

20.4: Compact RGB Laser Module for Embedded Laser Projection

Jan O. Drumm, Christian Gammer, Jens Richter, Claus Seibert
OSRAM GmbH, Leibnizstr. 4, 93055 Regensburg, Germany

Abstract

We report on a study of a miniaturized laser module suitable for embedded projection with the flying spot approach. The module comprises RGB lasers, a closely connected laser driver ASIC and optical components. Key aspects of our studies are light output and color mixing stability as well as transient performance of the module.

1. Introduction

RGB lasers and MEMS mirror devices grow more and more into a product ready stadium [1-7]. Consequently a companion projector based on the flying spot approach recently has been introduced [8]. Also the number of prototypes is increasing. However power consumption and the physical size of the devices is still not sufficient to fulfill the requirements for embedding in mobile devices like cell phones. A main obstacle is the lack of efficient and application specific integrated electronics. To cope with the issues a design from system level view is demanded. Consequently we introduce an integrated RGB laser module in the sense of a miniaturized combination of laser light sources and an application specific electronic control gear.

2. Module Concept

Figure 1 shows the functional diagram of a flying spot based laser projector. Herein a key component is the MEMS mirror which deflects the laser beam onto the screen. To project an image the mobile device transfers video data to the video processing unit. Then, this unit sorts the data according to the mirror's trajectory and delivers grey scale data to the respective laser driver channel. For correct pixel timing the video unit communicates with the mirror driver. Then, the modulated laser intensity generates the image information on the screen.

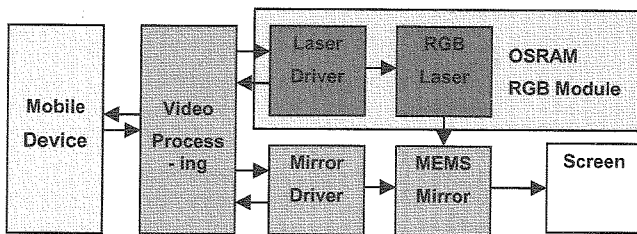


Figure 1. Electronic architecture of a flying spot based laser projector.

The electronic architecture of the projector points out two combined functional sub units. One sub unit consists out of the MEMS mirror, the mirror driver and the video processing unit. The other sub unit consists out of the RGB lasers and the laser driver. The requirements for this unit are: a) light output >10 screen lumens, b) efficiency >10lm/W, c) small form factor, maximum height of 7mm, d) supporting minimum pixel time of 10ns, e) providing real 8-bit grey level for individual pixels, f) white point control over ambient temperature range 10°C-50°C, g) module internal compensation of laser characteristic variations, h) power supply matched to individual laser driving voltages.

In a former publication already a RGB laser module comprising the RGB lasers, beam collimation and beam combination optics has been introduced [3]. The here presented study of the RGB module additionally comprises a rigid flex PCB with OSRAM's laser driver ASIC placed on the upper side and also comprising other electrical components for impedance matching and components of the switching power supply. Additionally photodiodes as part of an optical feedback are implemented.

In figure 2 a mechanical drawing of the module is shown. The length is 40mm and the width is 23mm. The height of the module matches the 7mm requirements resulting in a module volume of 6.5cc. The laser driver ASIC comes in an 8x8mm² QFN 56 pin package. Further development steps offer potential for module size reduction. The height is only limited by the 5.6mm diameter of the red and blue laser TO package, but smaller packages are conceivable. In future designs also a smaller module width is realizable.

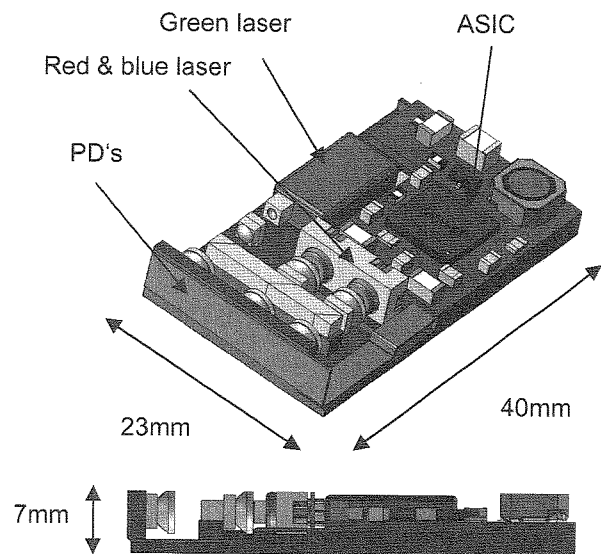


Figure 2. Mechanical drawing of the RGB laser module with integrated photodiodes, laser driver ASIC and switching power supply.

3. Module Performance

3.1. Light Output

To derive the corresponding continuous wave laser output power from the 10 screen lumens requirement we need to describe the mirror oscillation. Modern mirror concepts employ a quasi-static driving mode in the vertical (slow axis) direction [7,8]. The forward part of the oscillation takes typically 80% of the period time. During this time the light can be switched on. Along the horizontal direction the mirror usually oscillates in a resonant driving mode. Although the light could be switched on the whole

time, usually only 80% of time the light is switched on. The reason is cutting the overexposed turning points of the laser spot in the image. With 90% efficiency of the optics, approximately 60% of the continuous wave output power contributes to the image brightness on the screen. Additionally, the energy density of the pixels located in the center of the image is lower than the mean value. Compensation of this effect requires a reserve of 20% above the mean output power.

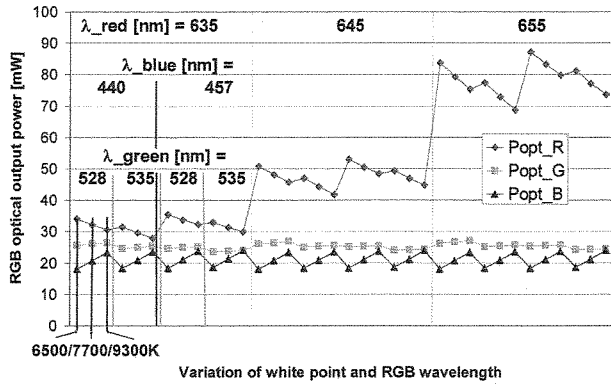


Figure 3. Required optical output power (continuous wave) for 20lm light output depending on laser wavelength and three white points 6500K/7700K/9300K.

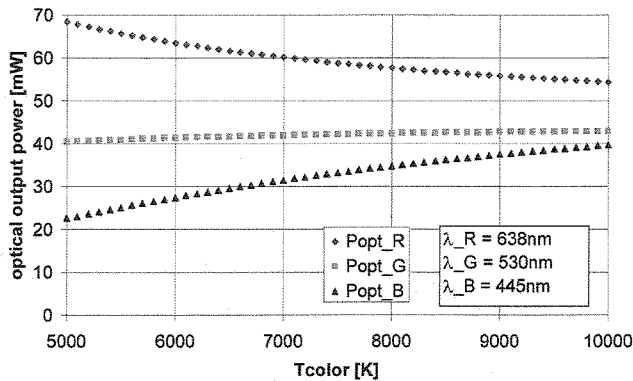


Figure 4. Required optical output power for 33lm cw light output for a fixed wavelength triple and depending on color temperature.

In figure 3 the required optical output power of the red, green and blue lasers for a 20lm continuous wave light output are shown. The given values can be scaled linearly to calculate the output power for other screen lumen values. The diagram indicates the power relations for three white points (6500K, 7700K, 9300K) as well as for several wavelength combinations of the red (635nm, 645nm, 655nm), the green (528nm, 535nm) and the blue (440nm, 457nm) laser. It is seen that there is only a minor variation of the output power for the green and the blue laser whereas the required optical power for the red laser strongly increases with wavelength. The variation of the laser output power depending on the color temperature but for fixed wavelength is shown in figure 4. In that diagram it is seen that the required optical output power for the red laser decreases about 25% from 5000K to 10000K color temperature whereas the blue power increases about 80% and the green power slightly increases about 8%.

At 25°C-30°C environment conditions state of the art lasers show 27% efficiency for a 638nm, 110mW red laser, 8% efficiency for a 530nm, 50mW green laser and 13% efficiency for a 445nm, 60mW blue laser [1,4,6]. For the green laser additionally heating power has to be considered. The 6500K white point is a suitable working point for an embedded laser projector. At this color temperature the relations between the R/G/B output power values for the wavelength triple 445nm/530nm/638nm are determined in figure 4 to 1.5/1/0.7. Calculating from maximum green output power as a reference and considering the 20% reserve the R/G/B average output power values 62mW/42mW/30mW correspond to the peak output power values 76mW/50mW/35mW. A hereafter dimensioned RGB module delivers 33lm in continuous wave mode and 20 screen lumens in the projection case considering the conditions mentioned above. During the non light output period the laser bias current can be switched off. Then, for a white image the efficiency including the laser driver is calculated to 18lm/W. For real images a so called effective efficiency can be defined because the flying spot laser approach has the advantage that the power consumption of every pixel is scaling with the grey scale level. In the image processing community often used images are the Lena and the Mandrill image [9]. These images both contain white pixels with full-brightness but only require (71%/53%) of the red, (39%/51%) of the green and (41%/44%) of the blue light output, respectively. Hereafter for both images an effective efficiency of 23lm/W can be calculated. These values are superior to LED based miniaturized projectors which currently show efficiencies around 5.5lm/W for product ready devices [10].

3.2. White Point Control

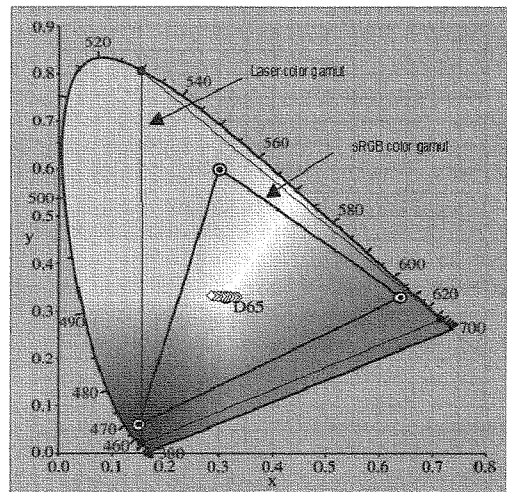


Figure 5. Resulting white point shift when only laser power is kept constant over temperature range from 20°C to 60°C.

A benefit of the module is the implemented white point control. This means a constant color impression over a specified temperature range. When only the laser output power is kept constant a white point shift towards a cyan colored white is the consequence. In figure 5 the white point shift is shown over a temperature range from 20°C to 60°C. The difference of the resulting white points at 20°C and 60°C is 8 times the just noticeable difference according to MacAdam's theory and hence strongly visible [11].

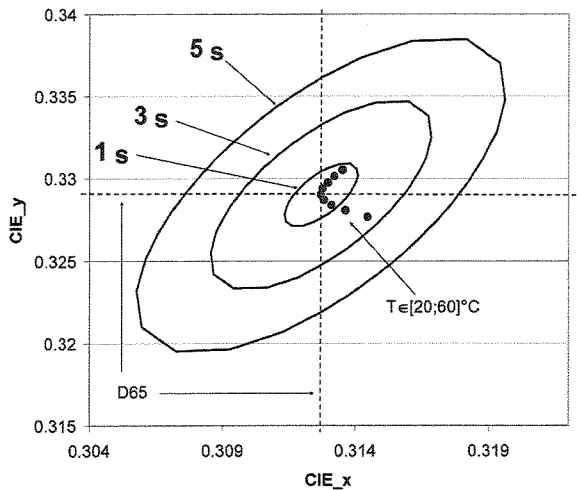


Figure 6. Resulting white point shift by using a wavelength sensitive detector.

The white point control employed in the module comprises a channel separated detection and regulation path. The photocurrents of the wavelength sensitive detectors are processed in the driver electronics which then modifies the laser driving currents. In figure 6 the residual white point shift is shown for a temperature range from 20°C to 60°C. It can be seen that the white point shift is below the perception threshold. The white point control also offers a user selectable white point.

3.3. Laser Driver ASIC

A key component of the module is the driver ASIC. As mentioned above, the design is specific for embedded laser projection applications. Basic requirements for the ASIC are derived from the electrical properties of the lasers. Key criteria are the compliance to the blue laser diode forward voltage of up to 6V and the capability to drive the green laser with currents up to 600mA. Additionally, high transient performance is required with an equivalent bandwidth of 170MHz. To fulfill these requirements we employ an analog mixed signal chip technology. The ASIC design concept comprises a current power stage for each color with upstream arranged analog signal processing units. For the data interface 8-bit digital to analog converter stages (DAC) are implemented. A serial interface provides communication with third party electronics.

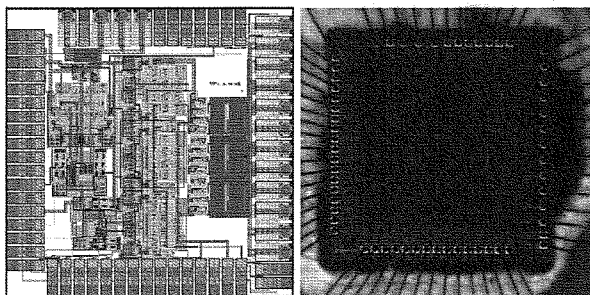


Figure 7. Chip layout (left) and the realized chip (right) of OSRAM’s laser driver ASIC.

The signal processing unit together with the photodiodes leads to a closed loop operation of the lasers providing white point and laser threshold stability over the specified temperature range. The

signal processing units are responsible for balancing the P-I curve bending. Besides the laser current driving function the ASIC also regulates the heater current of the second harmonic generation crystal. This regulation is especially matched to OSRAM’s green laser technology.

Figure 7 shows the layout and a photography of the laser driver ASIC. The driving currents for the red and the blue laser diode and for the green laser are dimensioned to achieve the above mentioned module light output. The efficiency of the ASIC is targeted to be higher than 80%.

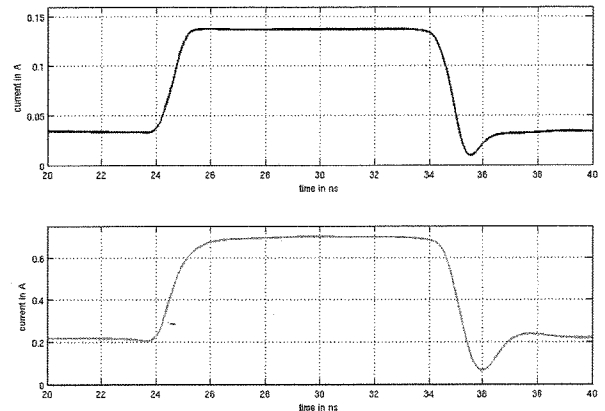


Figure 8. Transient performance simulation of the blue (upper curve) and the green (lower curve) channel.

A simulation of the transient performance of the blue and the green channel is shown in figure 8. At both channels single pulse patterns of 10ns length are applied. The rise times are determined to 0.8ns for the blue channel and 1.5ns for the green channel. The final signal shape will be correspondent to the chosen process options.

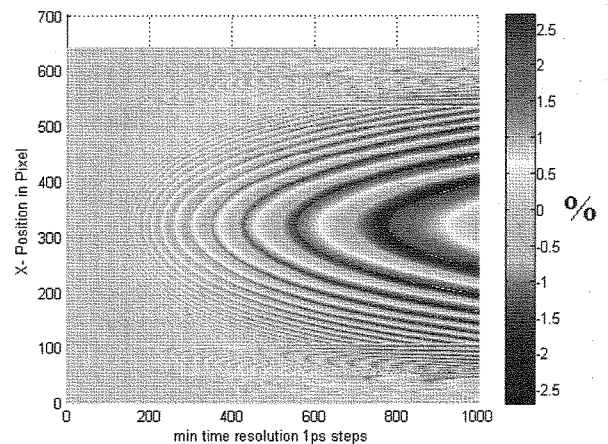


Figure 9. Pixel position errors of a VGA image in horizontal direction in dependence of the pixel clock resolution.

A further benefit of the chip concept is the option to decouple the grey scale data input and the pixel clock. The pixel clock defines the point of time when the gray scale data are applied to the output power stage. This decoupling makes sense as the horizontal oscillation is harmonic. Consequently, to receive equal sized pixels the temporal length of neighbored pixels has to be different. However, if discrete time steps of the pixel clock are

applied errors of the pixel positions occur. These position errors lead to image distortion effects. The distortion can be eliminated by interpolating the grey scale levels of neighbored pixels, but as a consequence the contrast of the projected image is reduced. Another possibility to reduce the distortion effects is to increase the pixel clock frequency. Such an approach leads to increased requirements for the video processing unit, higher power consumption and in the end higher projector costs. A better image quality is provided by the use of non-discrete time steps of the pixel clock.

In case of a VGA projection mode figure 9 shows the simulation of the position error in horizontal direction in dependence of the temporal pixel clock resolution. To project images with pixel position errors less than 1% pixel clock steps around 300ps are necessary. If pixel position errors of 3% are sufficient pixel clock steps of 1ns have to be used. For larger pixel clock steps pixel errors increase and especially in case of projection letters a reduced image quality is visible.

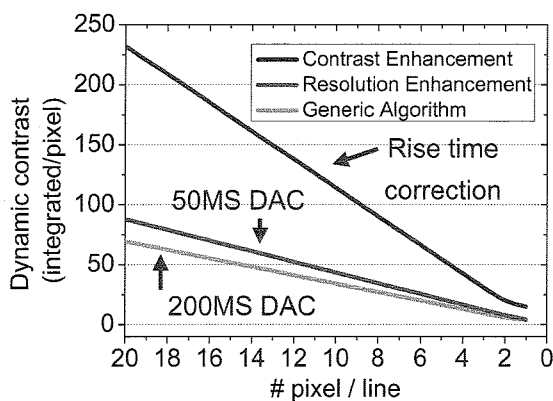


Figure 10. Dynamic contrast of a vertical grid line image in dependence of the number per pixel per line. Compared are three image processing approaches .

Figure 10 shows a comparison of the dynamic contrast of a vertical grid line image in dependence of the number of pixels per line. The simulations assume a VGA resolution, a rise time of 3ns and a spot size (full width half maximum) of 50% of the pixel size. Compared are three timing approaches of the pixel clock. The generic image processing algorithm employs a 200MS/s pixel clock and data flow rate. The resolution enhancement driving mode comprises a reduced data flow sampling rate (50MS/s) and an asynchronous pixel clock with 250ps temporal variation steps. For instance this temporal variation can be realized by analog mixed signal delay units. The contrast enhancement driving mode is based on the resolution enhancement approach but additionally takes rise time and spot size effects into account. It is seen that the resolution enhancement is superior to the generic approach and simultaneously reduces the frequency requirements of the video

processing unit. Employing the contrast enhancement resolution even a 150-200% improvement of the contrast is resulting.

4. Conclusion

A concept of an RGB laser module for the flying spot approach is presented. In addition to RGB lasers this module comprises beam collimation and beam combination optics, a switching power supply and a photodiode for every channel as well as an application specific laser driver IC. The size of the module is 6.5cc and for future modules smaller sizes are achievable. Employing state of the art lasers light output of 20 screen lumens with an efficiency of 18lm/W is realizable. In the case of projecting movies or photos even an effective efficiency is determined to 23lm/W resulting in power consumption below 1W. The closed loop driving mode of the lasers provides white point stability over the specified temperature range. Additionally the high transient performance of the laser driver ASIC and the asynchronous driving mode of the pixel clock supply enhanced image quality. All in all, the calibrated light source concept of the module enables projector manufacturer to go a further step in miniaturization and also in speeding up development time of flying spot based embedded projectors. In addition, the RGB laser module is also suitable to build up DMD, LCD or LCoS based projection units.

5. References

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