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DERPHOSA

PROJECT FINAL REPORT

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Executive summary

The Technology Development of Remote Phosphor (DERPHOSA) was a research project within the scope of Aeronautics Research of the 7th Framework Programme of the European Commission, which has started in August 2012 and has ended in December 2014. The project was a joint effort of four European companies.

Avionic Displays are widely used in cockpits of all fixed wing aircraft and helicopters and show a steadily technology improvement over the years. The current avionic displays are using Liquid Crystal Displays (LCD) with Light Emitting Diode (LED) Backlight assemblies. The benefits for the existing LED backlighting over previous solutions are well known: lower power consumption and more flat display systems resulting in size and weight reduction. The quality of the cockpit display unit is highly determined by the quality of the backlight unit.

In order to overcome the disadvantages of separate red, green and blue (RGB) LEDs (complexity) and white LEDs (short lifetime) solutions, the DERPHOSA consortium has developed technology for avionics displays with a new advanced backlight concept, based on Colour Conversion by Remote Phosphor. The objective of this project was to achieve substantial benefits on system simplicity, improving quality, reliability, power efficiency and reduction of supplier dependence, cost for development and maintenance/operations over lifetime.

The proposed Advanced Remote Phosphor Backlight concept is an evolution of the current LED backlights based on RGB or white LED’s. By using a blue pump light source (LED) and a dedicated external fluorescent phosphor layer (remote phosphor) the blue light will be converted to a very stable customized white light.

The main scientific objectives of the project were the adaptation of the fluorescent phosphors to the wavelength of the blue pump light source, the tuning of the fluorescent phosphors to the colour filter of the LCD, together with the total optical behaviour over lifetime.

The project evaluated and realized the remote phosphor backlight concept for both direct lit and edge lit application. In order to be able to evaluate the feasibility, advantages and drawbacks of remote phosphor for each application, two test set-ups have been realised, one of which was integrated in existing Display Units (hardware/ software). The optical performance and the feasibility of the concept have been verified in bench tests. Specific attention was given to verification of the humidity and lifetime characteristics of the remote phosphor. Validation of the optical behaviour of the remote phosphor concept was done in-flight using a test aircraft with real environment cockpit light conditions at 30.000Ft. This allowed assessment of the Display Unit operation in direct intense sunlight.

After reminding the project objectives and scope, this paper describes the DERPHOSA concept, including the two different backlight types. The results of the verification tests are presented briefly. This is followed by the validation test in a test aircraft. After the DERPHOSA research project, a further research and industrialisation phase will be needed before it can actually fly on aircraft.

It can be concluded that the principle of remote phosphor technology in backlights has been successfully validated. After some necessary further research and improvements to the prototype, it is likely that remote phosphor technology will be implemented within 2 or 3 years. Further development of the remote phosphor concept for avionics displays will certainly benefit to the avionics community, improving the quality of avionics display systems.

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1 Summary description of project context and objectives

1.1 Project Consortium

The Technology Development of Remote Phosphor DERPHOSA was a research project within the scope of Aeronautics Research of the 7th Framework Programme of the European Commission, which has started in August 2012 and has ended in December 2014. The project was a joint effort of four European companies. See figure 1.1 for the DERPHOSA Partners Logo.

Figure 1.1. DERPHOSA Partners Logo

1.2 Project Context

Avionic Displays are widely used in cockpits of all fixed wing aircraft and helicopters and show a steady technology improvement over the years. From old mechanical based systems, Cathode Ray Tube (CRT) systems to the modern Liquid Crystal Display (LCD) based systems are found in aircraft today. Worldwide the development of display systems is an emerging market for consumer as well as the aerospace industrial and military professional markets.

The LCD based systems all need a display backlight assembly since a LCD display does not provide light output itself. In the past (and still found in many applications today) backlight assemblies used Cold Cathode Fluorescent Lamps (CCFL). Current available Avionic Displays use Light Emitting Diode (LED) backlights, which have enormous advantages with respect to CCFL backlights.

The benefits for the existing LED backlighting are well known: lower power consumption (currently already, and projected to improve more as LED technology is still evolving), and more flat display systems resulting in size and weight reduction. Additionally, the production of CCFL lamps requires mercury which is not the case for LED's, making backlight production more environmentally friendly.

Because of the high demands on colour consistency and obtaining the required "white point" (a reference white), the current LED backlights contain red, green and blue (RGB) LED's. Complex and expensive electronic control systems need to compensate the depreciation of the individual LED's. Also, every manufacturer uses its own system, which does not benefit the system modularity and integration. RGB backlights need a relatively large mixing chamber for colour mixing and the heat development needs bigger cooling elements. This does not benefit the size, weight and energy consumption of the backlight unit.

Single white LED's are also considered, but they are a viable option only if they can meet and sustain the high demands and heavy stress avionics cockpit display systems have to withstand. Intense colour shift and lumen depreciation are making these single white LED's less suitable for avionics application.

1.3 Project Concept

The DERPHOSA consortium developed an avionics display concept with a new advanced backlight based on Colour Conversion by Remote Phosphor. The scope of this project was to achieve substantial benefits on system simplicity and power efficiency, leading to lower costs in the full life cycle (development, operation and maintenance), while improving image quality and system reliability.

The Advanced Remote Phosphor Backlight concept is an evolution of the current LED backlights based on RGB or white LED's. By using a blue pump light source (LED) and a dedicated external fluorescent phosphor layer (remote phosphor) the blue light will be converted to a very stable, customized white light.

The Remote Phosphor principle is further shown in figure 1.3.

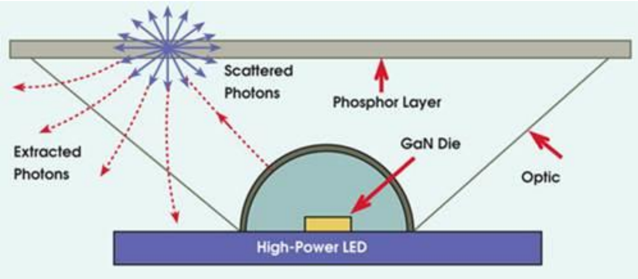

Figure 1.3. Remote Phosphor principle

A very good control of primary colours is guaranteed by selecting the right fluorescent phosphors. The thermal load on the fluorescent phosphors is relatively low for two reasons. Firstly as a full phosphor surface is available to generate the light output and secondly the phosphors are on distance, away from the heat of the light source. This will drastically reduce degradation of the brightness and improve colour performance over the life time compared to phosphor located in the near vicinity of the LED die, requiring complex electronics and control software to correct for colour differences.

Because the fluorescent phosphors will be hardly thermally and physically stressed, the light and colour quality of this new technique will be initially very stable over the lifetime. This technique will eliminate the use of multiple light sources and complex colour controlling systems. This single LED technology will simplify de LCD backlight unit and allow for a fault tolerant concept. Furthermore old and new remote phosphor systems can be used alongside each other without visible colour and light differences. This simplified new remote phosphor technology will hence reduce costs in development, production, operation and maintenance. Also the technology facilitates more modular concepts for avionics backlight components.

1.4 Project objectives

The General objectives of the project DERPHOSA were initially formulated as follows:

- Contribution to the reduction of the cost of ownership by improvement of the availability of avionic displays. The aim was to reduce the cost of ownership by 5%. This is realized through a cost effective, simple, high reliable and fault tolerant backlight system. The reduction of the cost of ownership will create competitive advantages for the Aircraft industry
- Increase the customer satisfaction due to higher performance of the avionic displays eliminating current state-of the art drawbacks as complex solutions to prevent colour variation and to enable a wide dimming range

- Contribution to dimensions reduction due to the use of a single (blue) LED type; the aim is to reduce the depth of the backlight system by 30%. For a direct lit backlight, the resulting depth should be less than 15 to 20 mm. For an edge lit backlight, a depth of 6 to 8 mm should be achievable.
- Contribution to weight reduction; the aim was to reduce the weight of a display unit by 15 to 20% due to the lower complexity and smaller dimensions of the backlight assembly.
- Contribution to more efficient production of avionics displays due to the lower complexity, as the display does not require any white-point calibration anymore.
- Improve system energy consumption; with regard to the expected higher quantum efficiency of remote phosphor due to the lower fluorescent phosphor temperature the aim is to bring the luminous efficacy 10% higher than white LED backlight systems.

The technological objectives of the project were related to

- The development of a new backlight technology concept based on colour conversion using remote phosphor for Avionics displays, both for direct lit and edge lit application
- Develop the backlight assembly concept in such a way that it improves display fault tolerance
- Investigate and test how this technology can also support operations as required for Search and Rescue (SAR) helicopters using night vision equipment.

The scientific objectives of the project were related to

- The adaptation of the fluorescent phosphors on the wavelength of the blue pump light source and the tuning of the fluorescent phosphors to the colour filter of the LCD, in combination with the SAR Mode operation requirements, together with the total optical behaviour over lifetime
- Development of a Simulation Model to assist in the design of display units with different dimensions

2 Project main S&T results/foregrounds

2.1 Remote phosphor development, conventional/ SAR-QD

Existing backlight solutions where Search and Rescue (SAR) night vision equipment such as Head-Up Displays (HUD) and/or night vision goggles are used need to avoid spectral emission of near infrared. In most cases this is accomplished by using a dual backlight system introducing complexity in electronics, mechanics, optical and SW design. The consequences are higher cost and reduced reliability.
Alternative backlight systems make use of one single system, but need heavy filtering to make the display SAR Night Mode compatible, resulting in even higher cost and poor colour performance.
The goal of the project was to develop an innovative approach to combine both operating modes (Day mode and SAR mode) in one single backlight system, effectively simplifying the overall structure and reducing complexity and cost, but without substantially impacting the performance of Day mode operation. The technical challenge will be that the spectral emission from the phosphor must be avoided in the near infrared above 650nm, because the infrared will affect the SAR night vision equipment.

For the DAY mode conventional phosphors have been selected that fulfil the DAY-requirements in combination with the selected LCD. This has been tested in edge-lit in an early phase of the project, see figure 2.1.1.

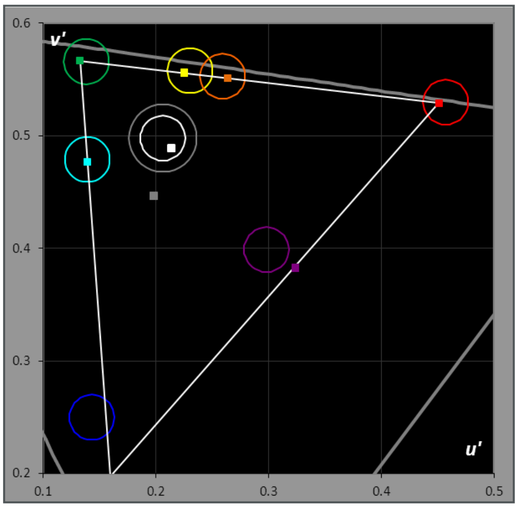

Figure 2.1.1 Chromaticity performance selected phosphors in edge-lit, measured at Barco

Besides phosphors, a UV-curing lacquer and a carrier foil for the remote phosphor have been selected. Large effort was needed to optimize the screen-printing process of the total system (phosphors, lacquer and carrier). Structured process development experiments have been done with variations in mesh size (screens), squeegee type, process settings (e.g. pressure, speed) to optimize the layer thickness, uniformity and visual appearance of the screen-printed foils. The remote phosphor concept is also known as ARPHOS®, a product of NDF Special Light Products.

Two examples of a uniformity measurement are represented in the next figure 2.1.2. On the left side a measurement of NDF is shown, on the right side a measurement of Phlox.

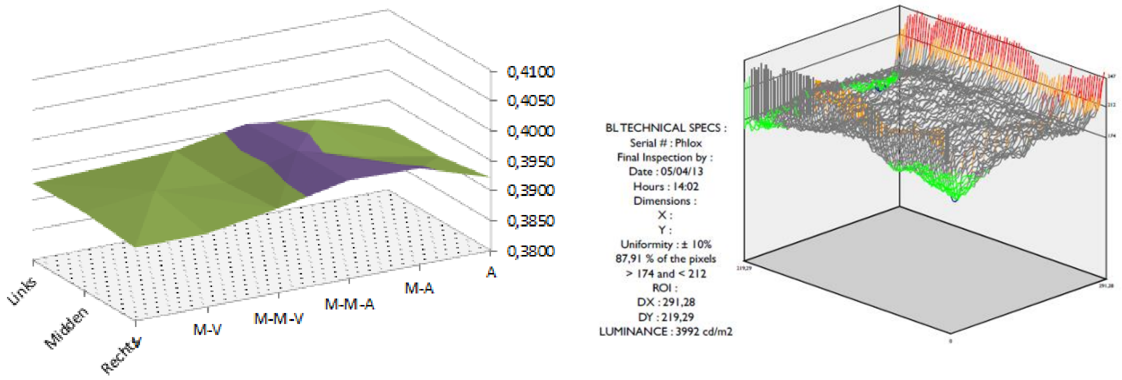

Figure 2.1.2 Optimized uniformity remote phosphor foils after structured process development, measured at NDF (left) and Phlox (right).

During the project it became clear that a SAR mode solution is not possible with the use of conventional phosphors because the phosphors are too broadband and emit in red. A conventional solution using filter techniques has been considered, but judged as not innovative and the added value of remote phosphor is limited in this way, see figure 2.1.3 below.

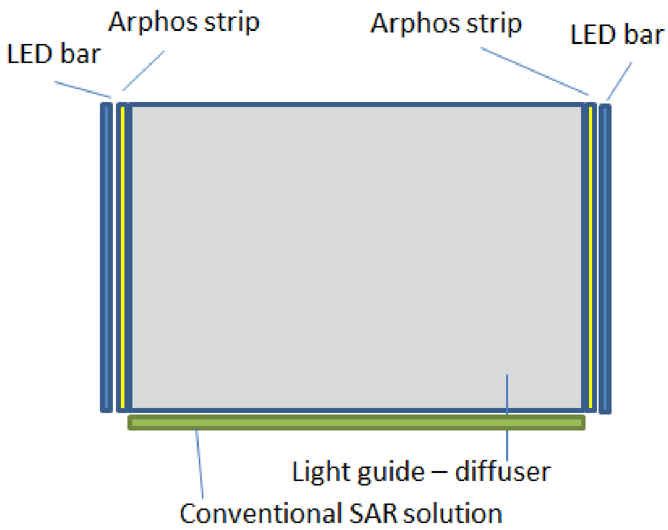

Figure 2.1.3 Conventional SAR solution

The concept of a conventional SAR mode solution can be described as follows: on the short sides royal blue LEDs are applied with an ARPHOS strip between LEDs and light guide for DAY mode. On 1 long side normal white LEDs with a filter between LEDs and light guide are applied for SAR mode.

The innovative solution has been found in the Quantum Dot (QD) technology. Quantum Dots are small (nanometer scale) emitting materials with small emission peaks. These small peaks make DAY and SAR mode requirements possible in one solution.

Quantum Dots were suspended in different matrices including the standard UV-curable, screen printable paste. Samples were prepared and analysed on initial performance, stability during blue light exposure and damp-heat testing (85 °C / 85% relative humidity). Emission data was used to simulate display performance and SAR mode compatibility, see figure 2.1.4.

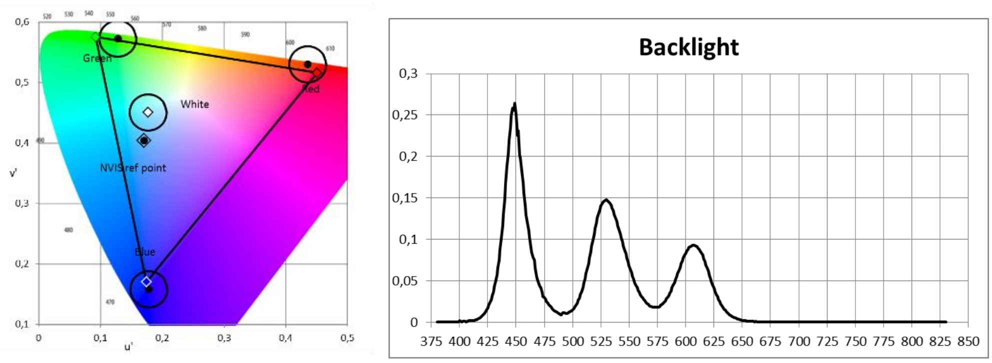

Figure 2.1.4 Display simulation using quantum dots as specified

Unfortunately, the performance of available QDs was not stable under illumination:

- Red: Reversible increase of Quantum efficiency
- Green: Peak broadening to longer wavelength

Further, absorption needs tuning to reach desired display targets.

Presently, experiments are running beyond the project end date with the aim to show the proof of concept on a small scale (not in the final 15.4” Display).

2.2 Backlight Direct Lit concept

2.2.1 Design and Realization

In this section a summary of the realization of the optical and mechanical design is given as well as the design of the LED board and LED driver.

For the Optical design a number of structured experiments with the following variables were tested:

- LED type
- Diffuser type (transmission and thickness)
- ARPHOS layer thickness
- Cavity distance
- Type of optical clear adhesive (OCA) between diffuser and ARPHOS foil to avoid moisture and to prevent sagging of the ARPHOS foil
- Reflector type

These tests have resulted in a selection of the right materials and optimization of the optical design.

Tests have been executed in a small 10x10 cm demo and information gathered has been used to develop the final 15.4 inch Direct Lit Backlight Unit. See figure 2.2.1.1.

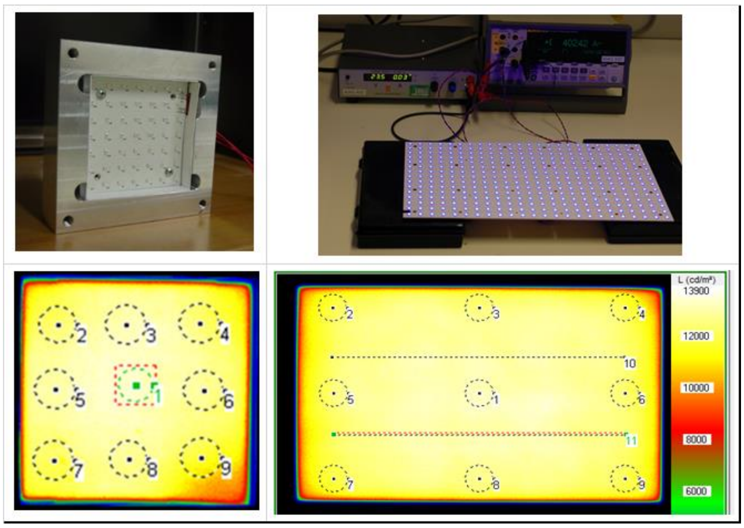

Figure 2.2.1.1From 10x10cm test board to the final Direct Lit Backlight

For the mechanical design the derived requirements (including environmental) and the optical design has been taken into account. The next figure 2.2.1.2 gives an exploded view of the Direct Lit Backlight.

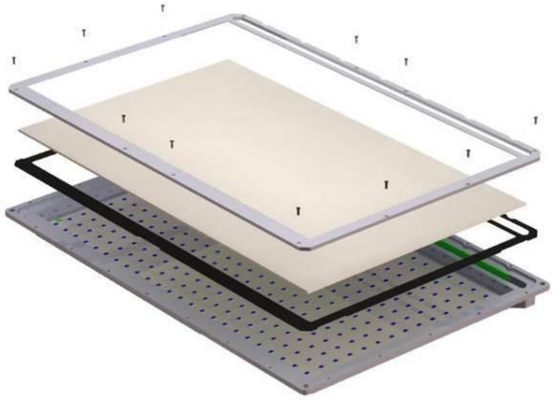

Figure 2.2.1.2 Exploded view of the DL-Backlight Unit

In the design phase special attention is given to the specific issues related to avionics:

- Vibration performance of the optical stack
- Humidity:
    - Optical stack bonded and sealed
    - BLU cavity:
        - Able to breathe by a controlled closed cavity using membranes
        - Pressure equalization for the rapid decompression requirements
- EMC rear cover

The LED board and LED Driver board have been developed in such a way that in case of LED-string failure or LED-driver failure no complete dark areas occur on the display. On the LED board optical and temperature sensors are present for control purposes.

The LED driver has 4 driver Integrated Circuits with 10 strings of 9 LEDs per driver. The backlight intensity is controlled by 4 Pulse Width Modulated (PWM) signals. The required high dimming ratio (min. 1:7000) has been realized.

2.2.2 *Functional verification*

The functional verification of the backlight has been done using a stand-alone test set-up as shown in figure 2.2.2.1.

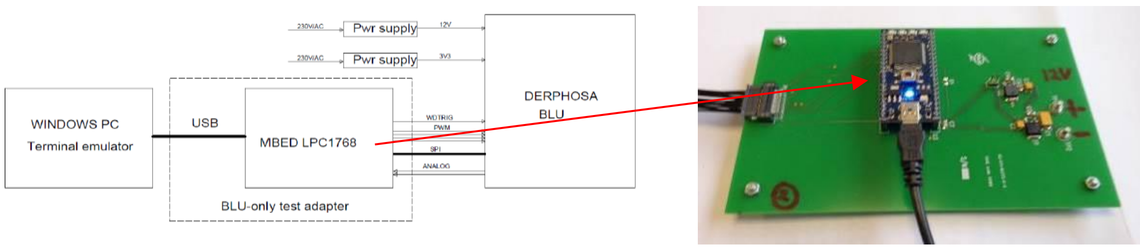

Figure 2.2.2.1 Stand-alone test-set up direct-lit backlight

Besides the functional verification optical tests were done using a light measurement sphere and a TechnoTeam LMK98-3 color video camera. The next figure 2.2.2.2 shows the light output and power as function of the PWM-signal.

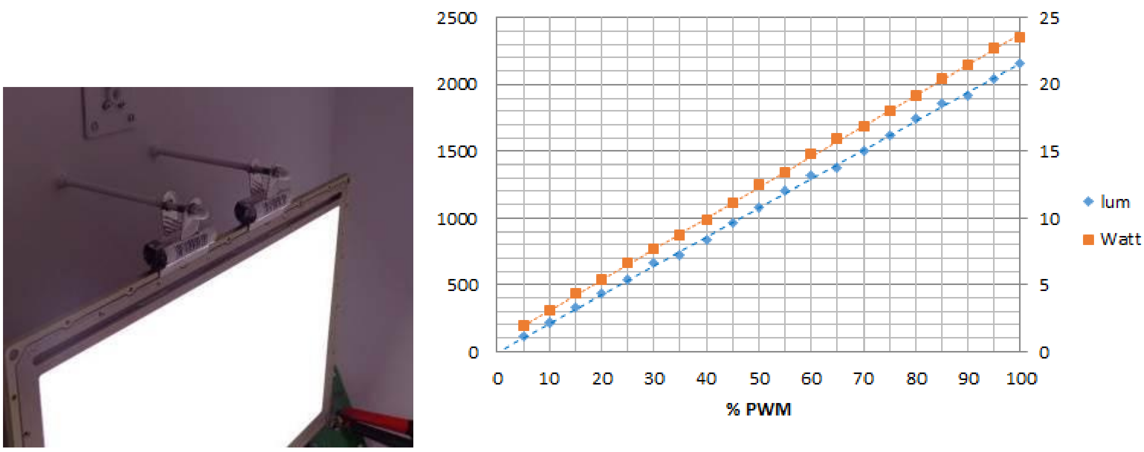

Figure 2.2.2.2 Light measurement sphere: light and power as function of PWM-signal

The realized luminance at the target power of 22W fulfils the requirements.

Good luminance uniformity and viewing angle characteristics have been measured see figure 2.2.2.3.

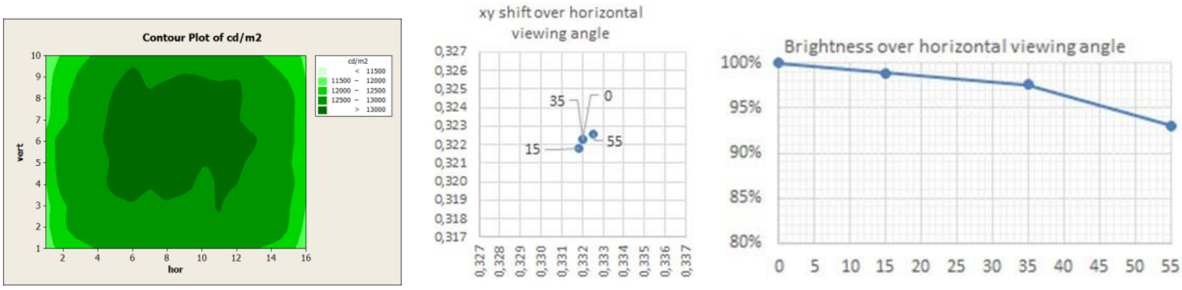

Figure 2.2.2.3 Luminance uniformity (left) color point shift (middle) and brightness over viewing angle (right)

The conclusion of the functional and optical verification is that the Direct Lit Backlight fulfils the requirements and can be used for optical verification in the total Display Head Assembly.

2.2.3 Simulation model

A simulation model has been made in Excel-format to calculate the white point, color gamut and SAR mode compatibility. The Simulation Model needs the following input parameters:

- LCD-transmission (color filter)
- Excitation spectra of the phosphors
- Emission spectra of the phosphors.

In figure 2.2.3 a screen-shot of the model is given.

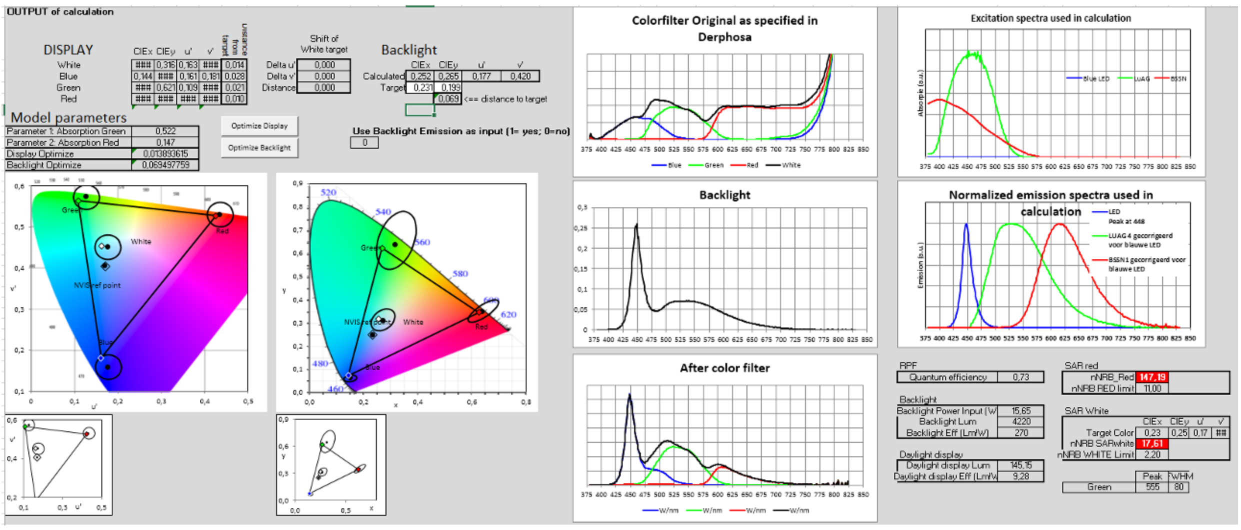

Figure 2.2.3 Screen-shot of the simulation model developed in the DERPHOSA project

2.2.4 Safety/ Fault tolerance analysis

The Led-board and LED-driver are designed in such a way that loss of a full LED block will result in an overall 75% LED reduction. In lower luminance values, this can be corrected through the optical feedback by increasing the 3 remaining block PWMs.

The overall fault tolerance of the DERPHOSA backlight concept is superior towards the current LED backlights. This is mainly achieved by the application of single color LEDs, together with the driver/chain/block redundancy.

2.3 Backlight EL concept

2.3.1 Design and Realization

The optical design is mainly focussed on the light guide, the LED type, ARPHOS layer and diffuser type. Tests were done in a 15" test backlight to find the best solutions that can be implemented in the final DERPHOSA 15.4” edge-lit backlight.

For the mechanical design the derived requirements (including environmental) and the optical design has been taken into account.

The next figure 2.3.1 gives an exploded view of the Edge Lit Backlight:

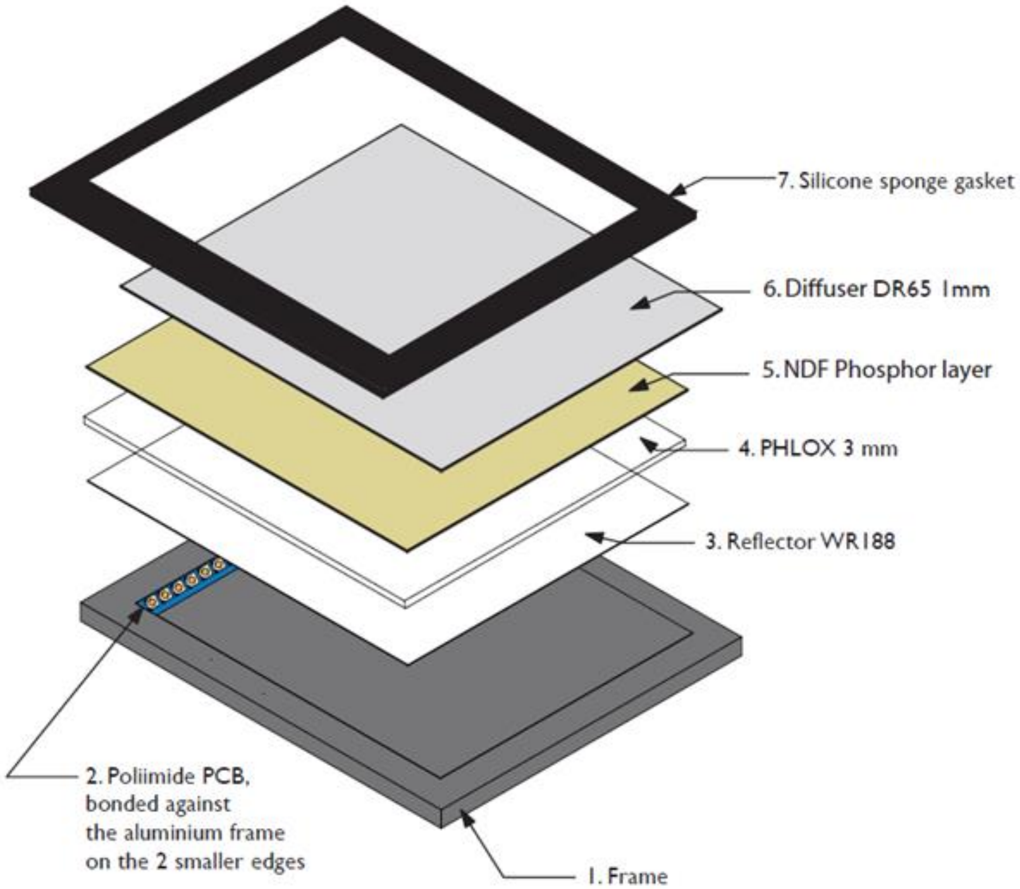

Figure 2.3.1.Exploded view of the EL-Backlight

LED-board and LED Driver design are laid out such that two strings of 7 LEDs are mounted on both sides of the backlight unit, so totally 28 LEDs. On 1 side an optical analogue sensor is located.
The driver board is similar to the direct-lit, but now each driver controls one string instead of 10.

2.3.2 Functional verification

The functional verification has been done in a limited way because of time constraint. A similar test set-up has been used as for the Direct-Lit Backlight.

Apart from the functional verification, optical measurements have been done on the Edge Lit Backlight unit. The light output, measured in an integrating sphere, as function of the PWM-signal is given in the figure 2.3.2.1.

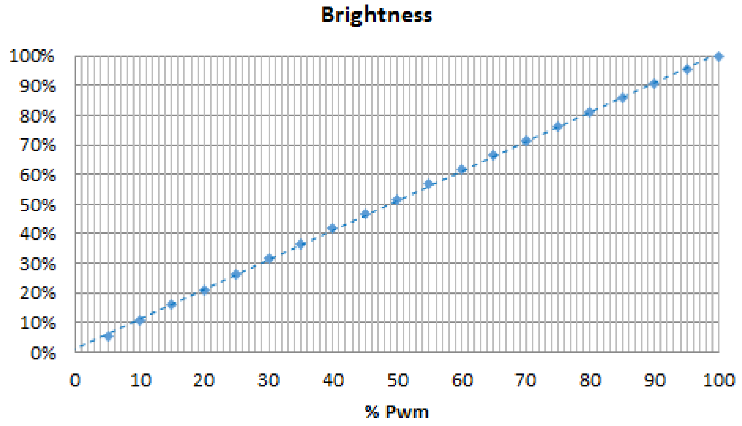

Figure 2.3.2.1 Edge-lit Backlight: light output as function of PWM-signal

The light output of the Edge Lit Backlight is lower than for the direct-lit at the same power, but this is normal for edge-lit systems as there are more light losses.

The luminance uniformity of the edge-lit backlight has been measured by means of a 9-points measurement (see figure 2.3.2.2) and is determined on 16% which is close to the target of <15%. Uniformity can be improved by another diffuser (with lower transmission) but this will have a negative influence on brightness.

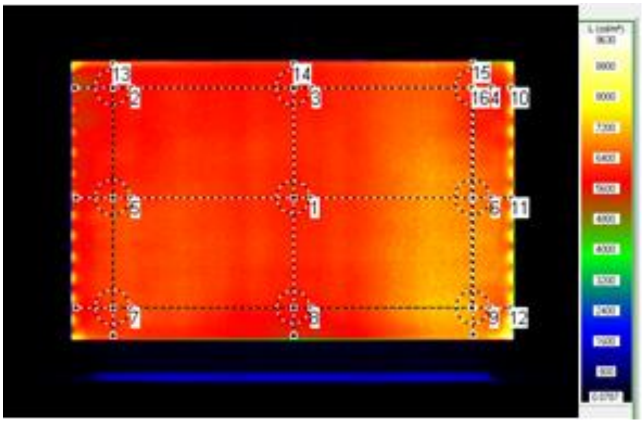

Figure 2.3.2.2 Luminance uniformity edge-lit backlight

Unfortunately, the LEDs are visible on the edges but to improve this it is necessary to increase the mixing chamber and this has also consequences for the housing. Because of time constraint the project team has decided not to improve on this point within the DERPHOSA project.

The viewing angle characteristics are represented in the following figure 2.3.2.3. One can see that the color point shift and brightness decrease over viewing angle is worse than for direct-lit, but this can also be attributed to the diffuser choice.

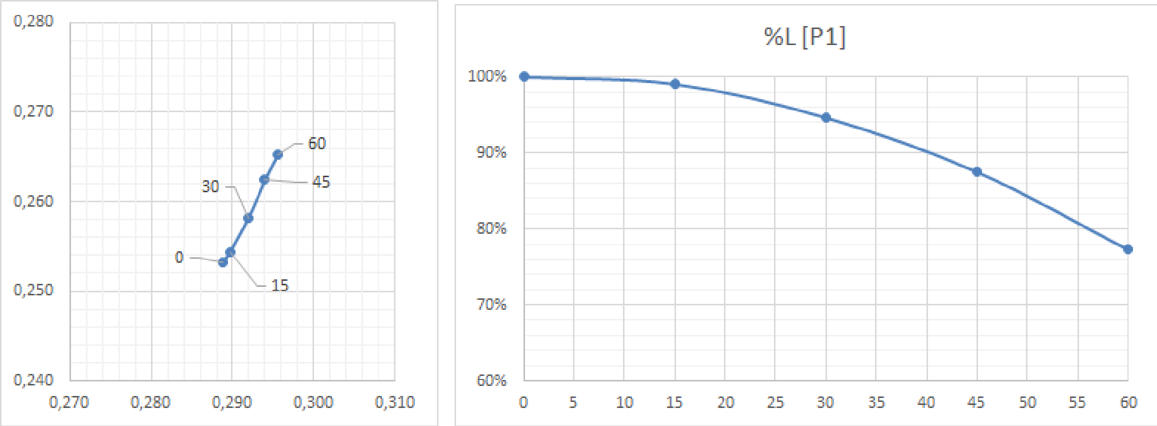

Figure 2.3.2.3 Edge-lit backlight: color point shift (left) and brightness over horizontal viewing angle (right)

2.3.3 Safety/ Fault tolerance analysis

The same conclusion can be drawn as for the Direct Lit Backlight with one remark.
As the LEDs in edge-lit are not interleaved, the effect of a driver loss will have a higher impact on the luminance decrease. One quarter of the display will have lower light output than the other three quarters.

2.4 Display Head Assembly

2.4.1 Design and Realization

The Direct Backlight unit (DL-BLU) has been integrated with other components to realize a complete Display Head Assembly.

The Display head assembly is composed of:

- Black bezel
- Display assembly
- 15,4" LCD with WSXGA+ resolution
- Front filter with EMI/EMC and Anti reflection coating
- Diffuser foil
- Direct Lit BLU
- Backlight driver board
- Controller board
- Video interface board (DVI to LVDS)
- Connectors

The following figure 2.4.1 shows the assembly of the different components:

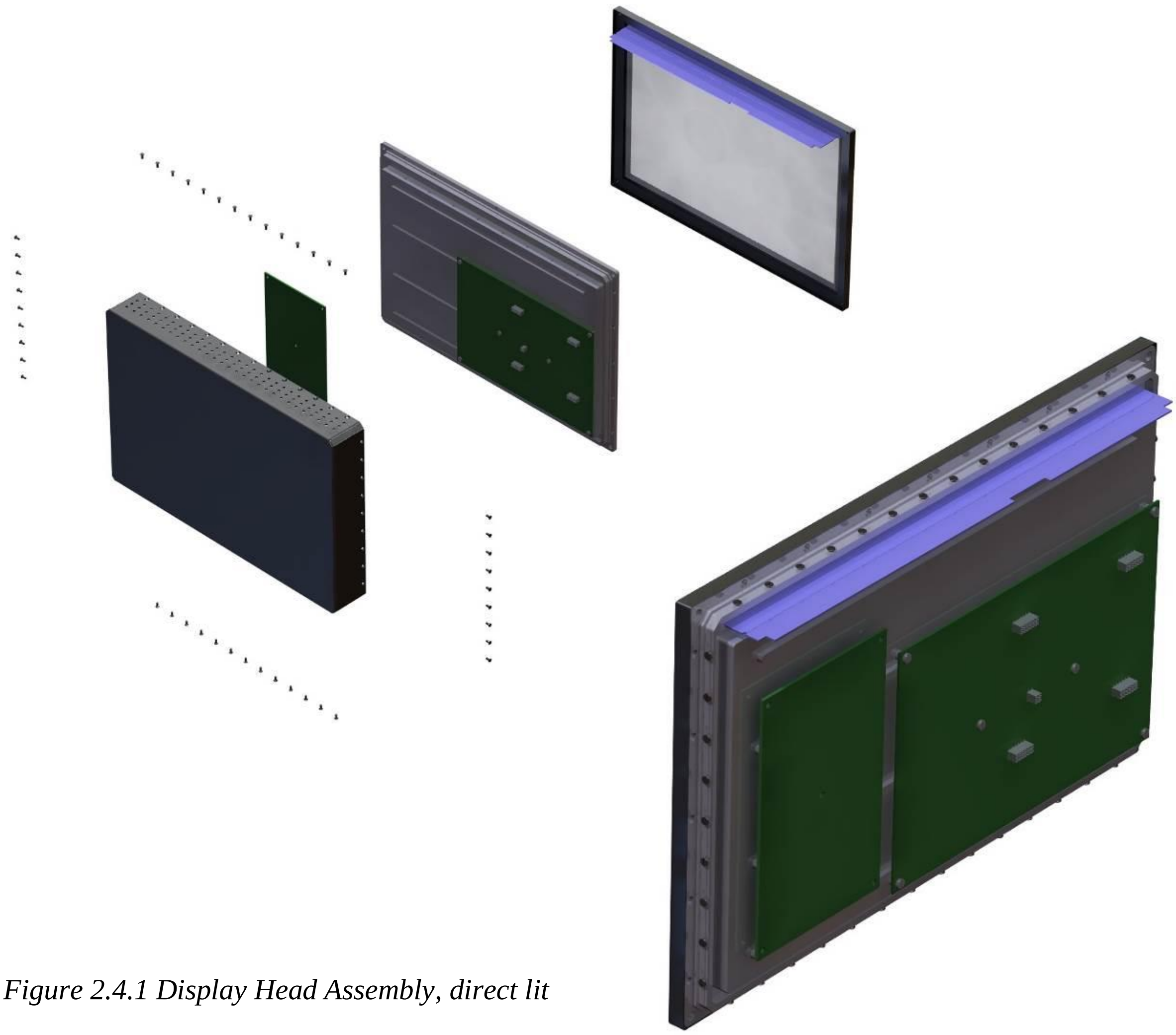

Figure 2.4.1 Display Head Assembly, direct lit

2.4.2 Integration and functional verification

Display Head Assembly test set-up is built in such a way that the DHA can be driven by standard equipment's. As such, next to the BLU and Controller board, a video interface board (DVI to LVDS converter) and a power supply module (28VDC to internal voltages converter) will be integrated in the DHA unit. As a result, there will be 3 cables going out of the DHA unit (see figure 2.4.2.1).

- A DVI cable to connect to the laptop
- A RS232 serial interface cable to connect to the laptop (for maintenance purposes)
- A power cable to connect to 28VDC power supply.

A potentiometer has been implemented on the DHA unit in order to control the display backlight dimming.

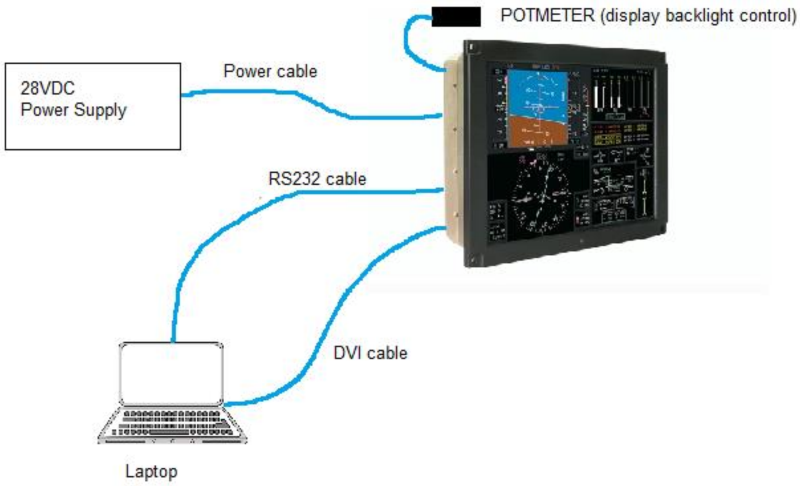

Figure 2.4.2.1 DHA wiring

The following figure 2.4.2.2 shows the realization of the set-up.

Figure 2.4.2.2 DHA on the test bench

Conclusion

The direct BLU has been successfully integrated in a DHA and its associated test set-up resulted in a fully operational display with a remote phosphor based Direct Lit BLU. The DHA was further used for verification and validation tests.

2.5 Verification tests

2.5.1 *LED life cycle tests*

The originally selected LEDs for direct-lit were put in a life cycle test at 45 °C, see figure 2.5.1.

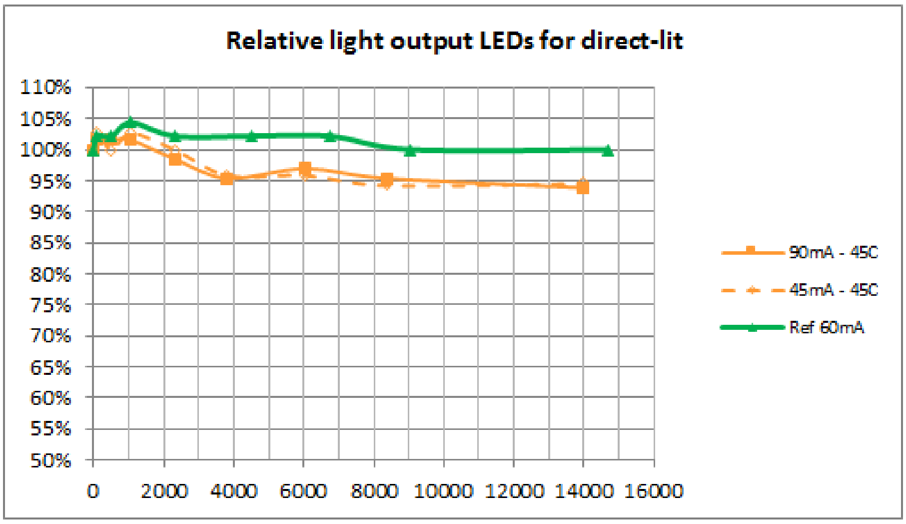

Figure 2.5.1 Relative light output LEDs for direct-lit as function of lifetime

This graph makes clear that the light depreciation after 14000 hours is limited to 5% at an ambient temperature of 45 °C.

The finally selected LEDs (higher efficiency) for the project are from the same brand but unfortunately lifetime data is not available yet.

The selected LED for the Edge Lit Backlight was also put in a lifetime test. The reasons of the choice of this Royal Blue LED are that Phlox has good experience with this same LED in white and it was the most efficient LED available. The Royal Blue version has been tested in a backlight at 85 °C for 3300 hours which is equal to 33000 hours at 20 °C. Light depreciation of only 6% has been reported.

2.5.2 *Phosphor life cycle tests*

Phosphor life cycle tests were performed, incl. Royal Blue LEDs, for 15000 hours at room temperature. Light depreciation was limited to 5% (probably caused by the LEDs) and x- and y-shift were limited to 0.003, which is negligible. Refer to figure 2.5.2.1.

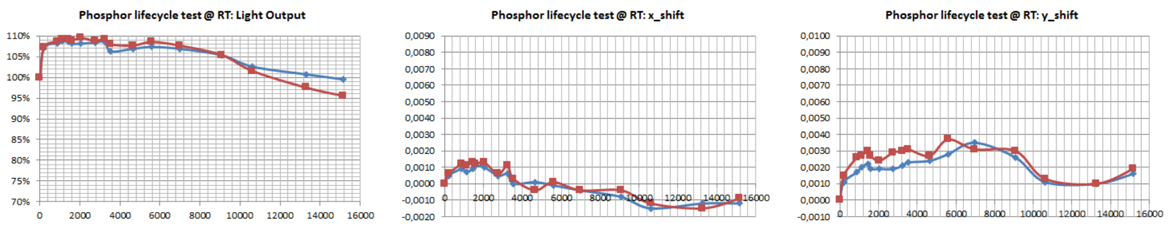

Figure 2.5.2.1 Phosphor life cycle test: limited depreciation in light output and color point after 15000 hours at room temperature

Chromaticity shift reported for edge-lit (same test at 85 °C as described in section 1.3.5.1) after 3300 hours was only 0,21% in x and 0,61% in y. For comparison: 2% in x and 1% in y for ceramic white LEDs is mentioned.

Apart from the lifetime tests a humidity stress test has been done to the remote phosphor foil: 500 hrs 85°C / 85% relative humidity.

- Luminescence: The maximum difference between a stressed foil and the reference foil is 1,5%, well within the specified light loss of ±5%.
- Color point shift: A small shift is seen in the first 125 hours, this shift is constant to 500 hours. The maximum colour point shift is limited to +0.002/+0.003 and is well within the specified colour point shift of ±0,010.

Luminescence and color point shift results are also given in a graphical way in figure 2.5.2.2.

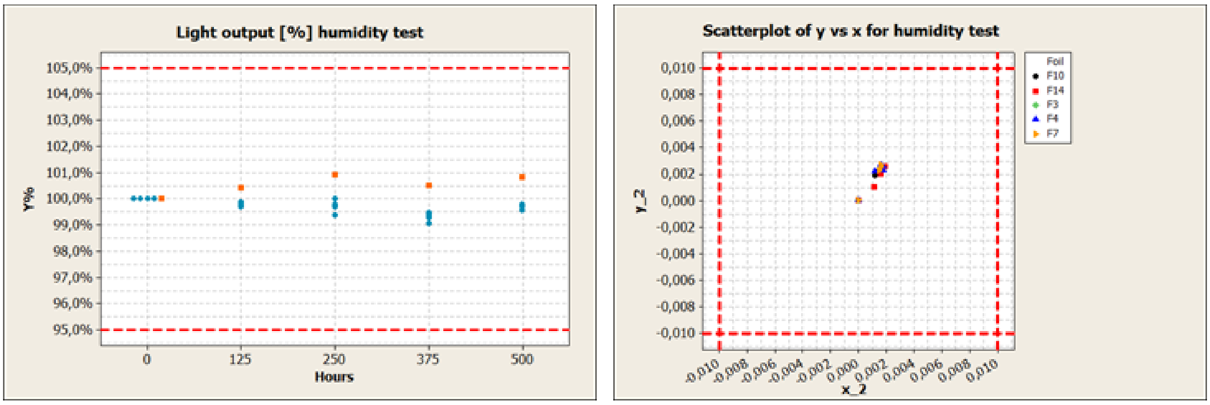

Figure 2.5.2.2 Humidity stress test (85°C / 85% r.h.) remote phosphor foil: limited depreciation in light output and hardly any color point shift after 500 hours

The Yellowing Index YI has been measured according to ASTM-D1925 (Doc 1, see section 8)for the carrier foil, the foil and lacquer and the complete system of foil, lacquer and remote phosphor.

Conclusion here is that the small change in YI is caused by the lacquer, but the delta of 1,5 is far below the maximum specified value. The figure 2.5.2.3 below shows more details of the measurement values.

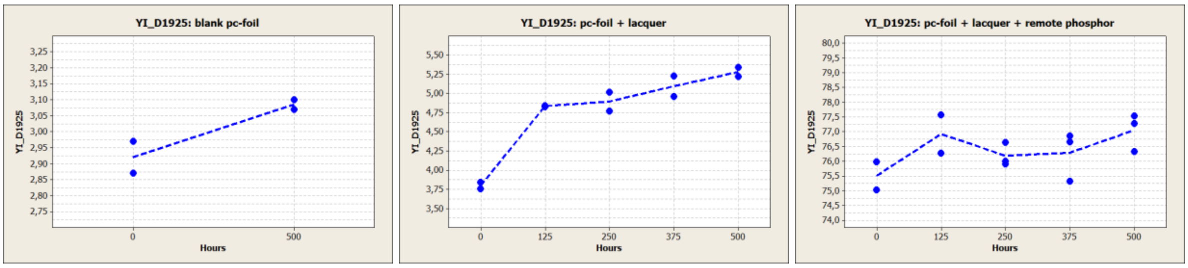

Figure 2.5.2.3 Humidity stress test (85°C / 85% r.h.) remote phosphor foil: small change in yellowing caused by the lacquer but far below max value specified.

2.5.3 HALT test

A HALT test is a Highly Accelerated Life Test with the purpose to intentionally stress the test subject in order to find possible design problems normally turn up after a long operating period. For the Direct Lit Backlight unit the Long term HALT is realized in line with the procedure described in the Integration and Verification plan.

The following temperature profile is applied as shown in figure 2.5.3.1.

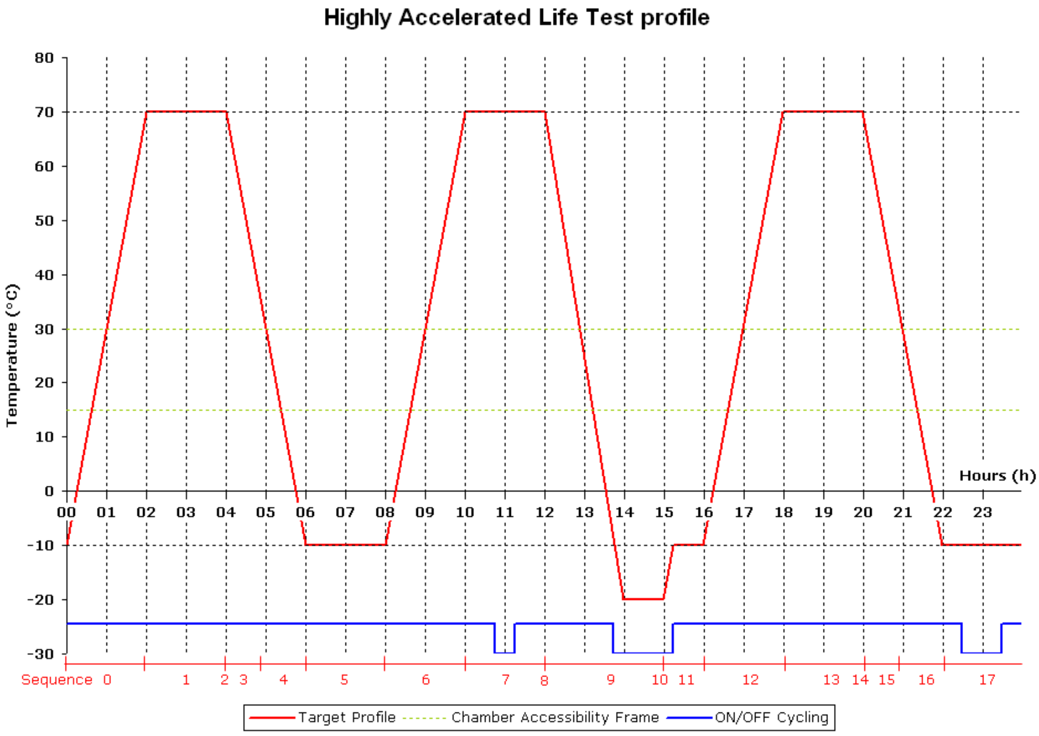

Figure 2.5.3.1 HALT test profile

The optical performances of the backlight are measured at the start of the test and checked every week.

Following characteristics are measured:

- Luminance level
- White point coordinates

The test will run for a maximum duration of 3500 hours.

The test is started on 13th November 2014, see figure 2.5.3.2.

Figure 2.5.3.2 DHA in the HALT test chamber

The HALT test has been started. Initial characteristics are recorded and monitored during the all duration of the test. Final results of this test will be available and analysed beyond the end date of the DERPHOSA project due to the time constraint.

2.5.4 Optical verification

2.5.4.1 Optical Verification description

A Display Head Assembly (DHA) demonstrator was built which is based on a Direct Lit Backlight system. A remote phosphor film was integrated into this DL-DHA, with phosphor mixture and concentration matched to the LCD and optical stack characteristics.
The optical verification focuses on the optical characteristics which are most relevant to the remote phosphor technology.
The following performances have been verified:

- Chromaticity
- Viewing Angle
- Uniformity
- SAR Mode
- Reflectance
- High ambient contrast ratio
- Power consumption

2.5.4.2 Optical Verification results

- Chromaticity

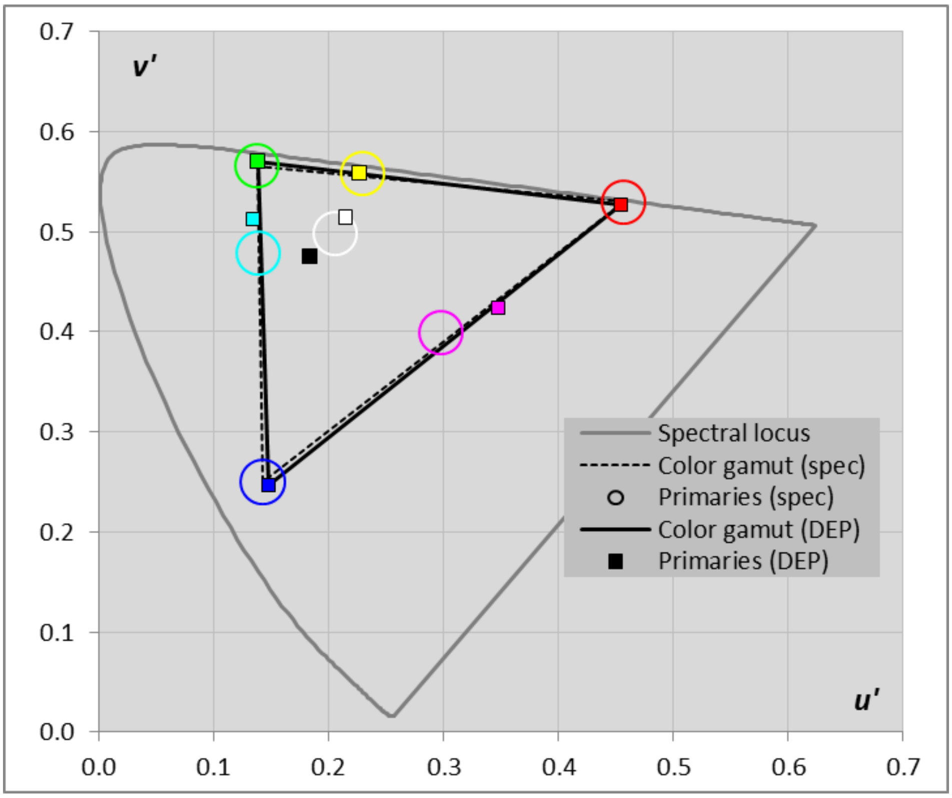

Figure 2.5.4.2 .1 Chromaticity

Based on these results, shown in figure 2.5.4.2.1, we can conclude that the phosphors used in the remote phosphor film are well suited to meet the targeted color gamut in combination with the LCD color filter characteristics. The color shift on WHT, CYN and MAG strongly suggests, however, that the phosphor concentration is too high in combination with the light control films used in the optical stack of the DHA, resulting in too much conversion of blue light into yellow.

- Viewing Angle

The measurement results show that the DL-DHA was measured performs extremely well on virtually all viewing angle requirements, see figure 2.5.4.2.2. While this is evidence of the state-of-the-art LCD technology selected for and integrated in this prototype, the results also show that the backlight performance has wide and stable luminance and color performance over the entire viewing envelope.

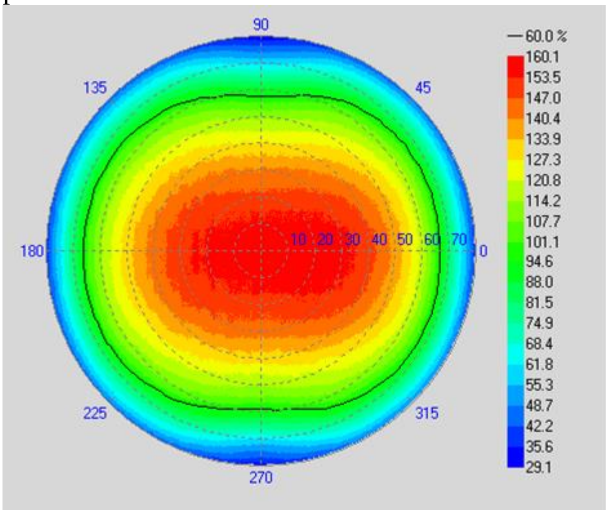

Figure 2.5.4.2.2 Viewing angle

The only major deviation from the DHA requirements was observed for the Contrast Ration (CR) over the DEP-VE. While the minimum CR value obtained for the DEP-VE is significantly lower than the limit defined in the spec, the viewing angle plot evidences that high CR performance is maintained over a wide viewing angle: CR is well above 200: 1 for horizontal viewing angles up to ±75°. Only at the extreme compound angles, a faster CR decay was observed.

For the majority of the evaluated display colors, only limited color shifts over the VE were measured. Only for very dark custom shades (e.g. RED50, CYN20, BLK), larger color shifts were measured. However, this is an intrinsic limitation of LCD technology. The performance obtained on this DL-DHA demonstrator is among the best displays previously characterized by Barco.

- Uniformity

The measurement results show that the remote phosphor backlight concept used in the DL-DHA can result in acceptable screen uniformity, see figure 2.5.4.2.3.

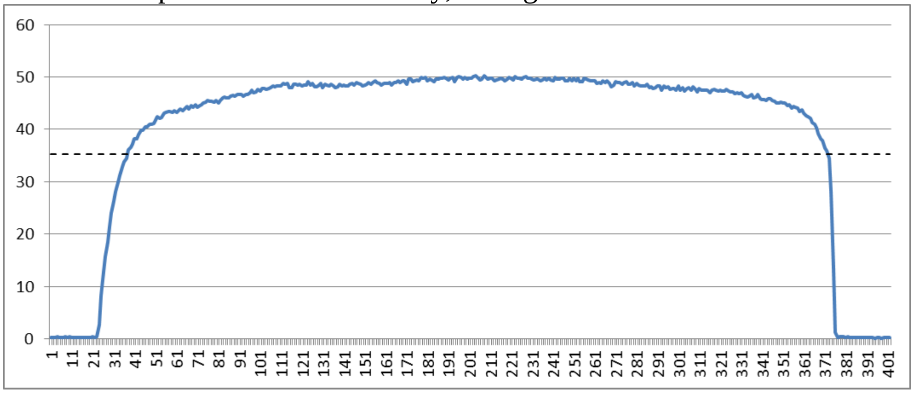

Figure 2.5.4.2.3 Horizontal cross section uniformity.

Our analysis suggest that a slight extension of the backlight size could potentially improve the uniformity up to the very edges of the active area, which should also be beneficial for uniformity when viewing the display from oblique viewing angles.

- SAR Mode

The results evidence that more narrow-band phosphors are needed to avoid interference of the displays with SAR Mode operation.

- Reflectance

The results evidence that the reflectance performance of the DL-DHA demonstrator is well within specification, after optimization.

- High ambient contrast ratio

As can be seen from the results above, the combination of a bright display luminance with the low reflectance of the LCD panel assembly used in the DL-DHA yields an excellent sunlight readability performance under all ambient illumination conditions.

- Power consumption

Based on these results, we can calculate that this corresponds with a power consumption of close to 20 W for at 200 fL. As such, the DL-DHA demonstrator meets the power consumption target of 22 W which was put forward after the change to a higher-performance IPS-based LCD, but with lower transparency than initially assumed.

2.5.4.3 Optical verification conclusion

Further optimization of the remote phosphor film used in the DL-DHA demonstrator should enable to obtain full compliance on the **chromaticity** requirements imposed at the start of this research project.

This optimization will, most probably, consist of a tuning (i.e. reduction) of phosphor concentration in the remote phosphor film, in order to shift the white balance to a cooler white.
Note: the wide-color-gamut color filter (CF) characteristics of the selected LCD have enabled to use wide-band emitting phosphors while still achieving a wide color gamut at display level. In case of an LCD with standard CF characteristics (40-50% NTSC), more narrow-band emitting phosphors will need to be selected.

The **viewing angle** results obtained for the DL-DHA evidence that the selected LCD for this prototype has excellent viewing angle performance. Good color stability was observed over the entire viewing envelope. The light control films of the optical stack were selected to have wide (‘cross-cockpit’) viewing performance, as is required on wide-body aircraft for civil transport.

The screen **uniformity** results show that good uniformity can be obtained with a limited backlight depth, even for a direct-lit backlight concept. No hot spots could be observed directly above the LEDs. The luminance fall-off near the edges is limited, but still visible.

On the other hand, the spectral emission characteristics show that **SAR Mode operation** is not possible using the currently selected phosphors for the remote phosphor film. More narrow-band emitting phosphors are needed to achieve the required substantial reduction of spectral emission in the NIR.

Finally, the results obtained for **reflectance** and **high ambient contrast ratio** evidence that the LCD panel assembly designed for the DERPHOSA DL-DHA meets the most stringent sunlight readability requirements of state-of-the-art avionics displays.

2.5.5 Environmental verification

2.5.5.1 Introduction

This section describes the environmental test according to RTCA DO-160F (Doc 2, see section 8); a test specification for airborne equipment. The following tests have been performed on the Direct Lit Backlight unit:

- EMC pre-compliance test
- Humidity Test
- Condensation Test
- Temperature Test

EMC tests (pre-compliance only) have been performed in order to verify compliance for cockpit operation. Temperature and Humidity test are carried out in order to verify the phosphor performance in humid and condensing conditions and to verify the thermal design of the Backlight assembly.

2.5.5.2 EMC Pre-compliance test

During the test the display was operated at nearly maximum backlight intensity (Duty Cycle 97%). A dynamic picture, generated by a PC, was send to the DHA via a HDMI/DVI cable. The DHA was powered by a 28V DC power supply. Both the power supply and PC were placed outside the Semi-Anechoic Shielded Room. Only conducted emission and radiated emission was tested.

For conducted emission the test failed for two measurements. For radiated emission the test failed for a few more measurements. In all cases the limit was exceeded by no more than 10 db.
Since the Display Unit was not operated during critical phases in the test flight, these excursions could be accepted.

Figure 2.5.5.2 shows an example of one of the conducted emission test results.

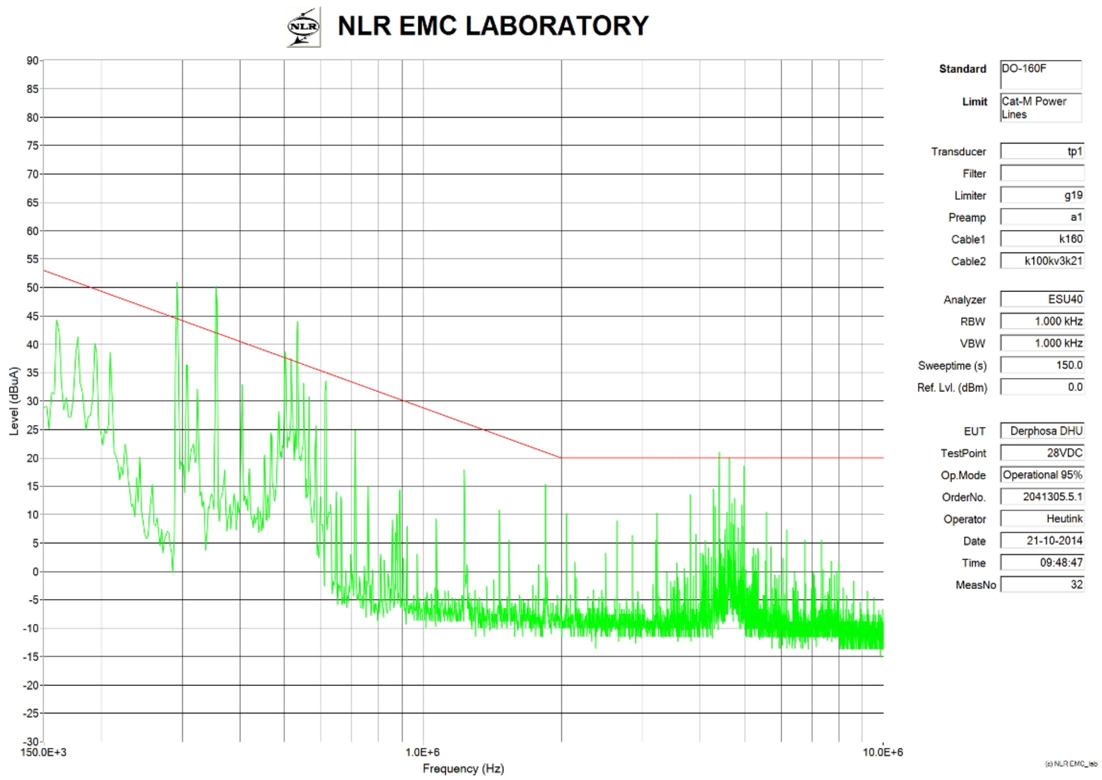

Figure 2.5.5.2 Conducted emission measurement

2.5.5.3 Humidity test

The display unit will be tested for humidity performances according Section 6 of RTCA DO-160F (Doc 2, see section 8) Category A (10 days).

Before the test, the total power supply current is measured for various Duty Cycle settings. After the humidity test has been conducted, the same measurement is performed to check if there was no demonstrable abnormality. It is also verified that the emitted light from the backlight unit was uniform without visible distortions due to bad or non-functioning LEDs or LED strings. See figure 2.5.5.3 for a view in the test chamber.

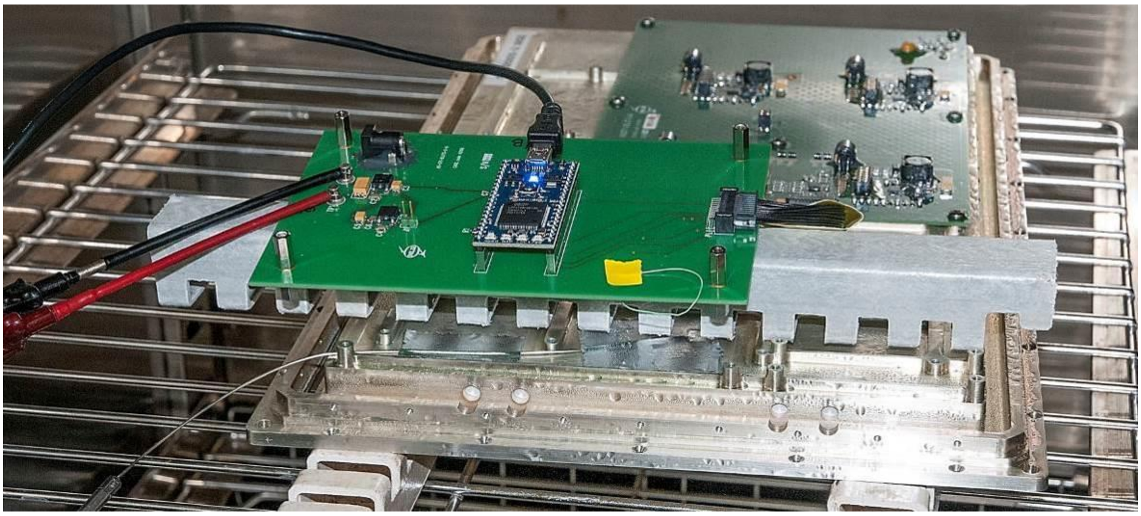

Figure 2.5.5.3 Humidity test

With regard to the measured results and the visual observations it can be concluded that the backlight unit is functioning normally as specified after the Humidity test.

2.5.5.4 Condensing Water Proof Test

The display unit was tested for condensation performance according to section 10 of RTCA DO-160F (Doc 2, see section 8) Category Y (Equipment for 3 hours non-operational at -10°c and then at 40°C,85% RH for 3 hours). These tests determine whether the equipment can withstand the effects of liquid water being sprayed or falling on the equipment or the effects of condensation.

Before the test, the total power supply current was measured for various Duty Cycle settings. After the humidity test has been conducted, the same measurement was performed to check if there was no demonstrable abnormality. It was also verified that the emitted light from the backlight unit was uniform without visible distortions due to bad or non-functioning LEDs or LED strings. See figure 2.5.5.4 showing the post condensation.
With regard to the measured results and the visual observations it can be concluded that the backlight unit was functioning normally as specified after the Condensation test.

Figure 2.5.5.4 Post Condensation test

2.5.5.5 Temperature test

The backlight unit was tested for low and high temperature performances according to section 4 of RTCA DO-160F Category A2. After stabilisation at the required temperature the unit was operational during minimal 2 hours. During this interval the unit must operate without any degradation.

During the test, the backlight unit was placed inside the test chamber and connected to the test setup with 2 cables. The power supply, test board and PC were located outside the test chamber. Through a window in the test chamber the backlight unit was visible and the correct operation i.e. producing a uniform backlight image could be examined.

The Low temperature was set to -15°C and the High temperature to +70°C. For the transition from ambient temperature to the required test temperature a rate of 1C/min was used, stabilisation time was 30 minutes for the Low temperature test and 20 minutes for the High temperature test.

After the test, a check was made with regard to the power consumption of the backlight unit for several settings of the backlight intensity. No abnormal deviations were observed with respect to measurements made before this temperature test. With regard to visual observations and the power consumption test at the end of all the tests it could be concluded that the backlight unit fully passed the temperature test.

2.6 Validation test

2.6.1 Introduction

This section describes the results from the validation test. The objective of this validation was to demonstrate a demonstration Display in a real aircraft and to evaluate the optical performance of the display at high altitudes under direct sunlight conditions. During this in-flight validation the DERPHOSA display has been rated by test-subjects, each with a certain expertise. Several questionnaires have been filled in and comments have been collected. The tests included a

- comparison test
- coloured contrast test
- ghost test
- coloured font test

From these questionnaires it is found that the Display is performing better than the existing cockpit avionics display. The first results show that the optical behaviour of display itself (i.e. LCD + Backlight) could be used as an avionics display in a cockpit without any modifications. The results also give a first idea about colour use and font use. A more in-depth research would be necessary to study usage of colour, and combinations of colours. This is also the case for fonts. A first step towards achieving TRL6 regarding the remote phosphor concept has been made.

A display unit demonstration model has been built and installed into NLR's laboratory aircraft Citation II. During an in-flight validation the display has been subjected to several tests, a test with symbology similar to the Proline21 PFD (see Figure 2.6.1.1) and a test with several test patterns (see Figure 2.6.1.2).

A total of three test-subjects were invited to rate the display during an extensive flight test where several input variables were varied: sunlight azimuth angle, position of the test subjects and the use of sunglasses. During the flight a total of 6 rounds were flown to obtain enough measurements to get a good qualitative impression of the new display. The measurements were executed using Haworth-Newman rating scales and simple rating scales. A total of approx. 1700 scores were recorded in questionnaire and analysed and reported in this document.

Figure 2.6.1.1. DERPHOSA display in NLR's Citation II cockpit

Figure 2.6.1.2. DERPHOSA display with test pattern

2.6.2 Test subjects

A total of three test-subjects have been invited to rate the display. In order to get a judgement by different experts the experts represent three areas:

- Certification, represented by a certification expert
- Human factors, represented by a human factors and display expert
- Flight operations, represented by an (airline) pilot

The certification expert is a well-known professional that has been involved in many certification projects of state-of-the-art aircraft like the B747-8, Embraer 195. The human factors expert is an NLR employee who has been involved in many human factors experiments for more than 20 years. The flight operations expert is an NLR pilot who works part-time as a regular airline pilot.

2.6.3 Comments given by test subjects

All three test subjects agreed that the new display is a comfortable display to work with during the test. It is better than the existing display although the existing display is a display based on technology developed 15 years ago. The new display has better brightness and contrast than existing display. On the negative side: The Mach number was not readable on new display. Also the fonts are not drawn that nicely as on the existing display. Also the white on the DERPHOSA display seems whiter (not brighter) than the white used on the existing display

> *JG: Although the simulation (i.e. graphics) on the new display is very good, it is not 100% identical to the existing display. For the simulation of the existing display limited information was used, which results in small difference with the existing display. The very white colour could be caused by the colour calibration or due to the colour gamut.100% white could also be replaced by a grey-ish white.*


Figure 2.6.3 General cockpit view

2.6.4 Conclusion

An in-flight test of the new DERPHOSA display has been conducted with three test subjects that carried out several tests. These tests included a comparison test, a coloured contrast test, a ghost test and a coloured font test. Results of these tests were recorded using questionnaires, analysed and discussed. From these tests is has become clear that the new display is a display that performs very well under high brightness conditions in an operational environment. Using the results from the comparison test and looking at the Haworth-Newman rating scale scores it could be concluded that the display can be used in an aircraft without modifications to the LCD and/or backlighting. The display performs well under every sunlight direction with and without sunglasses and from different observation positions. The responsiveness of the display is good enough for most airliners and business jets. The use of colours, colour combinations and coloured fonts should be studied in more detail. See figure 2.6.3 for a general cockpit view.

3 Conclusions on the project objectives

3.1 General objectives and results

The main objectives of the proposed project DERPHOSA are:

1. **Contribution to the reduction of the cost of ownership**
   The availability of avionic displays is improved by the realization of a cost effective, simple, high reliable and fault tolerant backlight system. Indeed the use of foils with phosphor technology allows a simple assembly concept. The reduction of the cost of ownership is creating competitive advantages for the Aircraft industry.

   Objective to reduce the cost by 5% is difficult to quantify.
   Expectation is that based on the conclusion of the Fault Tolerance Analysis carried out by Barco this objective will be reach. Additional, due to the use of 1 single colour LED instead of 3 RGB LED's the chance of errors and the associated costs are reduced 2/3.

2. **Increase the customer satisfaction**
   The higher performance of the avionic displays eliminating current state-of the art drawbacks as complex solutions to prevent color variation and to enable a wide dimming range.

   An impression of the customer satisfaction is achieved by using the direct-lit display in a real flight which has been validated by the pilot. This is extensively described in the Validation Report of NLR. The overall conclusion is that the display is assessed as "very good and can be used in an aircraft without necessary modifications". The use of colours and colour combination should be studied in more details.

3. **Contribution to dimensions reduction**
   The target depth of 15 till 20mm of the direct-lit backlight is almost achieved. The overall thickness which has been reached is 20,8mm. Important remark is that main focus of the design was on optical functionality which means that there still some space left for improve the thickness of the direct-lit backlight by a reduction 1,0mm. This will result in a thickness of 19,8 mm. The two areas where this could be taken from are the thickness of the led board and the thickness of the rear wall of the panel.

   The target depth of 6 till 8mm of the edge-lit backlight of 9,8mm.
   Also in this edge-lit backlight is still some space left to improve the thickness by a reduction of 1,0mm. This will result in a thickness of 8,8 mm. The two areas where this could be taken from are the thickness of the gasket and the thickness of back cover of the panel.

4. **Contribution to weight reduction**
   The weight is reduced thanks to the lower depth as mentioned here above and due to the lower complexity and smaller dimensions of the backlight assembly.

   The aim was to reduce the weight of the display by 15 till 20%.
   The weight of the new direct-lit backlight is now1,96 kg which results in a total expected weight reduction of 15%
   The above mentioned space for a thickness of 1,0 mm reduction will lead to a weight of 1,60 kg.

   The weight of the new edge-lit backlight is now1,80 kg which results in a total expected weight reduction of 20%

5. **Contribution to more efficient production of avionics displays.**
   This is realized thanks to the lower complexity, as the display does not require any white-point calibration anymore.

   The objective to reduce the complexity of the production of the display and thereby to improve the production efficiency is reached that no colour adjustment is necessary on backlight level as well on display level. In comparison to a RGB backlight no colour calibration on backlight level need to done. Because the colour out of the backlight can be adapted to the required white point.
   In comparison to white LED's hardly no colour adjustment on display level need to be done.

6. **Improve system energy consumption.**
   The aim is to bring the luminous efficacy on par with white LED backlight systems but taking into account the inherent losses from using more saturated phosphor mixtures. A luminous efficacy of 80 to 85% is targeted, when comparing an advanced remote phosphor backlight with a system based on white LED's with the same LED package as the blue LED's of the new concept.

   With regard to System energy consumption the following objectives are reached.
   On backlight level:
   Power target 23,5 Watt (incl. LED driver) with a backlight brightness 13240 cd/m2 has been reached

   Colour point x: 332 and y: 322
   7% higher efficiency is reach with Royal Blue led's with remote phosphor compared with white LED's with the right reflective material

   On display level:
   Power level of 20Watt (Incl. LED driver, LCD and control boards) with a surface brightness 685 cd/m2 has been reached

   Colour point (u'v')= 0.214 ,0.514

   Colour gamut:
   Change on display level required a change of the phosphor characteristics.
   We reached the required colour gamut with the remote phosphor rare earth phosphors.
   See for technical details DERPHOSA Final report chapter 2.1.

3.2 Technological and scientific objectives and results

Technological objectives

1. The development of a new backlight technology concept based on color conversion using remote phosphor for Avionics displays, both for direct lit application has been reached. For edge-lit still some improvement steps need to be made.
2. Develop the backlight assembly concept in such a way that it improves display fault tolerance. Fault tolerance study shows significant improvement was made.
   - No color integrity difference within the final image will occur
   - Luminance impact will be minor
3. Investigate and test how this technology can also support operations as required for search and rescue (night mode) helicopters
   - Theoretical calculation and simulation shows that this with QD's is possible
   - Demonstration prove of principle could not be performed in the course of the project

Scientific objectives:

1. The adaptation of the fluorescent phosphors on the wavelength of the blue pump light source and the tuning of the fluorescent phosphors to the color filter of the LCD, in combination with the

SAR can be showed s a prove of principle.
The optical behavior over lifetime of this concept could not be proved.

2. Development of a Simulation Model to assist in the design of display backlight units
Simulation and calculation model on phosphor characteristics, LCD transmission, color gamut and NVIS calculation is made.

4 Potential impact, main dissemination activities & exploitation of results

4.1 Potential impact

The DERPHOSA project will contribute in several ways to the impacts listed in the Work Programme 2012:

• Introduction of new European centred technology in the supply chain for avionics displays. The innovative Remote Phosphor backlight concept will be realized with phosphor lighting technology that is available at European companies. The blue pump LED's are also based on European know-how. With these components the system is basically independent of non-European suppliers, and will in fact, strengthen the competitive position of the European companies involved on the European and non-European market.

• Increased modularity and integration by realizing many (optical) functions with few components. Basically two core components: the blue pump LED's and the remote phosphor plate are creating the core of a full colour capable backlight system, at the same time high end optical performance is achieved, with less cooling requirements than traditional LCD solutions.

• Reduced recurring cost because of the limited number of component types, used at relative low quantities.

• Reduced development cost and time to market will be based on the realized simulator tool. When scaling up or down the display size the simulator tool will define the exact definition of the remote phosphor mix for an expected display colour performance. With this the scalability of the technology is achieved as well

• Reduced operational costs when in aircraft: the lower weight and power consumption will support reduced fuel consumption.

• The fault tolerance and high reliability because of simplicity of the structure will effectively reduce the life cycle cost of the display units. The technology will reduce unscheduled maintenance in airline operations compared to the current state of the art of display backlights.

• Integrated blue pump LED's and phosphor materials are well established base technologies resulting in a design that is relatively insensitive to obsolescence problems that are typically very difficult in the Avionics market that needs long term support.

The main market focus for this project is the Avionics Display market. Other markets that can benefit of this technology are display markets where high performance is important like Medical displays, Air Traffic Control display stations and automotive.

The partners Barco, Phlox and NDF will exploit this technology each in their markets: the Avionics display market and the Avionics Backlight market respectively.

Combining high colour performance with high power efficiency and at the same time realizing fault tolerance and reduced weight are the main advantages of the remote phosphor backlight technology.
A common solution is envisaged for the: day, night and search and rescue operational conditions. The technology will be European centred with reduced risk of obsolescence.

4.2 Main Dissemination activities and Exploitation of results

A Dissemination plan was established at the beginning of the project and defined the dissemination logic during the project duration, the process to achieve it, the scheduling of the steps and the related actions to spread out the information on the project, studies and results.

Conferences

A major dissemination event was the opportunity to attend with the DERPHOSA Display Unit Farnborough Air Show exhibition held mid July 2014.
In the period before the Air Show the partner's activities were related to the completion of a demonstrator Display Unit. NDF completed the Direct Lit Backlight unit and NLR manufactured the Display Front Bezel. Integration of the Direct Lit Backlight unit, the Cover and the LCD including the LCD Driver board took place at Barco's premises.
NLR realized a demo video content to be presented at the Display Unit. It comprises a view of a specific avionics display showing a terrain following guidance application.
The Display Unit was demonstrated at the NLR booth at the Farnborough Air Show. NLR provided exhibition booth space for an operating demonstration of the Display Unit, the unit operated throughout the exhibition period.
The Display Unit at the Air Show attracted quite some attention of people passing by the booth.

In figure 4.2.1 and 4.2.2 an impression of the NLR booth, showing the Demonstrator Display Unit.

Figure 4.2.1 NLR booth at the Farnborough Air Show Exhibition

Figure 4.2.2 Demonstrator Display Unit at the NLR booth

Promotional material, Newsletters

During the course of the project 3 Newsletters were published on the public website, see figure 4.2.3 for an impression.

Aiming at delivering information directly into the hands of those interested in it, the Newsletter is the second key element for communication. It helps promote the project and its progress within the industrial and scientific community.

Its content is defined as following:

- a brief reminder about the DERPHOSA project, for new readers to understand the background
- a status on the progress and last achievements of the project
- a focus on a technical topic related to DERPHOSA
- a presentation of the partners, to improve their visibility

DERPHOSA — Technology Development of Remote Phosphor for Avionic Cockpit Displays

DERPHOSA NEWSLETTER # 3 — September, 2014

PROJECT INFORMATION

DERPHOSA: Technology Development of Remote Phospho

From 2012-08-01 to 2014-11-30 | DERPHOSA website: htt

Project reference: 314509

Total cost: EUR 2 353 607

EU contribution: EUR 1 752 755

Programme acronym: FP7-TRANSPORT

Sub programme area: AAT.2012.1.1-5., AAT.2012.4.1-4.

Contract type: Small or medium-scale focused research pr

Coördinator: STICHTING NATIONAAL LUCHT- EN RUIMTEV

Participants:

BARCO NV, BELGIQUE-BELGIË

PHLOX SA, FRANCE

N.D.F. SPECIAL LIGHT PRODUCTS BV, NEDERLAND

The research leading to these results has received funding

Framework Programme (FP7/2007-2013) under grant agre

Project Summary

State of the Art - Background

Avionic Displays are widely used in cockpits of all fixed wing aircraft and helicopters and show a steadily technology improvement over the years. The current avionic displays are using Liquid Crystal Displays (LCD) with LED Backlight assemblies. The benefits for the existing LED backlighting over previous solutions are well known: lower power consumption and more flat display systems resulting in size and weight reduction. The quality of a cockpit display unit is highly determined by the quality of the backlight unit.

Because of the high requirements on colour consistency and obtaining the required so-called "white point" (a reference white) the current LED backlights contain red, green and blue (RGB) LED's. Complex and expensive electronic control systems are needed to compensate the depreciation of the individual LED's throughout the operational life. Single white LED's are also considered, but only if they can meet and sustain the high requirements and heavy stress avionics cockpit display systems have to withstand, throughout the envisaged display life cycle. Colour shift and lumen depreciation are making these single white LED's

DERPHOSA — Technology Development of Remote Phosphor for Avionic Cockpit Displays

DERPHOSA NEWSLETTER # 2 — June, 2014

Project Status

In the past period tests were performed to evaluate the remote phosphor optical behaviour and to evaluate the remote phosphor simulation model. Due to the specific performance of the LCD a number of corrections were necessary to the remote phosphor colour gamut and thickness. It was decided to use conventional phosphor for daylight applications and in parallel procure innovative Quantum Dot (QD) phosphors for improved day and night mode application.

Furthermore the realization of the Back Light Unit (BLU), both the Direct Lit and the Edge Lit version, took further shape.

The printed circuit board design of the DL-LED Board, the DL-LED Driver board and the EL-LED Driver board were completed. All printed circuit boards were manufactured. After delivery of the boards the components were placed and the first boards were tested. The DL-LED Board prototype worked first time right and the 2nd board was also realized and tested.

The BLU Test board was further realized and tested. This board simulates the controller and provides full functional testing of the DL- and EL-Driver boards. The Test board is connected to a PC with a simple low-level interface to realize the control functions.

The DL-LED Driver board prototype had some design problems related to the control stability of the driver chip. It took some time to solve the problem, but finally it worked well and in total 3 boards were realized and tested.

The EL-LED Driver board prototype was realized and tested, no problems were found and the 2nd and 3rd board were realized and tested.

The prototype of the DL- BLU Housing Frame and Edge was manufactured, after which the LED Board was mounted to verify the dimension tolerances. Some minor changes related to the mounting of the LED Board and the Optical Stack (Diffuser and Remote Phosphor film) had to be applied to the BLU Housing Frame and Edge.

The mechanical and electronic design was completed and the first prototype of the Direct Lit BLU was realized. In the last month of the past period the Back Light Unit was integrated with the LCD and the related assemblies like the power supply and Display Head Controller board. The objective is to have the completed Display Unit available for demonstration at the Farnborough Air Show mid July 2014.

DL-BLU without remote phosphor

DERPHOSA PARTNERS

Coordinator:

STICHTING NATIONAAL LUCHT- EN RUIMTEVAARTLABORATORIUM (NLR), NEDERLAND

Participants:

BARCO NV, BELGIQUE-BELGIË

PHLOX SA, FRANCE

N.D.F. SPECIAL LIGHT PRODUCTS BV, NEDERLAND

Websites:

www.nlr.nl

www.barco.com/en/

www.phlox-gc.com/

www.ndf.eu

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Figure 4.2.3 Newsletters

Promotional material, Video presentation

For NLR the main dissemination effort was dedicated to the dissemination activities regarding the validation test flight. This test flight using NLR's test aircraft the Citation II was considered a major source for dissemination material in the form of photographs and a video recording. NLR's media department was contacted early in the preparation effort of the flight test. Such a flight test requires a lot of effort regarding certification, resulting in authorization to perform the test flight authorised by the Airworthiness Authorities.

The validation test flight was done in October and was a great success; the Display Unit (DL-DHA) behaved very well and was judged by professional pilots as a very nice display. The whole process of preparation and the flight test itself was recorded on film and video providing a very nice overview of the results. NLR's media department made two video's; a long one for dissemination purposes by the DERPHOSA partners and a short version for release on the public YouTube.

See figure 4.2.4 and 4.2.5 for an impression of the aircraft and the cockpit in flight; clearly showing the DERPHOSA Display Unit at the right side of the instrumentation panel.

Figure 4.2.4 NLR's Citation II Research Aircraft

Figure 4.2.5 The DERPHOSA Display Unit in the Citation II

The results of the DERPHOSA project will be further disseminated in the network of the partners. It will be investigated if a follow-up research project can be set-up in order to bring the DERPHOSA Remote Phosphor concept to a higher TRL level regarding use in avionic displays.

A draft Technical Paper was prepared in the final weeks of the project and will be further detailed after the project end date.

4.3 Project public website

NLR has made available a public web site containing information on the different studies undertaken and an explanation of the most significant results achieved and explained.
Given the obvious advantages of Internet, DERPHOSA Public website is a key element of project communication.
The website content was defined so as to include:

- The presentation of the project: its approach and objectives, its organization, the partners, the schedule
- The publications, of any kinds, that will be produced during the course of DERPHOSA: papers of conferences, press articles, newsletter
- The news and major events: the latest developments and results of the project will be presented as well as key dates
- Links related to the project
- Contact information, for people to have an entry point when needed.

The address of the website is:
http://derphosa.nlr.nl

4.4 List of all beneficiaries with the corresponding contact names

Contacts	
Full Name	**Company**
Rob Zwemmer R&D Engineer/ DERPHOSA Project Manger	National Aerospace Laboratory NLR Amsterdam, The Netherlands Email: zwemmer@nlr.nl Telephone: +885113327
Coen van‘t Westeinde Managing Director	NDF Special Light Products Roosendaal, The Netherlands Email: c.westeinde@ndf.eu Telephone: +31165 538630
David Delbaere Manager	Barco Kortrijk, Belgium Email: david.delbaere@barco.com Telephone: +3256233961
Chris Blanc CEO	Phlox Corp. Aix-en-Provence, France Email: cb@phlox-gc.com Telephone: +33442907622

5 Use and dissemination of foreground

5.1 Section A -Dissemination measures (Public)

5.1.1 List of all scientific publications

LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main authors	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
1	*Technology Development of Remote Phosphor For Avionic Cockpit Displays (DERPHOSA)* ***DRAFT ONLY, not yet ready for publication***	Stefan Carton Gert Stuyven Rob Zwemmer	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*

5.1.2 List of Dissemination activities

LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	*Public Website*	*NLR*	*DERPHOSA*	*Active from Oct, 2013 to Dec, 2016*	*n.a.*	*General Public*	*unknown*	*unknown*
2	*Conference exhibition*	*NLR*	*Farnborough Air Show*	*Mid July 2014*	*Farnborough*	*Aerospace specialists/ general public*	*Appr. 100*	*unknown*
3	*Promotional material*	*NLR*	*Newsletter 1* *Newsletter 2* *Newsletter 3*	*March, 2014* *June, 2014* *Sep, 2014*	*Public website*	*Industrial community*	*unknown*	*unknown*
4	*Promotional material*	*NLR*	*Project Video*	*Dec, 2014*	*Public website* *NLR website*	*Industrial community*	*unknown*	*unknown*

5.2 Section B -Exploitable Foreground and Plans for Exploitation (Public)

5.2.1 List of applications for patents, trademarks, registered designs

The partners do not intent to initiate any patent filing in the frame of this project.

List of applications for patents, trademarks, registered designs, etc.						
Type of IP rights (Patents, Trademarks, Registered designs, Utility models, etc)	Confidential (Yes/No)	Foreseen embargo date Dd/mmm/yyyy	Application reference(s) (e.g. EPxxxxxxx)	Subject or title of application	Applicant (s) (as on the application)	URL of application
N/A	N/A	N/A	N/A	N/A	N/A	N/A

5.2.2 List of Exploitable Foreground and plans for exploitation

Foreground number	Type of Exploitation Foreground	Description of exploitation foreground	Confidential	Foreseen embargo date mmm-yyyy	Exploitation products or measures	Sector of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved
1.	Commercial exploitation of R&D results	Remote Phosphor Film design and production process for Backlights	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF
2.	Commercial exploitation of R&D results	Assembly and architecture of a stand-alone Direct Lit remote phosphor based backlight	Y	N/A	Aerospace display assembly	Aerospace	2016	N/A	NDF, BARCO
3.	Commercial exploitation of R&D results	Direct Lit Backlight Fault tolerant architecture	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF/BARCO
4.	Commercial exploitation of R&D results	Fixation reflector sheet in backlight cavity of direct-lit concept	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF
5.	Commercial exploitation of R&D results	Gasket construction of inner ring on frame of direct-lit backlight concept	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF
6.	Commercial exploitation of R&D results	Simulation Model for fine tuning of remote phosphor optical stack for direct-lit Avionic backlights	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF

7.	Commercial exploitation of R&D results	Colour and light stable Remote Phosphor Film on 85C/85% Relative Humidity test	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF
8.	Commercial exploitation of R&D results	Application of Quantum Dots for SAR mode	Y	N/A	Aerospace display assembly	Avionics	2016	N/A	NDF
9.	Commercial exploitation of R&D results	Application of an optical gel between layers of the optical stack in the Direct-Lit BLU. The highest brightness, improved uniformity and no negative effect on viewing angle characteristics and visual appearance	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF
10.	Commercial exploitation of R&D results	Improved efficacy gain of remote phosphor in combination with royal blue LED's compared to white LED's i.c.w. certain reflective material	Y	N/A	Aerospace display assembly	Avionics Medical ATC	2016	N/A	NDF

Foreground number	Type of Exploitation Foreground	Description of exploitation foreground	Confidential	Foreseen embargo date mmm-yyyy	Exploitation products or measures	Sector of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved
BAR_01	Commercial exploitation of R&D results	Requirements for display assembly based on remote phosphor backlight	Y	N/A	Aerospace display assembly	Aerospace	2016	N/A	Barco
BAR_02	Commercial exploitation of R&D results	Display assembly based on remote phosphor backlight	Y	N/A	Aerospace display assembly	Aerospace	2016	N/A	Barco
BAR_03	Commercial exploitation of R&D results	Optical characteristics of a remote phosphor backlight based display assembly.	Y	N/A	Aerospace display assembly	Aerospace	2016	N/A	Barco

Foreground number	Type of Exploitation Foreground	Description of exploitation foreground	Confidential	Foreseen embargo date mmm-yyyy	Exploitation products or measures	Sector of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved
	General advancement of knowledge	Remote phosphor (see 4.4.1 & 4.4.2 for more details)	Yes		a matrix of 10000 blue chips. Light is collected for each chip by a fiber optic of 250 µm. All the fiber optics are assembled in a tight matrix with the remote phosphor on top and a lens	Advertising		solution is patented	PHLOX
	General advancement of knowledge	Phosphor+lightpipe			Ambiant lighting with better luminance than white Led for color T° <4000°K	Interior design / decoration / lighting			PHLOX

6 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	314509
Title of Project:	DERPHOSA
Name and Title of Coordinator:	Rob Zwemmer, NLR

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***NONE***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	

• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders		5
Experienced researchers (i.e. PhD holders)		2
PhD Students		
Other	1	6

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	-
Of which, indicate the number of men:	

D Gender Aspects		
5. Did you carry out specific Gender Equality Actions under the project?	○ ●	Yes No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	○	○	○	○	○
❑	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
❑	Actions to improve work-life balance	○	○	○	○	○
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- ○ Yes- please specify
- ○ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- ○ Yes- please specify
- ● No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- ○ Yes- please specify
- ● No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- ● Main discipline[1]: **2.2**
- ○ Associated discipline[1]: **2.3**
- ○ Associated discipline[1]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ ●	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

[1] Insert number from list below (Frascati Manual).

11c	**In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ○	Yes No

12.	**Did you engage with government / public bodies or policy makers (including international organisations)**
○	No
○	Yes- in framing the research agenda
○	Yes - in implementing the research agenda
○	Yes, in communicating /disseminating / using the results of the project

13a	**Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?**
○	Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
○	Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
○	No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**0**
To how many of these is open access[2] provided?	
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[3]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	■	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
■	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*

[2] Open Access is defined as free of charge access for anyone via Internet.
[3] For instance: classification for security project.

	Difficult to estimate / not possible to quantify	☒
I	**Media and Communication to the general public**	
20.	**As part of the project, were any of the beneficiaries professionals in communication or media relations?** ○ Yes ● No	
21.	**As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?** ○ Yes ● No	
22	**Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?** ☐ Press Release ☐ Media briefing ☐ TV coverage / report ☐ Radio coverage / report ☒ Brochures /posters / flyers ☒ DVD /Film /Multimedia ☐ Coverage in specialist press ☐ Coverage in general (non-specialist) press ☐ Coverage in national press ☐ Coverage in international press ☒ Website for the general public / internet ☒ Event targeting general public (festival, conference, exhibition, science café)	
23	**In which languages are the information products for the general public produced?** ☐ Language of the coordinator ☐ Other language(s) ☒ English	

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

7 LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Description
ARPHOS	Advanced Remote Phosphor Technology
ATC	Air Traffic Control
ATM	Air Traffic Management
BLU	Back Light Unit
CAD	Computer Aided Design
CCFL	Cold Cathode Fluorescent Lamp
CF	Color Filter
CR	Contrast Ration
CRT	Cathode Ray Tube
DEP-VE	Design Eye Position Viewing Envelope
DERPHOSA	Technology Development of Remote Phosphor for Avionic Cockpit Displays
DHA	Display Head Assembly
DL	Direct Lit
DVI	Digital Visual Interface
EC	European Commission
EL	Edge Lit
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
fL	Foot Lambert
Ft	Foot
HALT	Highly Accelerated Life Test
HMI	Human Machine Interface
HUD	Head Up Display
HUD	Head-Up Display
HW	Hardware
IPS	In-plane switching (LCD display)
LCD	Liquid Cristal Display
LED	Light Emitting Diode
LVDS	Low-voltage differential signalling
NDF	NDF Special Light Products B.V.
NLR	National Aerospace Laboratory NLR
OCA	optical clear adhesive
OLED	Organic Light Emitting Diode
PDR	Preliminary Design Review
PFD	Primary Flight Display
PWM	Pulse Width Modulated
QD	Quantum Dot
RGB	Red Green & Blue
SAR	Search and Rescue
SW	Software
UV	Ultra Violet
W	Watt
WP	Work Package
WSXGA	Wide Screen XGA
YI	Yellowing Index

8 Reference Documents

(Doc 1) ASTM-D1925
Yellowness of Plastic - ASTM D1925 Plastic Test Standard
The American Standards Test Methods (ASTM) defines whiteness and yellowness indices for paper

(Doc. 2)RTCA DO-160F
DO-160, Environmental Conditions and Test Procedures for Airborne Equipment is a standard for environmental test of avionics hardware published by RTCA, Incorporated, Radio Technical Commission for Aeronautics