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ASSESSMENT OF THE MODULATION TRANSFER FUNCTION (MTF) RESPONSE OF A FIBER OPTIC SIGHT (FOS)

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14. ABSTRACT

The modulation transfer function (MTF) of a fiber optic sight direct view optic (DVO) was tested to show potential performance benefits. The MTF tests were also evaluated with representative optical filters to resemble real-life, fielded conditions.

15. SUBJECT TERMS

Modulation transfer function MTF Fiber optic Fiber optic sight Optical filter Direct view optic DVO

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INTRODUCTION

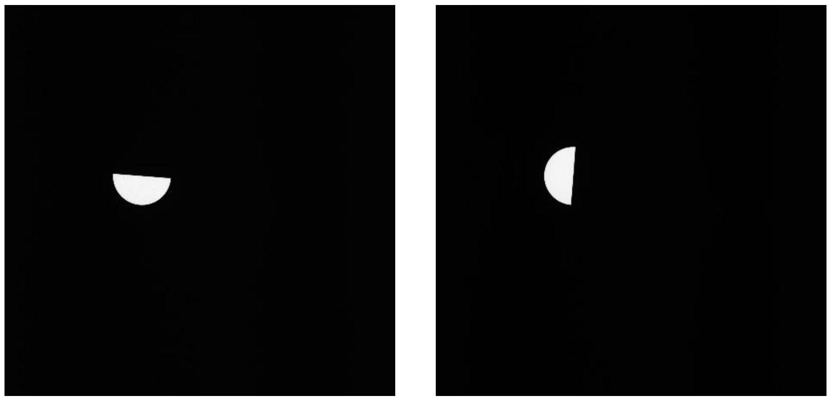
The fiber optic sight (FOS) is currently a prototypical system that consists of an objective lens, a series of mirrors and relay lenses, and an eyepiece that is rigidly mounted. The objective is coaligned to the bore of the weapon and travels in unison when the weapon is moved. In relation to the FOS itself, the eyepiece can only move in an up and down fashion as a result of a fixed extension between the main assembly and the eyepiece. A secondary design was configured by replacing the rigid assembly with a semi-flexible fiber optic tubular assembly. This design reduced the FOS's weight and can potentially allow more options for placement and functional use within the confined space that is typical of the constraints on a military vehicle. The end state of this project is to match and/or exceed the optical response of the current configuration in terms of measurable characteristics such as increased modulation transfer function (MTF), reduced aberrations, minimized distortions, and higher light transmission passing through the system as a whole. Previous tests on the current FOS system and fiber optic version have shown transmission values of approximately 20 and 6.7% across the photopic, respectively. However, the fiber optic prototype version is still in development and manufacturing design will likely minimize the differences as the system is optimized.

The measurement of the MTF was accomplished using a setup that met the requirements set within International Organization for Standardization (ISO) 14490 part 7 and 15529. The test collimator system in use was manufactured by the Santa Barbara Infrared Inc. (SBIR) company and used a polychromatic white light source that was predefined with the following settings: luminance = 1379.3 ft-L, target range = infinity, and color temperature = 2856K. The general layout of the testing device is shown in figure 1, which does not include the FOS inspection piece. The SBIR systems light source is projected through a series of targets that are then transmitted onto a series of mirrors that collimate the light output onto an external mirror that the inspection piece is aligned with. The camera in use, manufactured by Allied Vision Technology, Newburyport, MA, was built with a KAI-04022 sensor in a 2048x2048 pixelated area array with each pixel pitch measuring 7.4 µm. The camera used a focusing lens that was optimally set and affixed using the ISO 14490 part 7 compliant resolution target pattern until the resolution of the line pairs reached a pixelated threshold. This meant the resolution of the camera was the limiting factor in the detection of the line pairs.

Figure 1
Photograph of the SBIR measuring device and system

CAMERA BASELINE

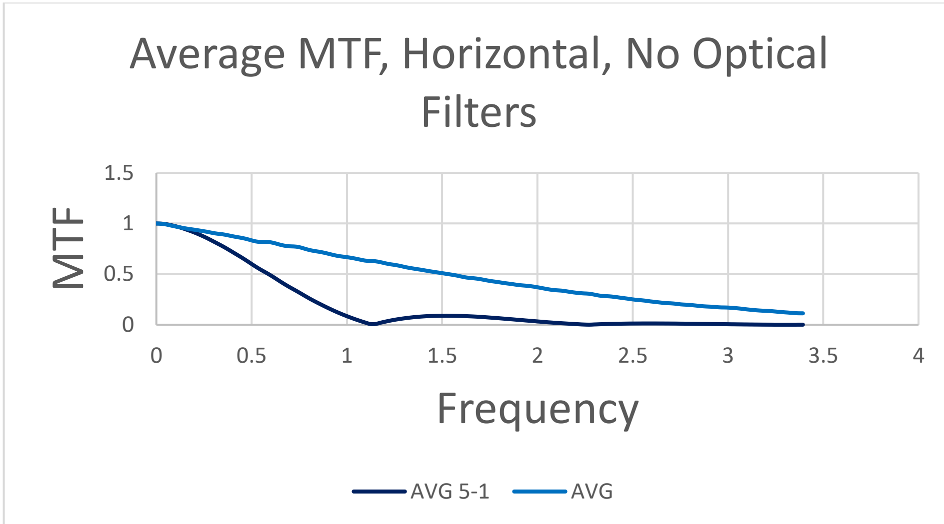
The first step in preparation of assessing the FOS system was to quantify the baseline response of the camera and system as a whole without the inspection piece in place. The resulting image in figure 2 shows the visible contrast differences between the illuminated target area (bright white region) and the unilluminated background (black region) as seen just through the camera for both the horizontal and vertical MTF targets. The most common point of comparison for optical and digital viewing systems is the spatial frequency that occurs at 50% modulation. This was the main point of interest that was reviewed to assess test responses. The resulting measurement of the MTF for the camera baseline is shown in figure 3.



(a)
Horizontal target

(b)
Vertical target

Figure 2
Camera image of the horizontal and vertical MTF targets



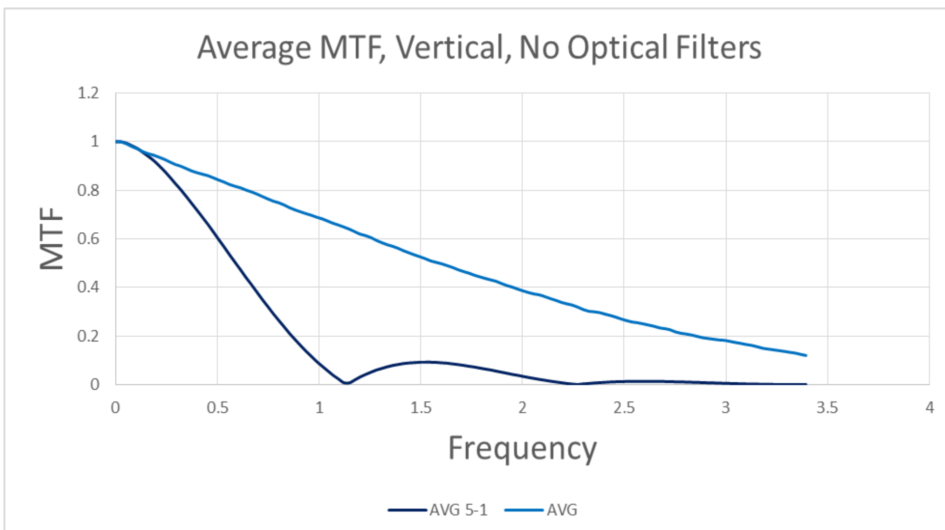


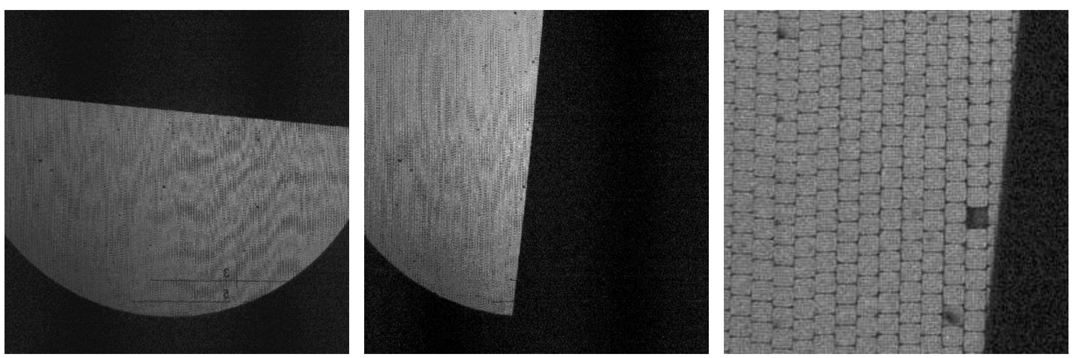
Figure 3
MTF curves for the camera baseline using a 10-frame average for both the raw data curve (light blue) and the digitally processed curve (dark blue)

During the testing in this experiment, it was found that digital filtering of the MTF values and curves was necessary in order to optimize all the variables in a fixed format that could be sustained throughout the entire process. The software provided with the test collimation system contained two digital filters: the pedestal and the smoothing functions. The smoothing function put simply is an averaging tool that assists in removing unwanted noise and variability in the sampling between frames by using the mean and standard deviation of each pixel in relation to its adjacent pixel values. The pedestal function is an additional noise reducing processing tool but uses a method such that no value can drop below a specified level. In most cases, this avoids noise that would result in a value less than zero or far beyond the standard deviation of the mean values collected for a specific pixel, pixel row, or pixel column. The baselining of the camera showed that a noticeable variation occurred between the raw unprocessed curve versus a curve with a smoothing value of 5 and a pedestal value of 1 that were found to be necessary to acquire MTF data for the FOS. The output of the MTF for the camera can be seen in figure 3. The cycles per mradian at 50% modulation were approximately 1.52 and 0.60, respectively, for the raw and processed data on the horizontal target. The cycles per mradian at 50% modulation were approximately 1.58 and 0.60, respectively, for the raw and processed data on the vertical target. These values remained constant throughout the remainder of the assessment of the FOS to sustain consistency from the baseline. The need for this processing was mainly determined to be a result of low light transmission levels through the FOS when advanced optical filtration is tested.

FIBER OPTIC SIGHT RESULT

The second stage of this experiment was performed by placing the FOS system into place, aligning the mirrors, verifying the focus of the camera and FOS were optimized, and ensuring the fiber optic was mounted in a stable position and the camera was aligned sufficiently with the eyepiece of the FOS fiber assembly. All the data gathered in this experiment was acquired with low light conditions such that the room lighting was not a measurable variable in the amount of noise that was seen within the test setup. In this case, all the direct lighting in the test area was off and light curtains were used to reduce any additional laboratory light that could be incident within the test fixture. In the case of FOS testing, the reticle was also adjusted so that is was not in the region of interest where the MTF measurement was made.

The resulting images of the horizontal and vertical target as seen through the FOS are shown in figure 4. The obvious qualitative review shows the magnification is higher than just the camera alone and the overall contrast of the target in relation to the background is significantly less. Figure 4 also includes a close up, digitally magnified view of the fiber optic assembly that shows slight manufacturing defects where some individual fibers are damaged or cut unevenly. This realistic condition is also a factor in the results of the MTF curves in terms of evenness throughout the data.



(a) Horizontal target (b) Vertical target (c) Close up of fiber

Figure 4
Comparative images of the horizontal and vertical MTF targets through the FOS and a close up of the fiber optic within the illuminated region

The output of the MTF for the FOS system can be seen in figure 5. The cycles per mradian at 50% modulation was measured to be approximately 0.37 on the horizontal target and 0.46 on the vertical target. These values in comparison to the camera baseline showed a reduction in spatial frequency by 37.3 and 23.3% for the horizontal and vertical targets, respectively.

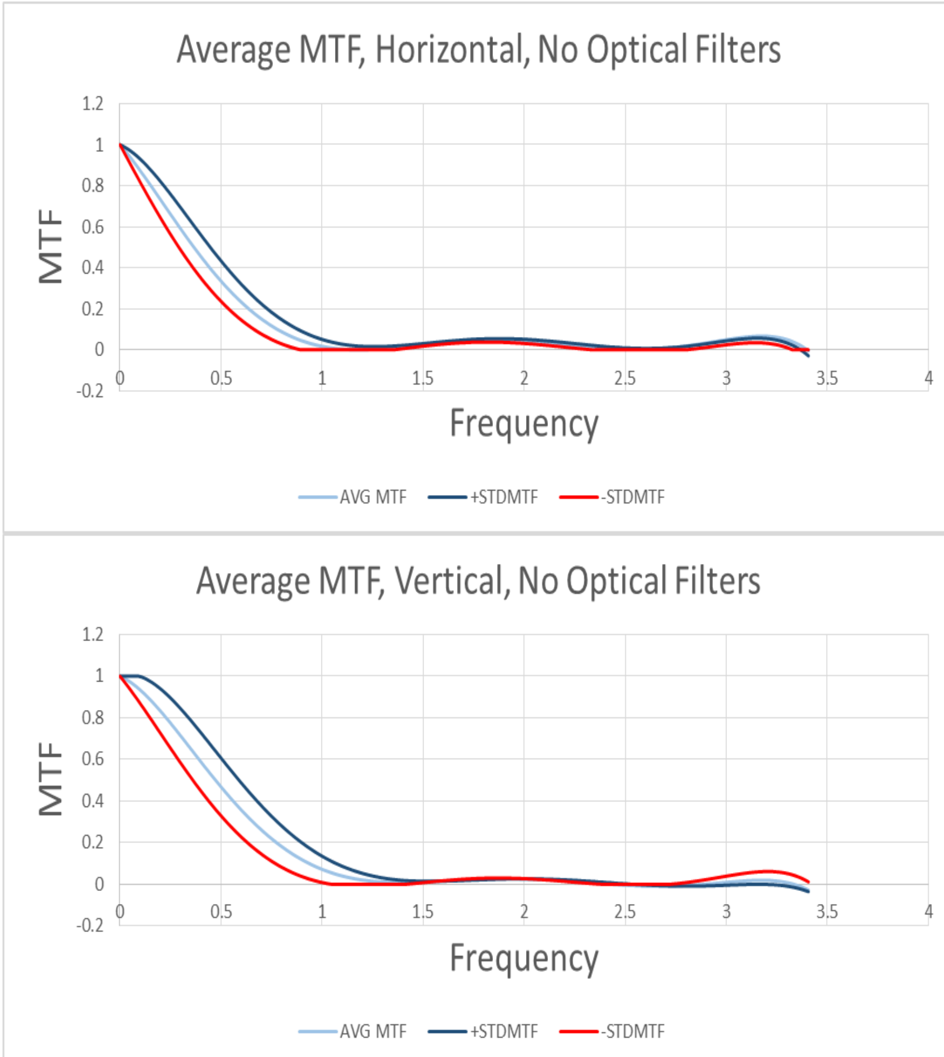
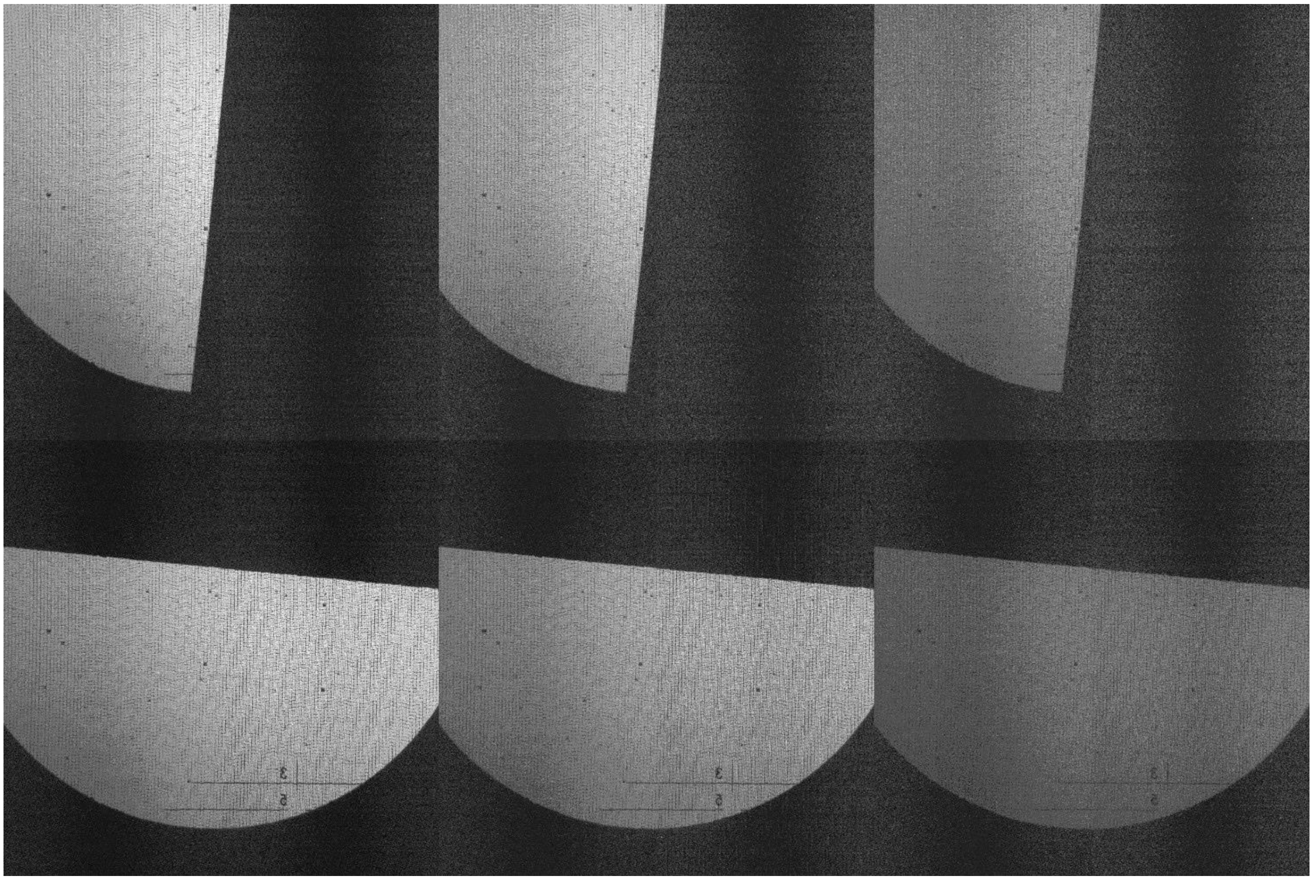


Figure 5
Horizontal and vertical target MTF curves for the FOS with no optical filters in place using a 10,000-frame average

IMPACT OF OPTICAL FILTRATION

In addition to evaluating the FOS unaided, a series of tests were applied where two different optical filters were used and placed between the objective lens of the FOS and the external mirror of the test collimator. These tests were performed in order to assess their response both through the camera alone and through the FOS system. These responses are needed for future planning for comparing the current FOS unit with the fiber optic design under review here. A basic analysis and comparison of the change in MTF values are shown in the following figures and tables for each of the filters in both target orientations. Figures 6 through 8 and table 1 provide a clear view of the general impact the addition of the KG3 glass simulating filter has on the overall contrast as well as the use of the Filter Unit, Picatinny (FUP). Both reduce the transmission of light entering the system, exiting the system, and exposing the camera, and all directly impact the contrast resolution of the experiment in a negative way. These results were expected. For reference, the KG3 glass is the general substrate on which many FUP coatings are deposited onto and represent the conditions if a FUP was applied to the optical system without the filtration coatings applied to it.



(a)
No filtration

(b)
KG3 filtration

(c)
FUP filtration

Figure 6
Comparative images of the vertical and horizontal MTF target through various optical filters: (a) no filter, (b) KG3 glass filter, and (c) FUP filter

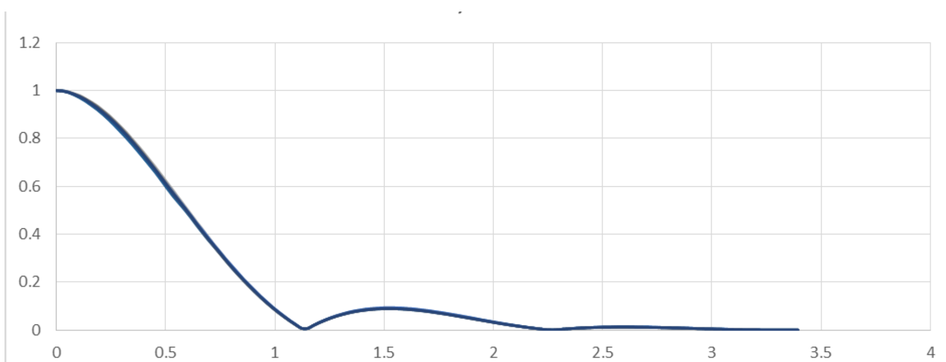
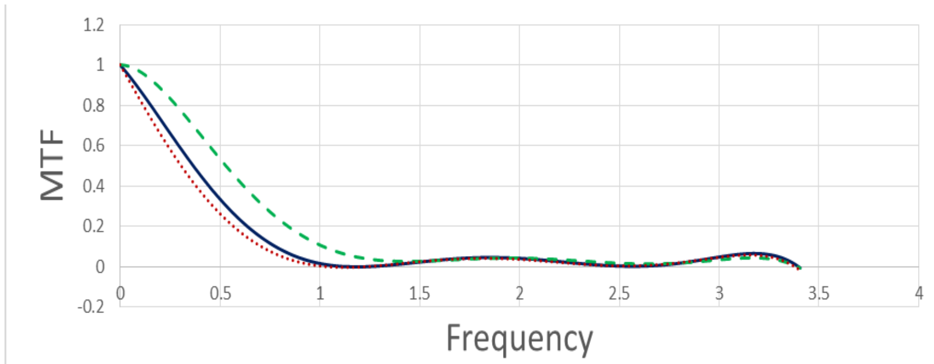
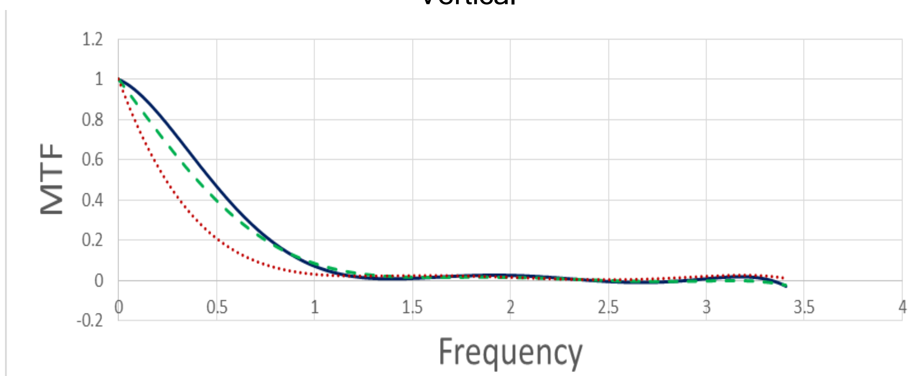


Figure 7
MTF assessment of different optical filtrations on the camera only



(a)
Vertical



Note: Blue solid line is no filtration, the red dotted line is KG3, and the green segmented line is using the FUP.

(b)
Horizontal

Figure 8
MTF assessment of different optical filtrations using the FOS system

Table 1
Acquired MTF values taken during this experiment

Average cycles/mradian at 50% modulation			
	No optical filters	KG3 glass	FUP
Camera horizontal	0.59	0.59	0.59
FOS horizontal	0.37	0.30	0.53
Camera vertical	0.60	0.60	0.60
FOS vertical	0.46	0.24	0.40

The results of the optical filtration tests showed that filtering had little impact on the exposure using the camera only baseline. However, when measuring the FOS system, the KG3 and FUP had a 18.9% reduction and 43.2% increase for the horizontal target measurement, respectively. For the vertical target measurement using the FOS, the KG3 and FUP had a 47.8% and 13.0% reduction, respectively, to the unfiltered system. The increase in response by the FUP in the horizontal orientation was not a fully understood result since it did not follow a common response in reducing the MTF with an added filter. However, further assessment lead to determining that the camera was asymmetrically responding to the filtered wavelengths remaining in the transmitted exposure. An additional note to make is that the tests using the KG3 filter used 1,000 frames averaged since the data was reliably convergent in comparison to a 10,000-frame average run using the same acquisition sequence.

CONCLUSIONS

The results between the camera only baseline and the data obtained through the fiber optic sight (FOS) system showed a clear reduction between 23 and 37%. The main contributor to this reduction is the transmission output of the FOS, which is going to be less than the ideal condition. The optics themselves reduce the exposure getting to the camera therefore reducing the contrast of any target that will directly reduce the modulation transfer function (MTF) values from the camera only baseline.

The Filter Unit, Picatinny (FUP) created difficulties in understanding the response of the FOS system. Due to the photopic shift created by the FUP, the response of the camera shifted as a result. In any filter that causes a shift in wavelength(s) of the exposing light by either moving the peak emission to a higher or shorter length or by reducing the content of a particular range of wavelengths, the specific detector under use will likely have some type of reaction. For instance, if the detector in use has an even distribution of response across the photopic range, a reduction in any one particular color (i.e., red 620 to 750 nm, blue 450 to 495 nm, green 495 to 570 nm) should cause a proportional decrease in exposure. However, this also causes an increased response to the remaining spectrum in which the detector is sensitive to. In many cases, the type of sensor material will dictate which range of light it responds to the most efficiently. In most silicon type detectors, either the blue or green range of wavelengths has the peak response of the detector. In which case, a decrease in either color range will amplify the response to the remaining spectrum of color. What this means is that a FUP can cause unexpected variances in the output of the test as a result of the camera over/under responding to the remaining information and therefore cause inaccurate data in comparison to the actual impact the FUP is having on a particular system.

Another constraint that occurred during testing of the FOS was an overall low light exposure when using the FUP. This could have potentially caused the camera’s automatic-gain correction to over/under respond trying to compensate for the lower sampling rate. This may have led to a greater noise level and overall fluctuation in the final datasets. This issue could have been corrected by using a brighter, higher yield light source that would have increased the transmitted light through the FOS and any filtering therefore increasing the exposure to the camera. This is an area of improvement for future testing of any lower transmission test pieces.

The consistency of the cutting process for the ends and edges of the fiber optics was also a variable that impacted the overall outcome of the test. Any degraded portion of the fibers within the region of interest (ROI) would have reduced the MTF. Although the tests attempted to use the cleanest region of the fibers, it was not possible to completely eliminate all the damaged or imperfect strands.

The sensor within the camera under use appears to have been tiled or assembled together using two separate segments of a pixelated area array. More specifically, the detector appears to have a distinguishable difference in response between the left and right halves of the sensor with a sharp gradient across the very center pixel column. Since this issue was detected early on during testing, the ROI used to measure the MTF was shifted to be on either side of the gradient to obtain the most consistent response. In the case of the vertical target, the best attempt was made to minimize the impact this had on the measurements.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

avg	average
c	centi-, 1E-2
ft	feet
g	grams
FOS	Fiber optic sight
in.	inch
ISO	International Organization of Standardization
k	kilo-, 1E3
K	Kelvin
KG3	Glass filter type, green
L	Lambert
FUP	Filter Unit, Picatinny
lp	line pair
M	Mega-, 1E6
m	meter
mm	millimeter, 1E-3
MTF	Modulation transfer function
n	nano-, 1E-9
ROI	Region of interest
SBIR	Santa Barbara Infrared
SD	Standard deviation
u	micro-, 1E-6

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