

Wide field-of-view digital night vision head-mounted display

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1. INTRODUCTION

Night vision has been a key enabling technology for the past 30 years that has allowed US pilots to “own the night”. In many engagements, our dominance of the nighttime environment was the decisive factor in victory. One of the big disadvantages of night vision systems is that they have not provided pilots with good peripheral vision, since most have a total field of view (TFOV) of only 40 degrees. A large survey of USAF pilots found that the most often requested improvement to night vision goggles was to have a larger field of view.¹ Wide field of view night vision goggles, such as the PNVG and QuadEye systems were designed to address this need. In the 15 years since the PNVG was designed, tremendous advances have been made both in microdisplay technology and high-resolution digital night vision sensors, which enable a new class of wide field of view digital night vision systems.

SA Photonics has developed a wide field of view digital night vision system for use by fixed-wing and rotorcraft pilots. This system can be attached to off-the-shelf aviator helmets and provides significant advantages compared to existing night vision goggles. The results of the design and preliminary testing of this HMD are given below, along with a discussion of future upgrades to the system.

2. HRNVS OVERVIEW

The 82.5 degree high resolution night vision system (HRNVS) module developed by SA Photonics is shown in Figure 1. This design was driven by our goals to 1) improve resolution, 2) reduce weight, 3) improve center of gravity, 4) reduce forward projection and 5) reduce peripheral obscurations compared to existing conventional wide field of view night vision systems, while providing the advantages of a digital night vision system.

HRNVS utilizes two solid-state digital night vision sensors per eye and couples them to a single high-resolution microdisplay. By designing an eyepiece without tiles or seams, the user will have a panoramic view of the night vision imagery without the visual distractions caused by using multiple displays or eyepiece optics per eye.

2.1 HRNVS features

There are a number of advantages in having a digital high resolution, wide field of view night vision system like the HRNVS. These include:

- Reduced peripheral obscuration. As can be seen in Figure 1, there are very little obscurations in the operator’s field of view besides the small eyepieces. This design preserves much of the operator’s up and downlook, especially compared to ANVIS and PNVG systems.
- HRNVS has a much reduced forward projection and swept volume than the ANVIS or PNVG systems. This will allow the operator to perform aggressive head maneuvers without worrying about striking the canopy



Figure 1: HRNVS Prototype

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- Increased performance. An 80 degree field of view provides much better situational awareness than current ANVIS night vision goggles do. The increased optical performance will mean that when a pilot pulls Gs the imagery will not degrade unlike existing panoramic night vision goggles under g-load.
- Zero-halo. The digital night vision sensors have a proprietary halo reduction structure that reduces halo around bright light sources to near-zero.
- Ability to stow each eyepiece independently. HRNVS has independently stowable eyepieces and a novel stowage mechanism. Instead of flipping upwards like ANVIS or the PNVG system, making a too-high, too-forward CG even worse, the combiners on HRNVS simply pivot out of the way, hardly changing CG at all. In the stowed position the HRNVS does not block the operator's peripheral vision at all, what they see is just determined by the extent of the helmet.
- Capability for image enhancement. A digital night vision system provides the ability to enhance night vision imagery by contrast/edge enhancement, speckle reduction, symbology overlay and video recording, none of which are possible with existing night vision systems. We will implement these features on the next-generation HRNVS, discussed in Section 5.

2.2 HRNVS architecture

Figure 2 is a block diagram for the HRNVS system. The major subassemblies are:

- Digital night vision sensors
- Custom objective lens with stray light rejection
- Video processor and electronics
- Helmet mounting system
- Adjustment system
- Digital microdisplay
- Eyepiece optics

There are four night vision sensors, two left and two right. Each sensor has an objective lens to focus the object. Each pair of sensors is processed into a single video stream which is fed into each eyepiece. Each eyepiece consists of a microdisplay and eyepiece optics. The adjustment system positions each eyepiece independently for each user and the helmet mounting system attaches the HRNVS to any standard flight helmet via a custom interface kit. Each of these systems will be discussed in more detail in the next section.

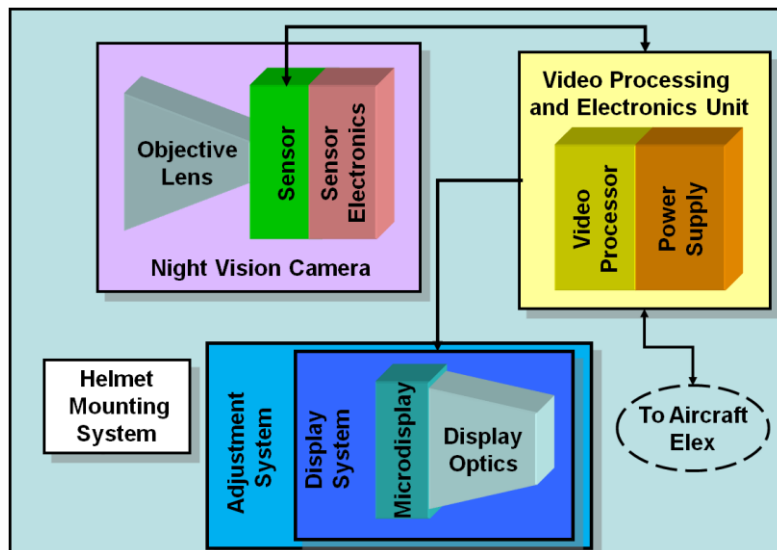


Figure 2: HRNVS Block Diagram

HRNVS' 80 degree field of view is achieved through partial binocular overlap. The architecture is shown in Figure 3. The top of the figure shows the layout of the night vision sensors and the bottom part of the figure shows the layout of the eyepieces.

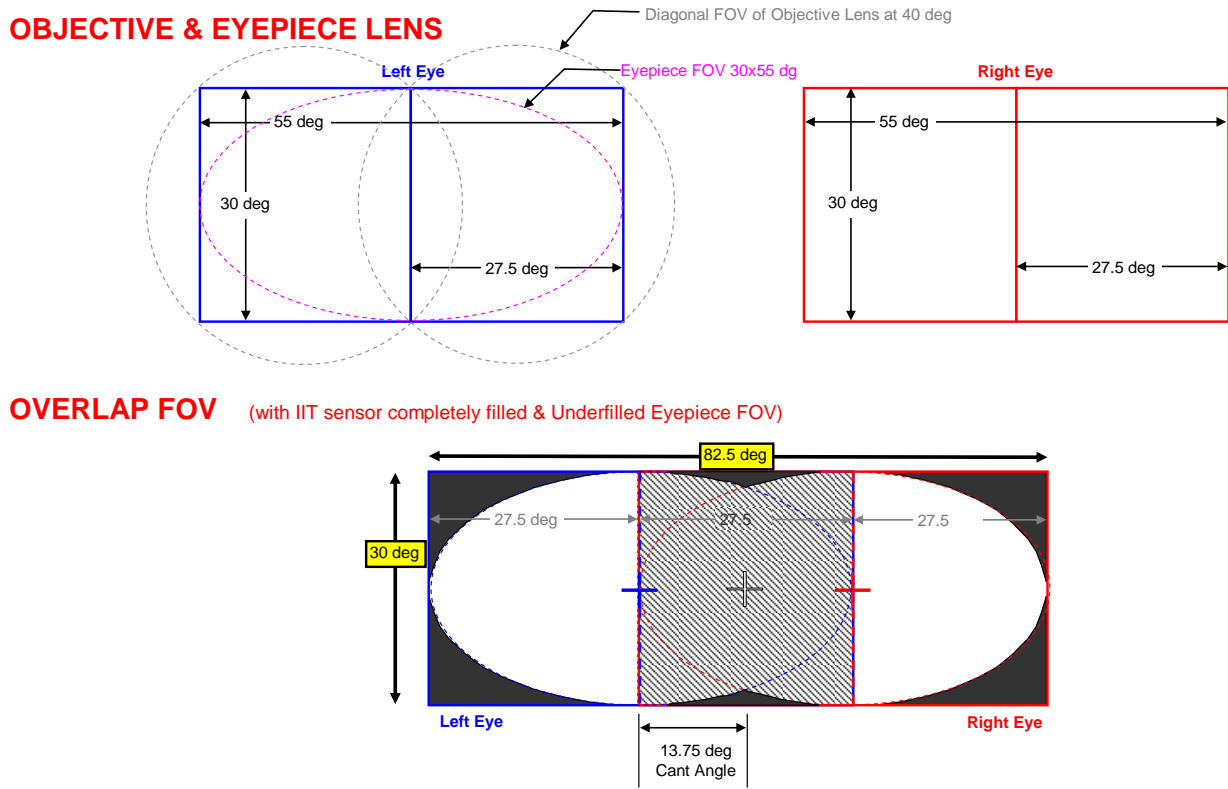


Figure 3: HRNVS Field of View and Layout

The night vision sensors each have a horizontal field of view of 27.5 degrees and two night vision devices feed into each 55 degree eyepiece. Each square represents the used area of the night vision sensor and the dashed circle represents the field of view of the objective lenses, which overfill the sensor.

Each eyepiece has a 55 degree horizontal field of view and is overlapped by 27.5 degrees. The eyepieces are canted at a 13.75 degree angle so that the field of view is centered with respect to the eyepiece.

3. SYSTEM DESIGN

Each of the subsystems listed in the previous section will be discussed in more detail below. System performance will be discussed in the following section.

3.1 Digital night vision cameras

The digital night vision cameras are Intevac Model ISIE 11 EBAPS (electron bombarded active pixel sensors). They have a GaAs photocathode, just like standard Gen III night vision goggles. Behind the photocathode is a Silicon CMOS sensor, which provides the digital output. A high voltage potential is applied between the photocathode and the sensor. This voltage accelerates photoelectrons and provides gain when the photoelectrons strike the sensor. The ISIE 11 sensors consist of 1600 x 1200 square pixels arranged on a regular grid. There is a finite spread as the electrons are imaged, which reduces the resolution or modulation transfer function (MTF) of the sensor, as will be shown in Section 4.

The Intevac ISIE 11 camera consists of 5 boards, which we removed from their original housing and repackaged within our HMD. We designed a set of custom flex cables to connect the boards together (they are normally connected in a camera via edge card connectors) in an orientation such that they fit in our HMD housing. We also designed a set of custom jumper cables to replace the shorter jumper cables that are standard on this camera. The end result is a digital night vision camera that can be folded up to fit within an HMD housing.

3.2 Custom objective lens with stray light rejection

The objective lens for the HRNVS has been custom designed for the EBAPS sensor by SA Photonics. This objective lens has very good performance over the entire field of view and has been designed with a wide chromatic bandwidth so it can operate well both with NVIS filtering and unfiltered. The measured performance of this lens is given in Table 1.

Table 1: HRNVS Objective Lens Performance

Objective Lens Parameter	Value	Comments
Diagonal Field of View	40 degrees	Can be used with any 18 mm night vision imager, analog or digital
F/#	1.25	A fast F/# provides for high sensitivity in low ambient light environments
Bandwidth	400-900 nm	Provides good performance for unfiltered operation
Maximum Distortion	-5.2%	Compensated by eyepiece distortion and electronically
Relative Illumination	75%	The edge of the field is only 25% less bright than the center.
Veiling Glare	0.4%	Provides very good stray light performance
Focus Range	12" to infinity	Allows for use inside of cockpits and cargo areas as well as viewing outside the aircraft

It has been reported to us by the Air Force that current night vision goggles can have a problem with veiling glare due to “excess leakage” in the night vision goggle NVIS Class C (leaky green) filters. This is so because the Class C filter is designed to let only a small amount of green light through from the HUD when viewed on-axis. Off axis, the filter shifts its wavelength response, allowing excess green light to leak in, which reduces the contrast of the night vision goggle. We have designed the HRNVS lens to have two filter positions. The first position is at the front of a lens, where users may easily add standard NVIS filters. The second is at the rear of the lens. This rear filter position uses the objective lens housing itself to reduce the incident angles to the filter, thereby reducing any “leakage” seen from cockpit displays. This filter is removable, but should be done in a clean environment (not in the field). We believe that this design will prove beneficial to all users who use the Class C filter. We have made a set of Class C rear-mounted filters and intend to test them in an operational environment.

3.3 Video processor and electronics

To maximize the benefit from a digital night vision system, a high speed video processing system is needed. Because we wanted to be able to retrofit this system easily into existing airframes, we did not want a system that would need a large electronics box installed into the aircraft. As such, we needed a state of the art video processing system that could be mounted on the helmet or in a chest pack eventually. Rockwell Collins Display Systems (RCDS) is developing their MicroCore™ system with funding from Vision Systems International (VSI) and the U. S. Government. MicroCore™ will provide on-helmet processing technology key to producing a high resolution digital vision system.

HRNVS currently uses a desktop electronics unit (DEU) which contains a prototype version of the MicroCore™ processor. These electronics will eventually be implemented in a chest pack or in the HMD fairing. The electrical system block diagram and data path is shown in Figure 4. The electrical system consists of the 4 sensors which send imagery to the MicroCore video processor. This video processor then outputs imagery to the left and right displays. In

In addition to tiling the two sensors per eye into a single display, the DEU also performs digital distortion correction and image resizing and resampling.

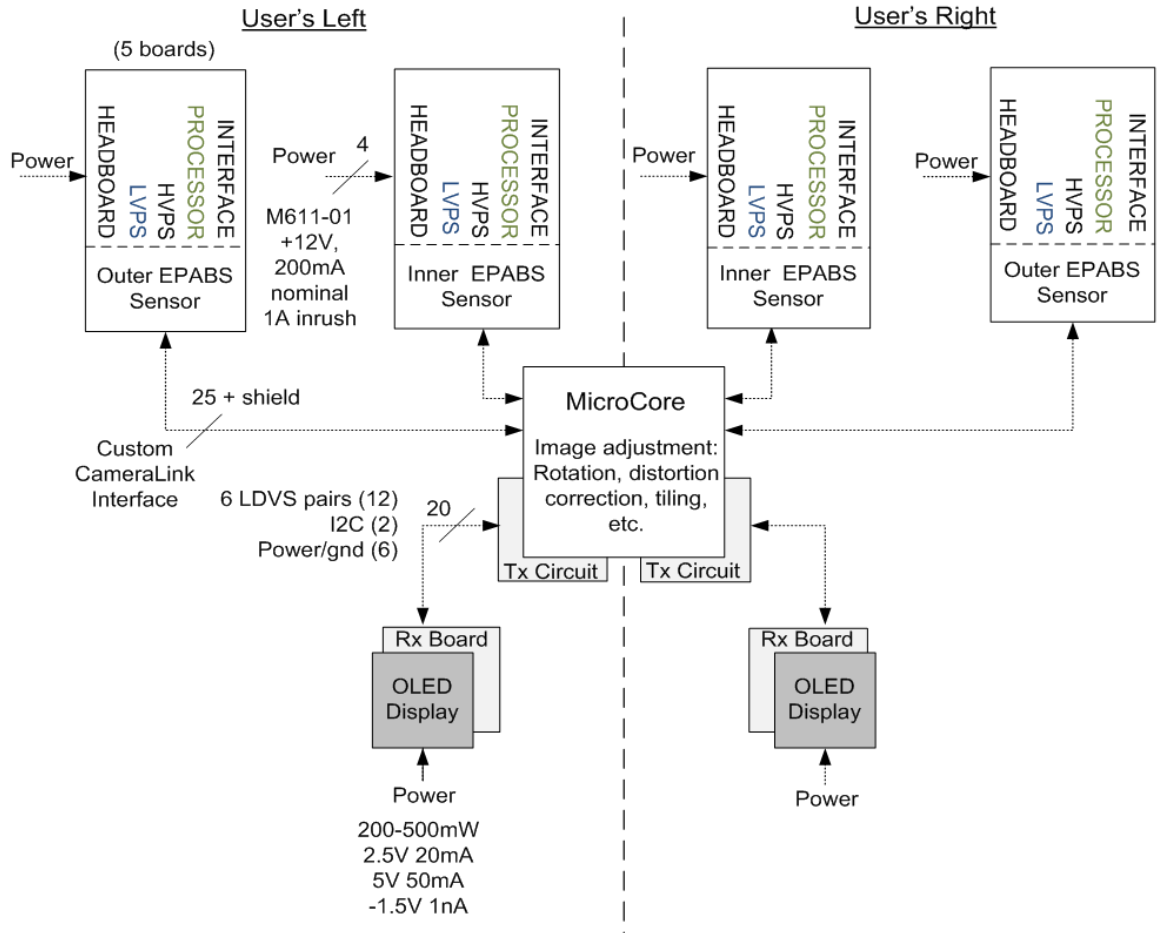


Figure 4: HRNVS Desktop Electronics Unit Block Diagram

Shown in the block diagram are the five boards that are part of each Intevac camera. Future HRNVS systems will have a reduced board count, but to minimize program risk we just repackaged the Intevac boards as-is, using custom mounts, flex cables and jumper cable sets designed by SA Photonics. The interconnection between these five boards is shown in Figure 5.

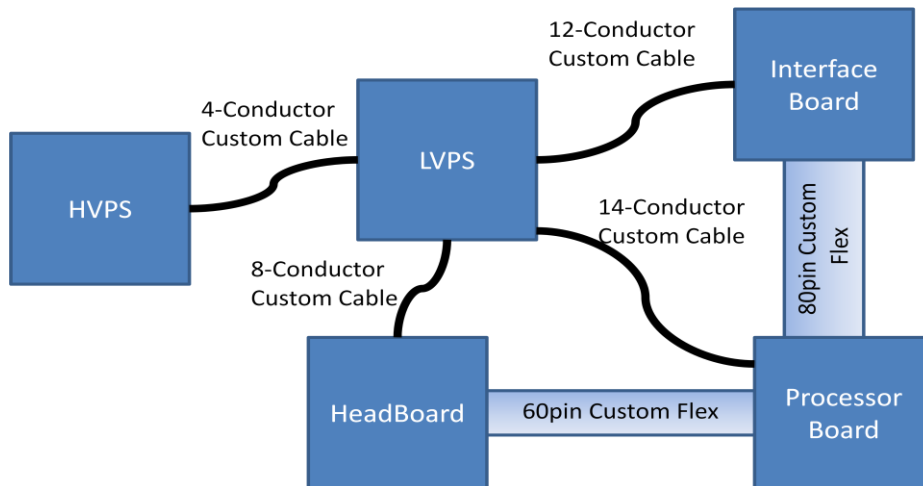


Figure 5: Interconnect Diagram Showing SA Photonics-designed Custom Flex Cables and Jumper Cables

The power distribution system consists of a single input voltage which is then regulated to supply the sensors, displays and video processor.

3.4 Helmet mounting system

The helmet mounting system allows the HRNVS to attach directly to an HGU 55 or 56/P helmet via an interface kit that uses a standard night vision goggle mounting plate attachment, as shown in Figure 6. We are also developing a kit to interface to an HGU-84/P, SPH-4/5 and the next generation of two-part helmets like the MACH helmet.



Figure 6: HRNVS Mounting Kit

3.5 Adjustment system

The adjustment system adjusts the fore/aft, vertical and interpupillary distance (IPD) of the displays. It has been designed to address the widest possible range of users, based on anthropometric studies done by both the USAF and the Army. The adjustments were designed to be easily operated one-handed with a gloved hand.

The adjustment ranges are shown in Table 2.

Since the stowed position, shown in Figure 7 is flat against the side of the helmet, and because we minimized the forward projection of HRNVS, the total swept volume, as shown in Figure 8, is much less than for PNVG or ANVIS. This means that pilots will have more freedom to turn their heads in the cockpit (especially for a “check 6” manoeuver) without worrying about impacting the canopy in either the deployed or stowed mode.



Figure 7: HRNVS with stowed eyepieces has no peripheral obscuration and a very low swept volume

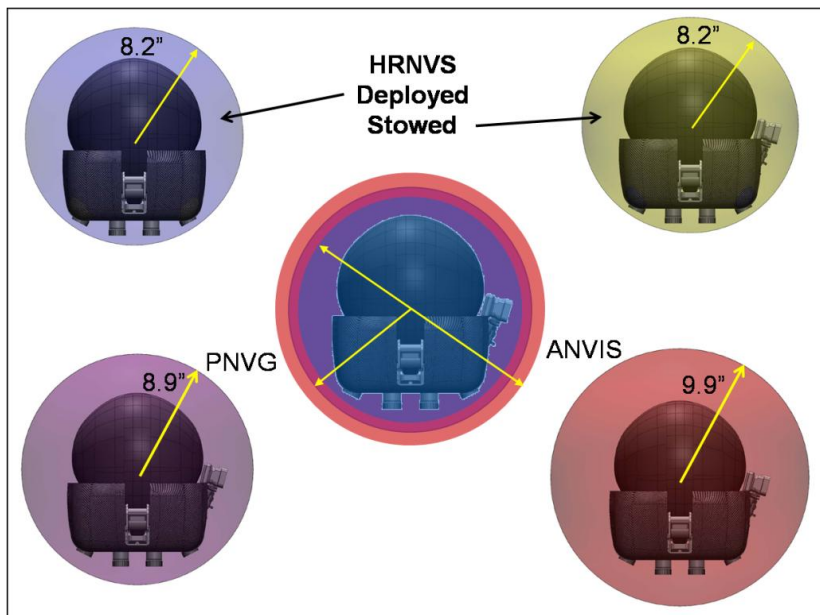


Figure 8: Both the Stowed and Deployed HRNVS System Have a Reduced Swept Volume Compared to ANVIS and PNVG

The adjustment range for the fit system is shown in Table 2. These adjustments have been designed to address the 1st percentile female through 99th percentile male population.

Table 2: HRNVS adjustment range.

Adjustment	Range (mm)
Interpupillary Distance (IPD)	55-75
Vertical	36
Fore/Aft	36

3.6 Digital microdisplay

We have selected eMagin’s SXGA (1280 x 1024 pixel) OLED display as the microdisplay source for HRNVS. This display has a small size and requires no front or backlight, which reduces the size and weight of the eyepiece, as well as simplifies the packaging and electronics requirements. The eMagin display (like many color microdisplays) has a pixel (shown in Figure 10) that consists of 3 sub-pixels, one for each primary color.

Using an eMagin display without the color filters allowed us to have a almost 4 megapixel display with 3840 (3 x 1280) by 1024 pixels per eye. Since these pixels were rectangular, we needed an anamorphic eyepiece to stretch them horizontally. This eyepiece is described in the next section.

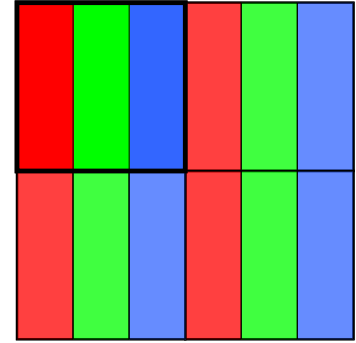


Figure 9: Striped Pixel Configuration (one pixel is shown inside bold line at upper left)

3.7 Eyepiece optics

Using the eMagin eyepiece without color filters would yield a display with three times as much resolution in the horizontal direction than the vertical direction for a given magnification. To stretch the horizontal pixels from a rectangular to a more square profile, we developed a patent pending anamorphic eyepiece which has a horizontal magnification that is greater than its vertical magnification, this helps balance out the vertical and horizontal resolution and allows for a large horizontal field of view. This eyepiece is very compact (46 mm wide x 28 mm high x 42 mm deep) and has good optical performance, as shown in Table 3.

Table 3: HRNVS Eyepiece Performance

Eyepiece Lens Parameter	Value	Comments
Horizontal Field of View	55 degrees	This large horizontal field of view, combined with a partial binocular overlap, provides for a very large 82.5 degree system horizontal field of view
Vertical Field of View	30 degrees	Vertical field of view is limited by the number of pixels on the microdisplay, improvements are planned to increase this resolution and field of view, as is discussed in Section 5
Focus	-0.5 Diopter	A fixed focus eyepiece avoids the problems seen in variable focus night vision goggles. The -0.5 diopter distance was chosen because it represented a balance between infinity focus and the -0.75 diopters average setting selected by pilots for best performance in the ANVIS system ²
Eye Relief Distance	25 mm	This eye relief distance provides sufficient clearance for personnel wearing military spectacles.
On-axis Exit Pupil Diameter	11.5 mm (vertical) 8.5 mm (horizontal)	The horizontal exit pupil diameter was within our measurement accuracy of the design value of 12 mm. The vertical exit pupil diameter was smaller than we expected, but will still give good performance. We will address increasing this in our next-generation design.
Exit Pupil Diameter at Full-field	7 mm	7 mm was also our design value, which will provide good performance at the edge of the field.

4. SYSTEM PERFORMANCE

We have completed the testing of the HRNVS system. The results of these tests are given in Table 4. We believe that this is the first wide field of view digital night vision system ever built and we were very pleased with the performance of this initial prototype. We discuss potential improvements to the system in Section 5.

Table 4: HRNVS System Performance

Specification	Value	Comments
Horizontal Field of View	82.5 degrees	This large field of view will provide for a very good situational awareness
Vertical Field of View	30 degrees	The vertical field of view was limited by the microdisplays, we will increase this in the next-generation design.
Binocular Overlap	27.5 degrees	This overlap was chosen as it allowed for an easy stitching of the two night vision sensors, with each filling one half the eyepiece field of view
Pixel Count	7.9 Mpix total	We believe this is the largest pixel count night vision HMD ever built
Forward Projection	<2.9"	This forward projection is almost 2" less than ANVIS
Halo Diameter	0.0 mm	By design, using Intevac's zero-halo sensors
Distortion (compensated)	<1.0%	By analysis. This is electronically compensated by the video processor

The system modulation transfer function (MTF) curves are shown in Figure 10. These curves give the modulation (or contrast) as a function of spatial frequency, expressed in cycles (line pairs) per milliradian. The curves shown in Figure 10 are actual measured performance and not design curves.

The MTF curves show the contribution for each system component including the microdisplay, the objective lens, the eyepiece and the EBAPS sensor. Since MTF is multiplicative, the system MTF is just the product of the individual sub-system MTFs. The display MTF is 100% up to the Nyquist resolution of the display, where it then drops to zero. In the vertical direction, this happens at 1 cy/mr. Since there are more pixels in the horizontal direction, even with the larger field of view and anamorphism, the display does not reach cutoff until well above 1.2 cy/mr. No matter what we do to increase the other elements' contribution to the vertical system MTF, cutoff resolution (the place where the MTF drops to 2%) is dominated by the MTF of the display. We have plans to increase the vertical display resolution, as discussed below in Section 5.

We can see from the curves the subsystem that reduces the MTF the most at all frequencies is the EBAPS sensor. Although it is a digital sensor, it does not have an MTF like the digital display does. This is so because as electrons propagate through the sensor, they have a finite spread to them, which reduces the resolution and MTF. Intevac is working on improving the MTF, which will help with future systems. The next contribution to system MTF is the objective lens. We have already brainstormed ways to improve the performance of the objective lens even further, raising its (and the system's) MTF. The final system to contribute to the MTF is the eyepiece. Although the eyepiece isn't perfect, we feel that the eyepiece design worked out very well and given the fact that it is anamorphic, we are quite pleased with its MTF values.

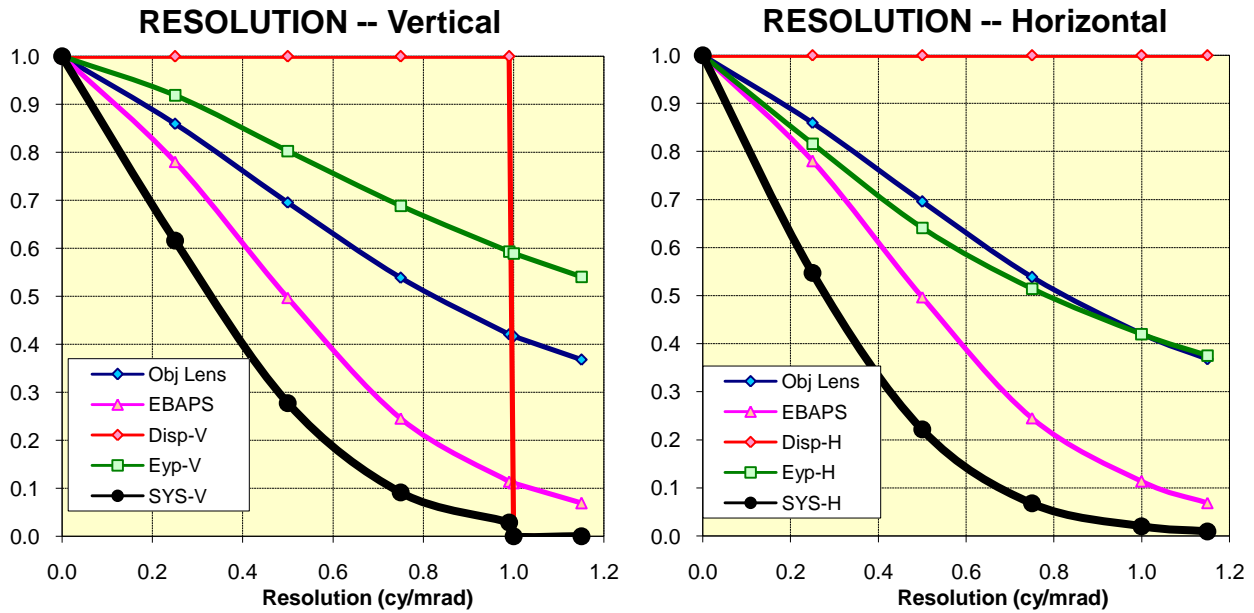


Figure 10: Vertical and Horizontal MTF Curves

5. FUTURE UPGRADES

Since this was the first digital night vision system SA Photonics built, we wanted to take an appropriate amount of risk so that the system would be buildable. As such, there are improvements and upgrades that can be made to the system with additional time and funding. The primary improvements are to reduce the size and weight of the HMD and electronics as well as to provide additional video processing capability. We also plan on increasing the performance of the system, including increasing the field of view and making it a color system. Each of these improvements will be discussed further below.

Table 5 gives the predicted performance of the next-generation HRNVS system. Having a working prototype dramatically reduces the risk of implementing these upgrades, as compared to doing this from scratch.

Table 5: Predicted Performance of Next-generation HRNVS

Specification	Value	Comments
Horizontal Field of View	100 degrees	This extremely wide field of view should give operators very good situational awareness
Vertical Field of View	45 degrees	Increased vertical field of view compared with ANVIS should provide increased situational awareness
Binocular Overlap	30 degrees	A 30 degree overlap should strike an appropriate balance between overlap width and total field of view
Visual Acuity	20/25 Snellen	The visual acuity of this system will be better than existing ANVIS systems with more than double the field of view
Exit Pupil Diameter	12 mm	A large exit pupil will provide stable imagery even with aggressive head maneuvers and while pulling large g-forces
Eye Relief Distance	30 mm	A large eye relief will allow this display to be worn with all military spectacles with ample clearance
Display	Color	A color display will provide for more intuitive symbology and allow the display of color maps, if desired.

The size of the HMD is driven primarily by the large number of boards from the Intevac cameras. With five boards per camera and four cameras in the system, the 20 boards take up a lot of room within the fairing of the HMD. By combining functionality and by sharing repeated functions among multiple cameras we believe that we can dramatically reduce the total number of boards, and hence the size, of the HMD.

In building the prototype unit we tried to minimize weight, but we believe that there are significant weight reductions still possible in the HRNVS system, given more time and funding. We will evaluate using lighter weight materials (carbon fiber instead of aluminum) where possible. We will also be able to reduce the weight of the support structure once we reduce the number of boards present in the system.

We also plan on working with Rockwell Collins to reduce the size of the DEU, first to a size that can be worn on the chest and ultimately to be a size that can be worn on the head. We also plan to add additional image processing capability, including:

- Contrast and edge enhancement
- Video compression and recording
- Symbology overlay
- Scintillation (speckle) reduction
- Sensor fusion

None of these operations are currently possible with traditional night vision sensors. We feel that the “digital advantage” will bring a significant increase in utility to operators above that provided by conventional night vision goggles.

6. CONCLUSIONS

SA Photonics has successfully created a digital wide field of view night vision system that can be easily attached to a flight helmet. This system provides increased situational awareness and is easy to adjust and use and stow. The reduced swept volume of the system will allow users to turn their head in the cockpit without worrying about striking the canopy and the reduced peripheral obscuration will provide for more natural viewing. As part of the evaluation of this system, we have also identified future improvements for the next generation digital night vision system including making it color and increasing the field of view.

ACKNOWLEDGEMENTS

SA Photonics gratefully acknowledges the financial support of the USAF, Army and VSI under SBIR Phase II Fast Track contract number FA8650-09-C-6018.

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