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The Gen 3 Advantage

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1.0 Introduction

An extensive amount of industry information exists that compares the performance of Gen 2 and Gen 3 image intensifier tubes. Most of it is based on performance results that employ varying and often inaccurate test methods – a source of significant inconsistency in the reported information. The fact is that Gen 2 and Gen 3 image intensifier tubes are tested differently using different standards, leading to results that can obscure true performance comparisons.

Some non-U.S. companies measure their Gen 2 tubes against 30+year-old Gen 2 test standards. These standards have since been superseded, but yield more favorable – albeit inaccurate – performance results. It is estimated that these outdated standards produce test results approximately 15-30% higher than the reality. This impacts test results for Signal-to-Noise Ratio (SNR), halo, and ultimately Figure of Merit (FOM), causing the performance of Gen 2 tubes to appear to be higher than it actually is.

Harris Corporation's Night Vision business uses only the highest and most stringent current U.S. Government test standards. Only when both generations are tested with common methods and parameters will the actual strengths and weaknesses of each be revealed. Extensive work is being done at Harris and the United States Government to quantify the real performance differences between Gen 2 and Gen 3 to dispel some industry misconceptions. This paper discusses the advantages of Gen 3 over Gen 2, and the benefits provided to the user by superior Gen 3 performance.

2.0 History

Generation 2 production began in the 1970s. These image intensifiers usually have an S-25 (extended red) photocathode (with photocathode of 240+ μA/lm and a MicroChannel Plate (MCP) to achieve gain) and can be found with either electrostatic or fiber-optic inversion. Gen 2 tubes do provide acceptable performance at low light levels but exhibit low distortion. Generation 3 production began in the 1980s, and introduced Gallium arsenide (Ga) for the photocathode and a MCP for gain. These were two key additions to the image intensifier tube that differentiate Gen 2 from Gen 3, as recently highlighted in current NATO opportunities requiring Ga photocathodes. The MCP is also coated with an ion barrier to increase tube life. It produces more than 800 μA/lm in the 450 to 950 nanometer (near-infrared) region of the spectrum. Gen 3 tubes provide very good low-light level performance, and long tube life. Recent mil-spec quality tubes have no perceptible distortion.

3.0 Testing Disparities

There are several reasons why some Gen 2 tubes appear to have performance similar to or better than Gen 3:

- Using outdated test standards, which impacts results for SNR, halo, FOM, etc.

- Using non-U.S. test standards
  - Reliability test standards with altered intensity
  - Low light performance – aka "white light photocathode response" – tested at higher light levels and a different measurement (lx versus fL/fc) for SNR than U.S. Government standards, which gives the impression that Gen 2 works better at low-light levels such as starlight and overcast starlight when, in fact, these tubes are completely dark in such environments. Low-light operational capability is one of the biggest advantages of Gen 3 over Gen 2 (Gen 3 has higher gain).
- Gen 2 test standards are lower than Gen 3 test standards, therefore one cannot make a direct comparison of the performance without correctly measuring them to the same standard.
  - Testing a Gen 3 tube according to Gen 2 standards would yield extremely high performance, since the Gen 2 test standards are lower. However, if/when testing a Gen 2 tube to Gen 3 standards, which truly represent modern-day operational requirements, Gen 2 would and does fail miserably.

A real-world example of this is in the automotive field. Newer vehicles are tested to today's standards in terms of performance, emissions and safety. They are held to higher standards and higher performance requirements. Older vehicles fail when measured by these updated standards, unless the measurements are skewed, as was recently seen by the Volkswagen emissions scandal.

Additional detail about testing differences is provided in Section 5.0.

4.0 Performance Benefits of Gen 3 over Gen 2

When comparing a Gen 2 to a Gen 3 image intensifier, there are some very distinct advantages that Gen 3 provides to the user. Gen 3 intensifiers were created to improve low-light performance and extend the true operational lifetime of tubes. Although the U.S. Department of State's Directorate of Defense Trade Controls (DDTC) imposes various tube performance limitations on Gen 3 on a country-by-country basis during its export license application review process, such as Figure of Merit and use of power supply auto-gating, there are other measurable factors that affect an image intensifier's performance. The following section describes these factors and their importance to a user's understanding of the strengths of Gen 3 over Gen 2. It is important to note that the U.S. State Department Technology Control Division only acknowledges U.S. manufacturer FOM performance because they have evaluated Gen 2 manufacturer tube performance and have ruled that the performance is measurably overstated.

4.1 White Light Photocathode Response

Photocathode Response (PR) is a measure of how efficient an image intensifier is at converting white light to an electronic signal. The higher the PR, the more efficient the image intensifier is at amplifying white light, which allows the user to see better in lower light-conditions. Since DDTC uses the industry standard FOM calculation – the ratio of a tube's amplified electronic signal to its inherent electronic noise (Signal to Noise Ratio) – to determine the maximum performance of an image intensifier for export purposes, a tube's PR is an important factor in calculating its FOM.

Gen 3 image intensifiers have a white light photocathode response of 1350 to 2800 μA/lm. Gen 2 tubes have a white light photocathode response between 700 and 800 μA/lm. This means that the maximum PR of a Gen 3 tube can be up to four times greater than a Gen 2 tube's minimum PR. For example, a 1250 FOM Gen 3 image intensifier with minimum PR of 1350 μA/lm would still be almost two times that of a Gen 2 tube.

This Gen 3 advantage becomes important when a user is working in low-light environments (such as clear or overcast starlight) where urban diffuse lighting is not present. In situations where there is a significant amount of urban lighting, there would be a minimal difference between Gen 2 and Gen 3 to a user's eye. Users must ask themselves: Do I want to be able to operate in the true dark of night or not? If they do, Gen 3 is the only technology that supports true operational capability in the darkest of night operations.

4.2 Brightness Gain

Brightness gain is the ratio of the output brightness of an image intensifier (in fL or cd/m2) to the input brightness to the photocathode (in fc or lux). This parameter defines how much an image intensifier amplifies given amounts of light. Gen 3 has a brightness gain of 40,000 to 70,000 fL/fc (13,000 to 23,000 cd/m2/lx) while Gen 2 (per Photonis datasheet) 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. The extra 30% gain provided by Gen 3 means that more light is getting to a user's eye without sacrificing a tube's performance or life. Combined with the increased photocathode response of Gen 3, a user is able to see more in lower light conditions at greater distances through a Gen 3 image intensifier than with Gen 2.

4.3 Reliability

Reliability is the 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 illumination levels, exposure time, elevated temperature, etc. Reliability testing is the way to quantify how long a tube will last in operation yet still meet a certain level of performance. It is a guarantee that an image intensifier will perform to a certain level over a specified number of hours.

Depending on the end-of-life criteria used, the reliability of an image intensifier can vary greatly. Reporting solely the hours of a tube's reliability tells only part of the story. In order to fully understand what the performance of an image intensifier will be at the end of those hours, the end-of-life criteria employed in the testing must be provided. Harris tests all military-grade Gen 3 image intensifiers to the same reliability criteria that the U.S. Government requires.

Harris tests Gen 3 reliability using a MIL-SPEC accelerated reliability testing method that allows the test time needed to be shortened, but still ensures that the tubes meet the reliability requirements. The U.S. Government 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 will not degrade more than what the end-of-life requirement allows for 10 years. Below is typical end-of-life criteria of a 1400 FOM Gen 3 image intensifier:

Table 4.3-1. Gen 3 End of Life Criteria

Requirement	Acceptance level
Luminance Gain at 2 x 10^{-6} fc	25,000 to 70,000
EBI	2.5 x 10^{-11} fc maximum
Signal-to-noise	16.0 minimum
Center resolution	Equal to beginning of life
High-light level center resolution	
Useful cathode diameter	
Output brightness uniformity	
Screen quality	

A visual representation of what Gen 2 reliability might look like against Gen 3 is pictured below:

Figure 4.3-1. Excerpt from Gen 2 v. Gen 3 video, linked here: https://youtu.be/_FluxGa8md8

In contrast, Gen 2 claims only a 10% degradation from Gen 3 after 10,000 hours of operation or 3 years of 24/7 use. Gen 2 states for 15,000 operational hours, the end-of-life criteria is 50% of the original sensitivity. This also means that the SNR degrades by about 50% and the brightness gain is reduced by four times. If one assumes that a Gen 2 image intensifier has a sensitivity of 800 µA/lm, SNR of 25, and 40,000 brightness gain at beginning of life, the end-of-life performance would be 400 µA/lm, SNR of 11, and 10,000 brightness gain. So, an end-of-life criteria of 50% of original sensitivity is only a partial requirement because sensitivity is not the only parameter that is degrading over time. It does not fully guarantee or describe what can be expected from the image intensifier at the end of the 15,000 hours.

If a Gen 2 image intensifier is tested per the MIL-SPEC accelerated reliability test method of Gen 3, it will prove to have only onefourth to one-fifth of the lifecycle, which is 2,000 - 2,500 hours. This would be equivalent to only two to 2.5 years of real operational capability vs. 10 years for Gen 3.

To summarize, the performance of Gen 2 tubes degrades much quicker than Gen 3s. This means that one Gen 3 image intensifier will last four to five times longer than a Gen 2, which reduces the number of replacements, cost involved and user down time. Gen 3 also gives the user a better performing image intensifier at a longer lifecycle. The performance of a Gen 3 intensifier only degrades slightly at the end of life; range performance only degrades slightly after 10,000 hours of operation. Figure 4.3-2 shows a comparison of range performance at the end of life for an XR5, XD-4, and a 1400 FOM Gen 3 image intensifier.

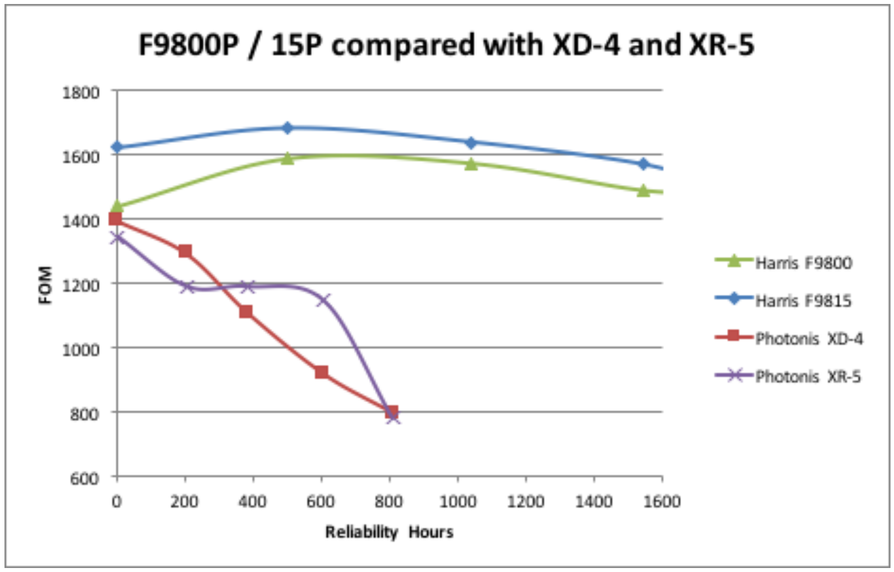

Figure 4.3-2. Gen 3 vs. Gen 2 Lifetime Operational Performance

Note for chart above: The two Photonis tube datasheets stated that the starting FOM were between 1600-1700, but measuring from a U.S. Government standard, they both registered at below 1400 FOM. The Harris tubes were 1600 and 1800 FOM respectively at the beginning of the accelerated reliability test.

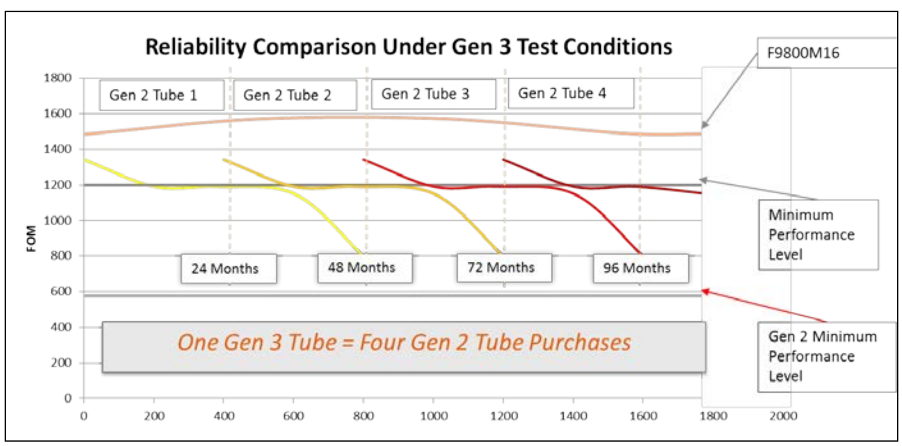

Figure 4.3-3. Gen 3 Operational Performance Lifetime Value

Operational lifetime mapping at a Gen 3 minimum reliability performance requires multiple Gen 2 tubes to equal the operational lifetime of one Gen 3 tube.

4.4 Storage Temperature

Storage temperature is specified by the customer and is dependent upon the environment in which a night vision goggle and spare parts will be stored. Gen 3 image intensifiers are designed to withstand harsh conditions and are able to do so because of the material choice and design of the image intensifier's housing. It allows the tube to have greater chemical, humidity and environmental stress resistance. Gen 3 image intensifiers are designed to withstand up to 85°C and still meet all specified requirements. Gen 2 is designed to withstand 65°C, – 20°C lower than Gen 3. A higher storage temperature allows the user to have greater flexibility with storage environments without degrading the image intensifier's performance.

5.0 Performance Testing and Common Test Methods—Why it's Important

As stated earlier, the evaluation of an image intensifier's performance is very dependent on the test equipment and test methods used to make the measurements. Different test methods can vary the test results and significantly change a reported tube's performance. In order to achieve a true performance comparison of Gen 2 and Gen 3, it is imperative that common test methods and parameters be used. Reliability and other tube performance parameters can be easily skewed and misrepresented when test equipment, parameters and performance requirements are not publicly acknowledged.

This is especially important when modeling range performance for a night vision goggle. The XR5 datasheet states a typical SNR of 28 and 25 minimum. Harris measured an SNR of 21, using stringent U.S. Government testing standards. As seen in Figure 5.0-1, if all tube parameters are held constant for the XR5 image intensifier and only SNR is varied, the distance at which a target can be recognized decreases by 8% by simply changing the SNR from 28 to 21 under clear starlight conditions. This becomes crucial if a Signal-to-Noise Ratio is being reported on a datasheet higher than what is actually measured or if different test methods are used that have conflicting results. It is important when comparing image intensifiers that a common test method is used to ensure the performance variation is due to differences in the image intensifiers and not the test method.

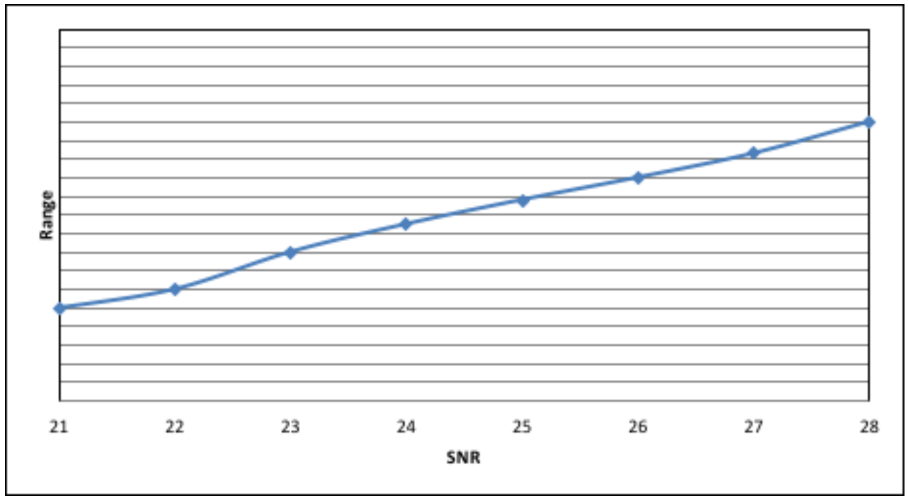

Figure 5.0-1. XR5 range performance with varying SNR under clear starlight condition

To accurately compare the performance of a Gen 3 to Gen 2 image intensifier, Harris has tested XR5 tubes using the same test equipment and methods as Gen 3. Below are the results in terms of range performance. Figure 5.0-2 shows the range using the technical datasheet stated specifications and Figure 5.0-3 shows the range using Harris-measured data (only XR5s were measured). Note the XR5 and XD-4 datasheet report the specifications for P-22 phosphor. Both image intensifiers are offered with P-22 or P-43 phosphor. The Harris-measured XR5s were P-43 phosphor.

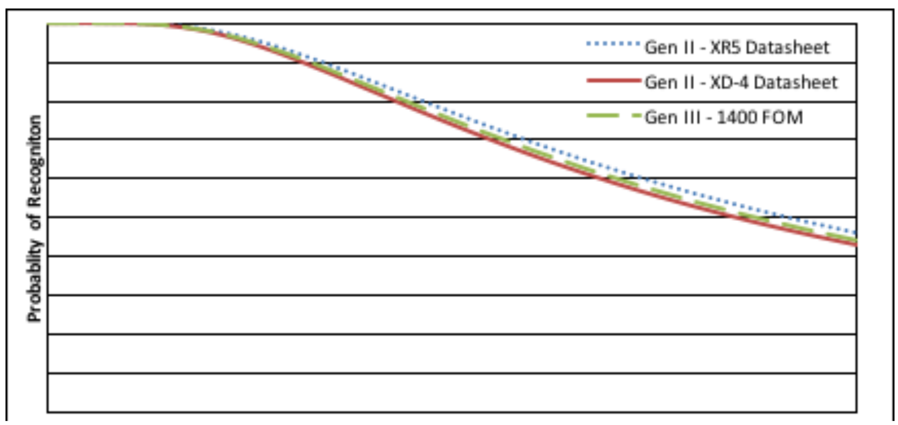

Figure 5.0-2. XR5 (Datasheet 1600 FOM), XD-4 (Datasheet 1600 FOM), and Gen 3 (1400 FOM) range performance using datasheet specifications

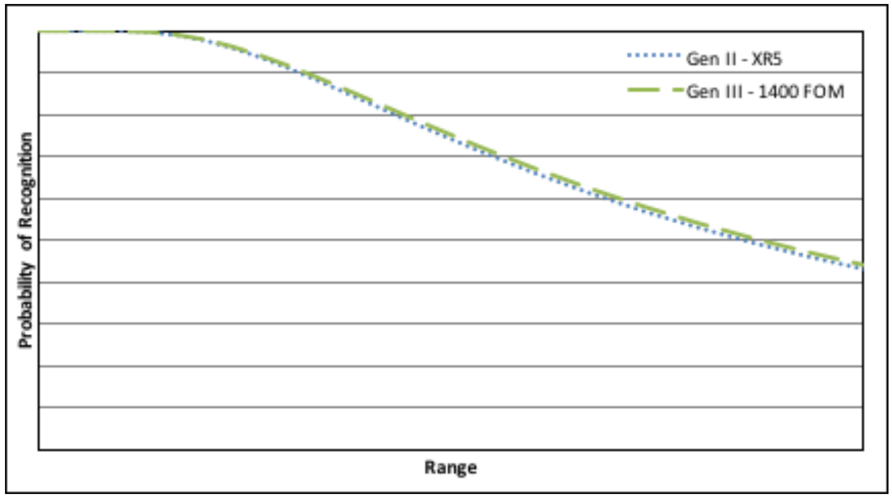

Figure 5.0-3. XR5 (Datasheet 1600 FOM) and Gen 3 (1400 FOM) range performance using Harris-measured data

As can be seen from the graphs, when the Harris-measured data is used, the Gen 2 XR5 and Gen 3 image intensifier have about equal range performance with a slight 2% advantage to Gen 3. When compared to the reported specification on the datasheet, it shows there is a 7% increase in range with the Gen 2 XR5.

5.1 Test Equipment

Most test benches are proprietary to the vendor or are very expensive and require extensive resources to calibrate and maintain. Customers typically don't have access to this type of equipment and can't justify the investment to only verify a small number of image intensifiers. The result is that they must rely on vendor-provided data to make purchasing decisions.

One tool that could be used by the customer is the Hoffman ANV-126 or 126A field-portable Night Vision Device (NVD) test set. It allows a user to test gain, low-light limiting resolution, high-light resolution, image quality, NVD battery, tube current and halo while the tube 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 could be measured at different lighting conditions. This test set is used all over the world for field maintenance and repair of night vision devices. It requires an export license for international customers, but is fully exportable.

The ANV-126/126-A utilizes an LED light source, which has a discrete wavelength. To properly test a Gen 2 and Gen 3 image intensifier, the input light level would need to be adjusted to properly reflect the differences of a tube's spectral sensitivity and gain. The adjustment of input light level would ensure that a user is seeing the image intensifier's proper performance for each lighting condition (clear starlight, overcast starlight, full moon, etc.). Harris can help provide the adjusted input light levels, or provide assistance on how they could be derived.

Conclusion

Gen 3 offers numerous advantages over Gen 2. It provides the customer with a better value image intensifier that performs to a higher standard for a longer period of time. This means a user is able to see at greater distances for a longer time with Gen 3. When purchasing image intensifiers, the end-of-life performance criteria must be considered. But operational life is only part of the requirements. The customer also needs to specify the desired performance at the end of life to ensure they receive the quality of product that they are expecting. Properly and accurately comparing Gen 2 and Gen 3 image intensifiers requires the tubes be tested by the same methods and performance requirements. Harris is working with industry and the U.S. Government to ensure that international customers have the latest information to accurately evaluate image intensifiers. This includes the important performance criteria, how to properly specify image intensifier performance, and the actual performance differences of Gen 2 versus Gen 3.

Works Cited

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