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# The Gen 3 Advantage


Night Vision and Communication Systems

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# THE GEN 3 ADVANTAGE

## INTRODUCTION AND TERMINOLOGY

The nighttime battlefield has changed dramatically in the past 20 years. Rather than operating in a defined-light environment, today's warfighter must have the tools to succeed in a wide range of changing visual conditions, from heavy foliage to open moonlit skies; from starlight alone to varying levels of urban light.

The key to this lies in the capability of the Night Vision Device's (NVD) image intensifier tube to amplify low-light scenes to useful levels. The challenge facing users making purchasing decisions is to fully understand the key criteria used to accurately evaluate previous and current generations of image intensifier technology.

This whitepaper offers a data-driven approach to understanding the true costs and benefits of Generation 3 (Gen 3) vs. Generation 2 (Gen 2) night vision technology. The information is presented as follows:

- An overview of image intensifiers, how they work, and the technology differences and capabilities of each generation
- A discussion of common testing standards and methods related to the key performance characteristics of 1) white light photocathode response, 2) luminance gain, 3) reliability, and 4) storage temperature
- An examination of disparities among testing standards and methods, and how they can result in misleading data

The data in this paper supports the position that: A) Gen 3 provides enhanced performance, especially in extreme low-light conditions, and B) Gen 3 results in lower total lifecycle ownership cost over a longer useful life span. Specifically:

- From the outset, Gen 3 performs better than Gen 2, and remains better throughout the tube's useful life
- Gen 2 performance drops off quickly and it has a much shorter useful life
- A minimum of four Gen 2 image intensifiers are needed to equal the performance life of one Gen 3 image intensifier

### Terminology Used in this Paper

*Equivalent Background Intensity (EBI)* – EBI is the lowest ambient light level at which an image intensifier is capable of producing a discernable image.

*Figure of Merit (FOM)* – FOM is intended to be a single metric for measuring image intensifier performance and is the product of the signal-to-noise ratio (SNR) multiplied by the low light resolution (measured in line pairs per mm, lp/mm). While FOM is a commonly used starting point for comparing tubes, it encompasses only two tube performance metrics, and therefore does not comprehensively describe intensifier performance.

*Gallium Arsenide (GaAs)* – The material from which a true Gen 3 photocathode is made.

*Generation* – A designation of image intensifier architecture, which at one time was an indicator of performance, with a higher generation being better than the preceding generations. As image intensifiers have matured, this term has lost some meaning. It is now better to compare all performance metrics under equal test conditions and standardized measurement units in order to make an informed decision. Traditionally, Gen 2 has referred to devices with a multi-alkali photocathode and a Microchannel Plate (MCP) lacking an ion barrier film, while Gen 3 has meant a GaAs photocathode and an

MCP with an ion barrier film. Over time, the multi-alkali photocathode has, in some cases, been replaced with more sophisticated structures, while some GaAs photocathodes do not use an ion barrier film. For the purposes of this paper, we will follow the traditional definitions of Gen 2 and Gen 3.

*II or I²* – Image Intensification, or Image Intensifier

Indium Gallium Arsenide (*InGaAs)* – Photocathode with extended spectral range (developed by Harris)

*Luminance Gain* – The intensifier screen luminance output (in fL) divided by the actual input illumination to the photocathode (fc). Units are in fL/fc.

*Photocathode Response (PR)* – A measure of how efficiently an image intensifier converts white light to an electronic signal.

*Photocathode Sensitivity* – This designates the photon-to-electron conversion efficiency of the photocathode using 2856 K light source. Typical units are in µA/lumen or in µA/lm.

*Reliability* **–** The probability of an image intensifier or NVG operating for a given amount of time without failure, where failure is defined as key performance metrics degrading to below a standardized threshold (such as U.S. MILSPEC defined standards).

*Resolution* – The maximum line pattern of the USAF 1951 target, where both the horizontal and vertical bars can be discerned at a low light level. Resolution is measured in line pairs per mm, lp/mm. Along with SNR (defined below), low light resolution is one of the two factors used in determining the FOM of the intensifier.

*Signal-to-Noise Ratio (SNR)* – A measure defined as the ratio of an intensifier's amplified electronic signal to its inherent electronic noise. As such, SNR represents the light signal output to the eye, divided by the total intensifier noise output to the eye. Along with low-light resolution, SNR is one of the two factors used in determining the FOM of the intensifier.

## Basic Principles and Technology Generations

Modern image intensifier tubes work as follows: Incoming light photons enter the tube through the objective lens and strike the photocathode, generating photoelectrons which are then drawn by a voltage differential through a Microchannel Plate (MCP), which contains millions of microscopic tunnels called channels. As the electrons pass through, they strike the sides of the channels and generate secondary electrons, yielding a thousands-fold multiplication in the number of electrons traveling toward the phosphor screen. The now-plentiful electrons strike the phosphor screen, where they in turn generate photons that the user sees as the intensified image.

**Production of Gen 2 intensifiers began in the 1970s** with the advent of the bialkali photocathode and the modern MCP for gain. The bialkali photocathodes had a spectral range from 185-750 nm and a sensitivity of 120 µA/lum. Over the years, the bialkali photocathodes have been replaced by multi-alkali photocathode with spectral range from 185-900 nm and sensitivity up to 800 µA/lm.

**Gen 3 production, which began in the 1980s,** introduced two key changes that differentiate it from Gen 2. First, GaAs is used for the photocathode, which provides a much higher level of photocathode sensitivity compared to the Gen 2 multi-alkali photocathode. As such, only Gen 3 image tubes have a GaAs photocathode, and tubes without GaAs photocathodes cannot correctly be labeled as Gen 3. Gen 3 image intensifiers started with photocathode sensitivity of 800 µA/lm in the 450-950 nanometer region of the light spectrum, but have since reached levels in excess of 2400 µA/lm on a production basis. The second key change from Gen 2 to Gen 3 was the addition of a protective ion barrier film coating to the MCP, shielding it from degradation from ionizing gases generated within the tube. This film barrier greatly increased the useful life and reliability of the Gen 3 intensifier.

## Testing Results Using Common Standards and Methods

This section discusses different testing methods for white light photocathode response, luminance gain, reliability, storage temperature, and the specific advantages of Gen 3 image intensifiers when equivalent testing standards and processes are applied.

There is no shortage of industry information comparing the performance of Gen 2 and Gen 3 image intensifiers. Some of this data gives the impression that Gen 2 image intensifiers have performance similar to, or better than, Gen 3. However, a detailed review of this research shows that much of the performance data is derived from varying or outdated test methods. The inconsistency of the reported information can lead to misinterpretation of performance characteristics relevant to the usability, safety, mission success, and overall cost of ownership of a Night Vision Device.* However, when applying modern testing standards and a common methodology to examine and compare the performance of Gen 2 vs. Gen 3 image intensifiers, the results show distinct advantages for the user who opts for Gen 3 night vision solutions.

**A discussion later in this paper highlights some past differences in testing methodology, equipment, and standards.*

## Measurable Factors that Define an Image Intensifiers Performance

Although the U.S. Department of State's Directorate of Defense Trade Controls (DDTC) imposes various export limitations on Gen 3 image intensifier performance on a country-by-country basis during its export license application review process – for example, limitations on FOM and use of power supply auto-gating – there are a number of other measurable factors that define an image intensifier's performance. The following sections describe these factors and their importance to a user's understanding of the strengths of Gen 3 over Gen 2.

### *White Light Photocathode Response (PR)*

PR is a measure of how efficiently an image intensifier converts white light to an electronic signal. The higher the PR, the more efficient the image intensifier is at converting white light into electrical current, which in turn yields a higher SNR and allows the user to see better in lower light conditions. DDTC uses the industry-standard FOM calculation – the product of a tube's resolution and its SNR – to determine the maximum performance of an image intensifier for export purposes. This makes the intensifier's PR an important factor in calculating its FOM.

Gen 3 image intensifiers have a white light PR of 1350 to 2800 µA/lm, while Gen 2 intensifiers have a white light PR between 700 and 800 µA/lm. This means that the maximum PR of a Gen 3 intensifier can be *3 to 4 times greater* than that of a Gen 2 intensifier. Even a 1250 FOM Gen 3 image intensifier with minimum PR of 1350 µA/lm will still have a minimum PR nearly double the maximum PR of a Gen 2 intensifier.

While PR is an important aspect of the photocathode sensitivity, PR is dependent not only on overall input light levels but also the wavelength components of that light. An image intensifier's wavelength-dependent quantum efficiency must be considered with particular regard to the visible red and near infrared (IR) portions of the color spectrum. Together these wavelengths make up a greater component of the night sky as compared to a sunlit sky. Daytime light is more evenly distributed across the entire visible spectrum, but as the evening sky darkens to night, the dwindling ambient light shifts comparatively toward the more persistent red and infrared wavelengths. Therefore, it is very important for an image intensifier to cover a broad spectral range extending into the near infrared, i.e. wavelengths longer than 770 nm. Overall, Gen 3 spectral range covers from 400 nm (the transition zone between visible violet and ultraviolet light) to just past 900 nm (well into the near IR spectrum) at room temperature, as seen in Figure 1.

Gen 2 intensifiers have been introduced with extended spectral range at less than 400 nm to 1000 nm, also shown in Figure 1. However, having a large response in the near UV range is generally not beneficial to a tactical night vision system for two reasons:
A) At nighttime low-light levels, the incoming spectrum has shifted toward the infrared and contains little signal at UV wavelengths shorter than 400 nm, and B) Most optical glasses used for system lenses do not transmit light of wavelengths shorter than 400 nm. In fact, in most aviation NVG applications, blue light is filtered out of the goggle in order to be cockpit-compatible.

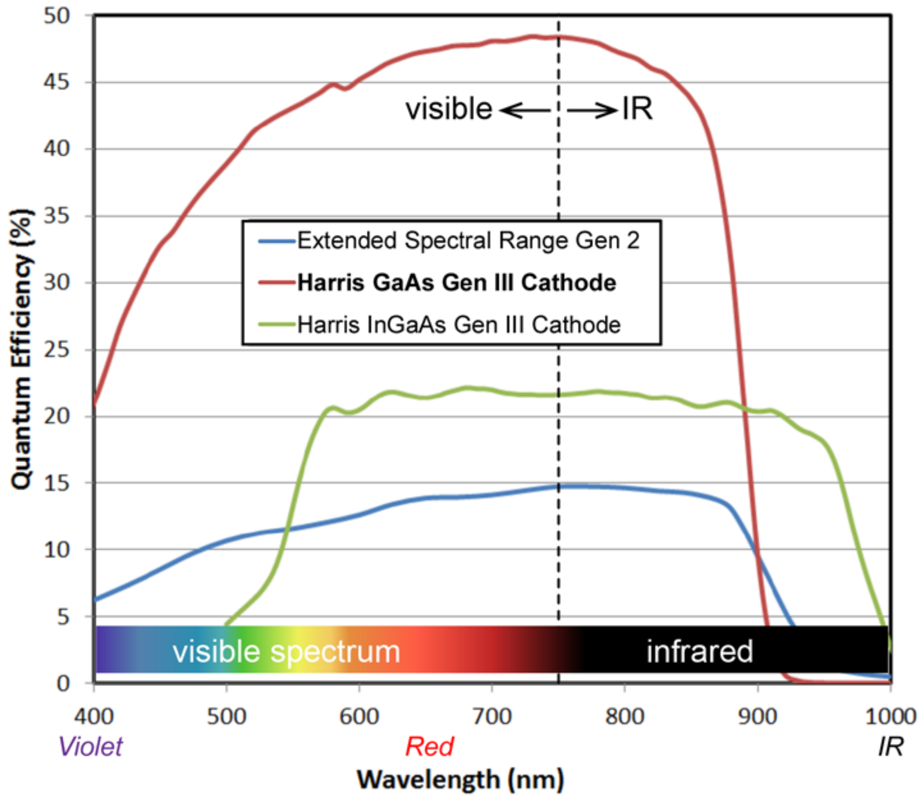


*Figure 1. Quantum efficiency curve of extended range Gen 2, GaAs Gen 3, and InGaAs Gen 3 photocathodes*

*(Note: Figure 1 above includes a PR curve for a Gen 3 tube made by Harris that uses an InGaAs photocathode with extended spectral range beyond even that of the extended range Gen 2 photocathodes. By adjusting the Indium composition in an InGaAs photocathode, a Gen 3 tube with a cutoff wavelength similar to the extended range Gen 2 can be fabricated, and would result in quantum efficiency between that of the GaAs and InGaAs curves shown in Figure 1.)*

The makers of the extended spectral range Gen 2 image intensifiers contend that their new photocathode offers increased sensitivity compared to the standard Gen 3 GaAs photocathode. To support this claim, they have introduced a new mathematical metric called "spectral SNR." However, there is no physical underlying basis for this parameter. It appears to be calculated based on a normalized quantum efficiency curve, like that in Figure 1 above, multiplied by the SNR of the image intensifier. But in fact, normalizing the quantum efficiency curves to the peak wavelength response of each type of cathode *hides the difference in the quantum efficiencies* of the Gen 2 and Gen 3 photocathodes. It masks the truth that Gen 3 has much better PR than Gen 2, especially in the all-important red and near-IR portion of the spectrum.

The Gen 3 advantage is very evident when a user is working in low-light environments without diffused lighting, such as clear or overcast starlight. In situations with new tubes and a significant amount of urban lighting, there would indeed be a minimal discernable difference between Gen 2 and Gen 3 to a user's eye. However, users must ask themselves a key question: "Do I want to be able to operate in the true dark of night?" If the answer is yes – as it surely must be in today's battle environments – Gen 3 is the only technology that enables true operational capability in the darkest of night operations.

Gen 2 manufacturers may contend that the ion barrier film of the Gen 3 device negates its PR advantage. The underlying reasoning has a basis in truth, however the SNR difference already takes this into account. In other words, Gen 3 tubes still have better PR than Gen 2. Moreover, if the ion barrier film in Gen 3 tubes is filtering the photocathode response, it is also filtering out some of the EBI, thus neutralizing any negative impact the ion barrier film would have on SNR. Published Gen 2 materials do not mention this, nor do they compensate their EBI specification to account for this difference. The bottom line – Gen 3 tubes maintain superior photo response performance over Gen 2 despite Gen 3 having an ion barrier film. In addition, the ion barrier film confers other distinct advantages for Gen 3, described further below.

### *Luminance Gain*

Luminance gain is the ratio of the output brightness of an image intensifier (in fL or cd/m2) to the input brightness of the photocathode (in fc or lux). This parameter defines how much an image intensifier amplifies a given amount of light. Gen 3 has a brightness gain of 40,000 to 70,000 fL/fc or 13,000 to 23,000 cd/m2/lx. In comparison, Gen 2 has a brightness gain of 30,000 to 55,000 fL/fc at 2e-6 fc or 10,000 to 18,000 cd/m2/lx at 2e-5 lx (per the manufacturer's datasheet). The extra 30% gain provided by Gen 3 means that more light is getting to a user's eye without sacrificing an intensifier's performance or useful service life. Combined with the increased photocathode response of Gen 3 discussed earlier, a user is able to see more, in lower light conditions, and at greater distances than with Gen 2.

Gen 2 manufacturers recognize the importance of luminance gain in their own marketing literature, but do not credit the additional gain for the Gen 3 product.[1] Even though the Gen 2 NVD user's eye may see what superficially seems to be a good image if the tube is relatively new and operated in relatively well-lit ambient conditions, it will become light-starved and cause user fatigue at lower ambient light levels, and be unable to form a useful image in near total darkness conditions.

### *Reliability*

Reliability is the single biggest differentiator between Gen 3 and Gen 2. Reliability tests are conducted to determine an image intensifier's resistance to harsh conditions such as extreme input illumination levels, exposure time, and elevated temperature. Reliability testing is the way to determine if an image intensifier will perform to a certain level over a specified number of hours.

Adhering to common evaluation standards is key to accurately measuring reliability. The reliability specifications of an image intensifier can vary greatly depending on the end-of-life criteria used. Reporting only the number of hours of an image intensifier's reliability tells only part of the story. In order to fully convey what the performance of an image intensifier will be at the end of a cited number of hours, the end-of-life criteria employed in testing must be provided, as well as trends *prior* to the end of life.

Harris tests Gen 3 reliability using the U.S. Government's (USG) required MILSPEC accelerated reliability testing method. This allows the test time to be shortened while still ensuring that the intensifiers meet reliability requirements equivalent to real-life conditions. The USG defines 2,000 hours of accelerated reliability testing to be equal to 10,000 hours of operational life. It also defines the operational life to be 1,000 hours of operation per year for a total of 10 years. This means that Gen 3 image intensifier performance during reliability testing will not degrade more than what the end-of-life requirement allows for 10 years or 10,000 hours of service life.

In the following chart (Figure 2), data from two Photonis (Gen 2) image intensifier data sheets states that the starting FOM was in the 1600-1700 range. However, measuring using the USG MILSPEC standard, they both registered at below 1400 FOM. Meanwhile, at the beginning of the accelerated reliability test, the Gen 3 intensifiers were 1400-1600 and 1600-1800 FOM, respectively, due to export requirements, which set an upper limit of FOM. If a Gen 2 image intensifier is tested per the same MILSPEC accelerated reliability test method used for a Gen 3, the Gen 2 will prove to have only one-fourth to one-fifth of its stated lifecycle, meaning an actual useful life of 2,000 to 2,500 hours. This would equal only 2 to 2.5 years of true operational capability under typical frequency of use, vs. 10+ years for Gen 3 tubes tested to the same standards.

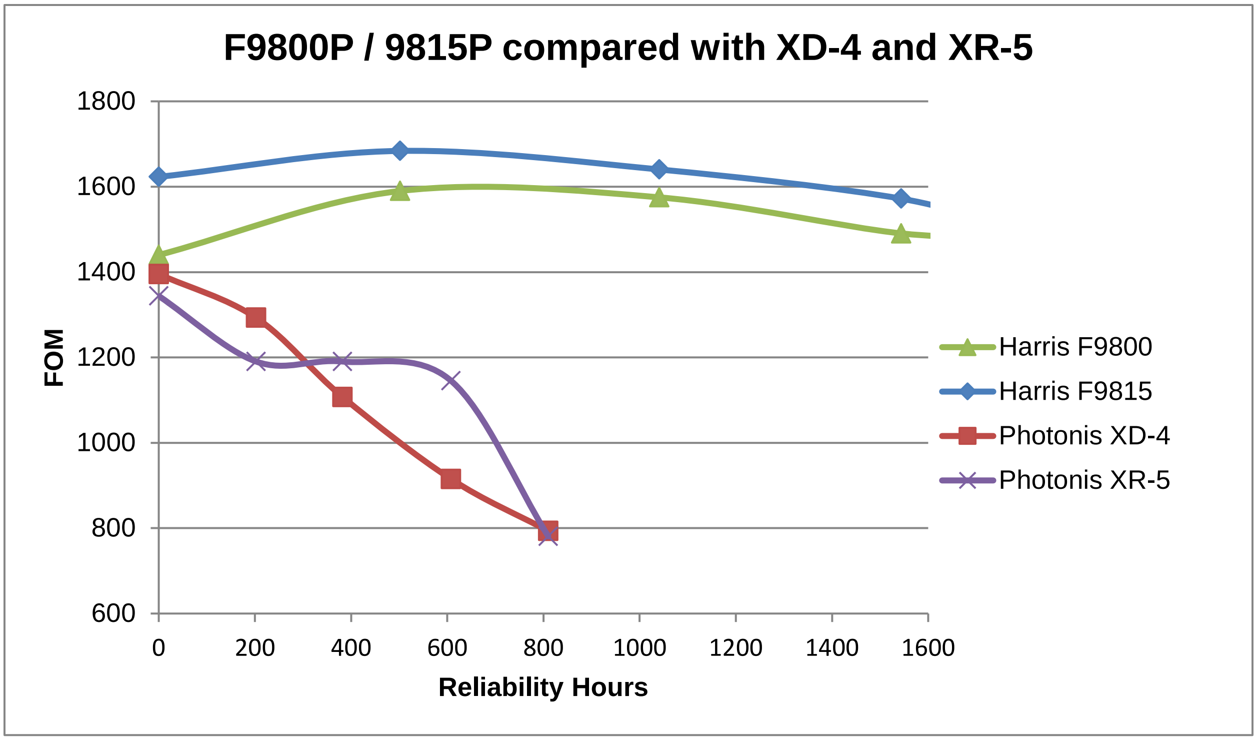


*Figure 2. Gen 3 vs. Gen 2 Lifetime Operational Performance, as tested to common U.S. MILSPEC standards. (Note: Harris tubes are Gen 3. Photonis tubes are Gen 2.)*

## Representation of Gen 2 vs. Gen 3 Image Intensifiers after Two Years of Typical Use

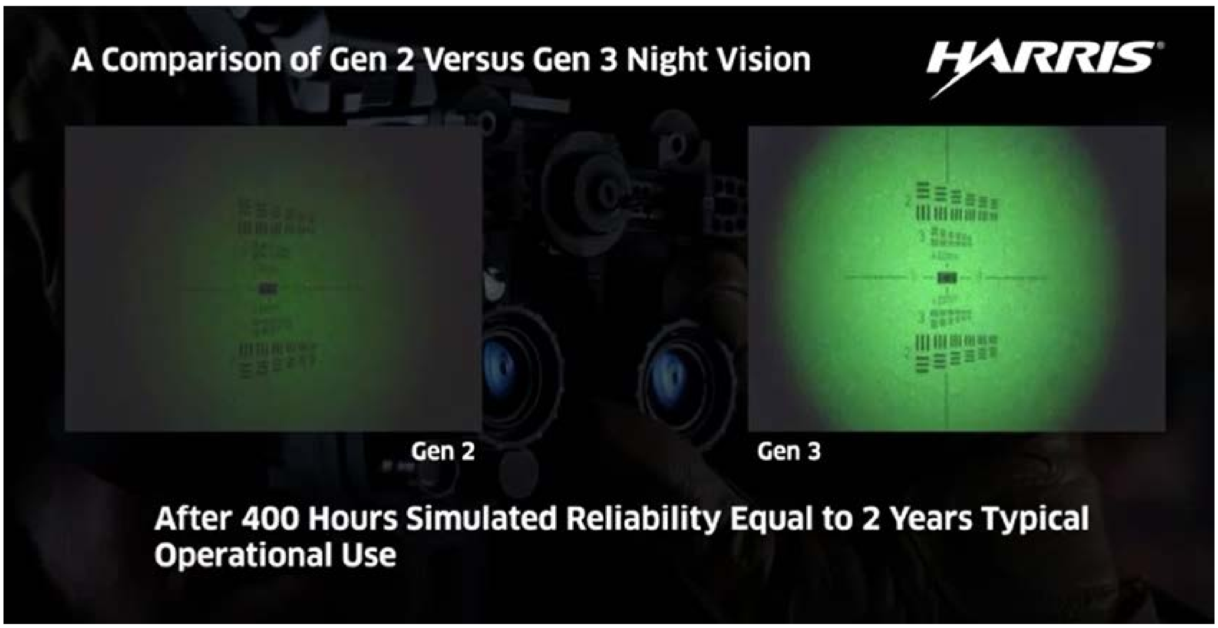


*Figure 3. Even after just two years of typical/moderate use, the Gen 2 intensifier is useless for challenging real-world operating conditions. Image is an excerpt from Gen 2 vs. Gen 3 video [https://youtu.be/_FluxGa8md8](https://youtu.be/_FluxGa8md8)*

The data depicted in Figure 2 and illustrated in Figure 3 demonstrates how performance of Gen 2 intensifiers degrades much more quickly than that of Gen 3 intensifiers. For example, recognition range performance of a Gen 3 intensifier is reduced only slightly after 10,000 hours of operation. Quite simply, Gen 3 provides the user a better performing image intensifier, over a longer lifecycle. This is a win for both the end user and purchasing decision-maker. Since one Gen 3 image intensifier will last four to five times longer than a Gen 2 image intensifier, frequency of replacement, user down time, and overall lifecycle cost are dramatically reduced.

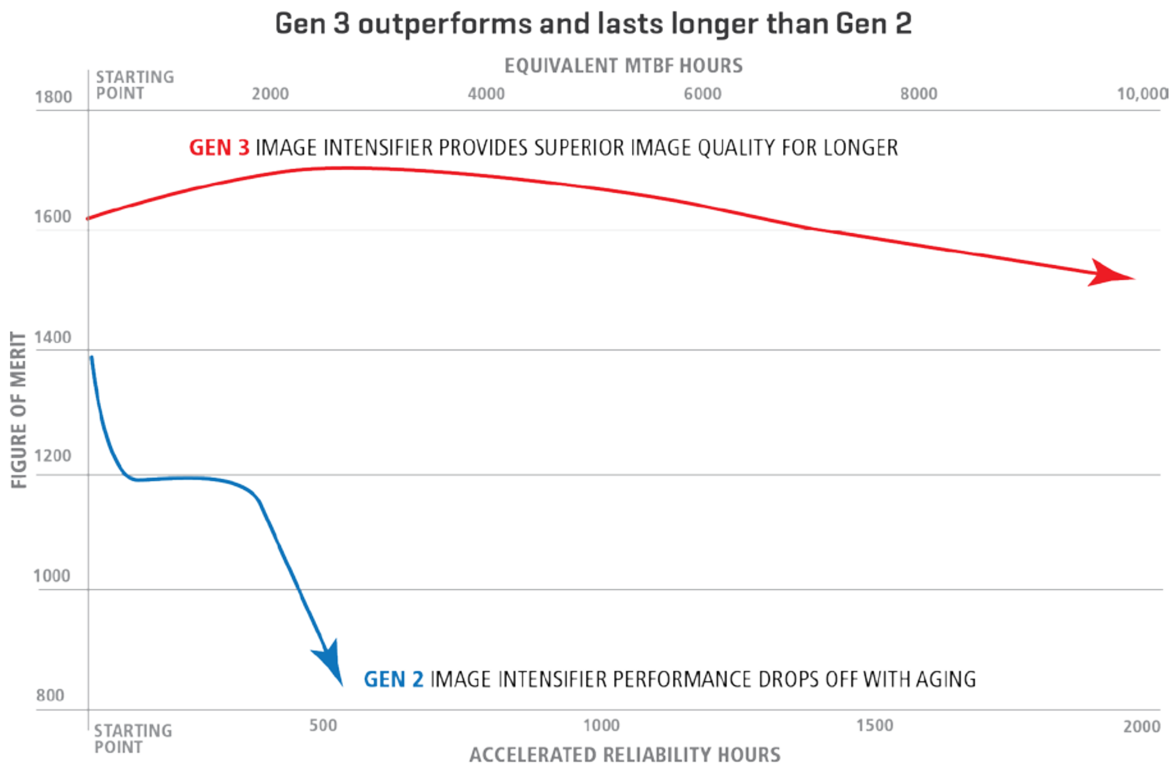


*Figure 4. Gen 3 Operational Performance Lifetime Value*

The graphic above (Figure 4) depicts the superior reliability, longer life, and lower lifecycle cost of Gen 3 vs. Gen 2 image intensifiers. At least four Gen 2 image intensifiers are required to equal the lifespan and reliability of a single Gen 3 image intensifier. Furthermore, Gen 2 performance is weaker even at the beginning of its service life, and drops off significantly with aging. The Gen 3 intensifier continues to provide superior image quality throughout its service life.

### *Storage Temperature*

Storage temperature is specified by the customer and is dependent upon the environment in which an NVG and spare parts will be stored. Gen 3 image intensifiers are designed to withstand harsh conditions because of the choice of construction materials and design of the image intensifier's housing. Both of these characteristics give the Gen 3 image intensifier greater resistance to chemical, humidity, and environmental stress and enable them to withstand up to 85°C and still meet all specified requirements. In contrast, Gen 2 image intensifiers are designed to withstand 65°C; that is, 20°C lower than Gen 3. The higher storage temperature tolerance of Gen 3 is beneficial, providing the user greater flexibility and choice of storage environments without degrading the image intensifier's performance.

## Disparities in Testing Standards

There are three key areas of testing disparity between Gen 2 and Gen 3 image intensifiers, producing misleading information regarding performance. In addition, U.S. companies are held to a higher standard of testing and use units of measure that do not directly compare with Gen 2 standards.

***Outdated Standards*** – Gen 2 intensifiers are often tested against performance standards developed more than 30 years ago. These older tests allow both modern Gen 2 and Gen 3 image intensifiers to pass the same performance metrics. However, in most cases, testing standards have become more stringent over the years to more accurately reflect real-world use and operating conditions. It is estimated that for Gen 2 tubes, the older testing standards produce results that are approximately 15-30% higher than the tubes' actual real-world performance. This inflates the results for critical features such as SNR, halo, and ultimately FOM, and causes the performance of Gen 2 intensifiers stated in published literature to appear higher than what the tubes can actually deliver.

***Non-U.S. Standards*** – U.S. companies must test to stringent U.S. Government standards. This is not the case for manufacturers outside the U.S., who use older reliability test criteria to argue that the performance of their Gen 2 image intensifiers is similar to, or even better than, that of Gen 3. For example, the luminance gain of Gen 2 is lower than Gen 3; so while increasing the gain of a Gen 2 tube might not degrade its SNR performance, it would have an impact on the device's reliability. Comparing only the SNR, without accounting for gain differences, gives the impression that Gen 2 works better at low-light levels such as starlight and overcast starlight, when in fact Gen 2 image intensifiers go dark and become useless in such environments. Indeed, low-light operational capability is one of the biggest advantages of Gen 3 over Gen 2, because Gen 3 has higher luminance gain and photocathode response due to the properties of GaAs.

***Less Stringent Standards*** – Gen 2 test standards are dated and require lower test standards than today's Gen 3. When a Gen 2 image intensifier is tested to Gen 3 standards (*representing modern-day operational requirements*), Gen 2 performance always falls significantly short.

One cannot make a direct and accurate comparison of performance without measuring both systems to the same standard. For example, if the starting FOM of a Gen 2 tube is 1800, but after only six months of operational life it has degraded to 1400 FOM and remains there, or falls slowly to 1200 FOM, then is it truly worth a premium price over a stated service life of 10 years or 10,000 hours? On the other hand, a Gen 3 tube, because of more advanced materials and higher manufacturing and testing standards, will reliably meet stringent U.S. MILSPEC performance standards over that same 10 year/10,000 hour expected service life and beyond.

## Disparities in Testing Methods and Equipment

A true performance comparison of Gen 2 vs. Gen 3 requires common and publicly defined and acknowledged testing methods and parameters. This eliminates skewed results and ensures that any performance variation is due to differences in the image intensifiers and not the test method. This is especially critical when modeling recognition range performance for night vision goggles.

In addition to testing standards, the accurate evaluation of an image intensifier's performance is highly dependent upon the test equipment and methods used to derive the measurements. Differing test methods can vary results and significantly change the meaning of an image intensifier's reported performance.

### *Test Equipment*

In addition to testing methods, the equipment used to perform the evaluations plays a key role in delivering accurate results. Most test benches are proprietary to the vendor, or are very expensive and require extensive resources to calibrate and maintain. This puts customers at a disadvantage in terms of verifying performance data, as they typically don't have access to this equipment, or can't justify the investment to test a statistically small representative sample of image intensifiers. Under these conditions, they must trust that vendor-provided data is accurate.

However, there is another tool available for customers to help them verify accuracy. The Hoffman ANV-126 or 126A field-portable Night Vision Device (NVD) Test Set allows a user to test gain, low-light limiting resolution, high-light resolution, image quality, NVD battery, image intensifier current, and halo – all while the image intensifier is installed in a night vision system. (The halo measurement requires the additional purchase of an adapter to be used with the ANV-126/126A.) Since the input light level is adjustable, resolution can be measured at different lighting conditions.

The ANV-126/126-A test set utilizes an LED light source, which has a discrete wavelength. In order to properly test a Gen 2 vs. a Gen 3 image intensifier, the input light level is adjusted to properly account for the differences of an intensifier's spectral sensitivity and gain. The adjustment of input light level ensures that a user is seeing the image intensifier's proper performance for each lighting condition (clear starlight, overcast starlight, full moon, etc.). The ANV-126/126-A test set is used around the world for field maintenance and repair of Night Vision Devices. While it requires an export license for non-U.S. customers, it is nonetheless fully exportable. Harris has experience in assisting customers to achieve the proper adjusted input light levels.

## Conclusion: Performance Benefits of Gen 3 over Gen 2

The use of outdated standards, methods, and tools to evaluate and communicate the performance of Gen 2 image intensifiers provides results that may appear to mirror the capabilities of Gen 3. As a result, potential customers may believe they can operate in the more challenging conditions supported by Gen 3, at only the cost of Gen 2. However, an accurate comparison using modern standards, processes, and equipment quickly shows that this is not the case. Gen 3 offers numerous advantages over Gen 2, at comparable cost. While both can have similar performance out of the box, only Gen 3 provides the customer with a better value image intensifier that performs to a higher standard and for a longer period of time. Only Gen 3 tubes provide tactical advantage even in the darkest real-world environments, and deliver reliable performance throughout an entire 10-year or 10,000-hour useful life.

Figure 5, below, illustrates how the performance of Gen 2 and Gen 3 image intensifiers is different even at the start of life. Gen 3 is the only functional solution for mission effectiveness in near total darkness. Performance of Gen 2 begins to show similarity to that of Gen 3 only when operating in bright full moonlight conditions. This can be observed when both types are tested side-by-side in a realistic, standardized environment. In this visual representation, the larger the area under the curve, the wider the range of missions that can be conducted successfully and safely.

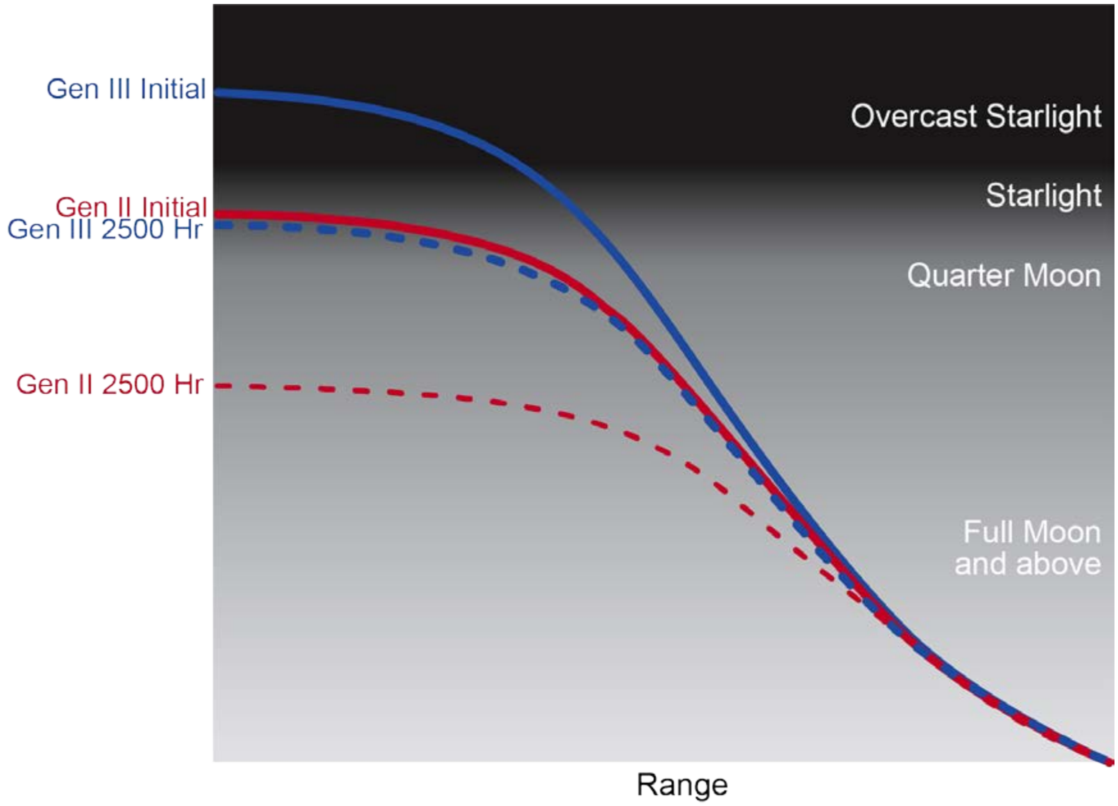


*Figure 5. Gen 3 (blue lines) vs. Gen 2 (red lines) recognition range performance in varying ambient light and darkness levels, depicting tubes both new and after 2,500 hours of operational use*

## Gen 3 Delivers

- Better photocathode response yield and higher luminance gain, which enhances recognition range and tactical advantage for the user
- Good image even in near-total darkness conditions in which Gen 2 tubes "fade to black"
- Longer tube life – able to deliver 10,000+ hours of operational use at or above U.S. MILSPEC-defined, high-performance standards
- Superior reliability with consistently good image quality across the already longer useful life of the image intensifier
- Much better value and lower overall lifecycle cost

Harris is working with industry experts and the U.S. Government to ensure that customers have the latest information in order to accurately evaluate image intensifiers, ensuring that warfighters never find themselves at a tactical disadvantage. This information includes the essential performance criteria, how to properly specify image intensifier performance, and the actual performance differences of Gen 3 vs. Gen 2.

## Works Cited


1. Photonis documentation: https://www.**photonis**.com/uploads/literature/iit/**Gain**.pd