Tutorial

Introduction to Light Technology

and Night Vision Systems

Presented by:

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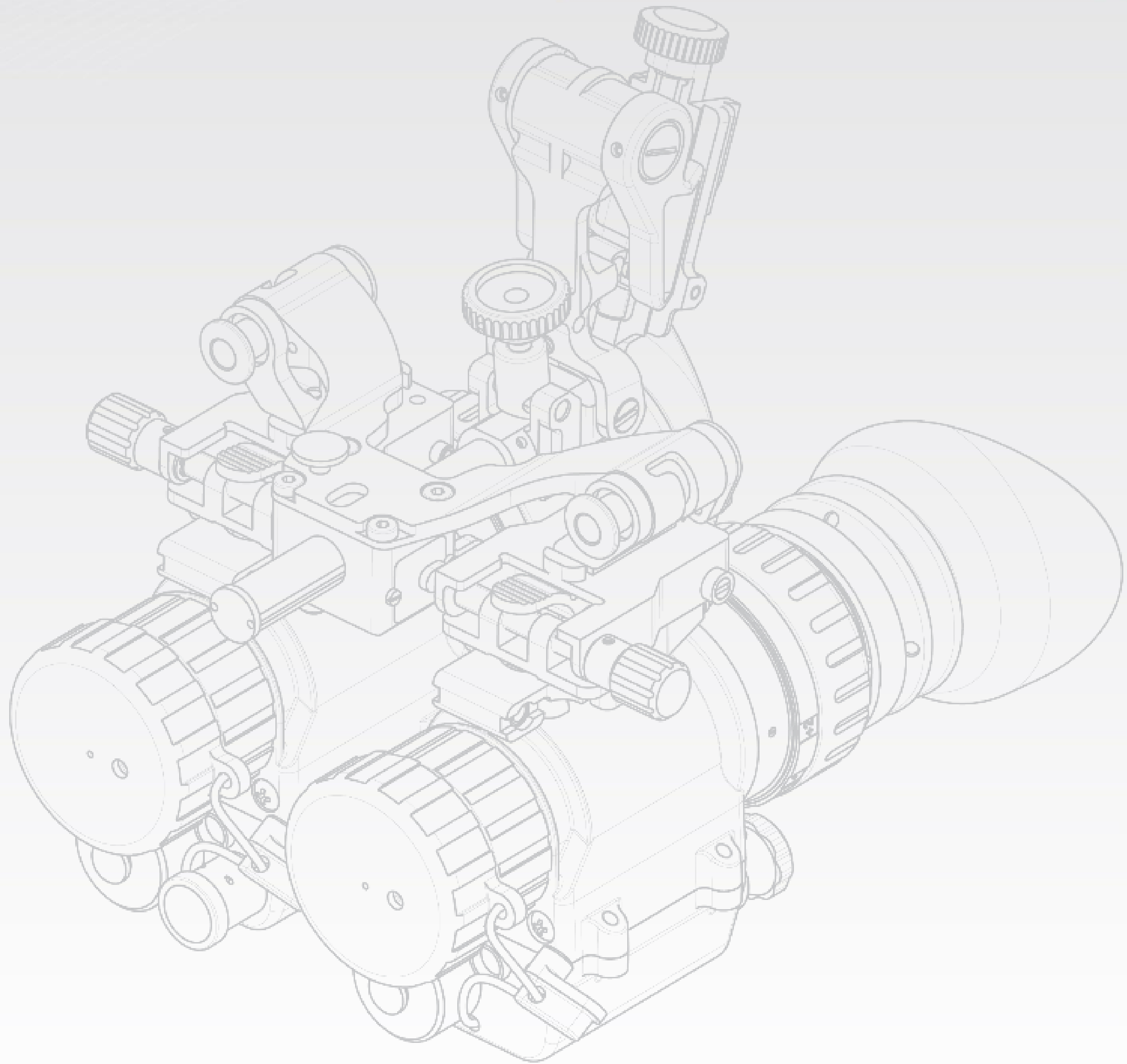

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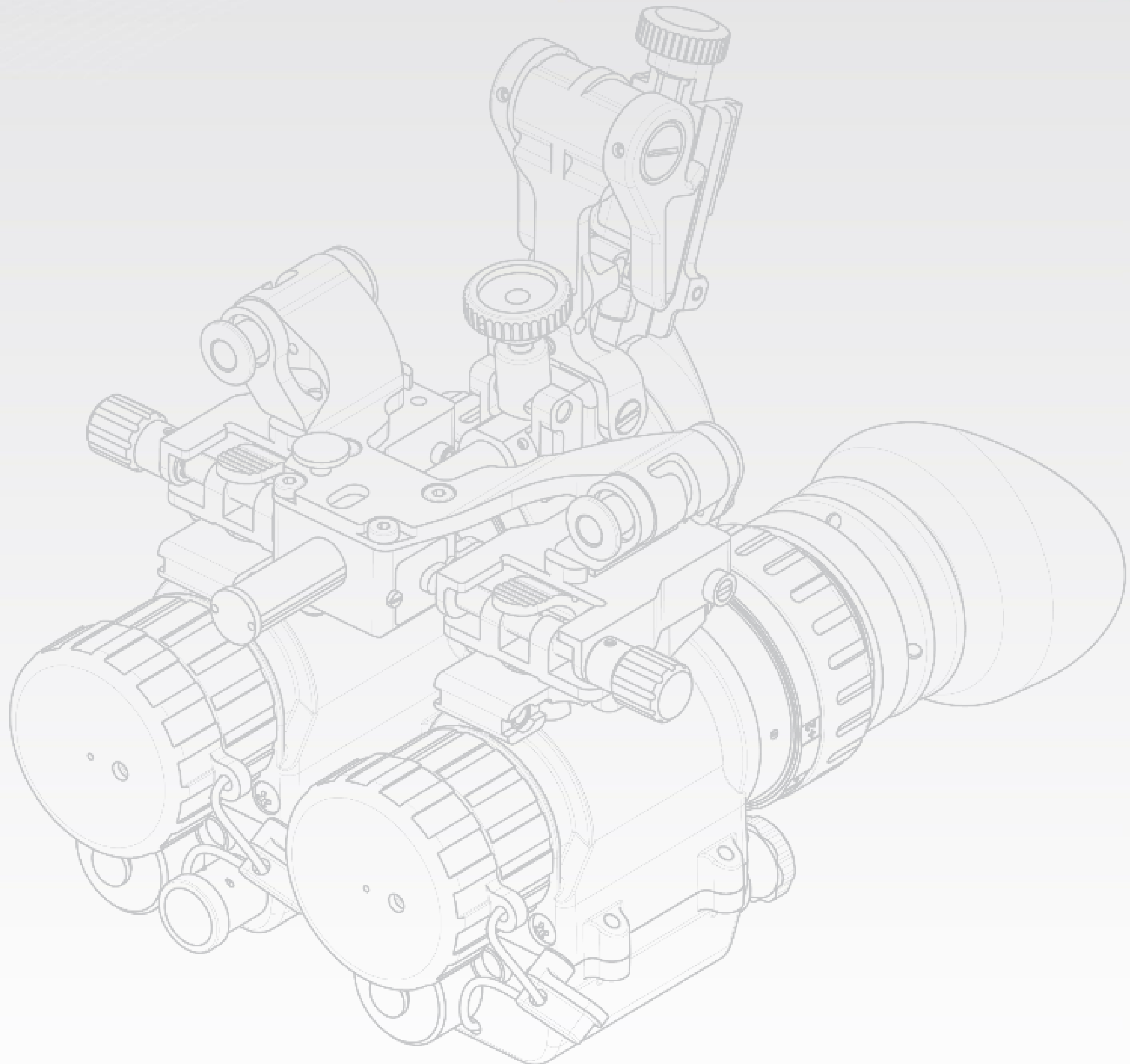
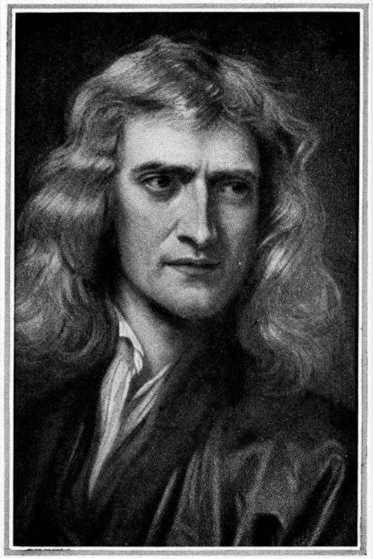
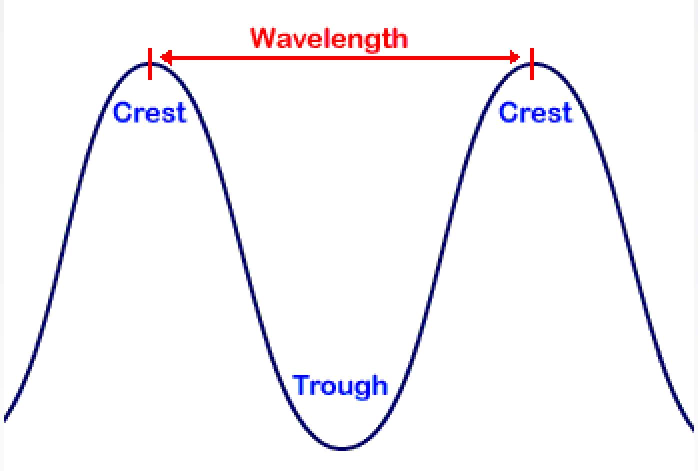


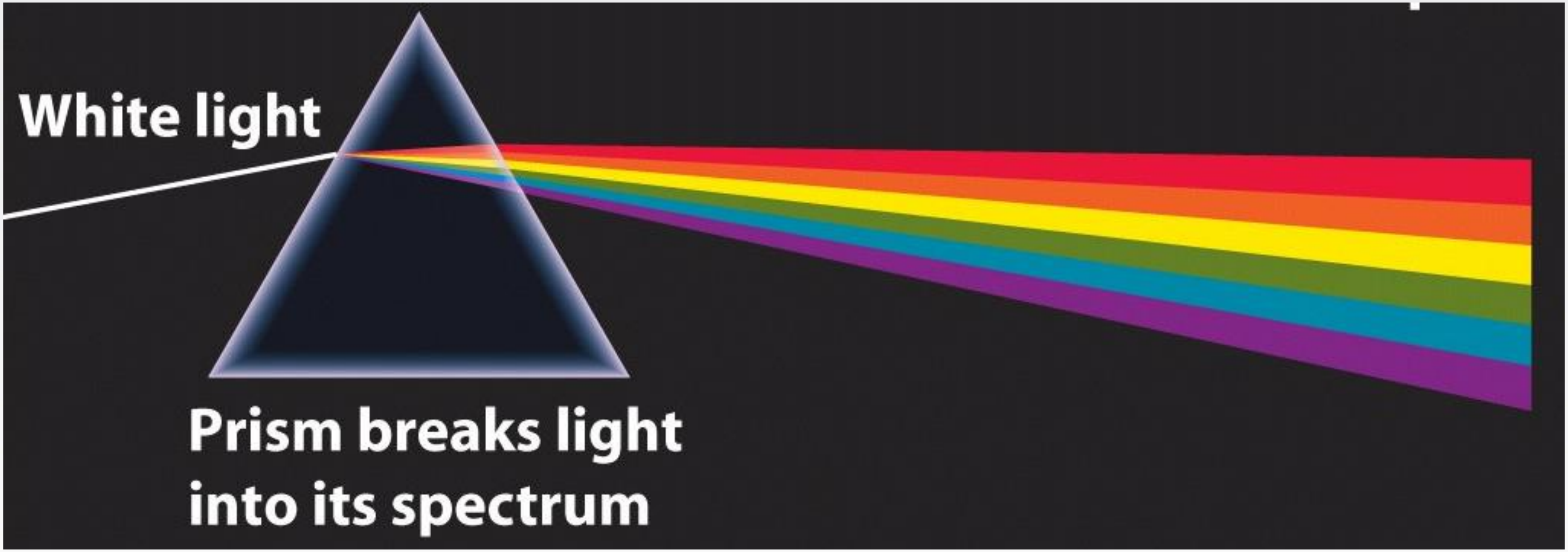
- Isaac Newton (1642-1727) believed light consisted of particles.

- By 1900 most scientists believed that light behaves as a wave.



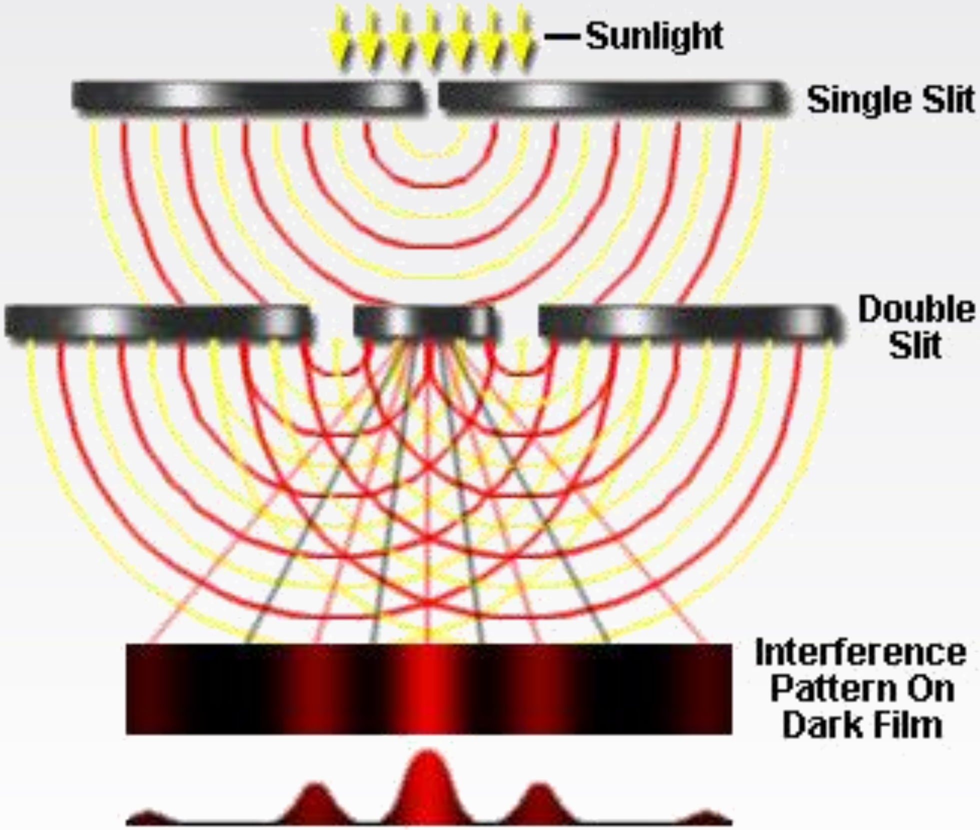


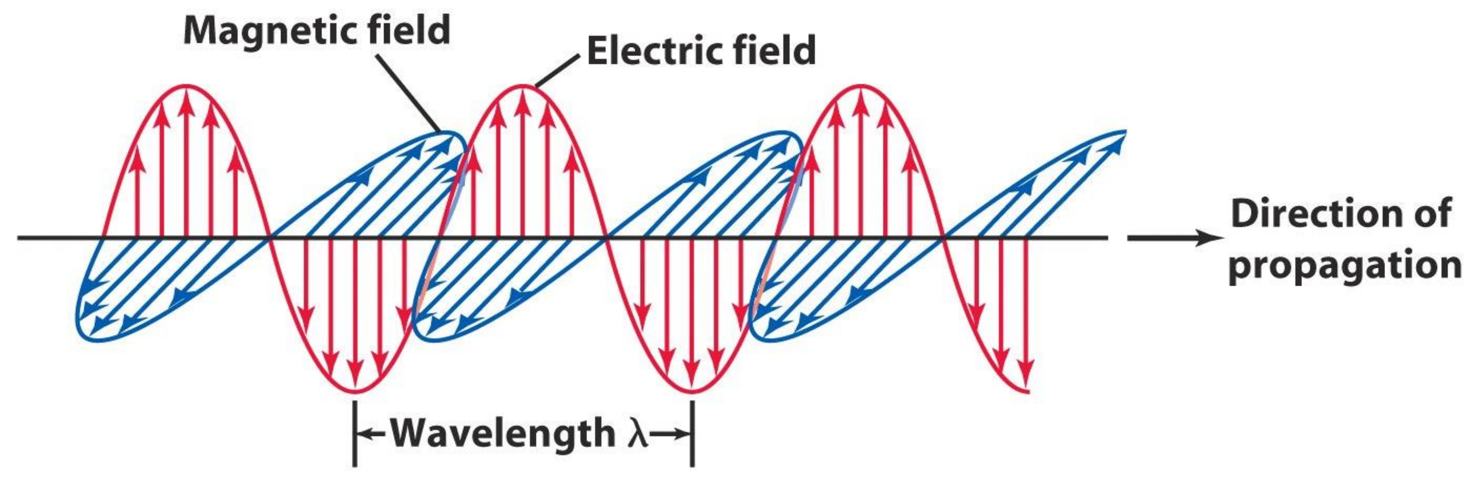
- Newton found that the white light from the Sun is composed of light of different color, or spectrum (1670).



Light has wave-like properties!

- Young's Double-Slit Experiment indicated light behaved as a wave (1801)
- The alternating bright and dark bands appearing on the screen is analogous to the water waves that pass through a barrier with two openings





$c = \lambda \times v$

- **The nature of light is electromagnetic radiation**
- In the 1860s, James Clerk **Maxwell** succeeded in describing all the basic properties of electricity and magnetism in four equations: the Maxwell equations of **electromagnetism.**
- Maxwell showed that electric and magnetic fields travel vertical to the propagation axis.

Light has particle-like properties!

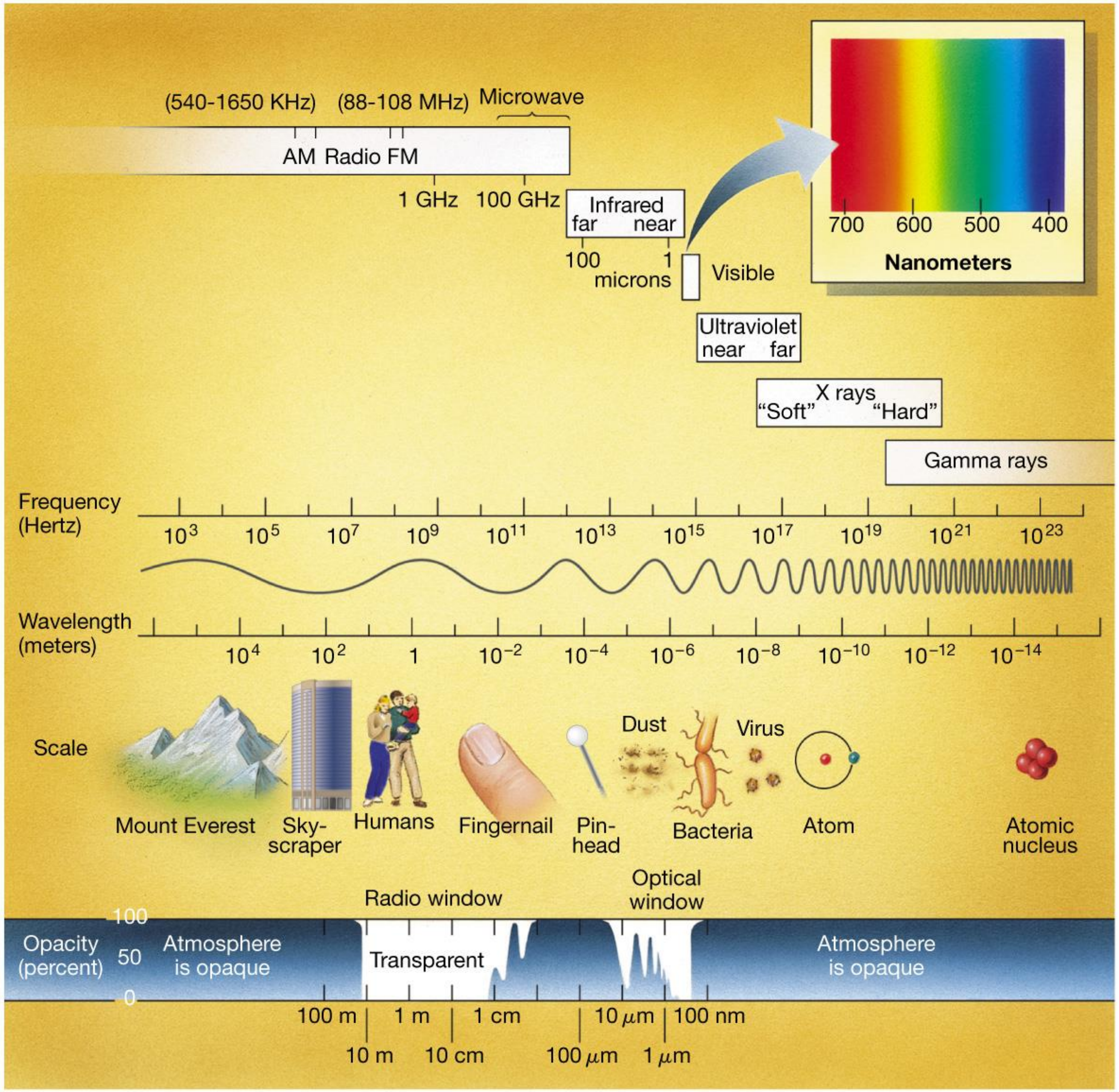
Phenomenon	Can be explained in terms of waves.	Can be explained in terms of particles.
Reflection	✓	✓
Refraction	✓	✓
Interference	✓	⊗
Diffraction	✓	⊗
Polarization	✓	⊗
Photoelectric effect	⊗	✓

I^2 Tube Shot Noise is a quantum effect.

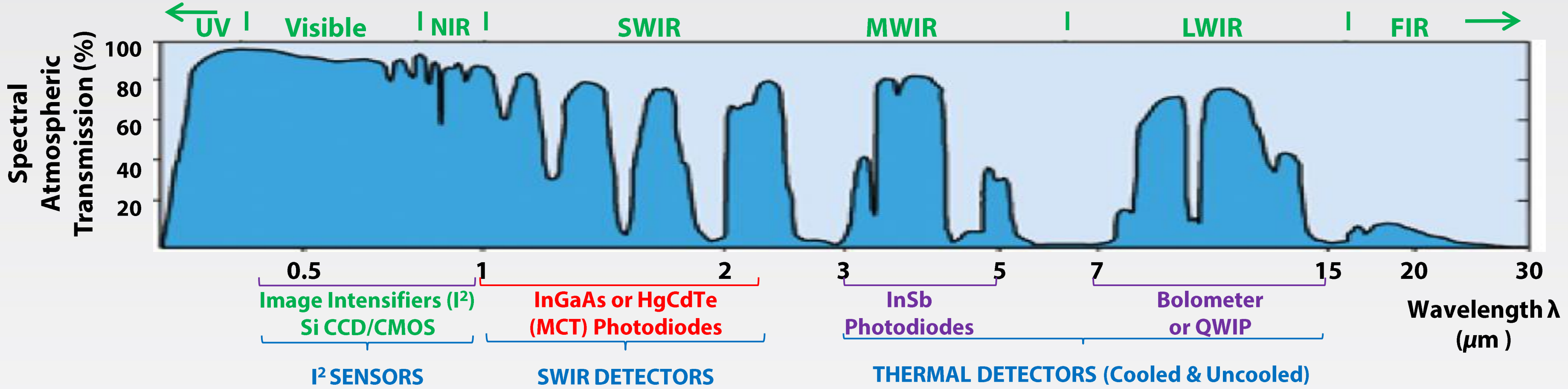
- **Most quantum effects cannot be explained with the wave-like description of light**
- Light has minimum packet of energy (quanta) that cannot be divided.

$$E = h \times \nu$$

- The frequency (ν) of a wave is the number of waves to cross a point in 1 second (units are Hertz – cycles/sec or sec^{-1})
- *h* is the Plank's constant


(540-1650 KHz)
(88-108 MHz)
Microwave
AM Radio FM
1 GHz
100 GHz
Infrared
far near
100
1
microns
Visible
700
600
500
400
Nanometers
Ultraviolet
near far
X rays
"Soft" "Hard"
Gamma rays
Frequency (Hertz)
10^3 10^5 10^7 10^9 10^{11} 10^{13} 10^{15} 10^{17} 10^{19} 10^{21} 10^{23}
Wavelength (meters)
10^4 10^2 1 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14}
Scale
Mount Everest
Sky-scraper
Humans
Fingernail
Pin-head
Dust
Bacteria
Virus
Atom
Atomic nucleus
Radio window
Optical window
Opacity (percent)
100
50
0
Atmosphere is opaque
Transparent
Atmosphere is opaque
100 m
1 m
1 cm
10 μm
100 nm
10 m
10 cm
100 μm
1 μm

- Atmospheric Spectral Transmission and respective sensor operating spectral band is shown below:



- A Night Vision Device is an optical instrument that allows images to be produced at spectral bands, OR light levels invisible to the human eye.
- Night vision is made possible by a combination of two approaches: sufficient spectral bandwidth and sufficient sensitivity range.
- Night Vision based products consist of:
  - Sensors (and if applicable, supporting electronics); and
  - Product defining components such as housing, objective and eyepiece lenses (Visible and IR), micro-displays, reticle assemblies, battery housings, etc.

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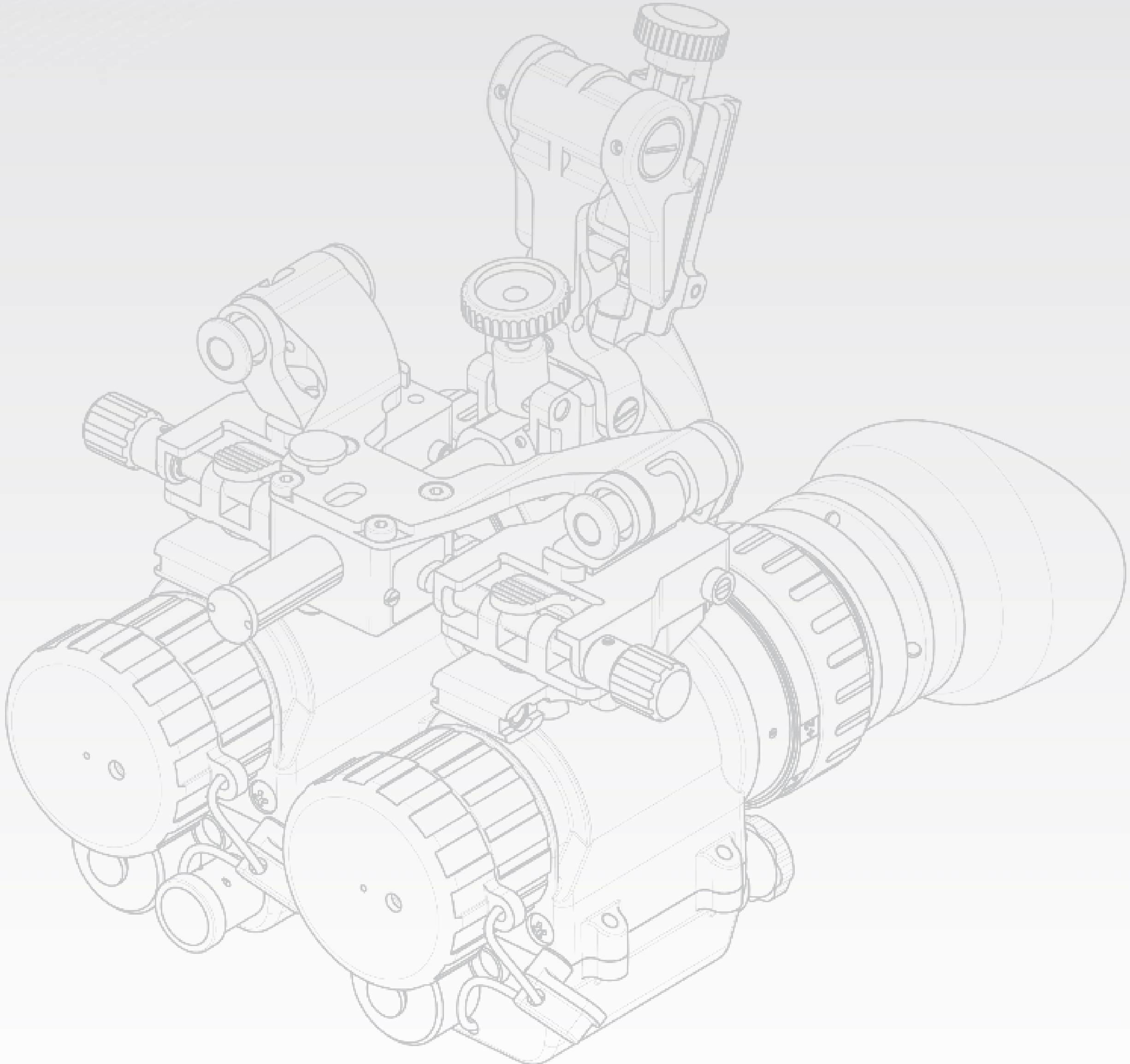
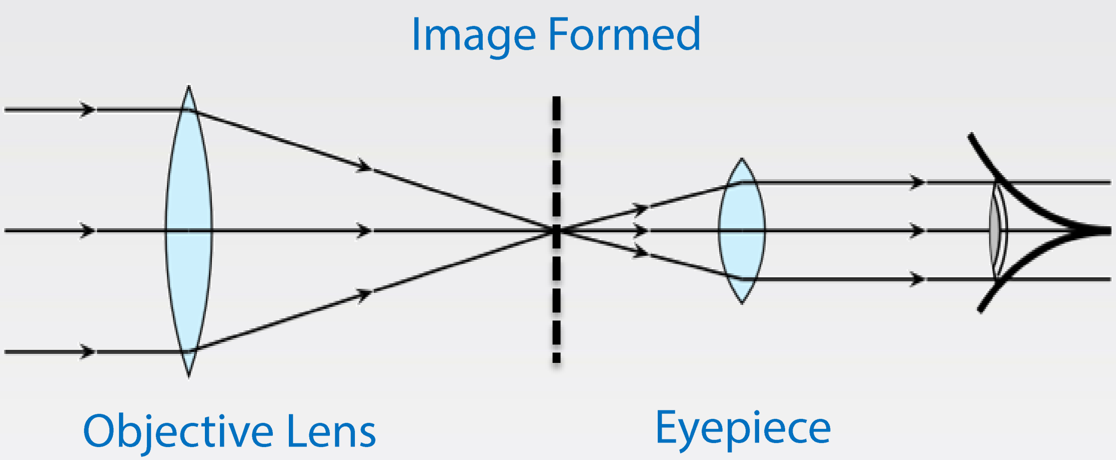


Optical Design

- Any optical system has an objective lens which collects the light from the observed scene and forms an image.

- The eyepiece lens projects the image to the eye.



- Important parameters of lenses are:

  Field-of-View (FOV) and Magnification (M),

  Focal Length (EFL),

  F number (F/#) and

  Modulation Transfer Function (MTF) -> Resolution

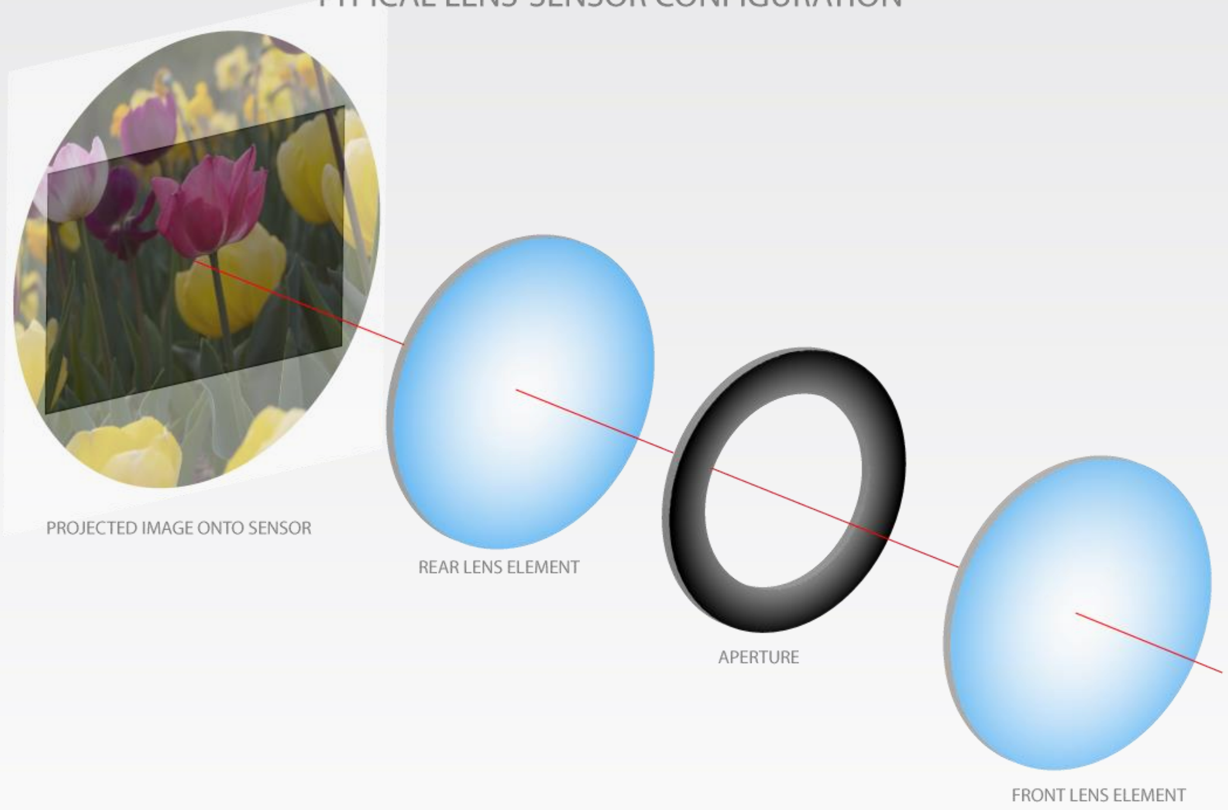
- The light enters through the objective lens in the device.

- The objective lens system focuses the image on the sensor (or photocathode of the Image Intensifier Tube, for I^2 systems).

- The sensor may capture part of the formed image.

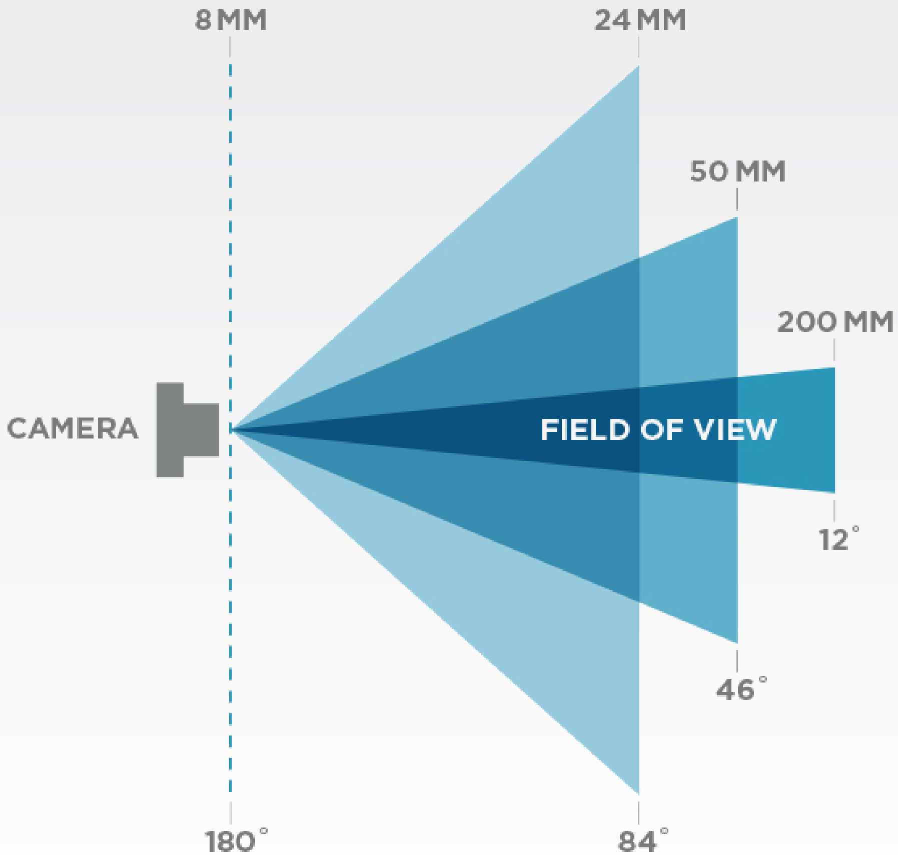
- The aperture is the iris/diaphragm that defines the light gathering capability of the lens system.

TYPICAL LENS-SENSOR CONFIGURATION



http://www.cameratechnica.com

- The objective lens is characterized by its Effective Focal Length (EFL).
- As the EFL increases, the systems Magnification (M) and resolution increases and the Field of View (FOV) decreases.



Magnification

$$M = \frac{EFL_{objective}}{EFL_{eyepiece}}$$

http://clarapersis.com

- F/# = EFL / (Lens Aperture)

$$F/\# = \frac{EFL}{D_{en}}$$

www.engadget.com

- The objective lens (front) F/# indicates the light gathering capability of the lens.

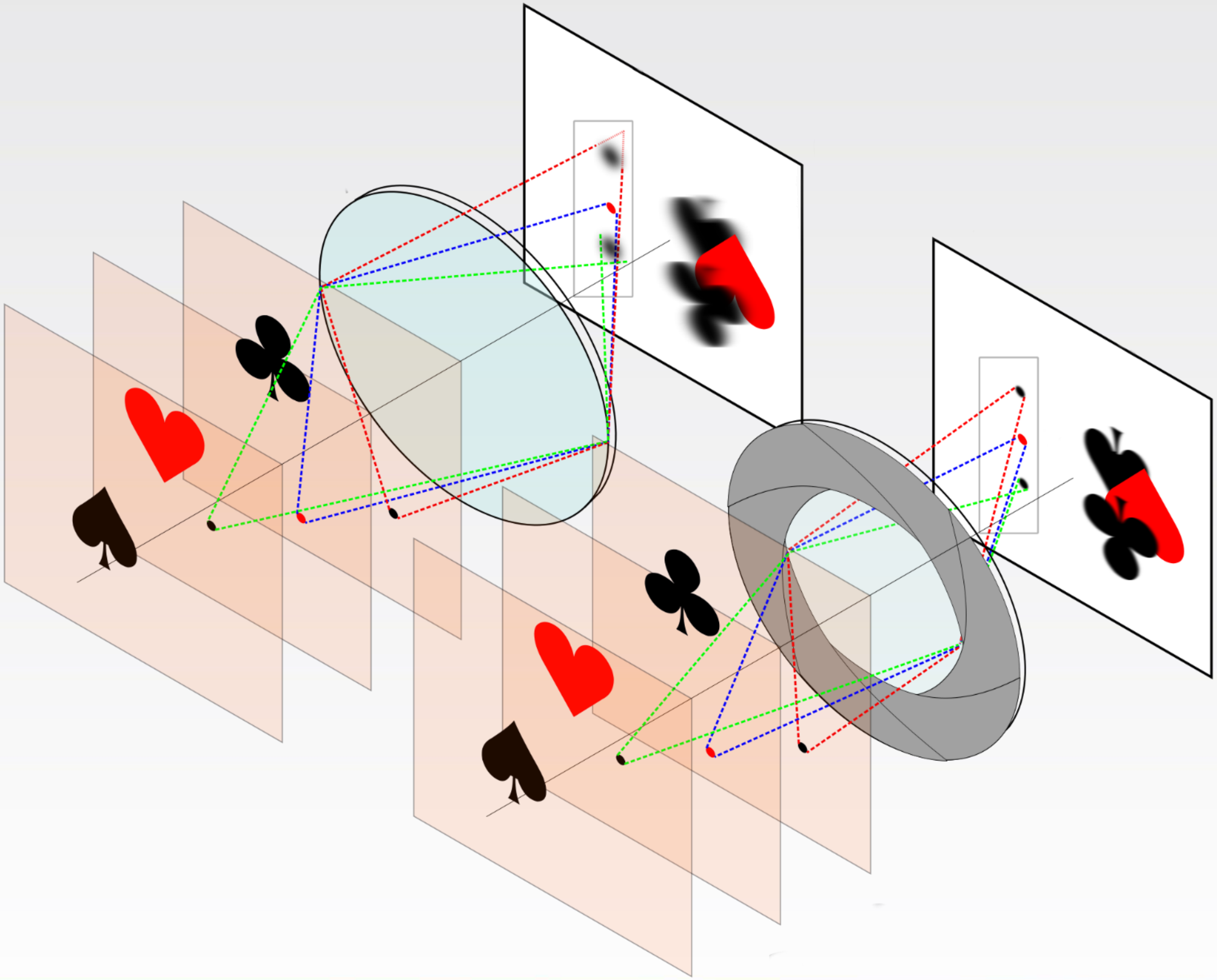
$$Sensor\ Illuminance \propto \frac{1}{(F/\#)^2}$$

- Thus the smaller the F/#, the larger the lens aperture, and the better its light gathering capability.

  -> Longer detection range at night

- For a night vision system it is very important to have as low F/# as possible. However, as the focal Length increases in order to obtain higher system resolution it is getting difficult to have low F/# due to size and weight limitations.
- ! Lower F/# means shallow depth of field

- Lower F/# means shallow depth of field



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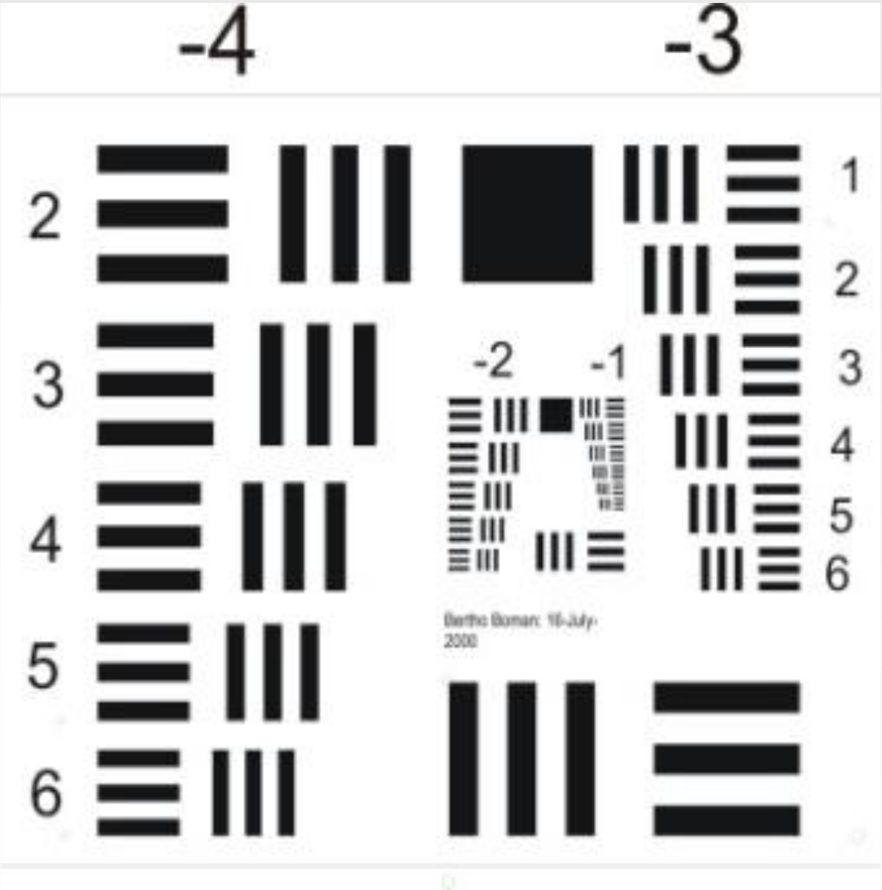
- Line Pairs per Millimeter (lp/mm) - Units used to measure image intensifier resolution. Usually determined from a 1951 Air Force Resolving Power test target.
- The target is a series of different sized patterns composed of three horizontal and three vertical lines.
- The lines and spacing between lines in each of the different patterns differ in width; the narrower the width, the greater the resolution is needed to distinguish the lines in a given pattern.
- Human test subjects must be able to clearly distinguish all the horizontal and vertical lines of a particular pattern in order for an image intensifier to achieve the resolution represented by that pattern.



- The System Resolution is the most important parameter of any optical system as it indicates the smallest pattern than can be resolved by the system and thus its range performance.

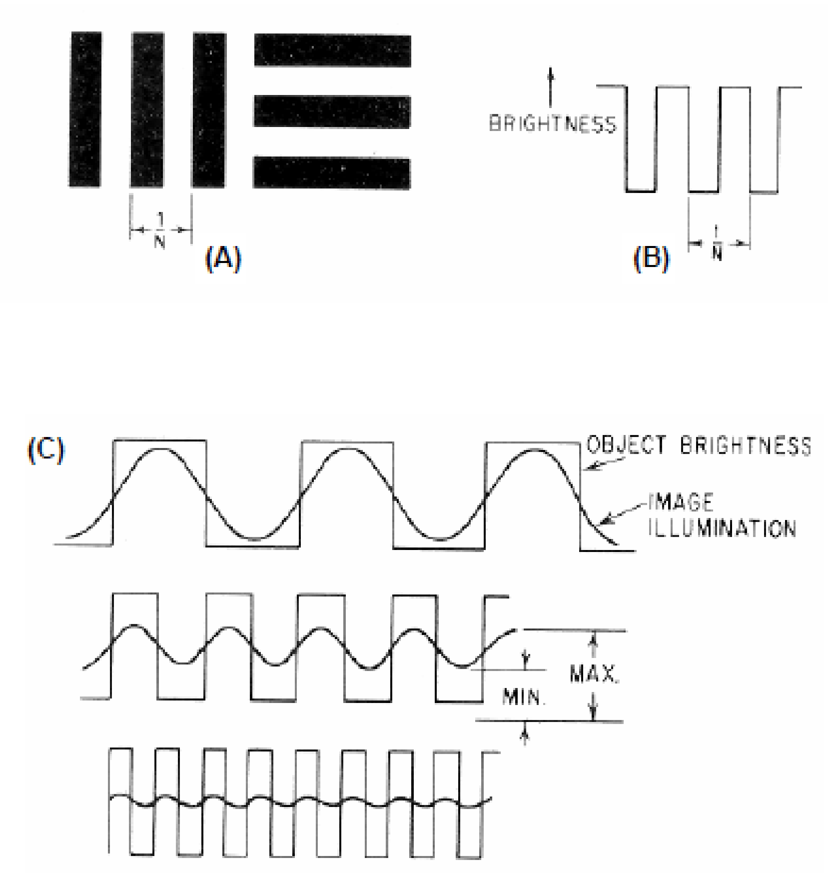
- System Resolution is defined as the smallest angle (mrad or MOA) for which two lines (one line pair) can be discerned as separate.

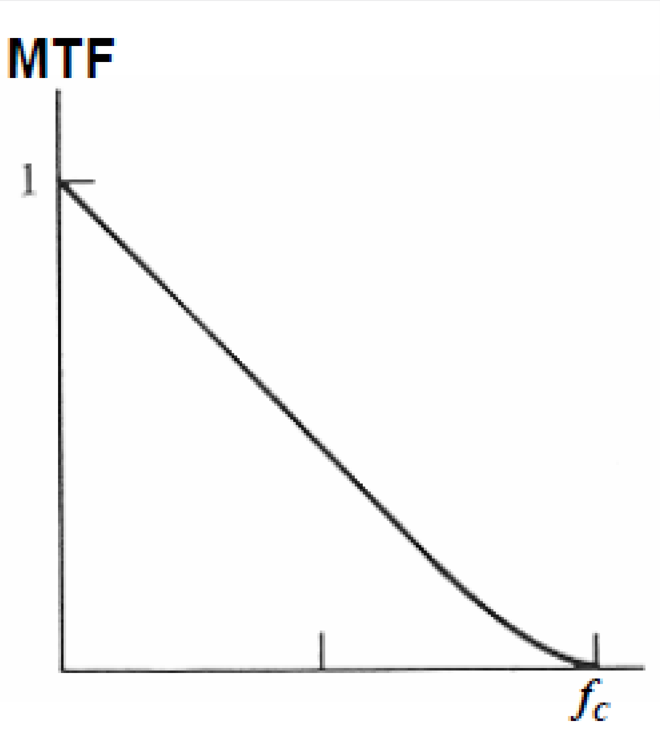
- For example, a resolution of 4.2 lp/mrad or equivalently if we take the inverse 0.24 mrad/lp means that you can barely discern two lines if they subtend an angle of 0.24 mrad which is 0.83 MOA (arc minutes).

- The higher is the system resolution the higher the systems range performance will be.

- For a night vision system the system resolution is defined by:
  - The objective lens design and quality
  - The image intensifier tube
  - The scene light level

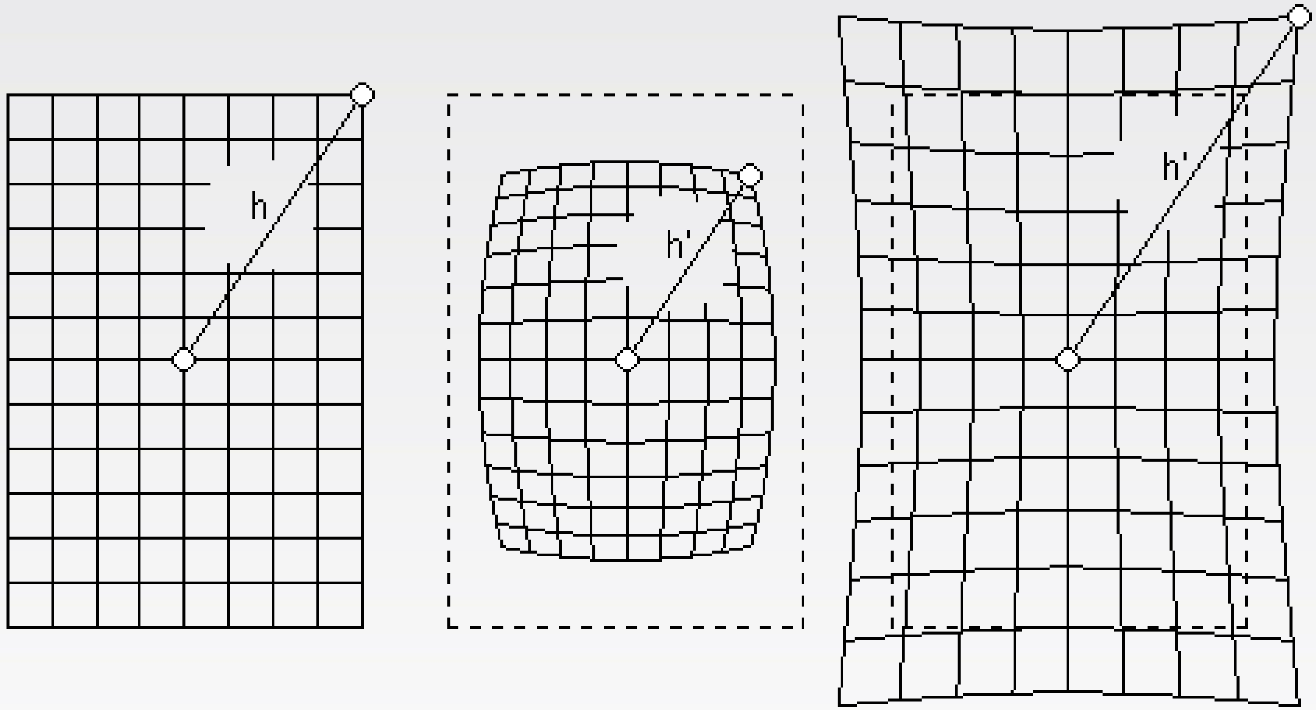
Contrast





$$MTF_{system} = MTF_{obj} \times MTF_{tube} \times MTF_{eyepiece}$$

J. Harvey



- No blurring
- Distorts the image
- Can lead to aiming errors

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- Distorts the image
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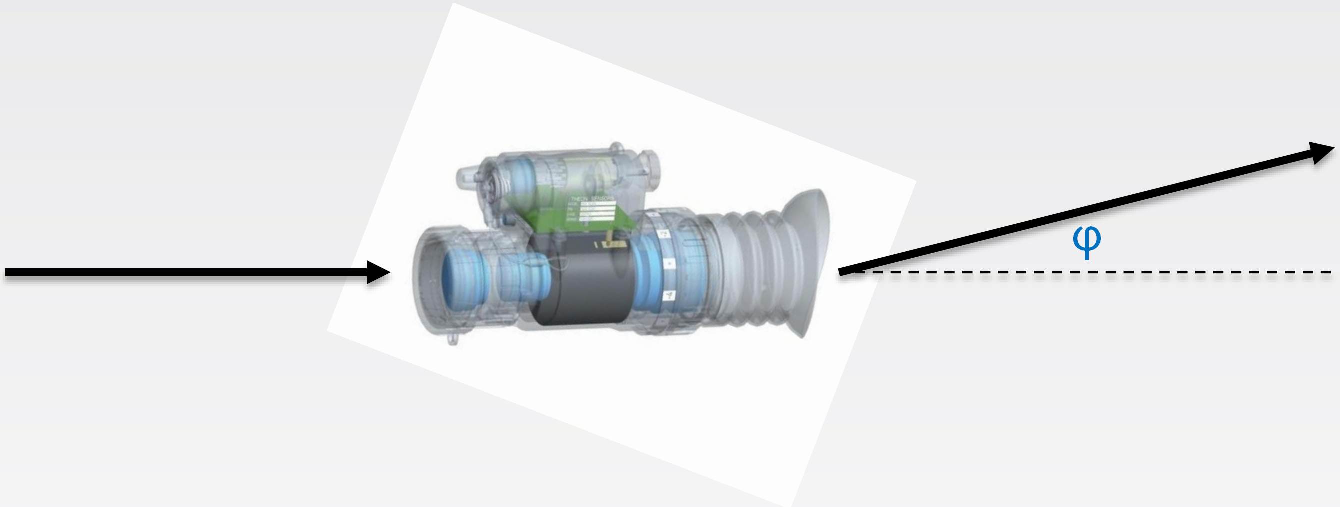

Collimation causes the output to be at an angle relative to the input.
Results in use fatigue

Relation between M, FOV, Resolution

OBJECTIVE LENS		EYEPIECE LENS	
EFL = 100 mm		EFL = 25 mm	Magnification: 100/25 = 4X Field of View = 10º Resolution = 3.6 lp/mrad Aperture = 67 mm
EFL = 125 mm		EFL = 125 mm	Magnification: 125/125 = 1X Field of View = 8º Resolution = 4.0 lp/mrad Aperture = 55 mm
EFL = 27 mm		EFL = 27 mm	Magnification: 27/27 = 1X Field of View = 40º Resolution = 1.2 lp/mrad Aperture = 22.5 mm

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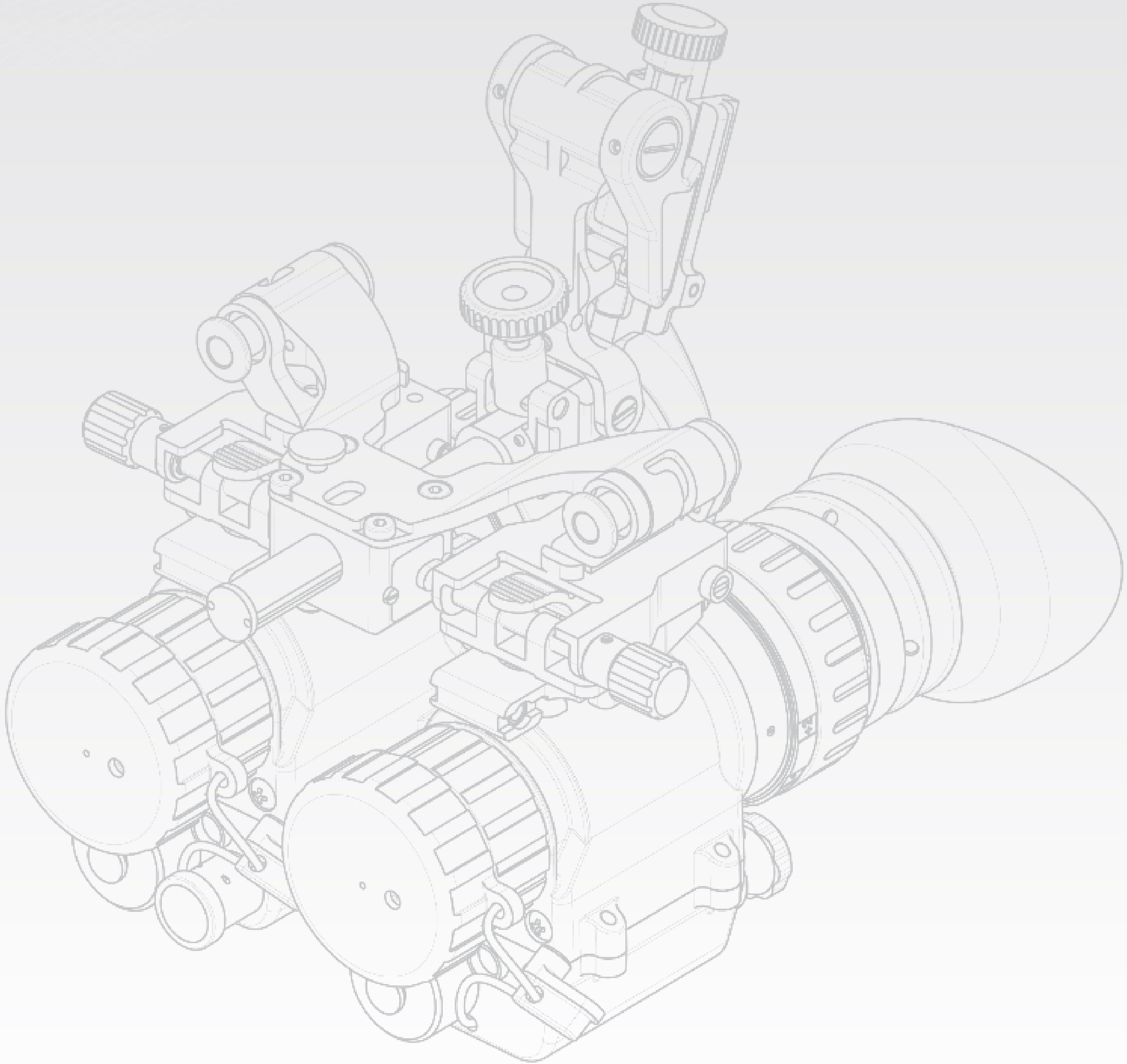
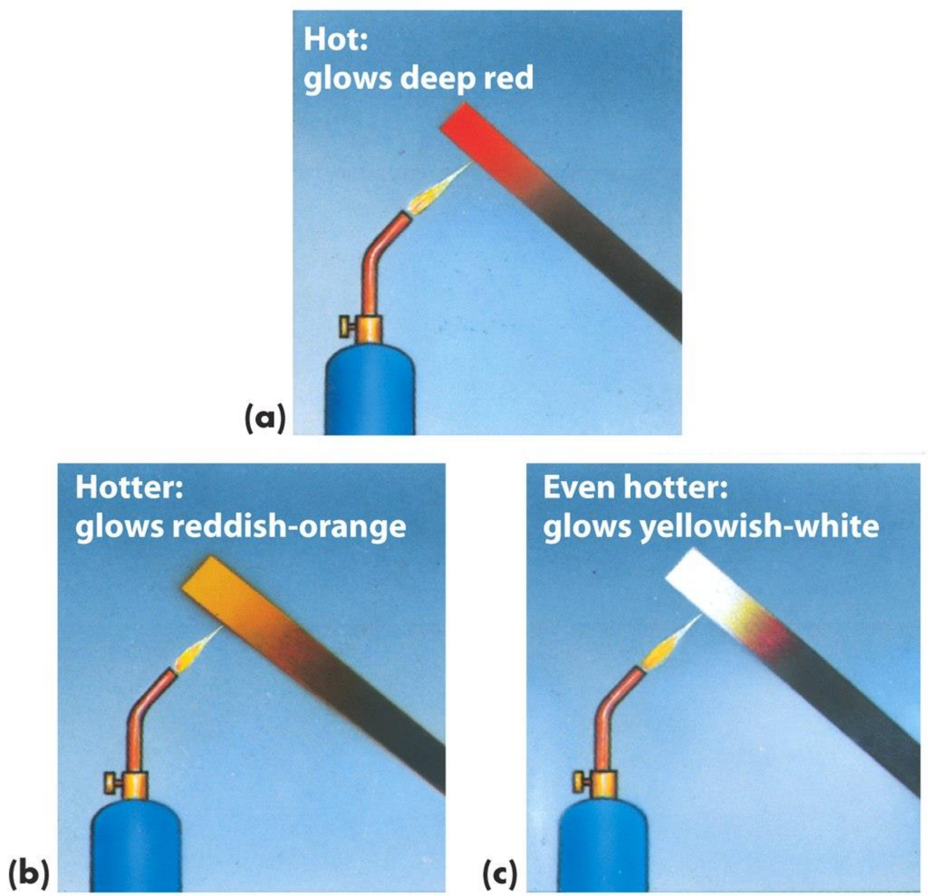


- Two main categories of Night Vision Systems based on the origin of imaged light:
  - Passive Illumination (Image Intensifiers, SWIR, etc.)
  - Light Emitted by target (Thermal Imagers)
  - Gen I image intensifiers used active illumination (obsolete)

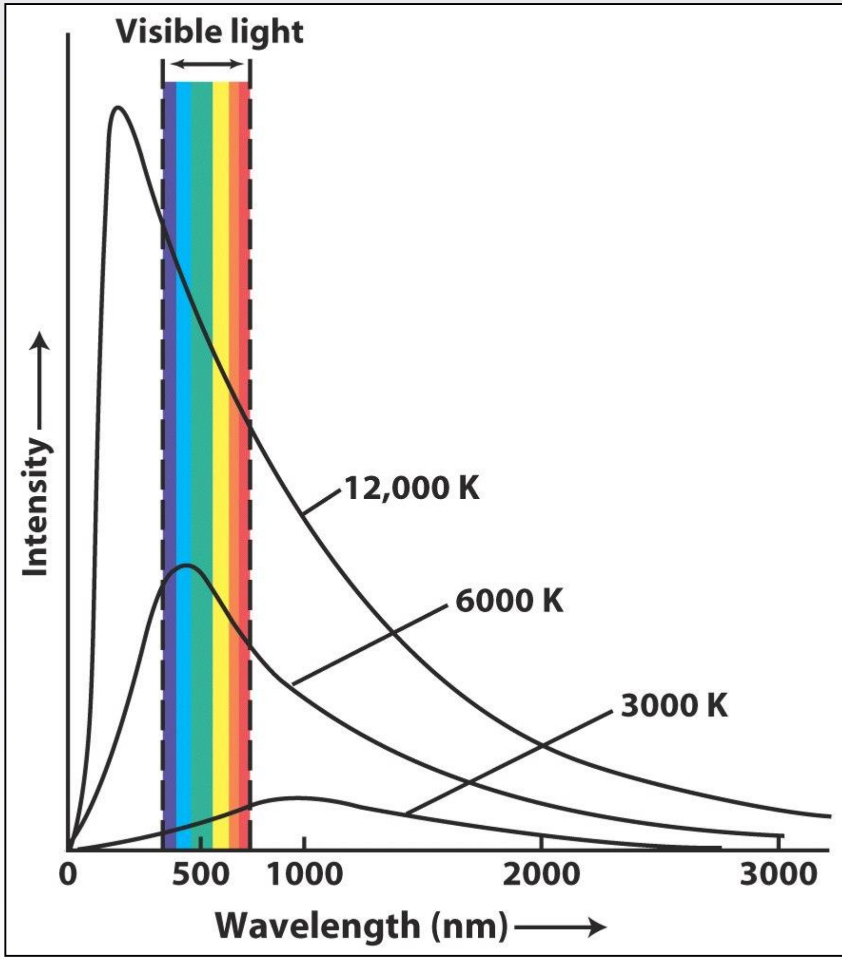
- Two main categories of Night Vision Systems based on the spectrum of imaged light:
  - Visible and NIR Spectrum (Image Intensifiers)
  - Invisible light (Thermal Images, SWIR, etc.)

- A general rule:

  The higher an object's temperature, the more intensely the object emits electromagnetic radiation and the shorter the wavelength at which emits more.

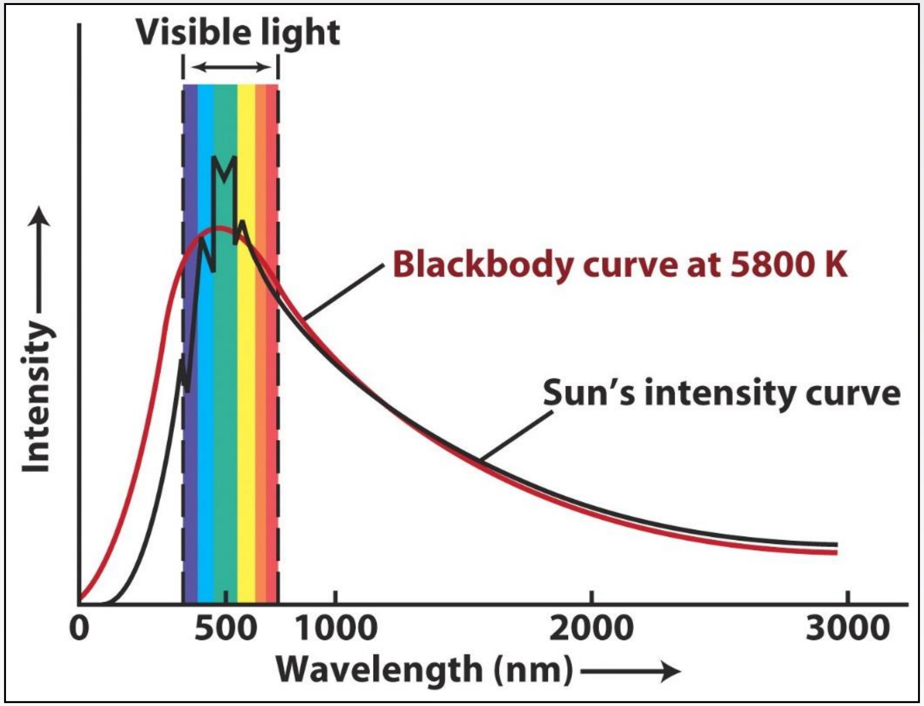


- A blackbody is an object that is a perfect absorber of electromagnetic radiation at all wavelengths
  - The radiation of a blackbody is entirely the result of its temperature
  - A blackbody does not reflect any light at all
- Blackbody spectrum: the intensities of radiation emitted at various wavelengths by a blackbody at a given temperature
  - The higher the temperature, the shorter the peak wavelength
  - The higher the temperature, the higher the intensity
- All objects (rocks, vehicles, humans, etc.) are –at some extend- blackbodies.
- Thus, emit thermal radiation at all times!!



Blackbody curve

- Hot and dense objects act like a blackbody
- Stars, which are opaque gas ball, closely approximate the behavior of blackbodies
- The Sun's radiation is remarkably close to that from a blackbody at a temperature of 5800 K



The Sun as a Blackbody

A human body at room temperature emits in the infrared

What is it?

Cooled thermal products (cameras) detect thermal radiation of objects invisible to the human eye. Cooled thermal products have higher performance than uncooled systems.

Key Features:

Cooled Thermal Imaging systems provide a far better picture but are heavier and bulkier than uncooled systems while coming at a considerably higher cost.

They are mainly used for long range applications. Not suitable for small/man- portable systems.

End Product (Camera)

Module (Detector + Electronics)

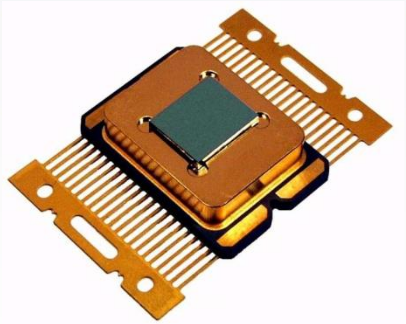
Detector & Cooler

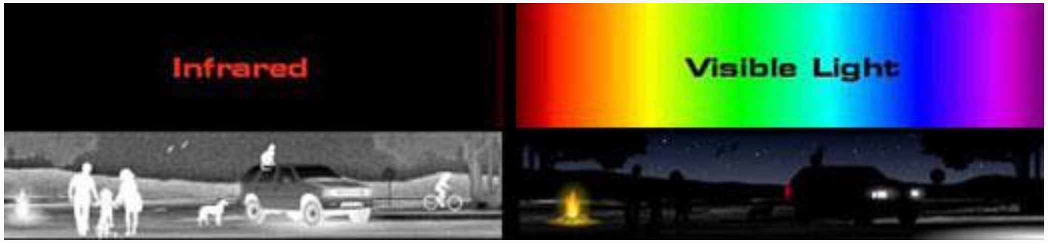
What is it?

- Thermal Imaging technology detect thermal radiation of objects invisible to the human eye making even small temperature changes visible. Uncooled Thermal Systems usually use a microbolometer detector.

Key features:

- The image : generated by thermal imaging is quite different **to the "day light" image** to which the human brain is conditioned to.
- While Thermal Imaging allows to see through smoke and haze and can be used in complete darkness, it is not suitable for **recognition and identification** tasks (only for detection).





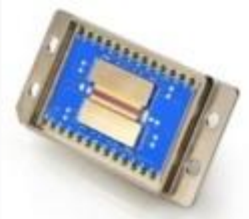
What is it? Short Wavelength Infrared (SWIR) systems catch reflected light from infrared sources like the stars, atmospheric glow or lasers rather than detecting thermal radiation. Some SWIR detectors operate in the spectrum of I^2 as well.
Aside from one UAV (unmanned aerial vehicle) application (observation), there are hardly any other as yet defense products.

Key Features: SWIR detectors combine the best of both I^2 and thermal imaging technologies, providing an image which is very similar to the "day light" image to which the human brain is conditioned.

SWIR technology allows the user to see through smoke and haze (like thermal) while being able to recognize and identify objects (like I^2). Thus while, for example, thermal imaging can detect the presence of a warm object against a cool background in complete darkness, the new technology SWIR, can actually identify what that object is.

The technology is currently focused on civilian applications (security, thermograph/industrial inspections) but has significant potential for military applications.

End Product (Camera)



SWIR Detector

Image Intensified Imaging (I^2)

What is it? Image Intensifiers (I^2) work on the principle of magnifying the amount of residual light from various natural sources such as starlight or moonlight.

Sensor Producers: Today there are a few main producers of image intensifier sensors (tubes) in the world: ITT (USA), L-3 Communications (USA), (NL/F) and Harder Digital (De).

End Product Producers: Theon Sensors is one of the leading companies worldwide in the field of Night Vision end products based on Image intensifier sensors.

Key Features: The image generated by a Night Vision System based on I^2 technology is very similar to the "day light" image to which the human brain is conditioned.
I^2 has been heavily used for many decades in defense applications, such as driving land and air vehicles, portable or weapon mounted sights and as goggles.

While Image Intensifying Technology is ideal for recognition and identification tasks, it can be limited due to the need for a minimum level of light required for operation.

End Product (Night Vision Monocular)

I^2 Sensor (tube)

What is it?

- Fusion is the overlay of signals of the same scene from different sensors and/or detectors in order to capitalize on their respective advantages

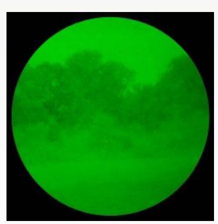
Fused Category:

- I^2 and Thermal - *Thermal imagery is overlaid on Image Intensification* [I^2&T] or [DIGITAL I^2&T]
- VISWIR (Visible SWIR) and Thermal - *Overlay of Video Image from both Sensors* [SWIR&T]

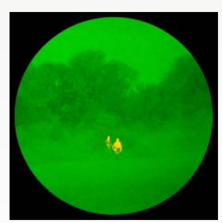
Night Vision Fused End Products:

- ENVG – Enhanced Night Vision Goggle [*Image Optical Overlay*] (ITT) [I^2&T]
- DEVNG – Digital Enhanced Night Vision Goggle [*video image overlay*]; has been tendered by the US Armed Forces (ITT, BAE, DRS, L-3) [DIGITAL I^2&T]
- Fused Driver Viewer [Digital *I^2 and Thermal combined video image*] (Zeiss) [DIGITAL I^2&T]

Zeiss Fused DNV
(DIGITAL I^2&T)



I^2 Image



Fused Image
(I^2&T)

ENVG

Operating Conditions	Image Intensified	Thermal
Target Detection		√
Target Identification	√	
Glass Penetration	√	
Minimal Temperature Difference (Thermal Crossover, Rain, Extremely Hot or Cold Environments)	√	
Scene Fine Details (required for Personnel Maneuverability and Vehicle operations)	√	
Low Light Conditions	√	√
Zero Light Conditions (indoors, caves, tunnels)		√
Limited Visibility (Fog, Dust, Sand, Smoke)		√
Daytime Operations		√

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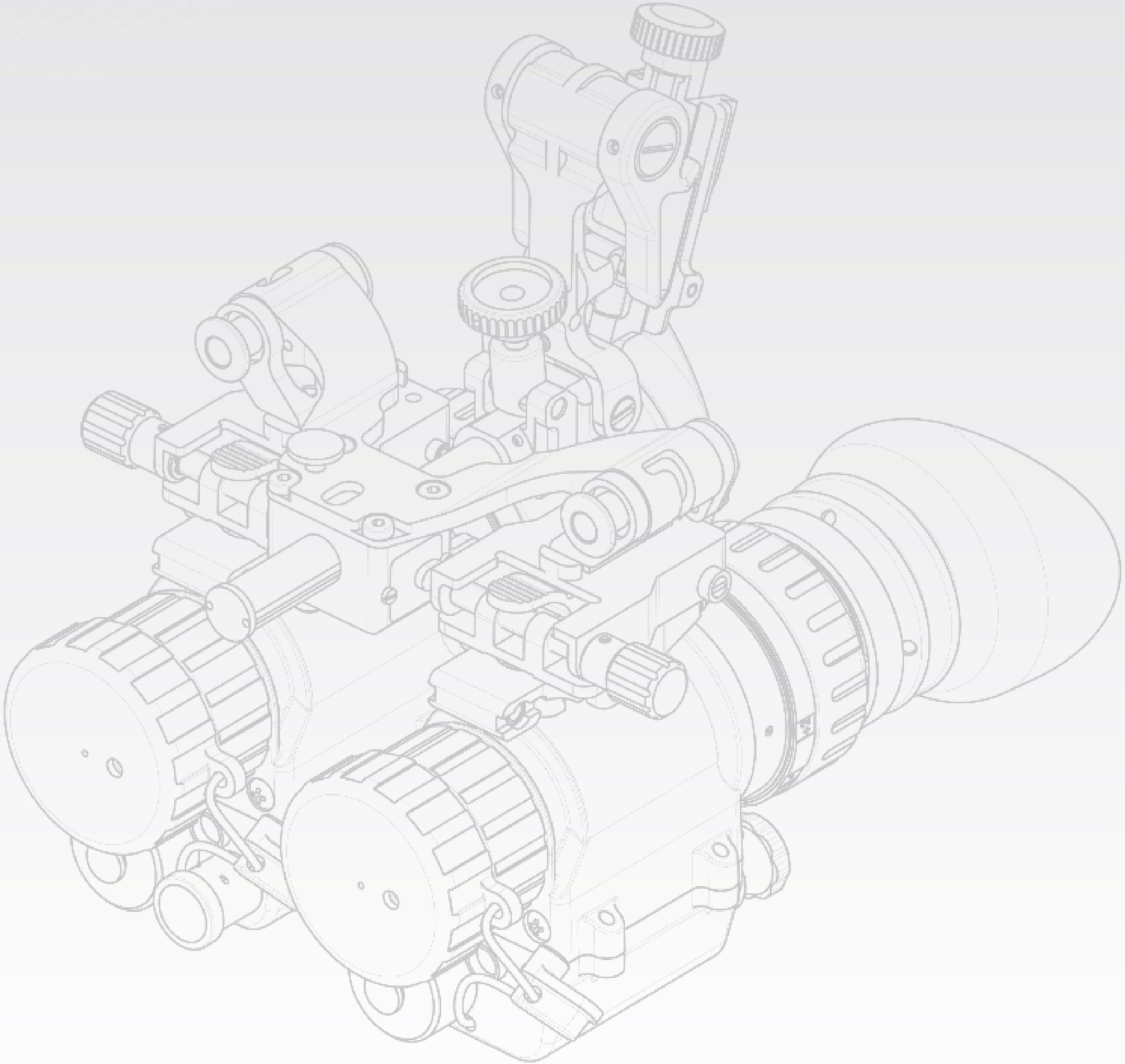
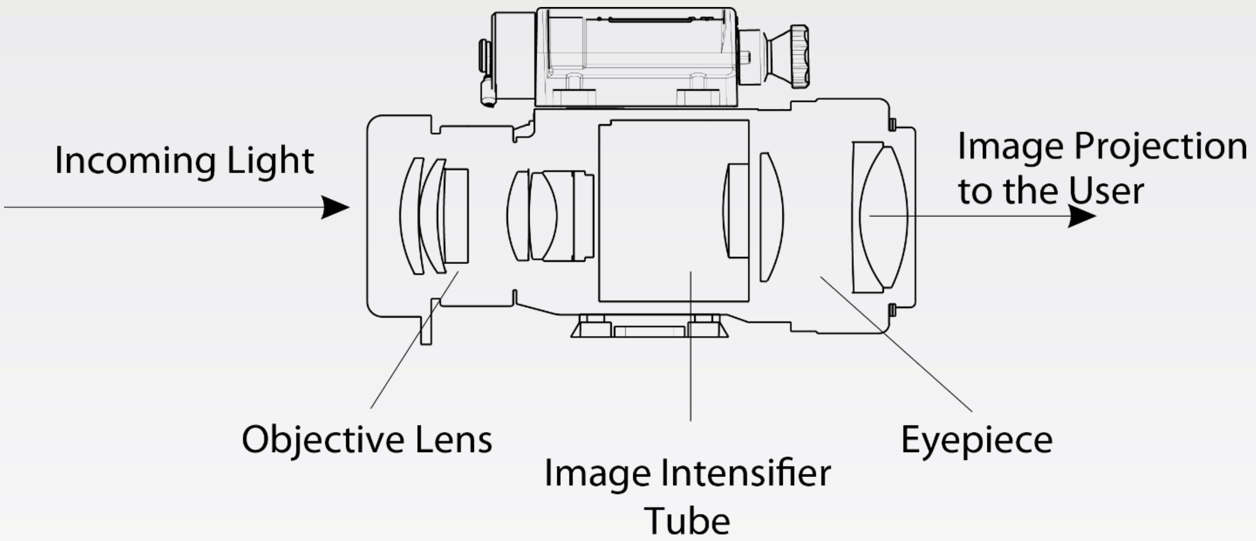


- The low night light enters through the objective lens in the device.
- The objective lens focuses the image onto the entrance of the Image Intensifier Tube.
- The image is intensified within the tube.
- The eyepiece lens looks at the intensified image on the tube output and projects it to the eye.



✓*Resolution (Cy/mrad):* The ability of an image intensifier or night vision system to distinguish between objects close together. Image intensifier resolution is measured in line pairs per millimeter (lp/mm) while system resolution is measured in cycles per milliradian (cy/mrad). For any particular night vision system, the image intensifier resolution will remain constant while the system resolution can be affected by altering the objective or eyepiece optics by adding magnification or relay lenses.

✓*Field Of View (FOV)*: The width or spatial angle of the outside scene that can be viewed through the intensifier tubes measured laterally and vertically.

✓*Magnification:* The magnifying power of the lens. Four power (4X) indicates that the image will appear four times larger than if viewed with a 1X lens.

✓*Collimation:* The act of making input and output light rays travel in parallel lines.

✓*Distortion:* The geometric differences in the output image with respect to the input image due to design or imperfections in the optics and the II tube.

✓*Diopter Range:* The range that the eyepiece lens can correct for eye imperfections.

✓*Focus Range:* The range that the night vision system can see from near distances to infinity.

✓*Parallax:* The difference in focus of the scene vs. a projected ballistic reticle.

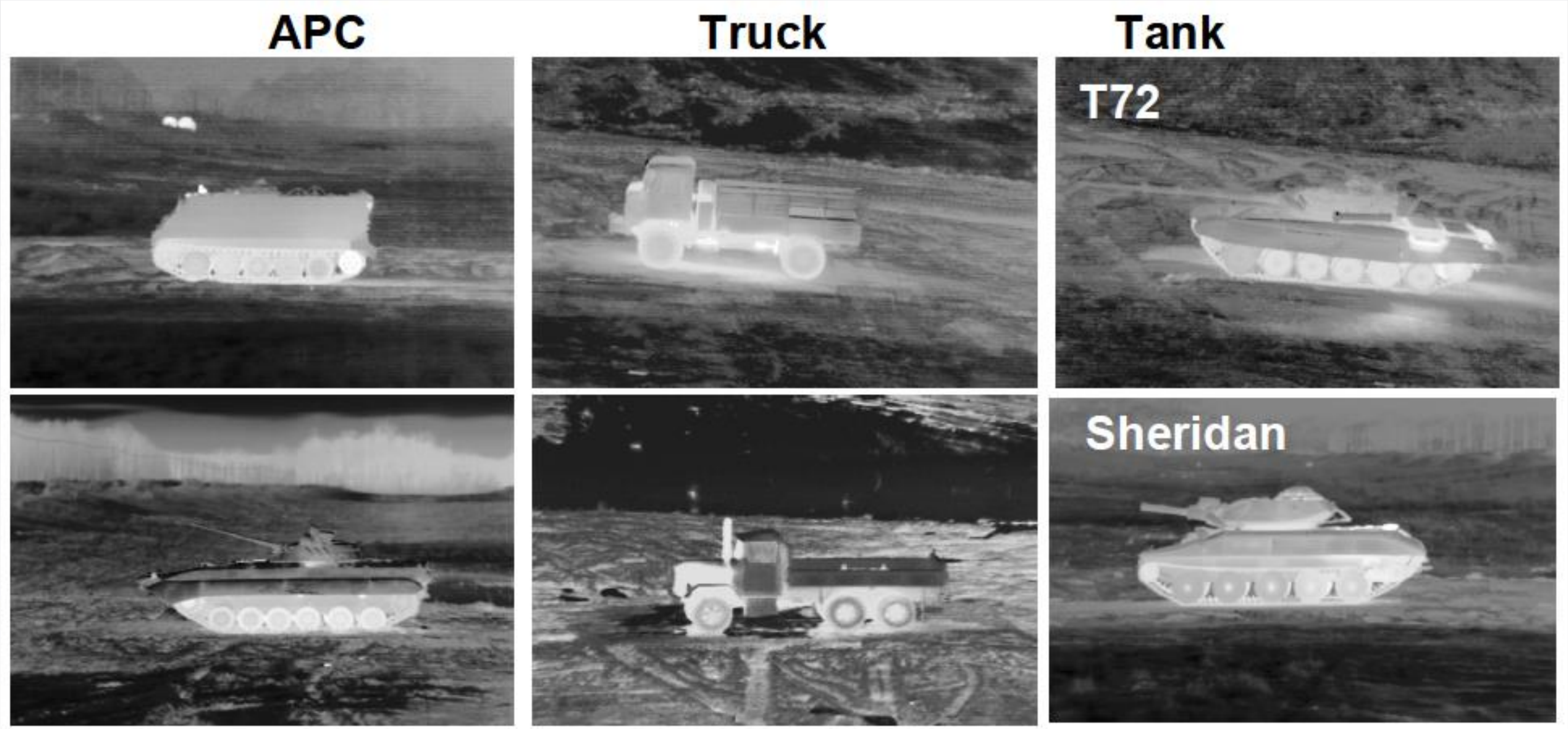
Lighting Range of Operation for NV instruments

Decrease of detection, recognition and identification ranges

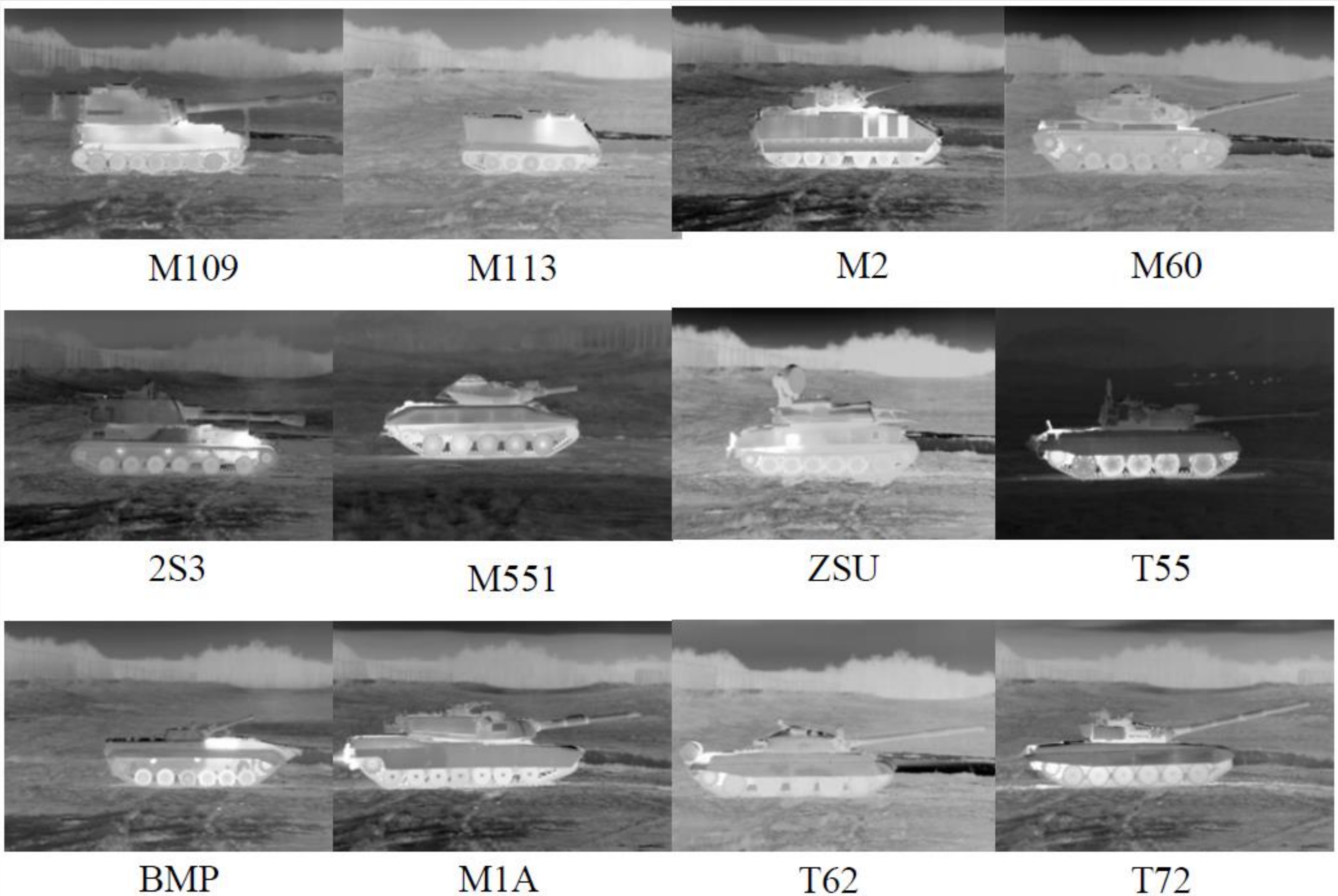
NVESD

http://www.thermaloutfitters.com

Recognition Example

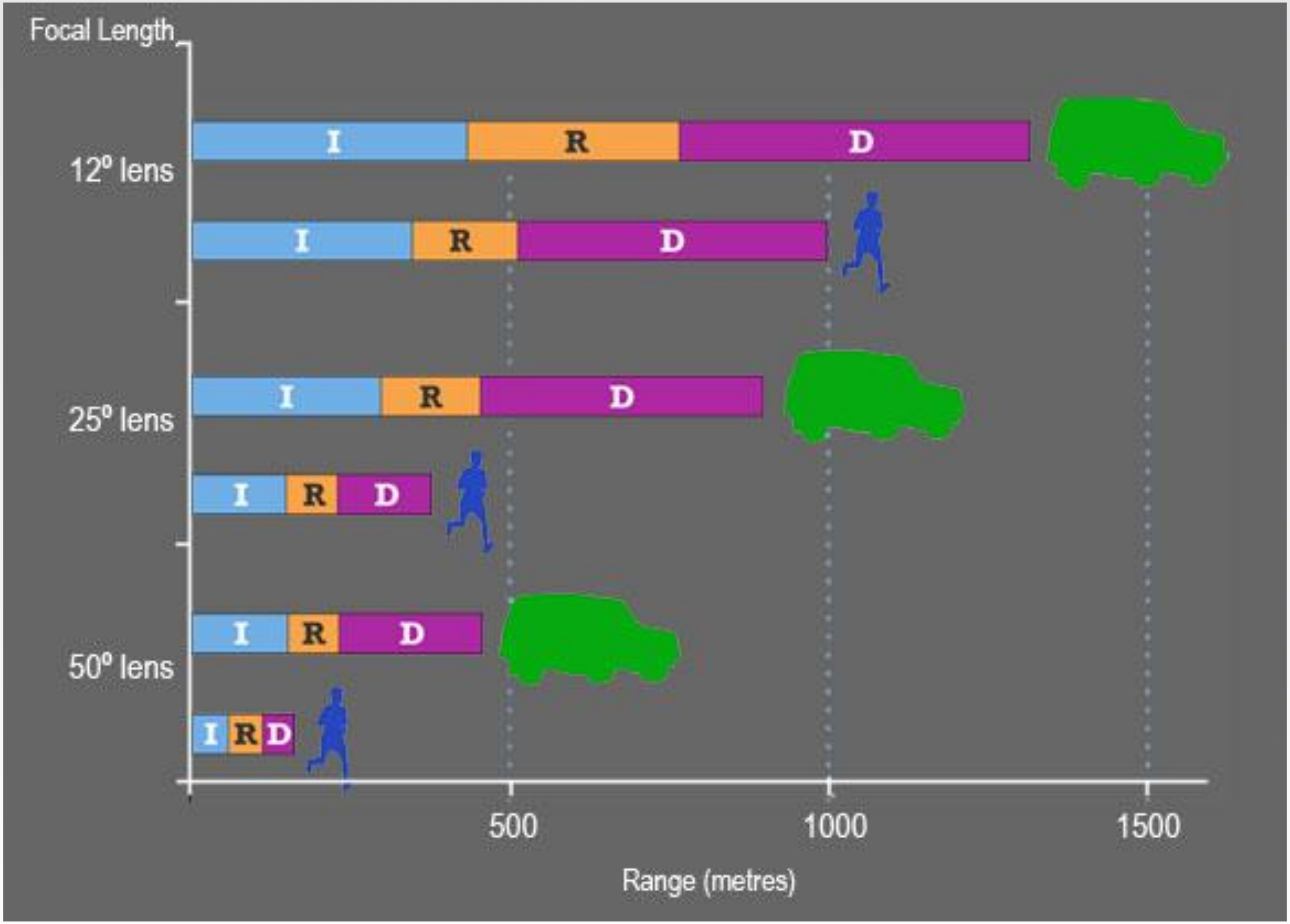


NVESD

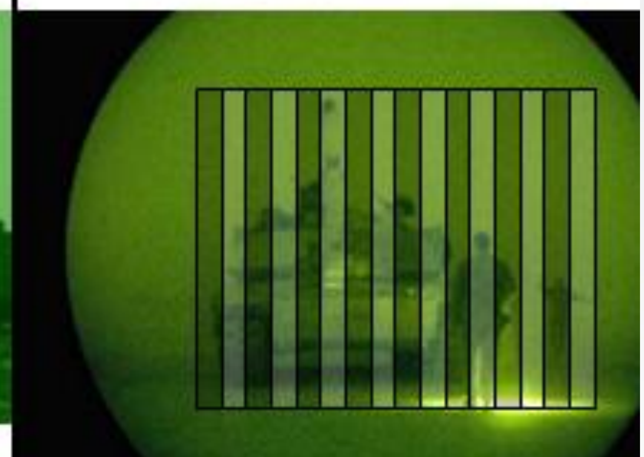


NVESD

Detection, Recognition, Identification Example



http://www.mass-solutions.co.za

Detection	Recognition	Identification
1.5 line pairs (standing man)	3.8 line pairs	8 line pairs
		

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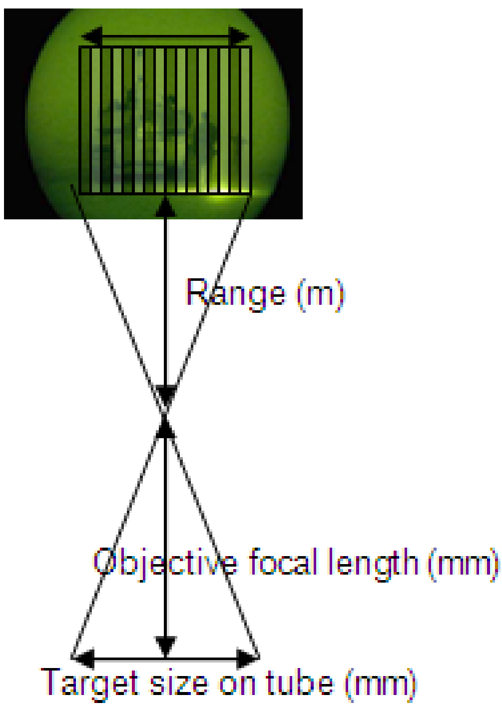

Limiting resolution and Range are then related by simple geometrical consideration :

$$\xi_{\lim}(lp/mm) = \frac{1000\xi_{\lim}(lp/mrad)}{f_{obj}} = \frac{N.Range}{f_{obj}.L_{tgt}}$$

Where :

$\xi_{\lim}$ is the limiting resolution expressed in lp/mm or lp/mrad.

N is the required number of line pairs according to the Johnson model to resolve the target.

f_{obj} is the objective focal length in mm/ and

L_{tgt} is the critical dimension of the target in meter, it standardized to 1.4m for a standing man.

The Range is expressed in meters.

Photonis

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