52.2: Application of a Novel, More Étendue-Efficient Light Engine Technology to Enable Micro-Portable DLP Projectors

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Abstract  
As the projection industry evolves, there is a perpetual push for smaller and brighter projectors. A newly developed étendue efficient light engine (eele-enhanced™) technology combined with Digital Light Processing (DLP™) holds promise to deliver improved brightness, lifetime and/or more compact projection display systems. This paper describes an application of the eele-enhanced™ technology for building Micro-Portable DLP projectors.

1. Introduction  
As projectors are reduced in size, weight, and cost, the light valves enabling these projectors are also scaled down in size, weight and cost. To maintain or even improve screen brightness while reducing the diagonal of a DMD™ (digital micro mirror device), one needs either a more efficient lamp (shorter arc and/or higher brightness arc lamp) and/or a more efficient optical light engine technology. Further advances in increasing the efficiency of a projection display light engine will enable additional component miniaturization and/or brightness increases, thus, leading to further manufacturing cost reductions and increases in projector sales volume. This will ultimately lead to high performance, low cost consumer projection display systems.

The étendue parameter\(^1\), \(E\), or optical extent, of a given light beam relates to the combination of its angle and spatial confinement. Just like its thermodynamic analogue entropy, the entropy value of a light beam can never be made smaller by transmitting a beam through a passive optical system. In simplified terms, this beam parameter represents for a given focused beam the product of its minimal cross sectional area \(A\) and the respective solid angle \(\Omega\) (i.e. \(E = A \cdot \Omega\)). In an analogous way, a DMD and an arc lamp has a respective acceptance and emission area \(A\) and a respective acceptance and emission solid angle \(\Omega\). Therefore, the étendue parameter \(E\) relates to the throughput of an optical system\(^1,2\).

A light engine is defined here as an optical system capable of collecting light from a lamp and concentrating and remote delivering it to a given light valve, for example a DMD. Preferably, such a light engine includes at least one beam-reformatting element for improving spatial, angular and/or spectral uniformities of the delivered light at the DMD location. The better the étendue efficiency of such a light engine (i.e. the smaller the increase of the lamp emission étendue as the emitted light beam passes through a given optical system), the larger is the emission area of an arc lamp that can be coupled onto a given illumination target (DMD). Most light engines on the market today use an elliptical or parabolic lamp reflector to collect and concentrate the light from an arc lamp. This causes\(^3\) an increase of the étendue of the emission source (arc lamp) by a factor of 2-10x. To improve the delivery efficiency of these light engines shorter arc and higher pressure Hg lamps have been developed leading to the recent market introduction of short arc VHP lamps introduced by Phillips, Osram and others.

This paper shows how the increased design freedom arising from a more étendue efficient light engine (eele) technology can be utilized to design next generation smaller and/or brighter DLP™ projection display systems. This patent pending technology\(^4\) and its respective components is been marketed by eele Laboratories under the trademark “eele-enhanced™”.

In summary, the eele-enhanced™ light engine technology uses and combines more efficient
beam reformatting elements such that the étendue of a light beam emitted from an arc lamp is substantially preserved. As many different light engine performance comparison studies have shown for a large variety of arc lamps and target collection étendue values, a suitable eele lamp reflector module can generally be designed to produce an output beam having less than 1/3 of the étendue value and less than ½ of beam cross sectional area at its secondary focus that can be obtained with an elliptical or parabolic reflector. When combined with a matched anamorphic beam transformer an eele-enhanced light engine can typically achieve a total 2-3X étendue efficiency advantage over traditional light engines. The bigger the arc gap and/or the smaller the light valve, the higher is in general the étendue efficiency advantage of an eele-enhanced light engine for given light engine design constraints.

Some of the other benefits of a customized eele-enhanced light engine solution typically are significantly increased lamp life, less projector output degradation over time, less stringent assembly tolerances, 30-50% smaller size reflector volumes, more efficient cooling options, wider operational range of the same arc lamp and reflector and a lower parts count.

2. eele-enhanced™ DLP light engine

Fig. 1 shows the primary components of a proposed next generation eele-enhanced single chip Micro-Portable DLP projection display system, i.e. an étendue efficient lamp reflector module (eele LRM), a matched eele-enhanced integrator (eele-ABT), a color wheel (CW), a coupling optic (CO), a DMD light valve, a projection optic (PO) and a projection screen (PS). To achieve the maximum delivery efficiency between a given arc lamp and a DMD having a given acceptance area \( A \), acceptance solid angle \( \Omega \), aspect ratio, spatial uniformity and spectral energy distribution requirement, both the reflector and the integrator needs to be optimized as a pair and in combination with the other light engine constraints, such as lumen requirements, height, weight, wattage, cooling, and lifetime, etc.

The eele-enhanced reflector module comprises in its simplest form a primary reflector and a retro-reflector. Contrary to most traditional reflector modules the lamp axis is aligned perpendicular to the optical axis of the reflector module. The retro-reflector collects less than 50% of the light emitted by the arc lamp and reflects it in an image-inverting manner back into the emission region thus creating effectively a less than 2\( \pi \) emission source having typically a red enhanced and more uniform spectra. This color reformattting effect results in a 7-50% color gain for a white balanced DLP projector depending on the type of Arc lamp and DLP light engines. The primary reflector collects the light emitted by this, color modified effective 2\( \pi \)-source located near its first focal point (F1) and concentrates it around the arc lamp near its secondary focal point (F2) thus forming a quasi-imaging magnification of the cross sectional intensity distribution of the arc lamps emission region. The eele reflector module performs angular and spectral beam reformatting functions while substantially preserving the spatial characteristics of the emission source. In parallel, the matched eele-integrator performs spatial and angular beam reformatting functions as well as spatial beam integration.

Fig. 2a and 2b show the calculated intensity distribution at the second focal point F2, i.e. near its first focal point (F1) and concentrates it around the arc lamp near its secondary focal point (F2) thus forming a quasi-imaging magnification of the cross sectional intensity distribution of the arc lamps emission region. The eele reflector module performs angular and spectral beam reformatting functions while substantially preserving the spatial characteristics of the emission source. In parallel, the matched eele-integrator performs spatial and angular beam reformatting functions as well as spatial beam integration.

In anticipation of future Micro-Portable DLP projector needs, this much smaller eele-LRM has been designed to have similar
optical delivery efficiencies at $E=24 \text{ mm}^2\text{-steradian}$ as the larger elliptical reflector and a superior delivery efficiencies for smaller collection étendue values. The methods used to build an accurate arc lamp model have been reported elsewhere\textsuperscript{5}. To maximize the delivery efficiency of such a miniaturized eele-enhanced light engines we used the arc lamp modeling and optimization capabilities (SITER command) of the ASAP program from Breault Research Organization to optimize and customize the geometry of the reflectors and integrator for various design constraints and collection étendue target values.

Fig. 2a shows the asymmetric angular dependent intensity distribution at F2 of the eele-LRM output beam. This is a result of the orthogonal orientation of the lamp axis with respect of the reflector symmetry axis and the inherent asymmetric angular dependent energy emission of the arc lamp. Note that the spatial and angular dependent intensity distributions of the output beam of the eele-LRM are étendue efficiently related, i.e. in the horizontal (vertical) direction the beam has a wider (narrower) spatial and a narrower (wider) angular dependent distribution. Given that a DMD and/or projection lens accepts in general a symmetric angular dependent energy beam we can use an étendue efficient matched anamorphic beam transformer (ABT), as indicated in Figure 1, to both quasi-symmetrize the angular dependent energy distribution and to spatially integrate the DMD illumination beam.

Clearly, the much more étendue efficient eele-LRM module produces a much smaller, more uniform and more rectangular shaped intensity distribution at F2 of the respective primary reflector. These effects can further help in increasing the throughput of a given size color wheel and/or in further reducing its diameter.
Figure 3b shows the angular dependent intensity distribution at the output of a matched eele-ABT made, for example, from a 1-D tapered, hollow, 25mm long, integrator. Fig 2a, 3a and 3b represent light engine design case for a 12° XGA DMD with a pixel spacing of 13.8µm, i.e. a collection étendue of E=24mm²-steradian. The delivery efficiency for this collection étendue value is approximately maximized for a 44mm high eele-LRM with a matched, eele-ABT collecting light at 28°x35° and emitting it at 28°x28° towards the collection Optic CO transforming it into a 12 deg divergent beam.

To obtain maximum light engine performance for an eele-enhanced light engine having predetermined design specs, a given light valve and a given lamp with its aging dependent spatial and angular emission characteristics, the area and angle gains of the respective eele-LRM and eele-ABT need ideally to be optimized together.

By trading area gains vs. angle gains in an étendue-efficient manner, for example, an eele-enhanced light engine design solution can be found using a standard 1.3mm arc gap VHP lamp that loses less than 13% of light when the throughput limiting collection étendue value of the light engine is changed by 300%, i.e. changed from 24 to 8mm²-steradian. Thus, when appropriately customized, the delivery efficiency of eele-enhanced light engines using either smaller light valves and/or other collection étendue limiting elements, such as the Sequential Color Recapture method from Texas Instruments, can be further significantly increased.

Fig. 4 shows the unusual lifetime behavior of a 45mm tall eele-LRM for two different collection étendue values showing (i) the typical observable 5%-15% initial output increase observable for all but the smallest étendue values in the first 200-500 h and (ii) the insensitivity of the aging output on the collection étendue values. The latter effect is in part a result of the inherent higher étendue efficiency of the eele-enhanced light engine. In addition it depends on the cooling design and on how well the eele-ABT is customized to a given light engine design constraints. Note that this is the same 120W VHP lamp that in a traditional Ultra-Portable DLP light engine often has a nominal lifetime of 1500-2000h.

3. Acknowledgements

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4. References


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eele-enhanced™) is a pending Trademark of eele Laboratories, LLC.