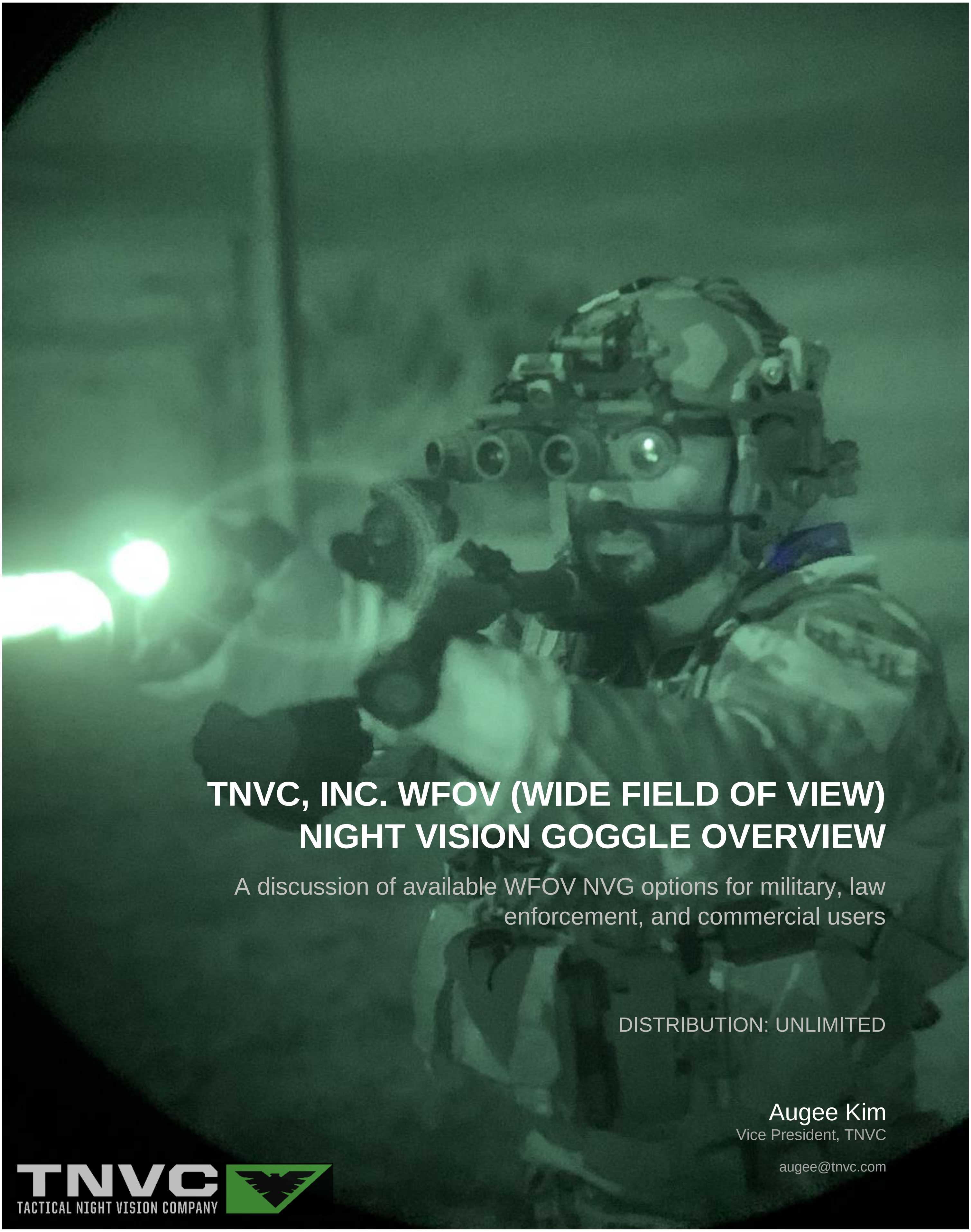

TNVC, INC. WFOV (WIDE FIELD OF VIEW) NIGHT VISION GOGGLE OVERVIEW

A discussion of available WFOV NVG options for military, law enforcement, and commercial users

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TNVC, INC. WFOV (Wide Field Of View) Night Vision Goggle Overview

Abstract:

WFOV NVGs have been one of the most highly sought after developments since the introduction of Generation III NVDs and have a long history of development by the DoD, Night Vision Manufacturers, and independent innovators. However, despite years of research and development and considerable desire to develop WFOV systems, few WFOV NVG systems have been successfully developed and fielded. Because of the limitations of current image intensifier and optical lens technologies, any attempts to increase FOV beyond the conventional 40º FOV incurs significant penalties in performance, weight, cost, or a combination of the three.

Of these systems, Panoramic Night Vision Goggles have been the most successful, offering the greatest increase in capabilities and least reduction in performance, but with a high cost and weight penalty. Commercially available systems like the Noise Fighters Panobridge offer an approximation of WFOV capabilities, however they come with their own significant penalties, particularly to performance. However, because of their low cost, they may appeal to some users desiring increased FOV assuming users are willing to accept the concomitant performance loss. However, for most users, conventional BNVG systems continue to offer the best value in terms of cost, performance, and weight/HFE considerations.

Background:

While lightweight, head-mounted Generation III Night Vision Devices (NVDs) have been potent tools for warfighters, law enforcement, and civilian users for over thirty years, one of the major limitations of traditional NVD configurations has been the restriction imposed by image intensifier technology and optical lenses to a nominal 40º circular Field of View (FOV).[1] This 40º FOV limitation remains generally consistent whether using monocular or binocular systems, though binocular systems provide the added benefit of binocular summation.[2] In contrast to a normal human FOV of approximately 200-220º horizontal (including peripheral vision) and 130-135º vertical FOV with natural eyesight, it is little wonder that almost since the inception of Gen. III NVDs that the DoD and other end-users, manufacturers, and independent innovators have sought to find ways to increase the available FOV to night vision users. Consequently, "WFOV," or "Wide Field of View" Night Vision Goggles (NVGs) have become something of a "holy grail" for night vision users, with multiple solutions having been developed and tested, though far fewer ultimately end up being fielded.

This paper is NOT meant to be a comprehensive discussion of the specific details of various WFOV technologies and methods, but rather a brief overview of the history of WFOV goggle development and the current "state of the art" to inform potential customers and end-users about the different WFOV NVG options that are currently available in order to make an informed and well-reasoned decision regarding their specific needs. Moreover, as active development programs still exist for WFOV NVGs, this document will ONLY make use of publicly available open sources in order to ensure confidentiality regarding ongoing development programs.

Historical Overview:

The practical reality of increasing NVD FOV while utilizing traditional Generation III image intensifier tubes is that it requires some form of compromise and cost, whether it is increased monetary cost, system complexity and/or weight, or performance penalties. In layman's terms: **you cannot use the same tubes to see more without giving something else up.**

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[1] https://en.wikipedia.org/wiki/Field_of_view

[2] https://en.wikipedia.org/wiki/Binocular_summation

There are currently three (3) primary methods of obtaining a WFOV utilizing traditional Generation III image intensifier tubes. These are:

a) **Panoramic Night Vision Goggles (PNVG)** – PNVGs accomplish an increased horizontal FOV (~95-104^{o}) by simply adding two (2) image intensifiers on either side of the primary image intensifiers (4 total) to provide peripheral vision: **more tubes/sensors = more information**

b) **Foveal/Foveated NVGs (F-NVG)** – "Foveal" or "Foveated" NVGs generally maintain a conventional parallel tube BNVG (Binocular Night Vision Goggle) configuration, however, they make use of specialized optical lens assemblies that increase the observed FOV.

c) **Diverging Image Tube NVGs (DIT-NVG)** – Unlike conventional BNVG configurations, which place the image intensifier tube and optical assemblies parallel to one another in front of the user's eyes, DIT-NVGs yaw the image intensifiers horizontally and diverging outward, resulting in a "double" image that overlaps in the center, increasing the user's horizontal FOV.

Of these three WFOV configurations, PNVGs have historically been and currently remain the most common and most successful WFOV NVG configuration, with systems such as the AN/AVS-10 PNVG and Ground Panoramic Night Vision Goggle (GPNVG) being commonly used in air and ground applications. In general, PNVGs provide the greatest performance of any WFOV NVG configuration, however, they do come with increased weight, complexity, and cost relative to other WFOV options.

Figure 1. L3Harris GPNVG, TNVC File Photograph

PNVG systems are able to retain performance while increasing the user's FOV through a relatively simple approach, though PNVGs somewhat less simple in execution. PNVGs simply add more sensors (image intensifier tubes) to provide more information. This then allows PNVGs to retain the performance of the two primary/central image intensifiers comprising "conventional" binocular vision, while providing the user with additional information via the peripheral tubes and increasing FOV with no loss of performance.

On the other hand, "Foveal" or "Foveated" NVG systems use specialized "WFOV" optical lenses to increase the FOV while remaining in a conventional BNVG configuration. However, as always, these WFOV lenses come with a compromise. As FOV is increased, image quality is decreased across the entire system, with particular penalties at the edges of the FOV. **Indeed, this is true even of conventional 40º optical lenses. As most lenses are designed to be viewed "straight through," optical lenses will favor the center of the user's FOV, providing the best image quality and greatest clarity in the center "zone," of the lens with varying amounts of loss of image quality and edge distortion as the user's focal point moves further from the center.** Moreover, image intensifier tubes themselves also favor the center of the output screen, which is why tube data records often used for gauging performance typically specify ***center*** resolution.

Figure 2. WFOV F-NVG AN/PVS-15 Variant[4]

F-NVG designs have been developed providing anywhere from 50º to 80º FOV depending on lens configuration, they have met with mixed success. In 2016, Kent Optronics Inc. was awarded a $47.6 Million small business innovation research (SBIR) contract by Naval Surface Warfare Center – Crane (NSWC-Crane) to explore a foveated variant of the AN/PVS-15.[3] [4] However, while both lighter and less expensive than PNVGs, F-NVGs have tended to have decreased image quality as well as increased edge distortion and image degradation at the edges of the image, and more constricted eye-boxes, limiting useable FOV or PPE use.[5] Commercial F-NVG variants such as the Armasight/FLIR/AGM BNVD-50 that opt for a more conservative FOV increase (50º circular), however they are nevertheless subject to the same constraints as other F-NVG designs.

Figure 3. AN/PVS-25 WFOV DIT-NVGs displayed at SHOT Show 2009, photo credit user SMGLee[6]

The final method of increasing NVG FOV is the use of a Diverging Image Tube configuration. In concept, Diverging Image Tube NVGs (DIT-NVGs) are relatively simple: increase user FOV by pointing the optical pods/ image intensifier tubes off to the side, rather than straight forward. The AN/PVS-25 system from the late-2000s provides an example execution of WFOV DIT-NVGs[6]. Whether or not they were previously aware of experimental DIT-NVG designs, many monocular users have invariably tried this in an *ad hoc* fashion by simply holding two monoculars up to their eyes and pointing each device out at an angle to provide a "longer" horizontal FOV.

In many cases dedicated DIT-NVGs will also utilize specialized optical lens assemblies

[3] https://www.militaryaerospace.com/power/article/16715058/navy-asks-kent-optronics-to-develop-widefieldofview-binocular-nightvision-goggles
[4] https://soldiersystems.net/2017/01/06/n-vision-optics-announces-new-wide-field-of-view-pvs-15-night-vision-binocular/
[5] "A Focus on Traditional Night Vision: Our Reliable Friend Has a Powerful New Trick." L3/Insight Technology, presented at the 9th NATO Military Sensing Symposium, May 30, 2017.
[6] https://www.m4carbine.net/showthread.php?45375-2009-SHOT-Show-Threads/page2

to compensate for image distortion and degradation related to the user looking through the NVD's optical components (both lenses and image intensifier tube) at an angle rather than straight through the center zone as with conventional BNVGs and lens designs. These specialized lenses may or may not also provide slightly increased FOV as well, increasing the center-image overlap that can benefit from binocular summation as well as improving the NVD's vertical FOV.

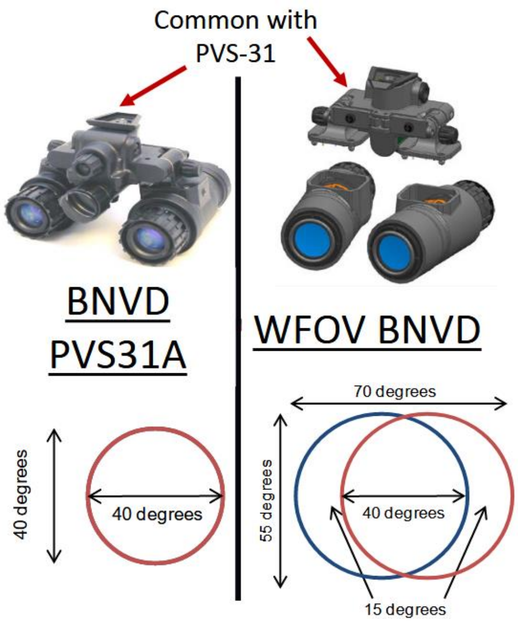

Figure 4. PVS-31A WFOV NVG Concept Render[7]

A WFOV variant of the AN/PVS-31A BNVD has been in development which provides a 70º horizontal FOV using a Diverging Image Tube format.[7] The "WFOV BNVD" PVS-31A variant also utilizes specialized optical lenses which not only increase the NVD's vertical FOV by 15º to 55ºs, but also provides the desired WFOV increase *while still retaining a 40º center image overlap.* Nevertheless, WFOV configurations are not without compromise—effectively increasing FOV results in image quality degradation that can be stated in terms of equivalent loss in Figure of Merit (FOM – Signal to Noise Ratio or "SNR" multiplied by center resolution in lp/mm). Alternatively, to maintain WFOV BNVD image quality equivalent to the specifications of the GPNVG and AN/PVS-31A, an increase in image intensifier tube FOM upwards of 13-25% is required to counteract the degradation from increased FOV.

In short, the WFOV BNVD would require a minimum 33 SNR and 82 lp/mm (2706 FOM) in order to provide the same performance as the AN/PVS-31A or GPNVG[8].

In early 2021 a small company called Noise Fighters, released a product known as the "Panobridge," a lightweight, articulating bridge system for PVS-14-style monocular night vision devices (MNVDs). In addition to allowing users to bridge MNVDs into a "binocular-like" configuration, the Panobridge also features monocular mounting arms with friction adjustable pivots, allowing the user to yaw the individual MNVDs from their neutral, parallel orientation (40º FOV) to approximately 20 degrees outboard, providing a ~75º FOV[9]. Unlike most other WFOV NVG systems discussed here, the Noise Fighters Panobridge is a retro-fit monocular bridge system rather than a dedicated WFOV goggle

Figure 5. Noise Fighters Panobridge set at approximately 55-60º FOV, TNVC File Photograph

[7] https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2017/armament/AshleyKeynote.pdf

[8] Ibid

[9] *In practice, TNVC internal testing suggests an optimal useable FOV of 55-60º horizontal FOV with the Noise Fighters Panobridge.*

system, a configuration that comes with its own unique set of advantages and disadvantages independent of WFOV systems.

Discussion:

While there is extensive room to discuss the merits of both WFOV NVGs in general as well as the advantages and disadvantages of specific methodologies to obtain WFOV, in the interests of [relative] brevity, this discussion will generally be limited to answering the basic question of: "are WFOV goggles for me?" In order to answer that question, prospective users must ask themselves a number of sub-questions, namely:

a) What does WFOV offer me? While the general benefits of increased situational awareness offered by WFOV are obvious, it is worth considering what the benefits an increased FOV would be to an individual/group's use case(s). What amount of FOV increase do ***I*** "need?"

b) To what extent am [I] willing to sacrifice resolution/image quality, which "drives… detection, recognition, and identification ranges" for situational awareness provided by a WFOV NVG?[10] Am I willing to sacrifice cost and/or weight as well?

c) What cost is acceptable to me for increased FOV, and/or what alternatives to WFOV systems do I have to increase situational awareness?

Depending on an individual or organization's answers to these questions could/should drive the choice of not only which WFOV system to select, but whether or not to pursue WFOV systems at all. In more formal settings could even be used to generate a weighted decision matrix.

While not all of the specific WFOV NVG systems discussed in this paper are available to commercial end-users and in many cases not available even to most government customers, **WFOV NVGs in one form or another are available to both commercial and government markets utilizing all of these WFOV methodologies.**

As noted earlier in this paper, in terms of raw performance, the best currently available WFOV option is likely the PNVG, providing the greatest potential performance with the fewest penalties. Moreover, the PNVGs increase to the user's FOV without performance penalty goes from 40ºs to 97ºs, a significant (>2x increase) improvement in situational awareness that provides operationally viable capability.

However PNVGs come at a greatly increased cost (~$30-40,000 per system)[11] as well as a significant increase in weight compared to many BNVGs. A portion of the increased cost of PNVGs is the increase from two (2) image intensifier tubes typically used in binocular systems to four (4), moreover these image intensifiers must be matched within reasonable performance tolerances to their companions, and aligned and collimated to provide a useable image and reduce potential user fatigue. This therefore increases the cost, time, and complexity to produce PNVGs. Consequently, both weight and cost may be significant limiting factors for many prospective users pursuing WFOV capabilities. Nevertheless, if the benefits of increased FOV and situational awareness to an individual user or organization exceeds the cost and weight penalties, PNVGs offer the fewest performance compromises of all available WFOV NVG options. Unlike other WFOV NVG systems PNVGs short circuit **the basic problem of trying to get more information out of the same sensors** by …adding more sensors.

[10] "A Focus on Traditional Night Vision: Our Reliable Friend Has a Powerful New Trick." L3/Insight Technology, presented at the 9th NATO Military Sensing Symposium, May 30, 2017.
[11] *Commercial "PNVG" systems produced in China for recreational markets and assembled in the U.S. are available at somewhat lower costs (~$20,000 range), however may be of questionable quality in terms of both materials and construction as well as optical lens performance.*

Users still desiring WFOV NVGs in but unwilling or unable to obtain PNVGs due to weight or cost will run into greater penalties in other areas in attempting to increase FOV:

> *"Increasing FOV, eye box, and/or eye relief increases eyepiece size and weight unless one of these other parameters is reduced to compensate. Increasing FOV drives resolution (detection, recognition, and identification ranges) down unless both the tube and optics are improved (or in the case of GPNVG, weight is markedly increased). Higher performing optics or adding additional tubes and optics will drive cost up 2x-3x."*[12]

In short, WFOV dual tube systems using conventional Generation III image intensifiers without modifications will always be a performance compromise. Within that context then, the question ultimately becomes "how much compromise is acceptable?" and "when does it become counter-productive?"

Widely available commercial F-NVG systems which increase the user's FOV from 40º to 50-51º do not likely justify the performance penalties incurred, particularly when many such systems use lower cost optical lenses with even more significant image distortion and degradation than those used in F-NVG systems tested by the government. This image distortion and degradation combined with a marginal increase in FOV (increasing scan pattern by a scant 5º would eliminate any situational awareness advantages of the increase—most end-users already and instinctively scan both horizontally and vertically while using conventional 40º NVDs).

More promising than more conventionally configured F-NVGs appears to be a hybrid foveal/Diverging Image Tube format such as the one used on the WFOV BNVD, using lens assemblies with slightly increased FOV and optimized for use in a DIT format BNVG. With both PNVGs and hybrid systems like the WFOV BNVD, users are able to retain a binocular overlap of 40ºs in addition to expanded FOV, making transition easier for users accustomed to traditional BNVG configurations and allowing binocular summation, increasing perceived performance, compensating for some of the performance loss inherent in the WFOV configuration in the case of the WFOV BNVD. However while hybrid Foveal/Diverging systems are under development and government testing, they are not widely available at this time.

Figure 6. Individual TNV/PVS-14 MNVDs mounted to Noise Fighters Panobridge, TNVC File Photograph

Among widely available WFOV NVG systems, the Diverging Image Tube format Noise Fighters Panobridge (PB) is unique in and that it is not a dedicated WFOV NVG, but rather a bridge accessory for individual MNVDs. The PB is not without several significant penalties in terms of both performance and weight. While the PB itself is extremely lightweight due to its construction, even without the Panobridge, two individual MNVDs outweigh most commonly available BNVGs.

Beyond that, as the main attraction to bridged MNVDs in general is the ability to use unaltered PVS-14 style MNVDs that may already exist in inventory (or be owned by an individual) in a binocular configuration without permanent

[12] Ibid

modifications. However, this also means that unlike other DIT-NVGs such as the WFOV BNVD, MNVDs configured in the PB do **not** utilize lens assembles optimized for the DIT format, but rather, conventional PVS-14-style optical lenses.

While on the one hand this means that they do not experience the loss of performance of WFOV lenses, because they are designed to be viewed “straight through,” they suffer from significant image distortion and degradation and loss of image quality when viewed through the extreme edges. Consequently in field testing the performance loss of the PB/dual PVS-14 configuration was perceived to approach approximately 20-30% compared to viewing directly through the device with the effects to resolution being particularly marked.

Based on a low-end estimation of performance loss, this would equate to a system with 2000 FOM image intensifiers performing at a roughly similar level to 1600 FOM image intensifiers in a traditional binocular. And while in many cases 1600 FOM (e.g.,) is more than adequate for many applications (particularly ground-based), given that in many cases system cost (both in terms of image intensifiers and finished goods) is directly related to tube performance, this represents a significant loss[13].

Moreover, while the theoretical maximum FOV provided by the PB is 75º, based on a combination of image and performance degradation and HFE (Human Factors Engineering) relating to interpupillary distance (IPD), system height, and helmet mount adjustment range, the useable FOV is limited to approximately 55-60º, or an increase of 15-20º from traditional BNVG systems as well as an improvement over widely available F-NVGs. Furthermore, at the maximum FOV of 75º, the user’s image overlap that benefits from binocular summation is limited to 5ºs (at 55ºs the image overlap for binocular summation is 15ºs).

Nevertheless, the Noise Fighters Panobridge has two (2) significant advantages over other widely available WFOV NVG systems:

a) **The Noise Fighters PB, by nature of its adjustable FOV design allows users to return their goggles to a conventional parallel tube configuration at any time** by rotating the MNVDs back to the “center-neutral” position, and allowing users to determine if and when WFOV is beneficial or desired versus dedicated WFOV systems where in many cases, end-users must guess at their needs and priorities without significant experience with WFOV systems and returning to conventional BNVGs requires total system replacement. While using the PB in a conventional parallel tube format retains the disadvantages of bridged MNVDs such as lack of image collimation and independent control interfaces, it is nevertheless a serviceable option for those choosing to use separate MNVDs rather than dedicated BNVGs.

b) **Cost.** For better or for worse, cost is often a driving factor in equipment decisions, whether for commercial or government customers. In most cases, WFOV NVGs represent a significant increase in cost over conventional NVGs, with PNVGs often costing 3-4x as much as conventional BNVGs of similar performance. In contrast, the PB is extremely cost effective.

Conclusions:

At the time of this writing (17 July 2021), for most user’s operational needs conventionally configured NVGs likely continue to represent the best value in terms of image quality/performance, HFE, and cost. While the 40º FOV of conventional NVGs is a known limitation, use of active scanning techniques, multi-spectrum sensors, and interlocking fields of observation from multiple sensors can, in most cases, effectively mitigate, if not eliminate these limitations.

[13] While the performance loss is here expressed in rough FOM values for simplicity, due to performance loss when moving away from the center of the image intensifier tube coupled with edge-to-edge distortion and loss of clarity, resolution and SNR do not degrade in a linear way—at a 20% loss a 72 lp/mm system would behave more closely to a 57 lp/mm system.

While the benefits of the increased situational awareness and FOV offered by WFOV NVGs are both obvious and considerable, for most users existing available WFOV NVGs carry too many penalties, whether in terms of weight, cost, or performance, or a combination of the three to justify those gains. Of the available options, PNVGs provide the greatest performance, but also the greatest weight and greatest cost. However, if weight and cost are not an issue, or the costs of **not** having the increased situational awareness of a WFOV NVG system outweigh them, PNVGs offer considerable advantages to conventional BNVG systems.

The Noise Fighters Panobridge offers some increases in potential FOV compared to conventional BNVG systems, but once again presents significant penalties in weight and performance when used in WFOV configuration. However its low cost of entry and the ability to quickly and easily return the system to a more traditional configuration makes it a potentially attractive option for those who may have occasional need for increased FOV at the cost of image quality or who simply want to explore and experiment with WFOV systems without spending considerable sums on a dedicated system that may or may not meet their needs. Nevertheless, as it is still fundamentally a bridged MNVD it continues to have disadvantages in terms of weight, image quality, and HFE compared to dedicated BNVGs.

Perhaps the most important conclusion, however, is to reinforce that FOV is not the sole or even most important consideration with regards to increased situational awareness, whether on the battlefield, in law enforcement work, hunting, or recreational use. In many cases there are multiple ways of improving situational awareness, often to a far greater degree than simply increasing the I^2 FOV, ranging from technology-based solutions such as employing multiple spectrums such as LWIR (thermal) and others, augmented reality, C4ISR systems and networks, to more holistic solutions such as mindset, training, and basic TTP (Tactics, Techniques, and Procedures) refinement.

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