Novel NED Metrology Systems Enable Consistent Display Production

Much attention has been paid recently to near eye displays (NED), specifically virtual reality (VR) and augmented reality (AR) viewers, particularly in the area of consumer electronics. And, as with many new technologies, the initial rush of enthusiasm and high demand has sometimes outpaced the ability of manufacturers to thoroughly characterize their products. Indeed, some NED system manufacturers have had no objective, quantitative way to test the quality of their displays, other than to have human operators view them subjectively, and say whether or not a given unit "looks good."

But, as NEDs transition from novelties to mainstream products, achieving dependable, predictable performance will become increasingly critical. For consumer NED systems, this is necessary in order to ensure a consistent customer experience, and to guarantee that products reliably meet both cosmetic and performance standards that are congruent with the manufacturer's brand identity. For commercial NEDs, particularly those for avionics and military uses, achieving a specified performance level is often critical to the correct functioning of the device in the application.

This lag in NED testing capabilities occurs because the optical systems employed in these devices, and the way they are utilized by the viewer, are both somewhat unique. Thus, traditional optical metrology equipment cannot be simply adapted to the demands of NED testing. A new approach is necessary. This article outlines some of the key needs for NED metrology and the solution that has been developed by Gamma Scientific to meet these requirements.

NED Basics

All NEDs include three essential elements. The first is a display or source of some type, which generates light or an image. The second is an optical system which projects the light into the viewer's eye(s). These optics are necessary because most people cannot comfortably focus on an object which appears to be close (e.g. less than two inches) to the eye. Thus, the optics create a virtual image of the display source which appears to be at a sufficient distance for easy accommodation, and also allows for stereoscopic image fusion if the device provides a 3D image. Furthermore, the optics may combine the display output with a view of the actual scene surrounding the user (AR), or entirely block off any view of the true environment (VR). The final component of a NED is the mechanics to hold the first two elements on, or in front of, the viewer's head and position them properly with respect to the user's eyes.

There are already quite a number of different design forms for NEDs in use or in development. These vary tremendously in terms of the technology used for image generation and the configuration of their optics. But, whatever the underlying design for a particular NED, the combined output of the display and optics can be characterized by a few key parameters. Specifically, these are:

Exit pupil: This is the area of the region of the image or beam of light formed by the NED optics. If the eye is placed anywhere within the exit pupil, it will see the entire field of view of the display. Typically, the exit pupil is in the range of 15 to 20 mm wide, since this size provides for some tolerance in the placement of the eye relative to the optics, and also allows for the variations in inter-pupillary distance which naturally occur in the population.

Eye box: This is a volume that starts at the NED exit pupil and extends back towards the eye. If the eye is placed anywhere within the eye box, the viewer will see entire the field of view of the display.

Eye relief This refers to the distance from the exit pupil to the nearest surface of the NED optics. Typically, eye relief is designed to be large enough (>20 mm) to allow space for the eyes of users who wear eyeglasses to access this point.

Field of view: Field of view (FOV) is the horizontal and vertical angle which the display appears to subtend as seen by the viewer's eye.

Measurement Requirements

The optical parameters most typically measured for NEDs, and indeed, for most types of displays, include output spatial uniformity, contrast ratio and absolute luminance and color accuracy. For larger displays, such as flat panel displays and projectors, uniformity is traditionally measured using an imaging colorimeter or some other type of calibrated, camera based system. Absolute luminance and color is usually measured using a spectroradiometer with narrow field of view collecting optics (e.g. a telescope).

Unfortunately, the physical size and optical characteristics of most head mounted NEDs create some specific problems related to using traditional spectroradiometer systems. In particular, the collection optics typically used with spectroradiometers have a relatively large entrance pupil (usually in the 20 mm to 40 mm range). This creates issues because, if the exit pupil of the source under test is smaller than (under fills) the entrance pupil of the light measurement device, then there will be significant errors in the absolute accuracy of the measurements.

It's also essential that the collection optics preserve the spatial information of the source. This is necessary in order to make accurate color and luminosity measurements of any given subregion of the display. For example, it might be desirable to measure the characteristics color and luminance of a single displayed character or symbol. Therefore, integrating spheres, fiber optics, or any other collection optics that don't preserve angular information are not useful for this type of NED measurement.

Another difficulty with employing traditional spectroradiometer collection optics with most NEDs is that they are typically too large to fit within the available space. Specifically, many NEDs are built into goggles, headsets or helmets, enabling them to be worn by the user. This means that the collection optics for any test gear must be able to fit into the same space as the user's head or eyes. Indeed, the test system should even be small enough to allow it to independently access the output of the left and right sides of the NED display. Thus, the ideal optics for NED testing should have a form factor which is about half the size of the available space for the viewer's eyes. Unfortunately, no high precision metrology equipment that meets all these requirements has existed in the past.

Figure 1. The optical system for the Gamma Scientific NED Measurement System is sufficiently compact to enable measurements within the viewing space of virtually any NED.

The Gamma Scientific Solution

Based on the preceding discussion, compact telescope optics with an entrance pupil of about 5 mm diameter or less would be optimum for use in a high accuracy NED color and luminance measurement system. When performing high absolute accuracy color and luminance measurements, it's generally desirable to look at a small section of the NED, perhaps a single character or symbol in the display, rather than view the entire display at once. Therefore, it is useful if the size of the telescope's field stop, and hence, the optics' field-of-view, can easily be changed in order to vary the size of the region sampled from the device under test (DUT).

The figure shows the main elements Gamma Scientific NED Measurement System, developed for performing high precision measurements of absolute color and luminance on NEDs based on this type of optics. The heart of the system is a physically compact telescope with 5 mm diameter entrance pupil, coupled to a Gamma Scientific GS-1290 CCD detector-based grating spectroradiometer. A series of six apertures can be automatically inserted at the field stop of the telescope system to define FOV sizes of 5°, 2°, 1°, 0.5°, 0.33° and 0.1°. In addition, the instrument also includes a graphics generator to display test patterns and color fields, an autocollimation reference mirror, and an LED based tunable light standard.

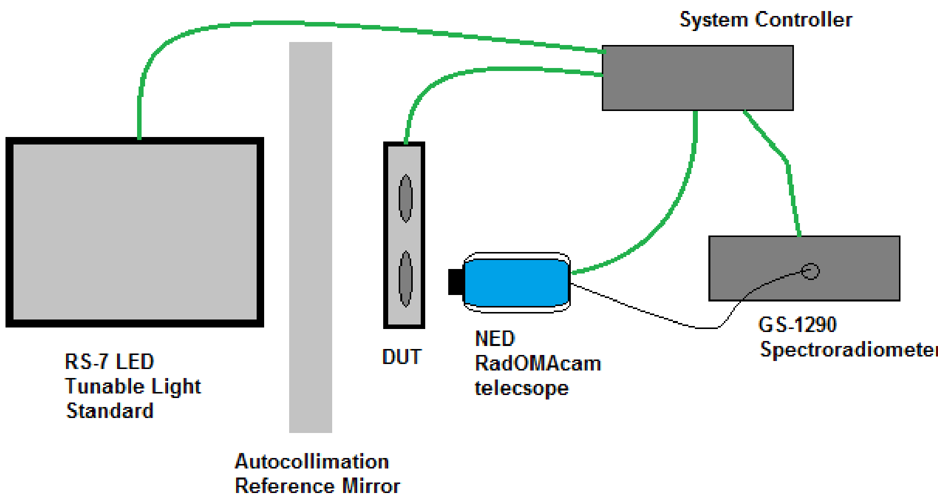


Figure 2. Schematic of the main elements of a system for performing high precision measurements of absolute color and luminance on NEDs. Mechanics for controlling the position and pointing direction of the telescope are not shown.

One reason that such a system has been difficult to produce in the past is that reducing the entrance pupil size on the collection optics (from a traditional value of 20 mm or greater down to 5 mm) creates a huge signal loss. This means that the spectroradiometer must be highly sensitive and have very low noise in order to produce accurate measurements. Gamma Scientific achieves this in our GS-1290 Spectroradiometer through the use of a backside thinned CCD, which increases detector sensitivity, combined with thermoelectric cooling, which substantially decreases sensor noise.

Making Accurate Spectroradiometric NED Measurements

The collection telescope has three built in modes of operation. The first allows the operator to view and define the measurement area, the second, to capture an image of the defined measurement area, and the third, to acquire a spectroradiometric measurement. In actual use, a single command from the user initiates both image capture and spectroradiometric measurement modes in rapid succession.

Figure 3. Imaged captured by the Viewfinder Camera showing the precise region of the NED under test which will be measured by the spectroradiometer.

When the system is being used to view and define the measurement area, reflex optics are employed in order to identify the exact portion of the NED that will be imaged by the telescope. To accomplish this, a thin beam splitter is inserted into the optical path. This enables light from an LED lamp, which is also positioned behind the field-of-view (FOV) aperture, to project onto the NED and illuminate the precise area on the display which is being viewed by the telescope. This illumination, along with anything displayed on the NED, are then reimaged on to the camera sensor plane. The operator views all this on a monitor, and can then easily match the telescope field of view and pointing position to the desired feature on the NED to be measured.

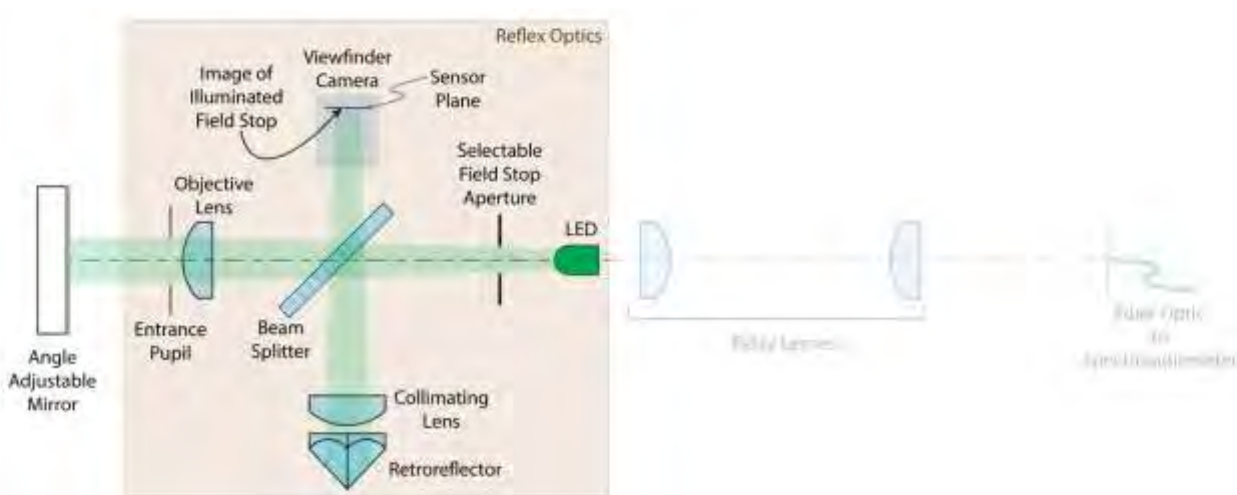


Figure 4. Schematic of the optical layout of the Gamma Scientific NED Measurement System in "viewing mode," and with an adjustable mirror in front of the NED. Aligning the optics to this mirror enables the system to take measurements from both the left and right side of the NED without any change in pointing direction.

When working with AR systems, this functionality also facilitates measurement system alignment, as well as the measurement of parallax, between the left and right eye sides of the NED. To accomplish this, a mirror which is large enough to cover both the left and right sides of the NED is placed where the virtual image appears. Then the reflex system is used as an autocollimator, and the mirror angle is adjusted until the beam is returned on itself. This means that the mirror is perfectly perpendicular to the telescope optics, and it provides a virtual object for the telescope (its own projected field stop) which appears to be at infinity. Now, if the telescope is moved from one side of the NED to the other, the autocollimator will show if there has been any change in pointing angle. Plus, if the telescope is moved a distance corresponding to the separation of the left and right eye displays in the NED, the measurement system can determine the shift (or parallax) of any element that appears in the displays.

In image capture mode, the viewfinder camera acquires an image of the sample area on the NED (defined by the field stop in the optics). A full suite of image analysis tools can then be used to determine metrics such as color uniformity, luminance uniformity, image contrast, MTF and chromatic aberration. These quantities, can, in turn, be correlated with the subsequent spectroradiometric measurement.

In spectroradiometric measurement mode, the beamsplitter assembly is automatically retracted from the telescope so that collected light is focused on to the end of a fiber optic cable, which feeds into the entrance slit of a grating spectroradiometer. Analysis of the spectroradiometer data yields luminance and color of the light from the NED contained within the telescope FOV. The telescope can be pivoted in the plane of the entrance pupil in order to sample anywhere within the virtual image.

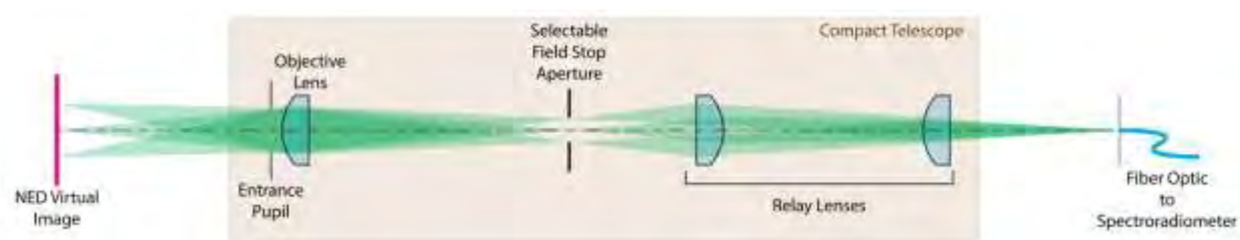
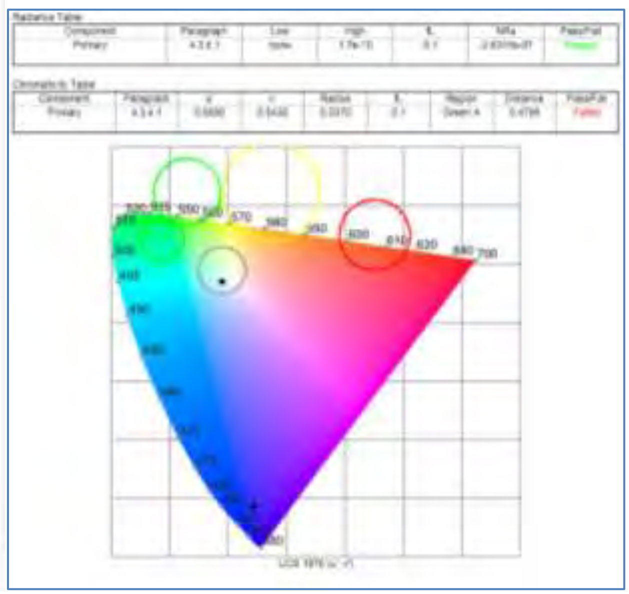


Figure 5. Schematic of the optical layout of the Gamma Scientific NED Measurement System in spectroradiometric measurement mode. Here, light from the virtual image of the NED enters the 5mm diameter entrance pupil from the left and is imaged into the end of the fiber optic cable which feeds the spectroradiometer.

Results

Performance of the instrument has been validated at Gamma Scientific by using an LED-based tunable standard light source (Gamma Scientific SpectralLED RS-7) with 35 spectral channels, with each channel having 16 bit resolution in intensity setting. Specifically, the variation in luminance and color was determined for five different FOV apertures, at 11 luminance values for each LED spectral channel.

The next figure shows part of an actual set of measurements, taken on a pair of Epson BT200 AR (augmented reality) glasses. Using the Gamma Scientific NED Measurement System, it was possible to precisely quantify the variations in display luminance and color resulting from positioning the measurement optical system entrance pupil in different areas of the design eye box. These measurements also compared color uniformity in the visual FOV through two different methods, namely, full visual field imaging (using the viewfinder camera), and directional mapping of the virtual image field (using the spectroradiometer). These types of measurements have never before been reported for NED displays. Together, these results demonstrate that the Gamma Scientific NED Measurement System provides an easy to use way to rapidly obtain highly accurate, absolute measurements of luminance and color, as well as other quantitative parameters, on virtually any type of NED.



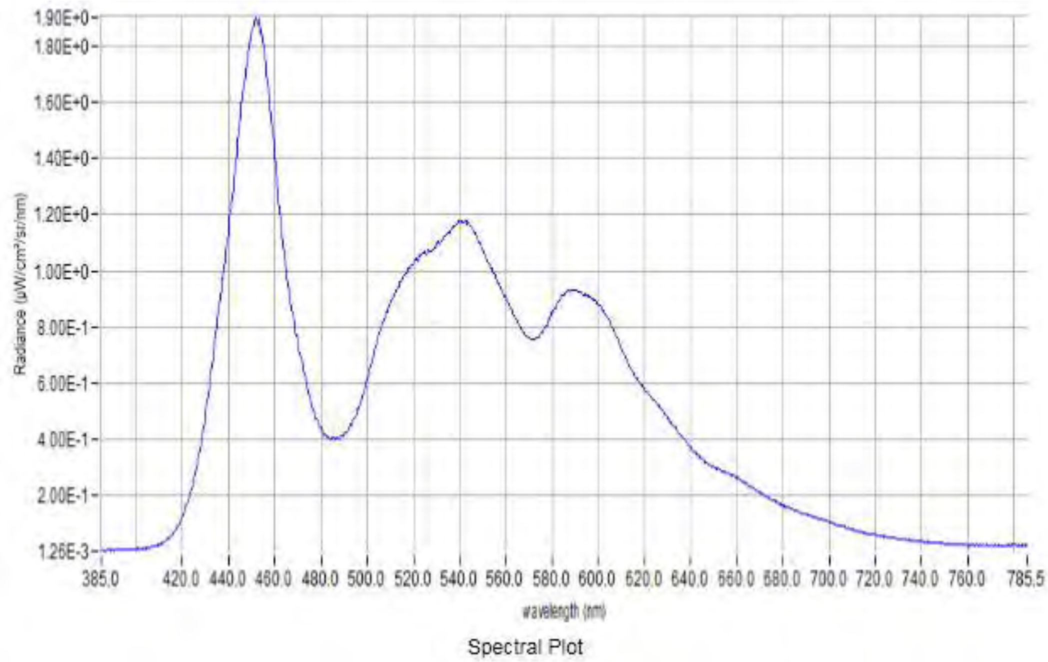


Figure 6. A single measurement performed by the Gamma Scientific NED Measurement System includes luminance, chromaticity and spectral data.