Applying the VIL350X High-Powered Villuminator™ Module for Illumination and Projection

The VIL350X high-powered Villuminator module provides a white output beam of diameter 35 mm containing up to 6 Watts of optical flux and top hat uniformity at working distance of 23 mm from the front of the module. To illuminate planes of various sizes, auxiliary projection optics may be employed to reduce or expand the output beam. We describe how this may be performed for illumination and projection applications.

1. INTRODUCTION

Villuminator™ modules are compact optical systems that produce output beams with exceptionally uniform light distributions [1–4]. Readers unfamiliar with these modules are encouraged to refer to the references cited above, which provide helpful basic introductions to the function and use of Villuminator modules.

While compact standard Villuminator modules have been optimized for illumination in microscopy [5], the VIL350X module is a slightly larger optical system that, when used with appropriate auxiliary optical components, is most suitable for illuminating wide surface areas, or projection of digital images and video onto a screen in a small office. Figure 1 provides highlights of some key mechanical features of the VIL350X module, which may be helpful information for system integration (e.g., if the module is being considered to be part of a projection system, or a scientific analytical instrument that requires illumination). As indicated, a high-powered white LED (from Luminus) is inside the module, which is being cooled by a heatsink and fan. These are needed because the LED may be operated at up to 27 Amps of current, which can lead to high LED junction temperatures.

Figure 1. Dimensions and key mechanical features of the VIL350X Villuminator module.

2. OPTICAL PROPERTIES OF THE VIL350X VILLUMINATOR MODULE

Figure 2 illustrates the geometry of rays exiting the VIL350X module. The **working distance** of 23 mm locates the plane (red dashed line) at which a circular beam with top hat illumination distribution is produced. At the optical laboratory of V-BMB, this distribution is characterized and measured using a thin diffuser mounted at the working distance (figure 3a). The illumination at the diffuser is projected into a camera, and its profile is digitally analyzed (figure 3b). As indicated, the top hat distribution has a diameter of 44 mm, defined by its full width at half the maximum irradiance (FWHM). However, note that the guaranteed top hat profile is for a circular area of diameter 35 mm, and the uniformity (defined as minimum over maximum irradiance, times 100%, noise removed) is computed within a square area inscribed by the 35 mm diameter.

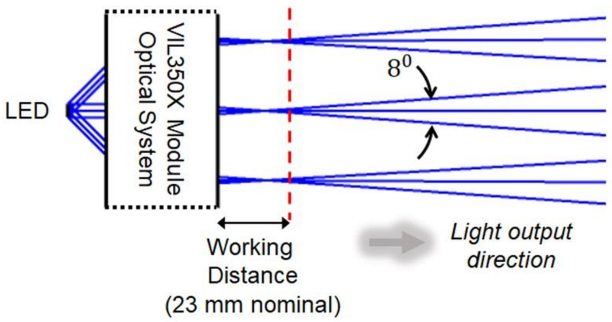

Figure 2. Geometry of rays exiting the VIL350X Villuminator module.

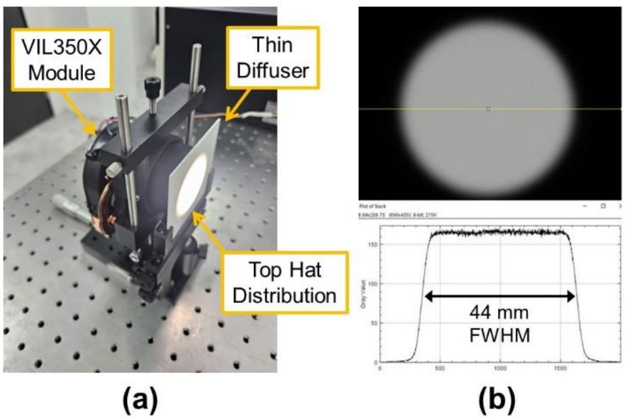

Figure 3. (a) Lab setup for characterizing the illumination. (b) Measured illumination at the diffuser with beam diameter 44 mm, FWHM.

As indicated in figure 2, the output beam from the VIL350X module possesses an angular divergence of roughly 8^0 (full cone angle). Consequently, the module's output beam size grows as it travels farther away from the module. At first glance, this may seem problematic, because it implies that any additional optical components used in the path of the beam have to be large in order to avoid clipping the beam. However, as shall be shown in the next section, it is possible to reduce the beam's size by mounting a positive-powered lens slightly beyond the working distance of the VIL350X module. In optical terms, such a lens is called a **field lens**.

3. APPLYING THE VIL350X MODULE FOR ILLUMINATION AND PROJECTION

It is important to note that the top hat illumination distribution only exists on a plane at the specified working distance from the VIL350X module (often, this plane is called the **top hat plane**). In order to make use of this beam profile for illumination, a secondary lens must project that top hat plane onto the final plane of interest (see, e.g., references 1 to 4). Usually, almost any well-designed imaging lens or a system of commercial off-the-shelf (COTS) elements with sufficiently reduced aberrations may be employed to project the top hat plane towards the final plane of illumination. However, in the case of the VIL350X Villuminator module, it is important to account for the output beam's divergence.

For example, suppose that a machine vision lens with the part number of 86-574 from Edmund Optics is used as a projection lens to relay the top hat plane onto a screen. This would be done by reversing the 86-574 lens such that its image plane is coincident with the top hat plane of the VIL350X module (see, e.g., figure 5 in reference 2). However, due to the relatively smaller size of the 86-574 lens, the vignetting (clipping) of the diverging rays from the VIL350X module causes the rays to strike the internal walls of the C-mount barrel at the rear of the 86-574 lens, resulting in a "ring" of light surrounding the projected beam, as shown in figure 4a. This effect can be easily simulated in an optical design program, as displayed in figure 4b. In order to eliminate this ring effect, a **field lens** may be mounted slightly in front of the top hat plane to bend the diverging rays ***into*** the 86-574 lens, thereby preventing rays from striking the internal walls of the lens's C-mount, as shown in figure 4c. This field lens can be almost any positive-powered lens. In the case of figure 4c, we have used a COTS achromatic doublet from Edmund Optics (part number 63-713).

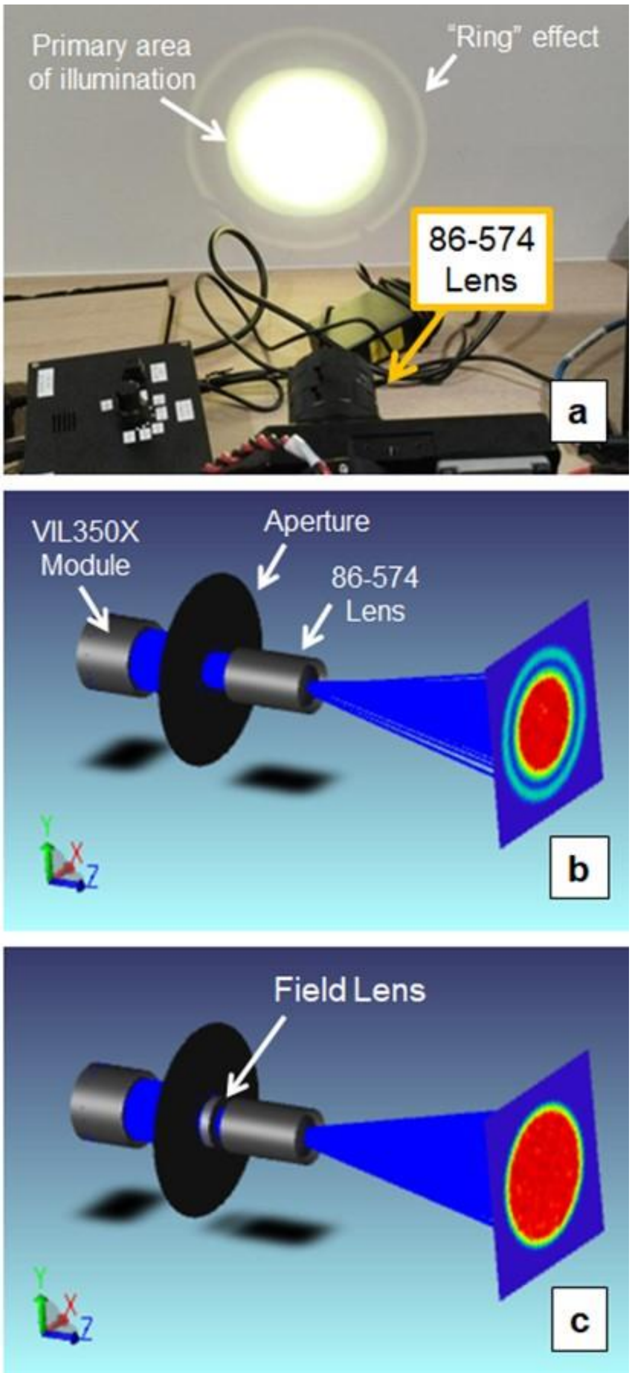

Figure 4. (a) The "ring" effect. (b) Optical model of the ring effect. (c) Eliminating the ring effect using a field lens between the top hat plane and projection lens.

It is not always necessary to use a COTS lens assembly (such as the Edmund Optics lens 86-574) to project the top hat plane towards a screen for illumination. For instance, it is also possible to use a combination of a COTS field lens and a pair of COTS achromatic doublets for illumination, as shown in the optical model and simulated illumination profile in figure 5. In this example, the field lens is part number 63-713 from Edmund Optics, and the COTS doublet lens pair is comprised of two of part number 47-740 from Edmund Optics. Note that the distance between the front of the VIL350X module and the field lens is larger than the 23 mm specified nominal working distance. In fact, it has been increased to roughly 50 mm. This increased working distance is used to compensate for an otherwise dome-shaped illumination profile caused by aberrations from the COTS doublet pair. As explained in references 1 to 4, the benefit of using Villuminator modules is that the working distance may be adjusted to tune the final illumination profile. Additionally, in the optical simulation shown in figure 5, we have added an aperture of 34 mm diameter to cut off residual aberrations at the edges of the illumination. Since the module's specified top hat profile is within a circular area of 35 mm diameter, this aperture's diameter is not too far off from specification. If a custom-designed field lens and projection lens are used instead of the COTS lenses, the illumination uniformity may be improved, and its area widened, as shown in figure 6. **If such customization is desired, V-BMB can perform the optical design and produce the custom lens**. Finally, note that it is possible to apply a customized version of the VIL350X module towards illumination on a plane at an oblique angle (see, e.g., a presentation on uniform top hat oblique illumination using a benchtop Villuminator module setup in reference 6).

The above discussion pertains to using the VIL350X module for illumination, in which a secondary lens (such as the COTS doublet pair in figure 5, or the custom projection lens in figure 6) is used to project the top hat plane onto a desired surface for illumination. In some other applications, perhaps it is desired to project digital video images onto a screen, such as done when using digital projectors for classrooms and offices. Such projection applications are possible using the VIL350X module for small offices (but with ambient room light switched off). The VIL350X module uses a white light LED from Luminus (part number CFT-90-WDH). According to its datasheet, this LED

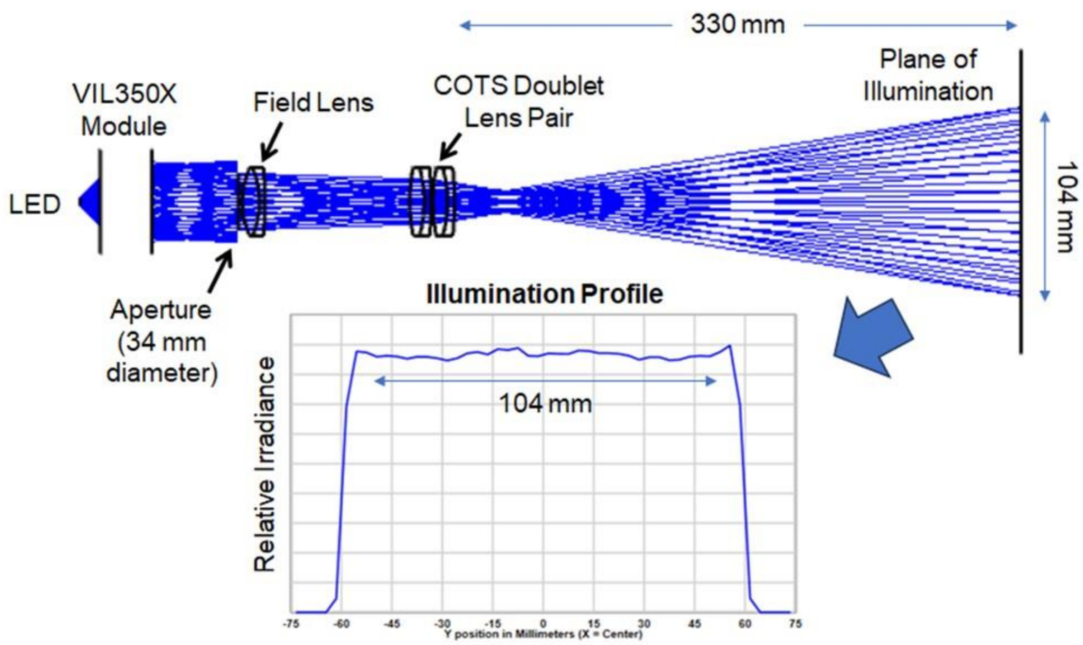

Figure 5. Using a COTS field lens and COTS pair of achromatic doublet lenses in combination to project the top hat illumination plane onto a final desired plane of illumination.

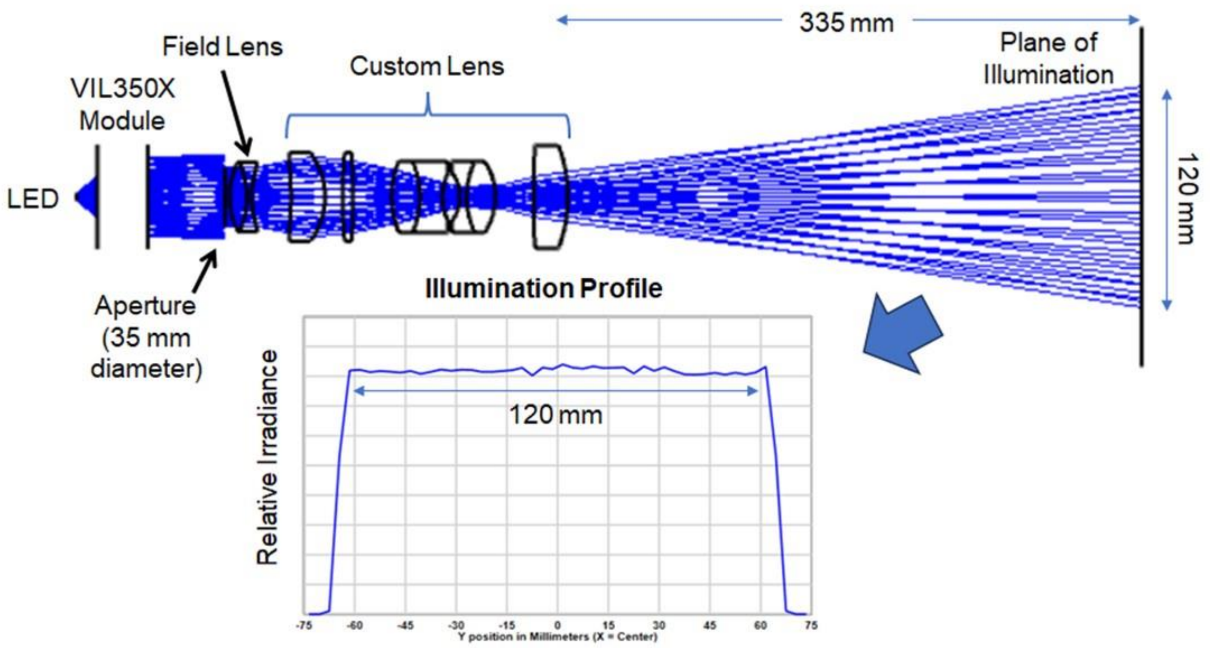

Figure 6. Using a customized field lens and projection lens in combination to improve the uniformity of the projected the top hat illumination distribution onto a final desired plane of illumination.

has an average minimum total luminous flux of roughly 2850 lumens at 22.5 Amps and a heat sink temperature of 40^0 C. At any current, roughly 50% of the LED's total output flux is contained in the illumination produced by the VIL350X module. Therefore, assuming the above conditions for current and heat sink temperature, the minimum luminous flux in the beam exiting the VIL350X module can be approximately 1425 lumens. This is roughly a third of the flux required for a classroom projector. Thus, if the

VIL350X module is integrated with a reflective spatial light modulator (SLM) such as the Texas Instruments DLP® chip, then it may be used in a projector for a small office of about a third the size of a typical classroom. On the other hand, if polarization-based SLMs (such as LCDs and LCOS displays) are employed, then the room size would be smaller. Still, digital video is not the only type of projection application. Integration of the VIL350X module with SLMs also enables uniform patterned illumination.

all comprised of part number 47-740 from Edmund Optics. Figure 7b illustrates one example of applying the layout from figure 7a towards using LCOS SLMs, based on a diagram provided by Canon, Inc. [7]. Figure 8 shows a simulated illumination profile for the system of lenses used in figures 7a and 7b. The use of customized lenses for the field lens and relay lens system would address vignetting effects and improve the final illumination profile's uniformity.

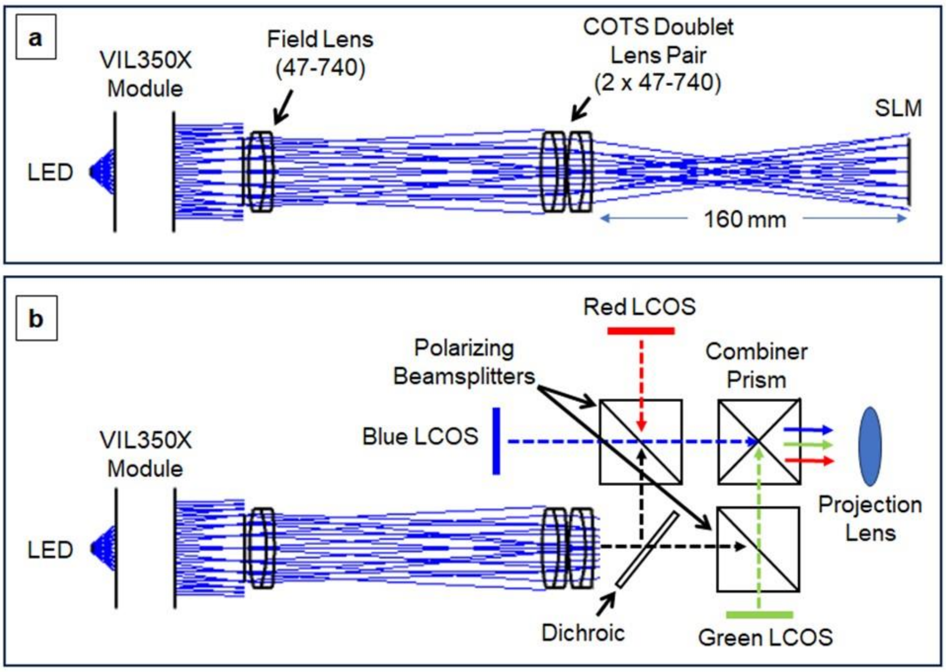

Figure 7. Applying the VIL350X module for projection of digital video. (a) Example of a conceptual optical layout using a COTS field lens and COTS doublet pair to relay the top hat plane onto a plane for mounting a SLM. (b) Example of applying the layout from figure 7a for a system of LCOS displays for digital video projection and/or patterned illumination.

In order to use the VIL350X module as a uniform light source for a projector in the applications stated above, space must be allocated for mounting a SLM at a plane coincident with the top hat plane. It is possible to illuminate such SLMs by relaying the top hat plane onto the plane of a SLM, as illustrated in figures 7a and 7b. In figure 7a, the idea is to provide a conceptual design layout in which the space given by the distance of 160 mm allows mounting of beam-splitting prism components to divide the white light into red, green, and blue colors used by SLMs to modulate both the grey scale and color hue to provide full-color digital video. The COTS field lens and COTS doublet pair are

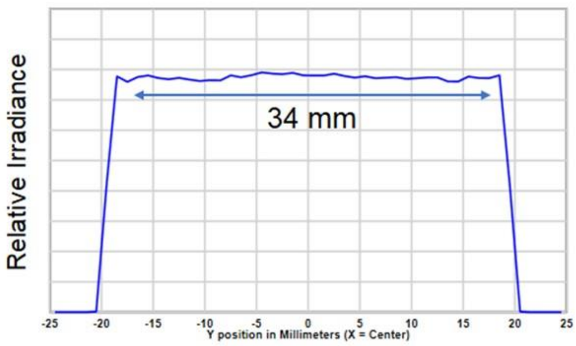

Figure 8. Simulated illumination profile at the SLM plane of figure 7a.

4. SUMMARY

- Use VIL350X high-powered Villuminator modules for general illumination and projection
- For applications involving illumination in microscopy, use compact standard Villuminator modules (see reference 5)
- Usage of appropriate secondary optics combined with the VIL350X module enables the provision of top hat illumination onto planes of virtually any size
- Oblique top hat illumination is feasible using a custom version of the VIL350X module
- Actually, customized versions of compact standard Villuminator modules may also be used for oblique top hat illumination
- The VIL350X module is a suitable uniform light source for projectors used in a small room (with ambient lights turned off), and also for applications involving patterned illumination

REFERENCES & NOTES

[1] R. Siew and L. Tan, "Top Hat Illumination Provides Even Light Distribution Across Samples," *Biophotonics* **30**(1), pp 32-37.
[2] https://v-bmb.com/vil-whitepapers.
[3] How to use Villuminator™ modules to produce uniform "top hat" illumination in projection and bioimaging: watch on YouTube.
[4] Tuning illumination uniformity using Villuminator™ modules: watch on YouTube
[5] Compact standard Villuminator modules are modules whose part numbers are written in the form "VIL151X", where the letter "X" identifies the wavelength choice. The complete brochure for standard Villuminator modules is available at https://v-bmb.com/villuminator%E2%84%A2
[6] See, e.g., the forthcoming Vision Spectra Conference 2024 presentation (online) given by V-BMB optical consultant, Ronian Siew, in July 2024, titled, "Uniform Top Hat Oblique Illumination in Machine Vision Applications", https://events.photonics.com/Presentation.aspx?EID=27&PID=571
[7] https://global.canon/en/technology/projector2021s.html

ABBREVIATIONS

COTS, commercial off-the-shelf
DLP®, digital light processing (Texas Instruments)
FWHM, full width at half maximum
LCD, liquid crystal display
LCOS, liquid crystal on Silicon
LED, light emitting diode
SLM, spatial light modulator
V-BMB, Venture Biotech Modules Business Pte. Ltd.

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ABOUT V-BMB

V-BMB (https://v-bmb.com) specializes in advanced precision control technology solutions ranging from ready-to-use, plug-and-play modules to bespoke, customized modules in precision thermal control, optical systems and fluidic controls. V-BMB also offers customized consumable solutions and liquid handling modules for the Life Science and Medtech industries.

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