Digital combiner achieves low cost and high reliability for head-up display applications

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A novel technique replaces the costly traditional volume-holographic approach with mass-replicable, thin-plastic diffractive optics for automotive and avionics applications.

The first head-up displays (HUDs) were introduced more than four decades ago for use in jet fighters and commercial airplanes. They are now making inroads in the automotive industry.1 HUD systems produce virtual images superimposed on the user’s field of view. These appear to float several feet in front of the HUD combiner, thus presenting data without requiring one to look away from one’s typical view point. An HUD uses an optical combiner—a transparent panel in front of the user—to display the computer-generated data in the forward field of view. This combiner enables the virtual image and the real-world view to be seen through the panel, so both images appear to be at the same distance. Typically, HUD combiners are constructed of simple sandwiched wedge windows, curved dichroic mirrors, or volume-holographic plates.

If optical power is not included in the combiner, HUD uses cumbersome catadioptric optics buried underneath the dashboard, similar to today’s automotive HUD applications. The combiners in the Chevrolet Corvette and Pontiac Grand Prix, for example, are simply their front windshields. When optical power is directly implemented in the combiner, primarily for space and budget reasons, a diverging-lens shape is used with the compensation surface on the opposite side, such as in curved dichroic-mirror combiners. Alternatively, a volume hologram can be implemented on the flat combiner plate, as commonly done in avionics HUDs. The holographic approach is desirable since it provides a simple, flat combiner without additional optics. However, holograms, traditionally recorded in dichromated gelatin, are very expensive, have short lifetimes, and are sensitive to environmental changes (including vibrations, humidity, and temperature).

We propose a novel HUD-combiner concept based on a digital subwavelength optical element that combines the best of both worlds: the optical functionality of a thick volume hologram and the reliability of replicated thin-plastic diffractive optics (see Figure 1). We use a miniature laser projector situated in the dashboard. This can be either a traditional imaging projector based on digital light processing or light-crystal-over-silicon microdisplays and a LED or laser-light engine, similar those in use for cell-phone picoprojectors, or a diffractive projector similar to those developed by HOLOEYE Photonics AG (Germany) or Light Blue Optics (UK). Because the image in the latter application is formed directly in the far field rather than imaged, the optical prescriptions of both types of combiners will differ.

The new architecture achieves full color by time sequencing the three colors generated by three lasers and a single microdisplay. Optical power is accomplished by introducing an off-axis diffractive Fresnel-lens phase profile,2 optimized for the off-axis illumination scheme illustrated in Figure 1. Diffraction of the three wavelengths is achieved using harmonic (or multi-order) diffractive structures, a technique initially developed for hybrid optics.3 High overall diffraction efficiency through effective analog-surface-relief elements4 is realized by binary subwavelength grating carriers,5,6 which implement an effective

Continued on next page
refractive medium. Therefore, the resulting diffracted angles remain small (several degrees), although the system is based on subwavelength element structures.

The basis of the new HUD-combiner architecture is defined by the way it discriminates between the diffraction efficiency at one (or several) wavelengths for a fixed angle (the projected image onto the combiner), and the diffraction efficiency of the wide-spectrum incoming field (which is relatively normal to the combiner). Ideally, the former should be at maximum and the latter minimal. This can be achieved by slanting the subwavelength gratings into a direction that yields the highest efficiency for laser illumination and the lowest efficiency for the incoming field. The design procedure used to develop the subwavelength structures is shown in Figure 2. It uses geometrical optics (ray tracing) to design the phase profile of the off-axis lens, scalar diffraction theory to define the adequate harmonic fringes (much larger than visible wavelengths), and rigorous electromagnetic theory to optimize the subwavelength structures used to implement these fringes through effective-medium theory (EMT).

We fabricated several prototypes using traditional microlithography. The first generation of combiners exhibit normal structures (see Figures 3 to 5). Figure 3 shows a first prototype etched into a quartz substrate. The surface profilometry plot of the digital combiner shows the pulse-density modulation technique used to implement the effective medium through binary subwavelength (normal) structures (see Figure 4). Although the fringe period is greater than that of visible wavelengths, the individual binary structures are smaller, thus creating an effective-index modulation.

The first optical results are shown in Figure 5. The focus is set on the microdisplay color pixels. We show the results of two off-axis diffractive combiner lenses, one with standard binary structures and the other with subwavelength EMT structures. The digital combiner on the lower left-hand side is lithographically patterned as a conventional binary off-axis diffractive lens, thus yielding two conjugate orders, carrying both the virtual and real images generated by the microdisplay. The digital combiner on the lower right-hand side has been fabricated with binary vertical subwavelength EMT structures. This yields only one diffraction order, carrying the virtual image of the microdisplay. The microdisplay is a simple color-LCD screen, thus showing that such combiners—both in conventional and EMT modes—can produce decent images with sources that have neither temporal nor spatial coherence. However, for better
efficiency and a sharper image, a laser picoprojector will be used in the future.

Our next step is to fabricate second-generation combiner masters with tilted structures using inclined lithography, specifically inclined reactive-ion etching to define the tilted subwavelength structures.\textsuperscript{11,12} Tilting the structures will allow greater discrimination between the diffraction efficiencies of the three combined individual wavelengths and the diffraction efficiency of the wide-band transmitted field. We will use UV embossing to replicate these structures on thin plastic films.\textsuperscript{11,12}

References


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