Tutorial

Introduction to

Image Intensifier Tubes Technology

Presented by:

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1. Introduction to Military Imaging
2. Principle of Operation of Image Intensifier Tubes
3. Performance Characteristics of Image Intensifier Tubes
4. Cosmetic Blemishes of Image Intensifier Tubes
5. Comparison of Image Intensifier Tubes & Export Control
6. End

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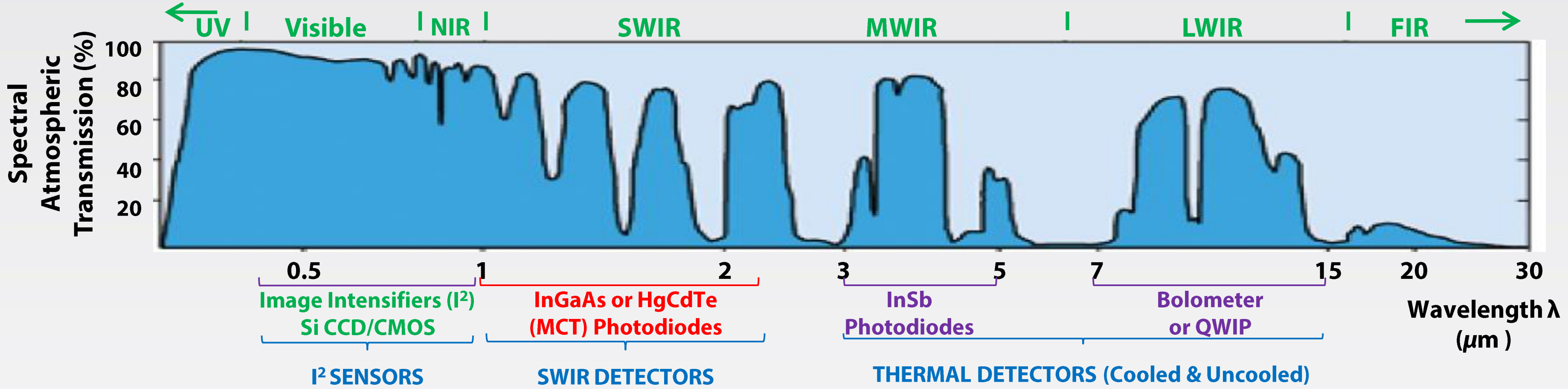
- Two main categories of Night Vision Systems based on the origin of imaged light:
  - Passive Illumination (Image Intensifiers, SWIR, etc.)
  - Light Emitted by target (Thermal Imagers)
  - Gen I image intensifiers used active illumination (obsolete)

- 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.)

- 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.

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)

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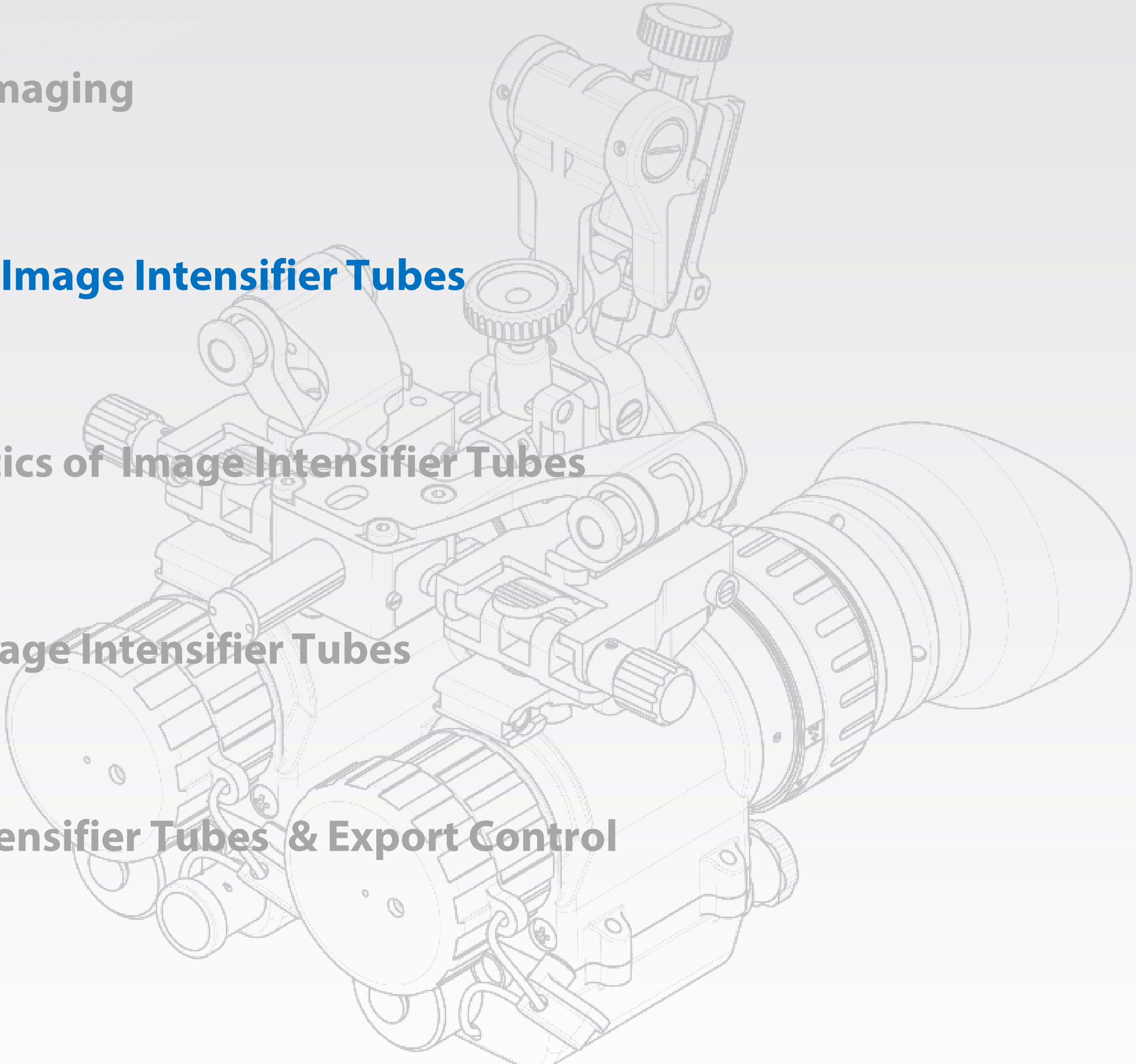

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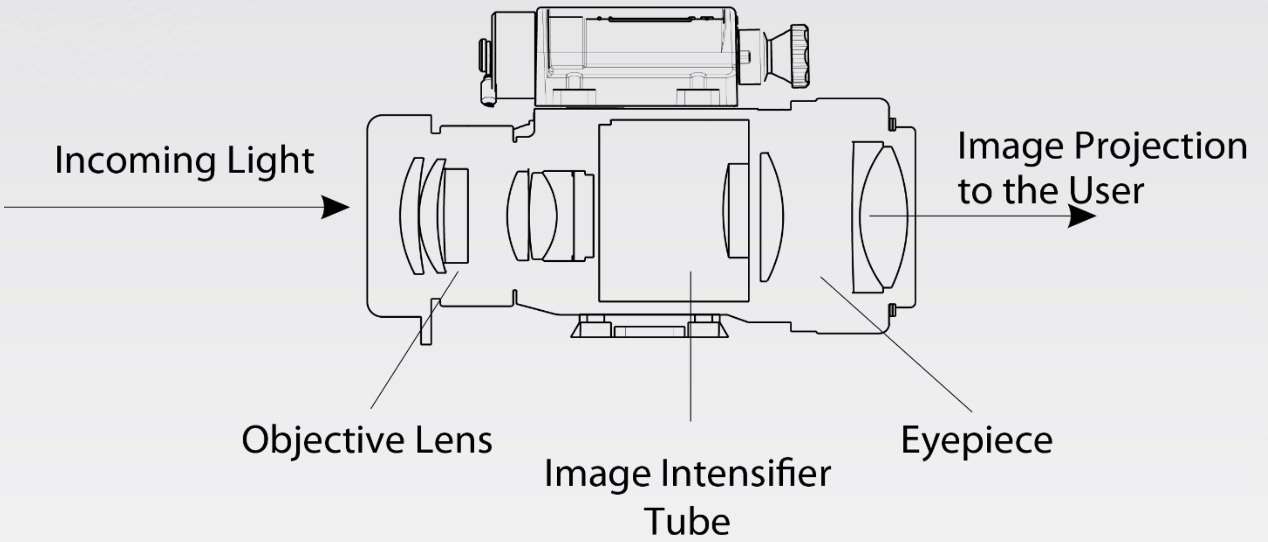
+
–
INPUT 2,7 V DC SER. NR.

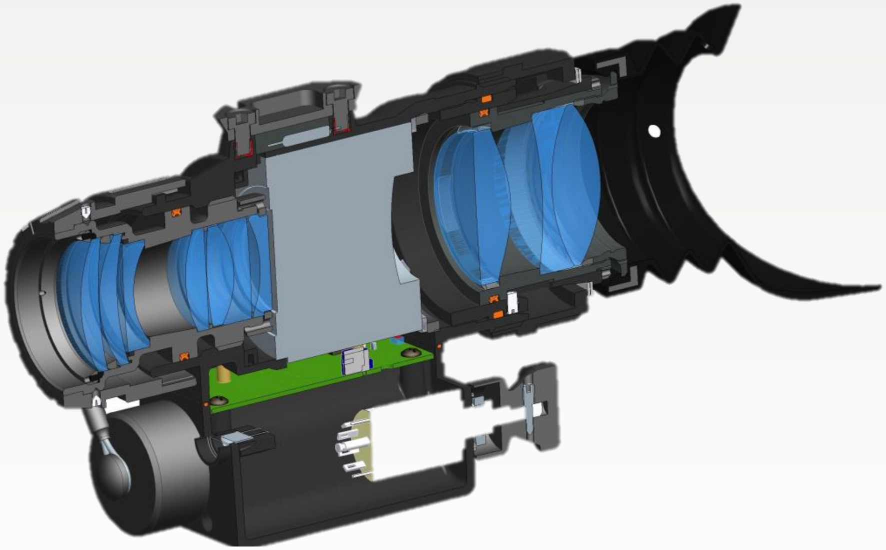
- The low night light enters through the objective lens in the device.

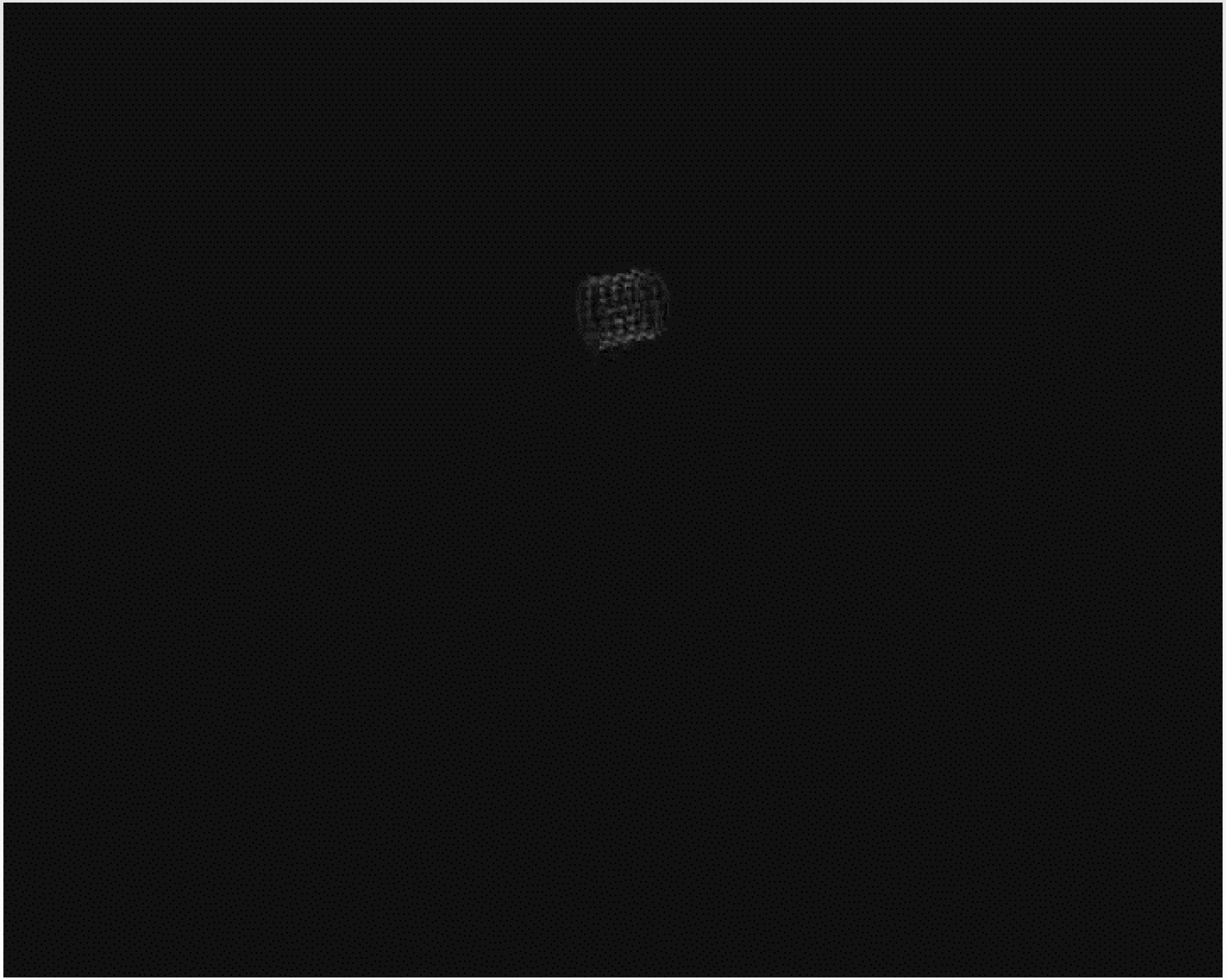
- The objective lens focuses the image onto the entrance of the Image Intensifier Tube.

- 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.







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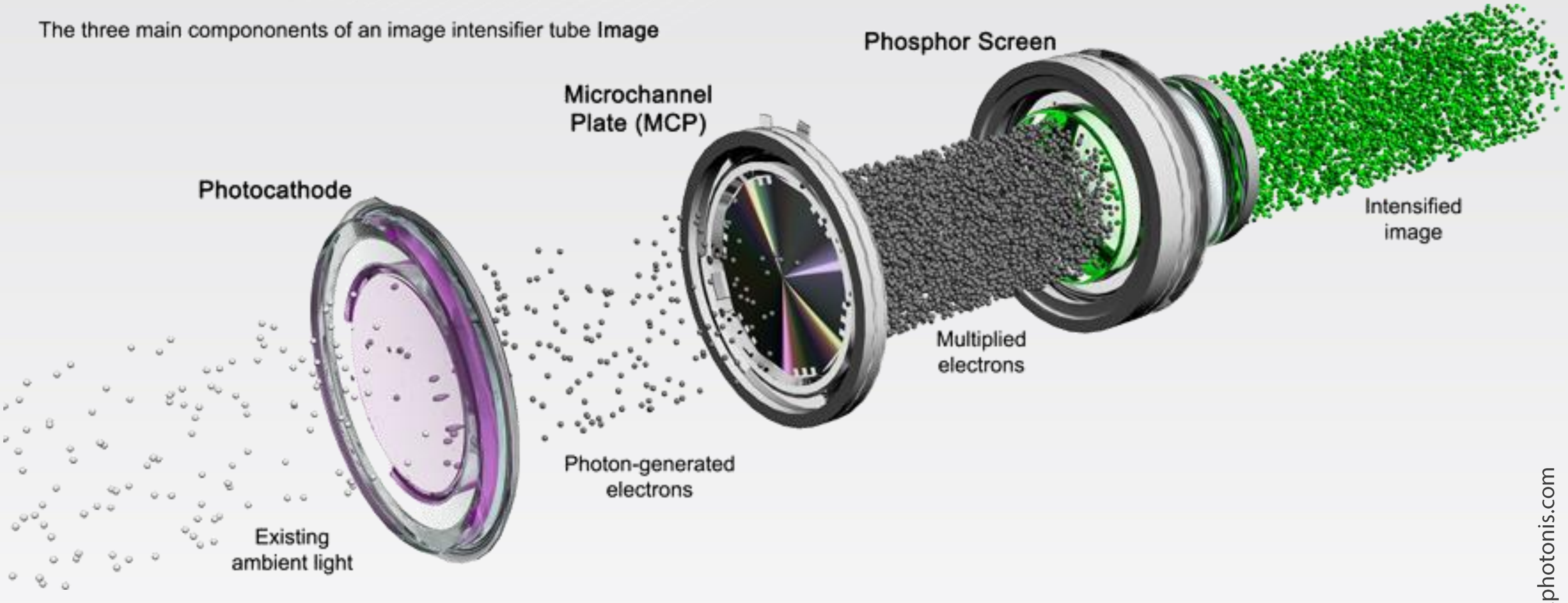
Night Vision Basics – IIT Principle of Operation



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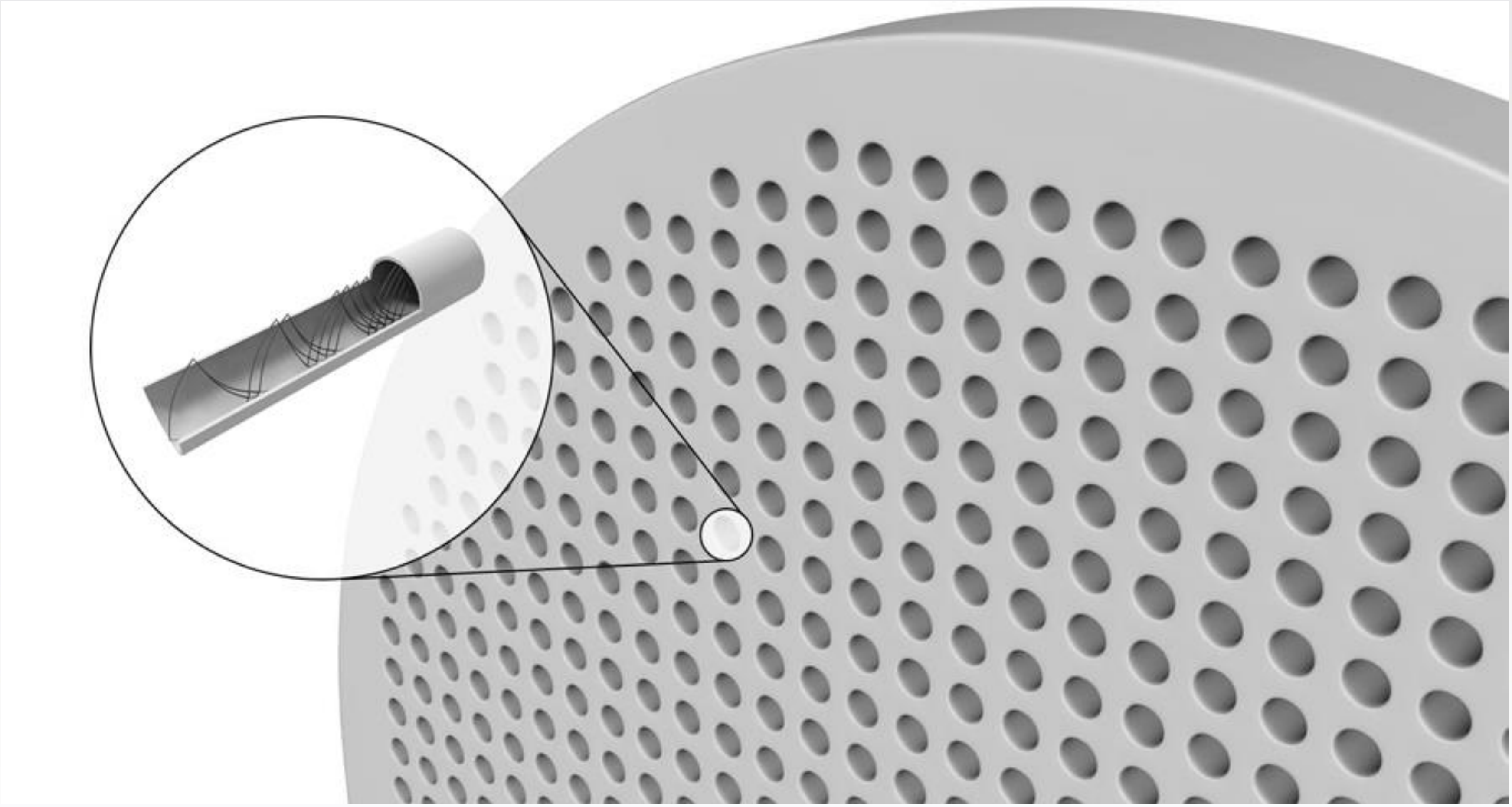
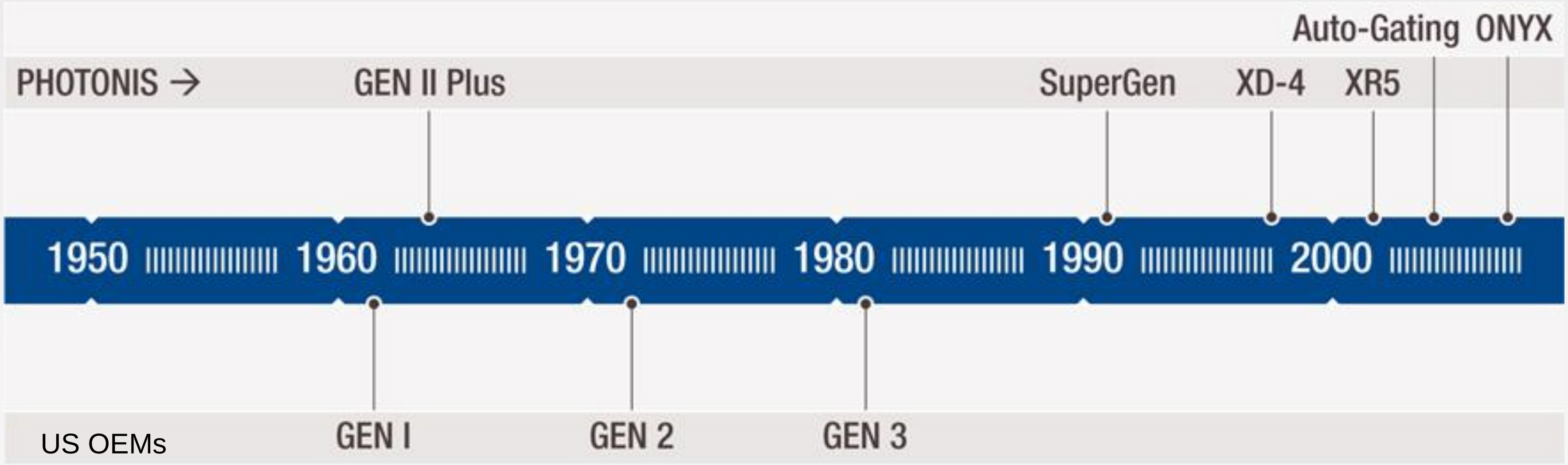
- An Image Intensifier tube (ITT) is a vacuum tube that amplifies a low light scene to observable levels.
- At the photocathode of the IT the light is converted into photoelectrons.
- The photoelectrons are accelerated in an electric field and multiplied by a MCP (Micro Channel Plate).
- The highly intensified photoelectrons strike the phosphor screen and a bright image is produced.

Detail of Micro channel Plate





History timeline of Image Intensifiers

✓*Generation 0:* The earliest 1950's night vision products were based on image conversion rather than intensification. They required a source of IR light mounted on the device to illuminate the target area.

✓*Generation I:* Developed in early 1960's, could detect images under ambient light intensity as low as 0.1 lux (equivalent to full moon). Problems included image distortion, short-lived components and the large size of the devices. Gen I are now out of date.

✓*Generation II:* In the early 1970's these intensifiers incorporated MCPs. Substantially improved gain (up to 20 000) is accomplished by accelerating electrons, as well as by multiplying electrons by the MCP channels. The Gen II tubes have high resolution, are small, produce no image distortion and detect images under ambient light intensity as low as 0.01 lux (quarter moon)

✓*Super-Gen II:* They are Gen II intensifiers that employ novel photocathodes with extended spectral range in a particular wavelength range (NIR)

✓*Generation III:* The Gen III intensifiers are Gen II technology tubes with GaAs added as the photocathode coating, which is extremely photosensitive in the NIR region (>800 nm) and an ion-barrier film on MCP. The GaAs enabled detection of objects at greater distances under much more darker conditions,as low as 0.0001 lux (overcast sky). The ion barrier film increased the operational life of the tube (from 2 000- 4 000 to >10 000 hours)

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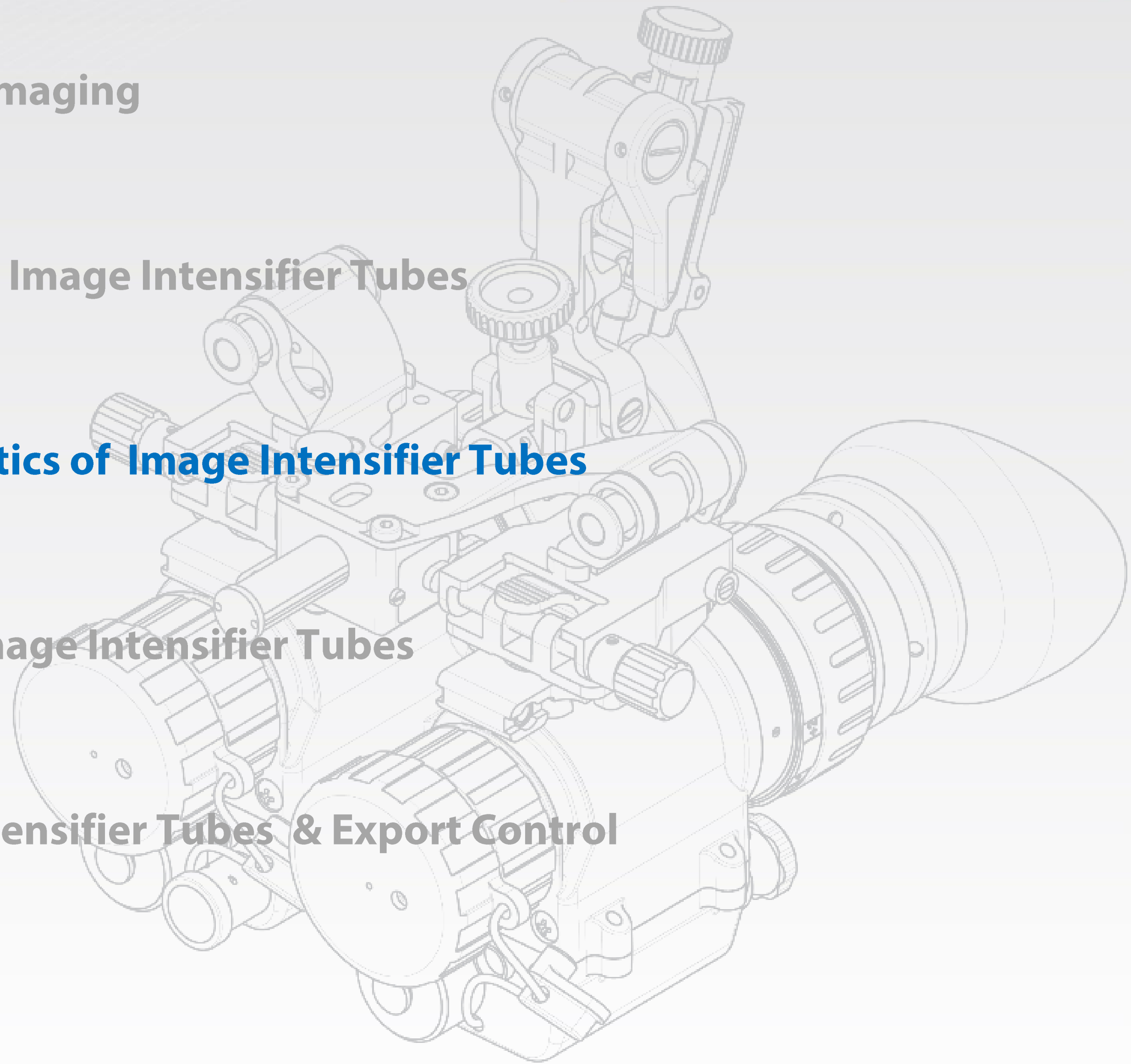


Typical Specifications for I^2 tubes:

- **Maximum Range**: The user needs to see farther than the target. This equates to the ability to see (detect, recognize, or identify, "DRI") their target at the best distance possible.

- **Varying lighting conditions**: The ability to see (detect, recognize, or identify) the target from overcast starlight to full moon conditions, and under a rapid change in lighting (dynamic effects).

- **Cosmetics**: Allowable defects

- **Reliability/MTTF**: Failure rates and times

- **Cost**: Life Cycle Costs and Initial Costs

The required system **Maximum Range** is a function of clarity and contrast

- **Clarity**– is a function of the system magnification, optics performance, tube resolution and the Modulation Transfer Functions (MTF) of all the involved components.

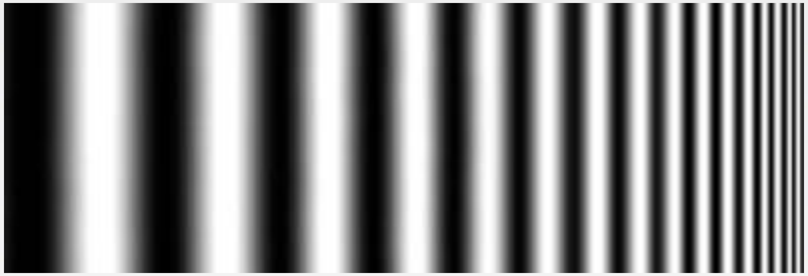
- **Contrast** – is a function the target and scene background properties relative to the photocathode (Gen 3 or Gen 2), luminous gain, and of the signal-to-noise ratio (SNR)
  - Signal-to-noise ratio (SNR) – the ratio of the input signal to the noise induced by the night vision system
  - Luminous Gain - the ratio of the output brightness to the eye divided by the illumination on the photocathode

- **Tube Limiting Resolution** measures the smallest size which can be resolved from a very high contract target where light level can be varied to see smallest feature. Measured in line pairs per millimeter **(lp/mm).**

- Tube **MTF** measures the output contrast over the input contrast at a specified spatial frequency, normalized to the input at 100%.

- The MTF better specifies the tube "clarity" performance with differing light levels or scene contrasts

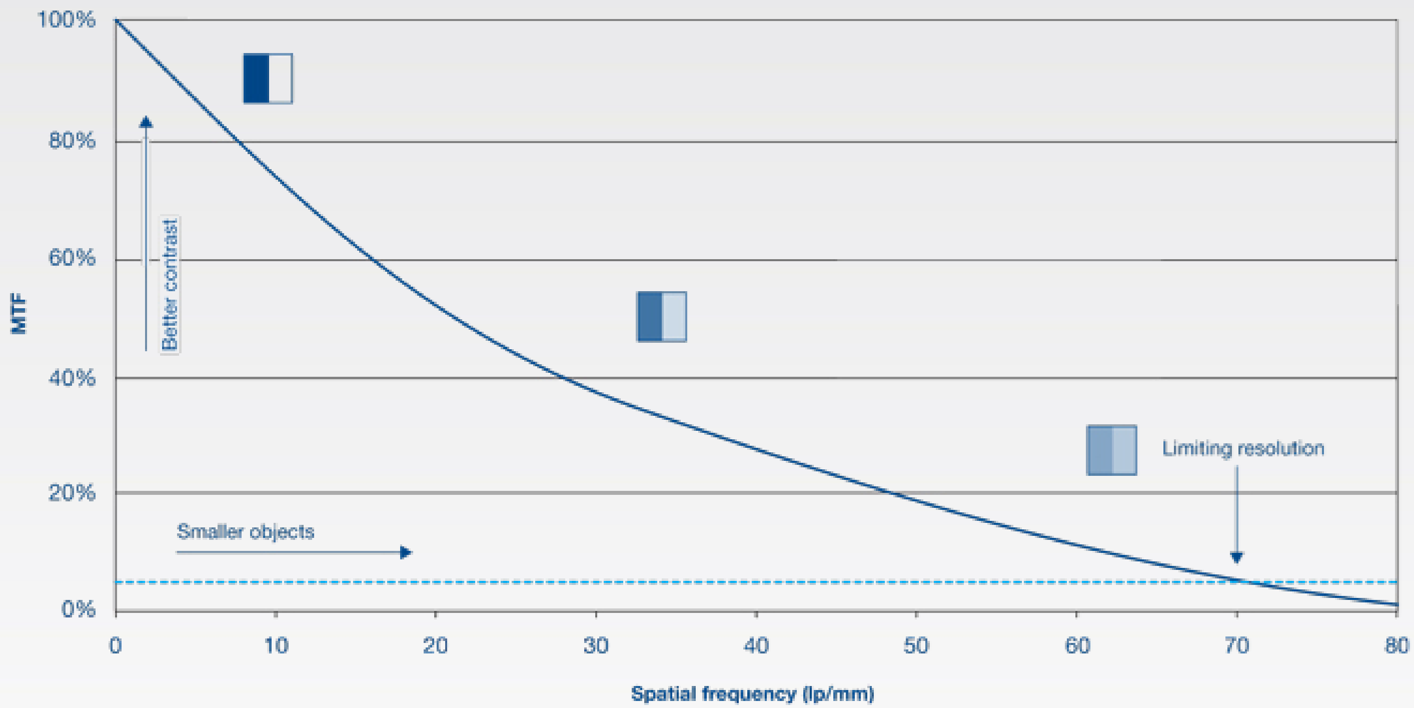
At low light level, e.g. starlight, <u>tube MTF is better than resolution</u> as a measurement of the "clarity" performance of an image intensifier tube



100% Contrast input image

Output image: the contrast decreases
as the lines become thinner and thinner

2.5 lp/mm	92 %
7.5 lp/mm	80 %
15 lp/mm	58 %
25 lp/mm	45 %
30 lp/mm	35 %



Typical MTF curve of an I² tube

- ***Signal-to-Noise Ratio (SNR)****:* The SNR is a ratio of the magnitude of the signal to the magnitude of the noise. If the noise of the scene is as bright as the image, you cannot see the image. The SNR changes with light level because the noise remains constant but the signal increases at higher light levels. The value of the SNR determines the resolution at very low light-levels. Therefore, the higher the SNR the better the ability to resolve image details under low light-level conditions. The SNR is related to the specific design of the tubes.

Low SNR image

High SNR image

Low SNR image

High SNR image

- ***Luminous Gain (fL/fc)***: The number of times a IIT amplifies light input. It is measured as the light output (in fL) divided by the light input (in fc).

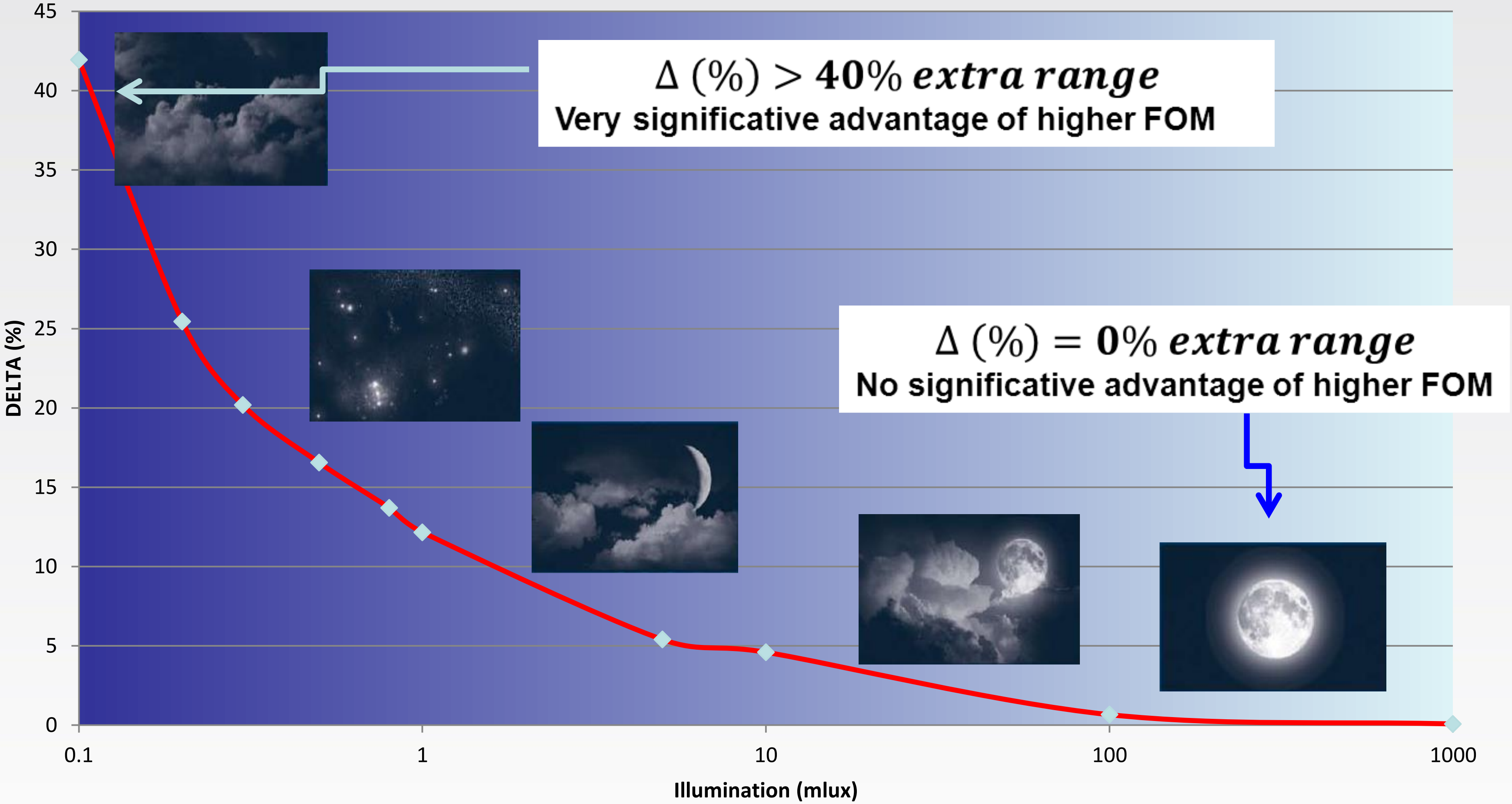
Low Gain High Gain

- **Figure of Merit (FOM)** has become the discriminator
  - FOM was defined by the U.S. Army to simplify U.S. export policy.
  - FOM is computed by multiplying the resolution by the signal-to-noise ratio (SNR).

$$FOM = \text{Resolution x } SNR$$

  - Many night vision tubes are now at a minimum of 64 lp/mm – hence FOM differences results from SNR
  - Gen 3 exportable Figure of Merit varies from 1250 – 1600 maximum
  - Photonis Gen 2 FOM stated as 1600 with new tubes to >2000

Range impact of SNR and FOM at overcast starlight



Low light levels: Performance provided by **SNR and FOM**
Medium to High light level: Performance provided by **ATG and Resolution**

Gen III Range Performance vs FOM

FOM	Recognition Task		
	Full Moon	Clear Starlight	Overcast Starlight
1250	1	1	1
1400 (1.12)	1	1.03	1.10
1600 (1.28)	1	1.06	1.14

FOM	Identification Task		
	Full Moon	Clear Starlight	Overcast Starlight
1250	1	1	1
1400 (1.12)	1	1.02	1.1
1600 (1.28)	1	1.05	1.2

Assumptions:

> 1x Magnification

> 40 deg FOV NVG

> Man-sized Target in Forest

> 64 lp/mm Tube

> SNR adjusted to achieve FOM

> Probability of 80% used

> Ranges are reported relative to the range for the 1250 FOM system for each light level and task

> Model used is NVESD model - 2009

Sensitivity (μA/lm): It defines how many electrons (electrical current) are produced per quantity of light that falls on the photocathode. This measurement is made under standardized conditions (an emitter with defined color temperature of 2856° K). Typically, the higher the value, the more sensitive the tube is to light

Detected Quantum Efficiency (%): Is the percent of the photons hitting the photocathode that are converted to –useful- electrons that reach the MCP. It can be spectrally analyzed. DQE is closely related to the Sensitivity.

***Mean Time To Failure (hrs)**:* The MTTF, expressed in hours, gives an idea how long a tube typically should last.

***Halo**:* Bright regions in the image outlining spots brighter than the image average.
Primary cause is the fraction of photoelectrons generated by the photocathode when they hit the surface between holes of the MCP input, and backscatter. Another cause is the optical reflection at the input gap and backscattered electrons on the anode side. The diameter of the halo is approximately equal to four times the gap between the photocathode and the MCP. Since electrons also backscatter from the electron barrier film and GaAs tubes have a larger input gap, GaAs based tubes suffer the most.

Reduced Halo

Large halo

Better Identification with small halos

Reduced Halo

Large halo

Less blooming, no blinded area, better situational awareness

Automatic Brightness Control (ABC): An electronic feature that automatically reduces voltage to the MCP to keep the image intensifier's brightness within optimal limits. The effect of this can be seen when rapidly changing from low light to high light conditions.

Bright Source Protection (BSP): An electronic function that reduces the voltage to the photocathode when the night vision device is exposed to bright light sources such as room lights or car lights.

- Both provide protection from the user seeing complete image washout during increased light or point source exposure by maintaining the image at a constant light level.
- Both protect the image tube from damage and significantly extend its life.
- Exelis ABC/BSP functions activate within 1.5 second response time to manage rapid changes in scene brightness even without “auto-gating” capability
- Exelis tubes typically deliver High Light Resolution in the mid 20s

Autogating & Resolution in light-polluted areas (Static conditions)

Auto Gating (ATG)

Standard
Bright Source Protection (BSP)

ATG = Best image contrast
Better identification

- ***Phosphor Type:*** *Three types of phosphor are used.*
  - *P43*
  - *P22*
  - *White (onyx)*

White phosphor, operational improvements :

Image quality and contrast level improved
Noise perception reduced
Image more realistic
Analysis and understanding of the scene made easier

➢ Analysis and reaction time reduced.

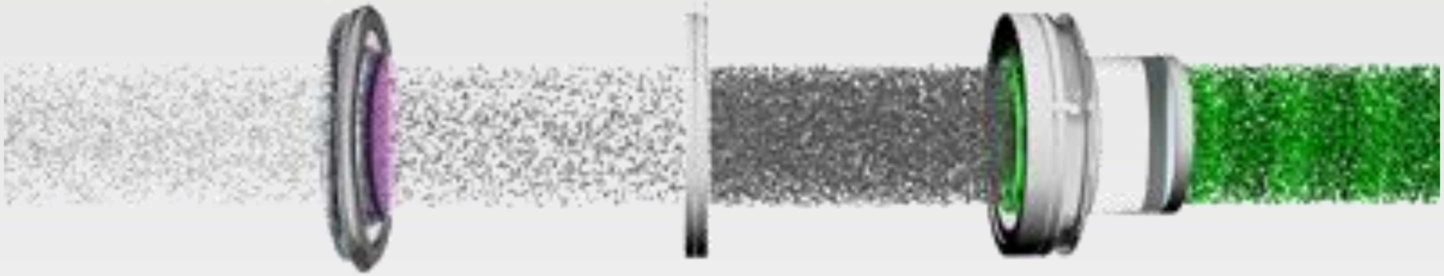
XR5 phosphor P43

XR5 Phosphor Black and white (ONYX)

XR5 phosphor P43

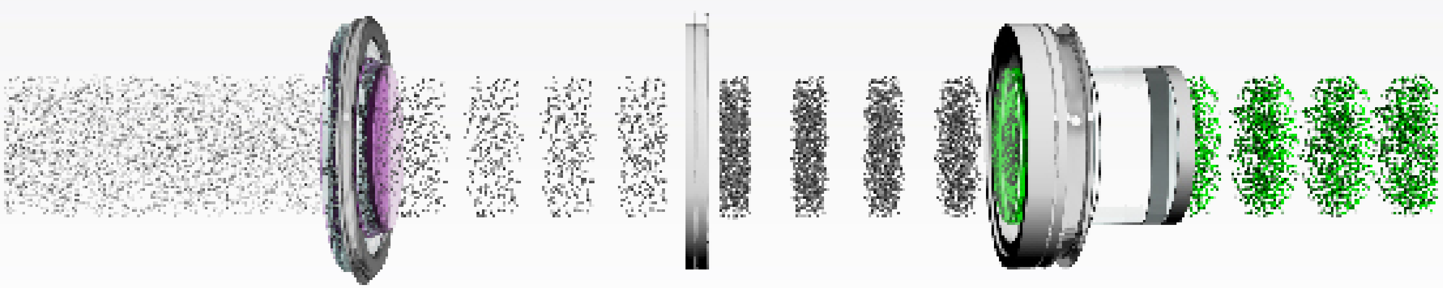
XR5 Phosphor Black and white (ONYX)

No Autogating



Autogating actively controls the output brightness by gating the active time IIT. This results in optimum amplified scene illumination suitable for environments with rapidly varying light conditions. It gives an advantage when used indoors, around explosions, etc.

Autogating



Images from www.photonis.com

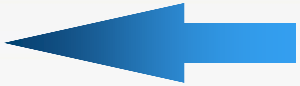
Explosion comparison as seen by tubes with and without autogating

No Autogating

Autogating

Images from www.photonis.com

Images from www.photonis.com



Resolution, Halo, Autogating

Signal-to-Noise, FOM

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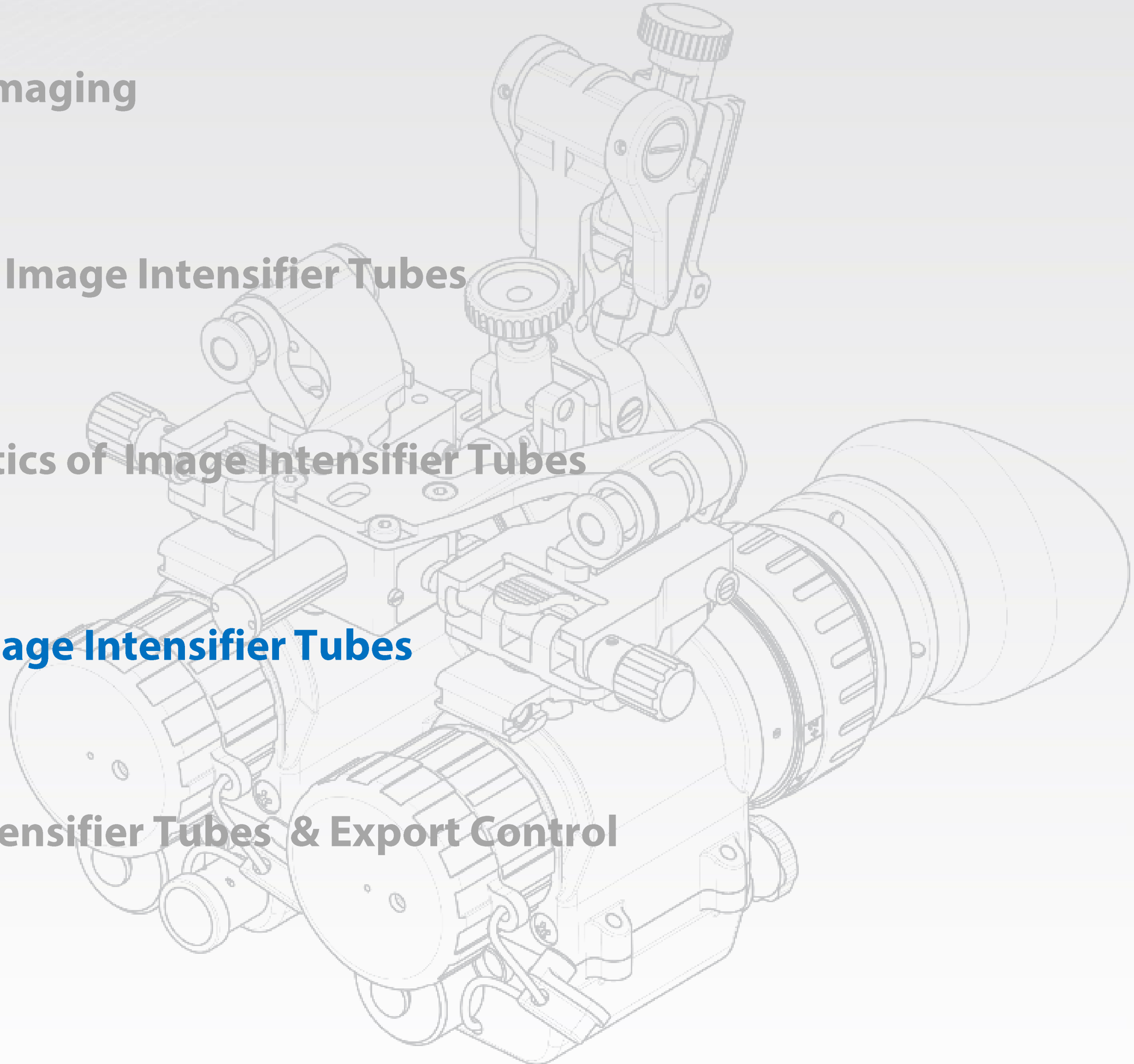
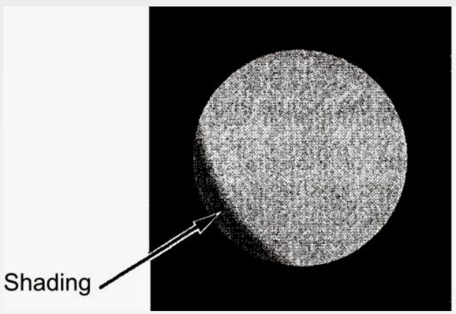
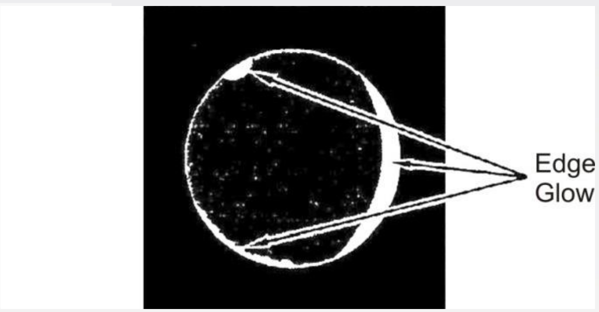
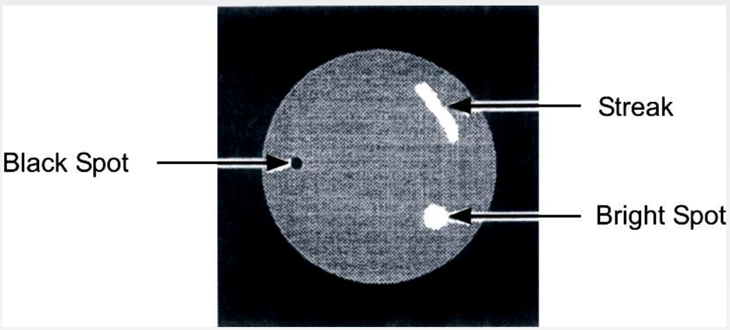


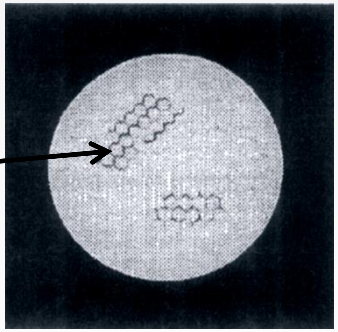
- Inspection Criteria for Image Intensifier Operation

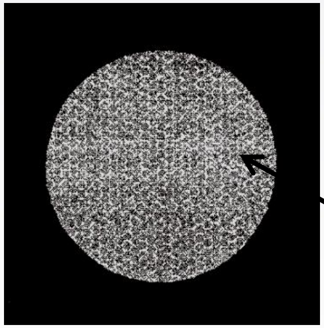






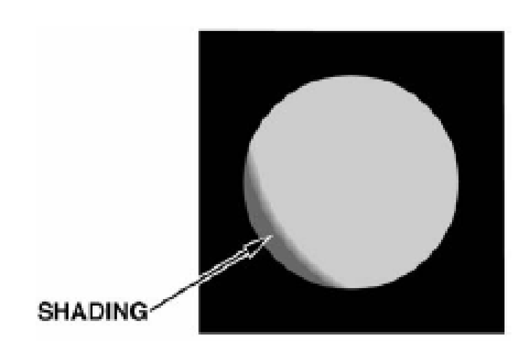
Chicken Wire

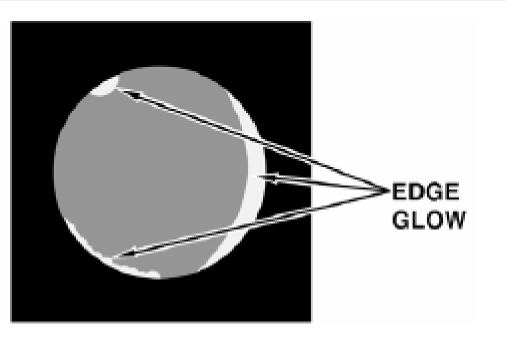


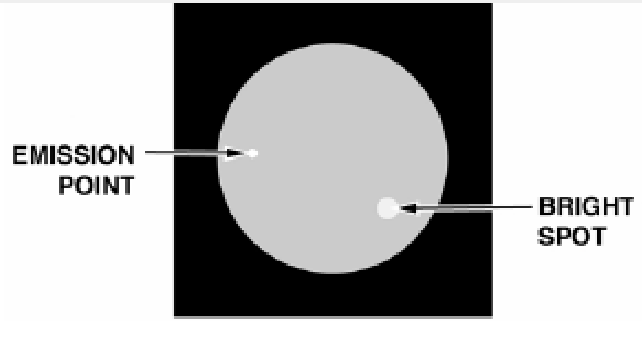


Fixed Pattern Noise

- Operational Defects

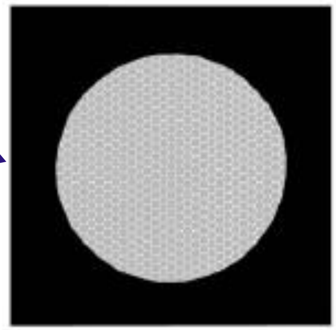


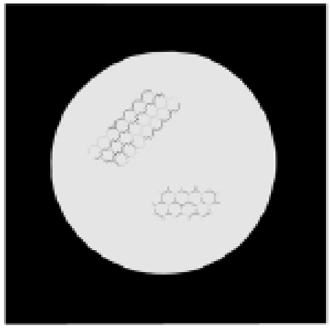




- Cosmetic Blemishes

Fixed Pattern Noise





Chicken Wire

Example of Accepted Black Spots on IIT

Spot Diameter (μm)	ZONE 1 (dia. 5.6 mm)	ZONE 2 (dia.5.6-14.7 mm)	ZONE 3 dia. 14.7-17.5 mm)
>300	0	0	0
230-300	0	0	0
150-230	0	1	1
75-150	0	2	2
<75	Minimal	Minimal	Minimal

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<table>
<tr><th rowspan="2">Key Performance Parameters</th><th colspan="2">Photonis</th><th colspan="3">Exelis Gen 3, max FOM</th></tr>
<tr><th>XR5</th><th>XD-4</th><th>1250</th><th>1400</th><th>1600</th></tr>
<tr><td>Resolution (lp/mm)</td><td>64</td><td>57</td><td>57/64</td><td>57/64</td><td>64</td></tr>
<tr><td>SNR</td><td>25/23 P43</td><td>20</td><td>21/19 max</td><td>24/21 max</td><td>25 max</td></tr>
<tr><td>FOM</td><td>1600 min</td><td>1140 min</td><td>1250 max</td><td>1400 max</td><td>1600 max</td></tr>
<tr><td>Gain at 2e-5 lx (cd/m²/lx)
Luminous Gain, 2e-6fc (fL/fc)</td><td colspan="2">10,000-18,000
33,000-55,000</td><td colspan="3">13,000-23,000
40,000-70,000</td></tr>
<tr><td>MTTF (hr)</td><td>15,000</td><td>10,000</td><td colspan="3">10,000</td></tr>
<tr><td>End of Life Criteria</td><td colspan="2">"50% of original sensitivity"</td><td colspan="3">More stringent than Photonis</td></tr>
<tr><td>Reliability Test Method</td><td colspan="2">Unknown, US Gen 2?</td><td colspan="3">Gen 3 Accelerated</td></tr>
<tr><td>Halo (mm)</td><td colspan="2">0.8 typ</td><td colspan="3">1.25</td></tr>
<tr><td>High light resolution (lp/mm)</td><td>55</td><td>20 / 50 AG</td><td colspan="3">12 / 29 HLC</td></tr>
<tr><td>Max Storage Temp (°C)</td><td colspan="2">65</td><td colspan="3">85</td></tr>
<tr><td>Phosphor</td><td colspan="2">P22 or P43</td><td colspan="3">P43</td></tr>
<tr><td>Luminous Sensitivity - µA/lm</td><td>700</td><td>600</td><td>1350</td><td>1350</td><td>1500</td></tr>
<tr><td>Cosmetics</td><td colspan="5">Gen 3, Gen 2 cosmetics differences represent cost vs performance</td></tr>
<tr><td>MTF, 15lp/mm</td><td>70 typ</td><td>58 typ</td><td>54</td><td>61</td><td>61</td></tr>
<tr><td>MTF, 25lp/mm</td><td>50 typ</td><td>45 typ</td><td>27</td><td>38</td><td>38</td></tr>
<tr><td colspan="6">Min values unless noted, MTF under DSP-5, Min FOM 100-200 pts less than max FOM
All Exelis Gen 3 Parameters are measured per US approved and correlated MIL-SPEC procedures</td></tr>
</table>

Tube comparison summary

	Standard Tube		High performing tube		
Tube type	Gen III	XD4	XR5	XR5 Onyx	
Performance (FOM)	Maximum 1400	Typically 1400	Minimum 1600	Minimum 1600	
Autogating	No	No	YES	YES	
Black and White	No	No	No	YES	

Comparison between US and European export regulations

Based on FOM (Figure of Merit = Resolution x SNR values)

	GEN II+	OMNIBUS III SUPERGEN	OMNIBUS IV XD-4	XR5
Typ.	16x40	20x50	24*64	28*72
FOM :	**640**	**1000**	**1536**	**2016**

FOM $_{max}$ 1250

USA → **Non NATO Countries**

FOM $_{max}$ 1600

USA → **NATO Countries**

2 other characteritics are strictly prohibited:

→ **AUTOGATED power supplies**

→ **HALO Size**

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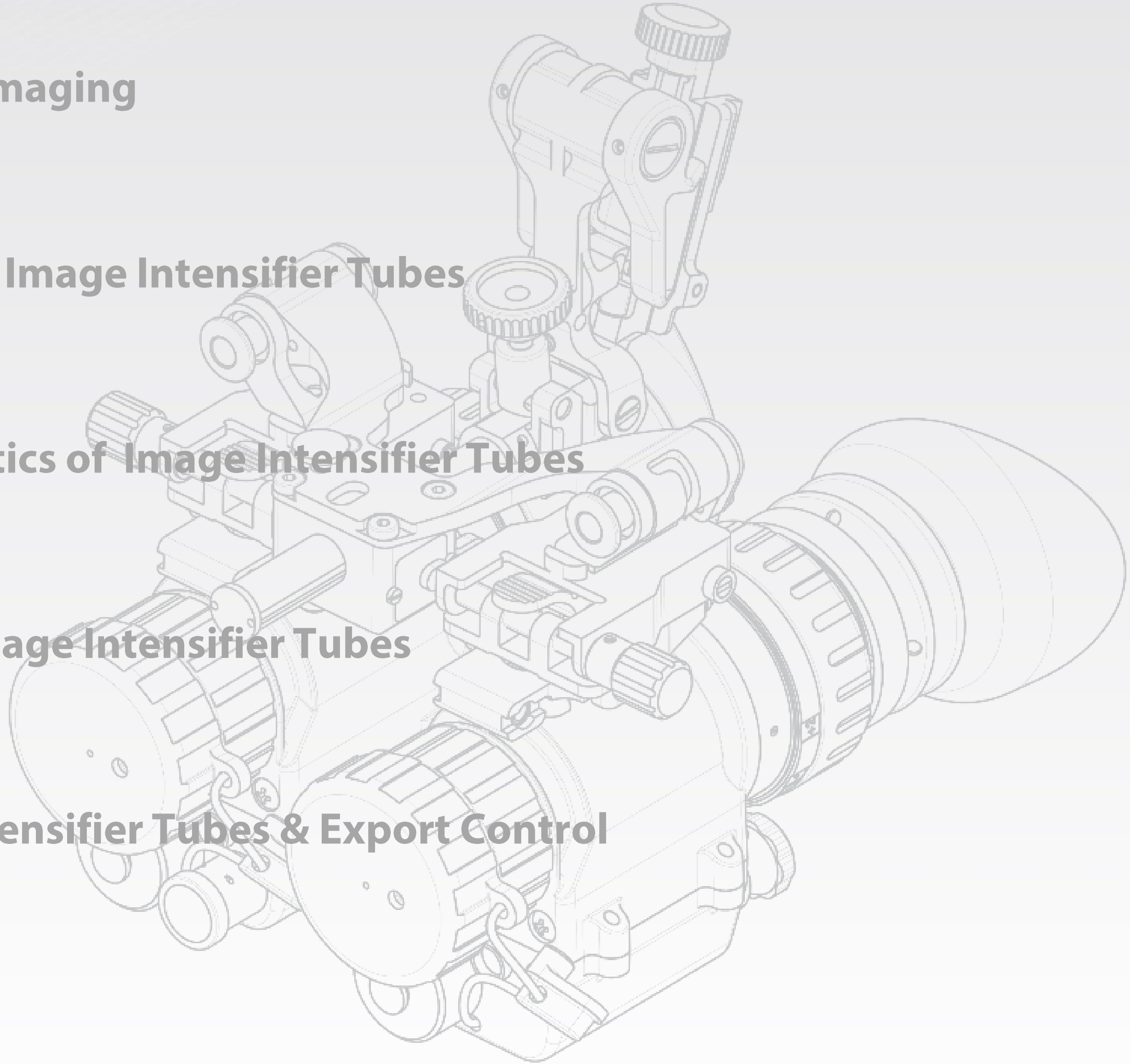

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