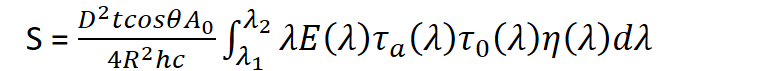
From this, we can calculate the **optic diameter D**:

= = ≈ 0.06933 m

This diameter will be used in the following signal calculation.

### 1.4 Signal Calculation

The total signal S, i.e., the number of photons received by the detector, is given by:



Where:

| **Symbol** | **Description** | **Value** |
| --- | --- | --- |
| D | Optical diameter | 0.06933 m |
| t | Integration time | 0.01 s |
| θ | angle between a line drawn from the target to the detector and the line normal to the target's surface | 0° ( cos⁡θ=1) |
|  | Observed ground area | 10 m² |
| R | Satellite altitude | 460,000 m |
| h | Planck’s constant | 6.626×10^−34 Js |
| c | Speed of light | 3×10^8 m |
|  | Atmospheric transmittance | 0.85 |
|  | Optical system transmittance | 0.89 |
| η | Quantum efficiency | 0.7 |

**Note**: The quantum efficiency η=0.7 was selected based on a representative value from Jacob Wilson's 2024 Master's Report at the University of Arizona [link](https://wp.optics.arizona.edu/alumni/wp-content/uploads/sites/113/2024/06/Jacob_Wilson_Master_s_Report_2024.pdf).

The spectral irradiance E(λ) is assumed constant across the 8–12 μm LWIR band, with a value of:

E(λ)=173.185

then:

≈ 3749.75

and:

S = 3749.75 ≈

S ≈

### 1.5 Noise Assumptions

In the standard radiometric noise model, the total noise NNN is defined as:

Where:

* ​: is the signal (photon) noise,
* ​: is the background noise
* ​: is the detector noise.

According to the paper, the **signal noise** is defined by the relation:

=

#### Simplifying the Total Noise Expression

In our case:

* ​ (detector noise) is negligible due to the use of an uncooled microbolometer without amplification,
* ​ (background noise) is negligible due to narrow GSD and minimal scene clutter.

**Simplifying the Total Noise Expression**

In our case:

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* ​ (background noise) is negligible due to narrow GSD and minimal scene clutter.

Thus, we simplify the total noise to:

And the SNR becomes:

=

### 1.6 SNR Calculation

Following the assumptions and simplifications adopted in the previous section, the total noise in our system is defined by photon shot noise alone, where:

and

Using the previously calculated signal value:

 photoelectrons

We obtain:

≈

≈

This high Signal-to-Noise Ratio indicates excellent radiometric performance under the modeled conditions, with the detector signal significantly exceeding the inherent statistical noise of the photon stream.

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