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(54) Backlight unit and control method for the same

(57) Presented is a backlight unit and control method for the same. The backlight unit comprises a plurality of spatially arranged light sources and a light source controller adapted to supply a control signal for controlling a brightness of the light sources. When the control signal is adapted to control the plurality of light sources to output a maximum operating brightness for the backlight unit, the luminance value of each of the plurality of light source units is substantially equal to a nominal 100% luminance value. The light source controller is adapted modify the control signal so as to control the luminance value of one or more first light sources to be greater than the nominal 100% luminance value and to control the luminance value of one or more light second sources to be less than the nominal 100% luminance value.

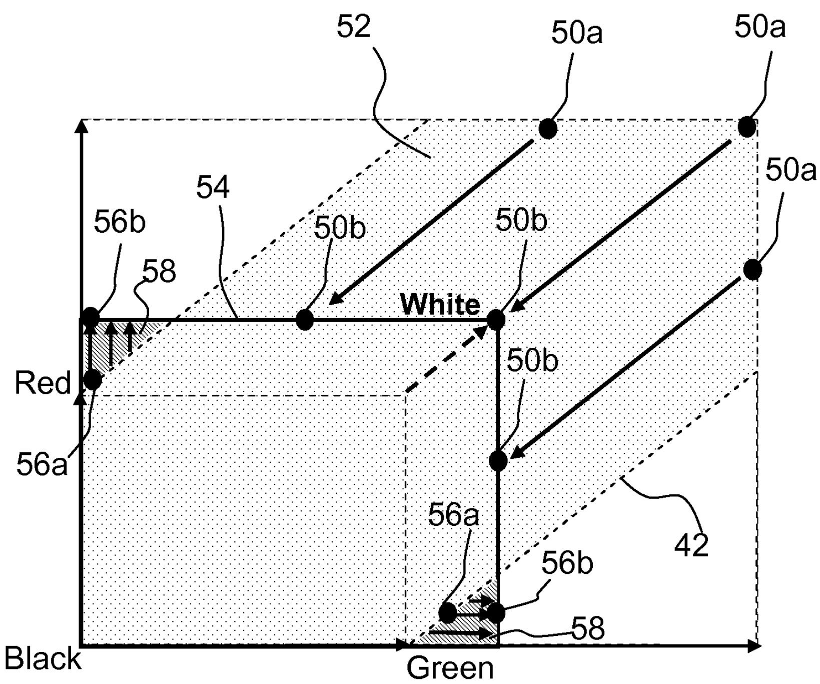

Figure 5

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Description

[0001] The present invention relates to a backlight unit and control method for the same, and more particularly to a dimming backlight unit and control method thereof for use in a flat panel display device.

[0002] The common form of pixellated colour display is currently the colour liquid crystal display (LCD). Colour LCDs typically comprise a two-dimensional spatial array of display elements, each element including red (R), green (G) and blue (B) sub-pixels employing associated colour filters. The colour filters of each element absorb approximately 2/3 of the white light spectrum passing through them. In order to increase optical transmittance, it is known practice in the art to add a white sub-pixel (W) to each element in a manner as depicted in Figure 1 wherein a three-sub-pixel RGB element is indicated by 10, and a four-sub-pixel RGBW element including a white (W) sub-pixel is indicated by 20.

[0003] In the element 20, the red (R), green (G) and blue (B) sub-pixels each have an area which is 75% of that of a corresponding colour-sub-pixel included in the element 10. However, as the white (W) sub-pixel of the element 20 does not include a colour filter to absorb parts of the spectrum of white light, in operation it is able to transmit an amount of light corresponding approximately to the sum of light transmissions through the red (R), green (G) and blue (B) sub-pixels of the element 20. Thus, the element 20 is capable of transmitting substantially 1.5 times more light than the element 10. Such enhanced transmission is of benefit in LCDs employed to implement television, in lap-top computers where increased display brightness is desired, in projection television (rear and front view, LCD and DLP), in lap-top computers where highly energy-efficient back-lit displays are desired to conserve power and thereby prolong useful battery life, and in LCD/DLP graphics projectors (beamers). However, introduction of the white (W) sub-pixel in to the element 10 to generate the element 20 introduces a technical problem regarding optimal drive to the R, G, B, W sub-pixels of each element 20 to provide optimal rendition of a colour image on the display.

[0004] Liquid crystal displays (LCDs) each comprising an array of elements, wherein each element includes red (R), green (G), blue (B) and white (W) sub-pixels, are described in US 2004/0046725. Moreover, the displays described also include gate lines for transmitting gate signals to their sub-pixels, and data lines for transmitting data signal to their sub-pixels. The displays described each further include a gate driver for supplying gate signals to the gate lines, a data driver for supplying data voltage to the data lines, and an image signal modifier. The image signal modifier includes a data converter for converting three-colour image signals into four-colour image signals, a data optimiser for optimising the four-colour image signals from the data converter, and a data output unit supplying the optimised image signals to the data driver in synchronisation with a clock.

[0005] Red-Green-Blue (RGB) space is a three-dimensional colour space whose components are the red, green, blue intensities that make up a given colour. RGB-based colour spaces are the most commonly used colour spaces in computer graphics, primarily because they are directly supported by most colour displays, using the standard sRGB format. The groups of colour spaces within the RGB base family include Hue-Lightness-Saturation (HLS) spaces and RGB spaces.

[0006] Figure 2 is a diagram of an HLS space, which is a double hexcone. The colour components of an HLS space are hue, lightness and saturation. Hue is what is normally thought of as colour. Lightness is the amount of black or white in a colour (increasing lightness makes the colour brighter, decreasing lightness makes the colour darker). Saturation is a measure of the purity of a colour. As saturation is decreased, the colour becomes more grey, and a saturation value of zero results in a grey-scale value.

[0007] Mapping the colours red, green, and blue onto a 3-D Cartesian coordinate system creates an RGB colour space. This results in a 3-D cube, an example of which is shown in Figure 3a. The origin of the coordinates system is black, where the RGB colour components are all zero. The diagonally opposite corner of the cube is white, where the RGB colour components are at their maximum value. The primary colours are red, green, and blue. The secondary colours are cyan, yellow, and magenta.

[0008] Introduction of the white (W) sub-pixel to generate the element 20 increases the brightness of the colour space along the grey axis. As a result, the RGB colour space is modified such that it extends in the lightness axis to produce an RGBW colour space as illustrated in Figure 3b. It can therefore be appreciated that the range of colour available from an RGBW colour space is greater than that of an RGB colour space.

[0009] The range of colour that a given device can produce is known as the gamut. Thus, it is apparent that the colour gamut of an RGBW display with elements 20 is larger than the gamut of an RGB display with elements 10.

[0010] For convenience and improved clarity, it is convenient to work in 2-D colour space, and this is achieved by projection of the 3-D colour space onto a plane. Figures 4a and 4b are projections of the 3-D colour space illustrated in Figures 3a and 3b respectively, whereby the value of the blue component is constant. In the following description, it will be assumed that the output gamuts are normalised, so that the maximum dimension along the axes of Figure 4a is 1 and the maximum dimension along the axes of Figure 4b is 2.

[0011] The shaded areas illustrate the colour gamut of each space. If the RGB colour gamut is defined as the input gamut 40, and the RGBW colour gamut is defined as the output gamut 42, it can be appreciated that conversion of the RGB input into a RGBW output defines a range of possible outputs which is larger than the output gamut of the RGBW element 20. The output colours that cannot be produced by the RGBW display are outside of the RGBW colour gamut, within the empty areas 44,46. Hence, the inclusion of the white (W) sub-pixel in the element 20 means that there exists a range of colours that cannot be displayed by the RGBW element. In particular, high saturation colours (e.g. a rich red) cannot be displayed with high brightness.

[0012] The process of redefining the input colours of a given device so that its gamut becomes substantially equal to that of a second device is called 'gamut mapping', and it is gamut mapping that has become an important problem in colour management. The optimal gamut mapping approach for a given case depends on input and output device gamuts, image content, user intent and preference.

[0013] A number of approaches to pixel-wise gamut mapping from RGB to RGBW are known. Such mapping schemes can result in inaccurate colour rendition for colours outside of the output gamut, for example.

[0014] When two colours are scaled differently and placed next to each other, they look different. This phenomenon is known as "simultaneous contrast". In most known RGB-to-RGBW conversion algorithms, colours such as pure yellow with maximum luminance, (r, g, b) = (1, 1, 0), are not scaled because any addition of white would change the saturation. On the other hand, colours with low saturation are scaled by adding a proper amount of white. For example, the full white (r, g, b) = (1, 1, 1) is scaled by a factor of two with the addition of the white sub-pixel (r, g, b, w) = (1, 1, 1, 1), thus becoming twice as bright.

[0015] The requirement of converting RGB signals into RGBW signals to obtain an optimal compromise between enhanced brightness and the best colour rendition remains an area of difficulty. Consequently, RGBW display panels are not yet often used in display applications, as colour reproduction of bright, saturated colours is a problem.

[0016] According to a first aspect of the invention, there is provided a backlight unit for a display device comprising: a plurality of spatially arranged light sources; and a light source controller adapted to supply a control signal for controlling a brightness of the light sources, wherein, when the control signal is adapted to control the plurality of light sources to output a maximum uniform brightness for the display system, the luminance value of each of the plurality of light source units is substantially equal to a nominal 100% luminance value, and wherein the light source controller is adapted modify the control signal so as to control the luminance value of one or more first light sources to be greater than the nominal 100% luminance value (boosting) and to control the luminance value of one or more second light sources to be less than the nominal 100% luminance value (dimming).

[0017] Thus, embodiments take advantage of the unused potential of light sources in a backlight system to create additional backlight brightness for improved colour reproduction of pixels driven with bright, saturated colours. Furthermore, reduced backlight brightness is provided for improved reproduction of pixels not driven with bright or saturated colours. Improved overall picture quality can therefore be obtained whilst a reduction in power consumption and cost can also be provided.

[0018] The invention also provides a backlight unit for a display device comprising: a plurality of spatially arranged light sources; a light source controller adapted to supply a control signal for controlling a brightness of the light source units; a plurality of light source drive units adapted to supply different driving signals to different light source units based on the control signal; and an image signal classification unit adapted to classify an image signal based on the local luminance and saturation of the image signal, wherein, if the image signal is classified as an improvement target, the light source controller is adapted to modify the control signal so as to first: increase a brightness of one or more light sources and/or to decrease a brightness of one or more light sources, and second: process the corresponding local video-data such that the requested colors are truly reproduced on the RGBW LCD panel, corrected for the changed brightness of the light sources.

[0019] The invention further provides a display system comprising: an LCD panel comprising a matrix of pixels, wherein, each pixel comprises a plurality of spatially arranged sub-pixels, consisting of at least one ore more colour filtered sub-pixels, and each sub-pixel is adapted to be modulated in transparency; a backlight unit comprising a plurality of spatially arranged light sources, wherein, each one or more light sources has an optical profile and is adapted to be modulated in brightness;

an image rendering unit adapted to convert input pixel data into a corresponding set of sub-pixel transparency values, corresponding with the colour filters of the sub-pixels the nominal brightness and colour of the backlight; and a dim and boost unit, wherein, the rendered sub-pixel transparency values and backlight optical profiles are spatially analyzed and, wherein, the analysis result is used to generate a control signal for modulating the local brightness of the backlight and, wherein, the analysis result is used to adapt the local sub-pixel transparency values to correspond with the modulated local brightness of the backlight.

[0020] Embodiments of the invention will now be described, by way of example only, with reference to the following diagrams wherein:

Figure 1 is a schematic illustration of an element of a pixel display, one implementation of the element including red (R), green (G) and blue (B) sub-pixels only, in contradiction to another implementation of the element including red (R), green (G), blue (B) and white (W) sub-pixels;

Figure 2 is a diagram of a Hue-Lightness-Saturation (HLS) space; and

Figure 3 is an illustration of a) a 3-D RGB colour space and b) a 3-D RGBW colour space;

Figures 4a and 4b illustrate the 2-D RGB and RGBW colour spaces projected from the 3-D colour space illustrated in Figures 3a and 3b respectively, whereby the value of the blue component is constant and the brightness of the W component equals the brightness of the sum of the RGB components;

Figure 5 illustrates in 2-D how embodiments of the invention may modify the RGBW colour gamut of Figure 4b, to match it with the original input RGB colour gamut, by modulating the luminance;

Figure 6 illustrates, in a perpendicular cross-section of the CIE 1931 xyY chromaticity diagram using the sRGB colour space, how embodiments of the invention may modify the RGBW colour gamut, to match it with the original input RGB colour gamut, by modulating the luminance.

Figure 7 shows an exemplary illustration of a thermal gradient of a backlight system after being operated for a time period of one hour at a nominal 100% luminance output;

Figure 8 illustrates an integrated driver circuit for an LED light source of a backlight with embedded temperature sensing according to an embodiment of the invention; and

Figure 9 is a schematic cross sectional view of a Liquid Crystal Display (LCD) device according to an embodiment of the invention.

[0021] Dimming backlight technology is used in a liquid crystal display (LCD) device applications to improve on the contrast and black level of the display device, as well as to reduce power consumption. A flat panel display device, such as a liquid crystal display (LCD), typically employ backlight units or assemblies for illuminating or lighting up the LCD from the rear surface thereof. It is known to adjust or control the brightness of a backlight, by adjusting or controlling a controller device for the backlight in conjunction with the inverse filtering of the video-data, in order to obtain improved display quality.

[0022] A backlight unit may be segmented and comprise a plurality of light source units, or segments, arranged in a matrix form, and a light source controller outputting a (dimming) signal to control a brightness of the segments. The number of segments is defined by the number of independently controlled light sources, typically a plurality of spatially arranged (white) light sources emitting light at various wavelengths. The number of segments per unit area may be otherwise referred to as the resolution of the backlight unit.

[0023] The maximum brightness of a segment of a backlight system for a display device/panel is typically limited by its specifications, providing a guaranteed operation for the weakest light source of the segment under worstcase conditions. This maximum brightness of the display system, referred to as a nominal luminance level, corresponds to a brightness of 100%. Typically, the luminance of a light source can be reduced to lower levels, under control of a Pulse Width Modulated (PWM) signal. A PWM signal with 100% duty-cycle typically corresponds to 100% luminance, wherein a lower duty-cycle (i.e. of less than 100%) will result in a reduced luminance. Normally, the light source devices in the backlight of an LCD device are adapted to not create more then their nominal luminance during operation, as the temperature of the light source(s) may otherwise become too hot, degrading performance and lifetime.

[0024] For maximum luminance of a display system, the least power-efficient parts (i.e. the weakest part) of the backlight are typically driven towards their maximum local luminance (100%) and may reach their maximum operating temperature. The more power-efficient parts will be driven at only a part of their maximum local luminance, and these parts will stay below the maximum operating temperature.

[0025] Embodiments of the invention combine the advantages of RGBW displays with local dimming backlight technology. The extra luminance provided by the RGBW display is compensated for, by conditionally dimming light sources of the backlight to locally produce less light and hence consume less energy and still provide the require brightness. While, for bright, saturated colours where the RGBW display is not generating sufficient brightness, extra light is provided by conditionally driving one or more light sources of the backlight beyond their nominal brightness to locally produce more light.

[0026] In other words, an image signal classification unit is provided for classifying an image signal based on its luminance and saturation. If the image signal is classified as an improvement target (because it is a bright saturated colour outside of the output colour gamut of the RGBW display device for example), the brightness of a first light source unit corresponding to the image signals is increased.

[0027] For example, when a lot of light in a specific area is required, one or more light sources of the backlight can be driven beyond their nominal settings to create more than 100% luminance. Since many of the surrounding backlight segments will typically be dimmed, the reduced temperature of the surrounding segments can be used to compensate for the locally increased temperature of the boosted (or over-driven) light source(s).

[0028] When a property of a light source, such as a Light Emitting Diode (LED) junction temperature, becomes a limiting factor, an embedded control loop can be used to limit the local brightness by dimming the local brightness, and request neighbouring or proximate LEDs to assist creating the missing light when possible.

[0029] Thus, the combination of RGBW and local dimming backlight technologies enables a display system to more accurately reproduce all (sRGB) input colours. Compared to either a conventional RGBW display system or a 2D-Dimming RGB display system, embodiments can create improved local brightness and contrast, render more realistic colours, consume less power and be of lower cost.

[0030] Boosting the luminance of backlight segments, enables a higher local light level to be attained. Such an adaptively controlled luminance enables more local brightness, preserving the luminance of the RGBW pixels driven with bright saturated colours.

[0031] Figure 5 illustrates how embodiments modify the RGBW colour gamut to match with the RGB color gamut.

[0032] The RGBW output gamut is shrunk by dimming the backlight for colours with a large white component, as the pixels would have been too bright, so that colours 50a in the area 52 of the output gamut 42 are mapped to a colour 50b on the edge of the effective gamut 54. Also, for bright, saturated colours 56a such as those in areas 58 but outside of output gamut 42 (because the RGBW display is not generating sufficient brightness), extra light is provided by driving one or more light sources of the backlight beyond a nominal brightness to locally produce more light and map the colour 56a to a colour 56b of the effective gamut 54.

[0033] It can be appreciated that the nominal luminance points of the RGB and RGBW gamuts are maintained, while the boosting of the backlight makes RGB gamut colours fit to the area of the RGBW gamut. The dimming of the backlight saves the power associated with the bright portion of the RGBW output gamut. Thus, the effective gamut of a display according to the embodiment is expanded when compared to the RGB gamut of Figure 4a, yet the bright saturated colours are unaltered.

[0034] Turning to Figure 6, an illustration of how this embodiment modifies the luminance of an sRGB image is now depicted as a cross section of the CIE 1931 xyY chromaticity diagram.

[0035] It can be seen that saturated colours, such as those in areas 60, are provided with extra light by driving corresponding light sources of the backlight beyond a nominal brightness, whereas colours of high luminance, such as those in area 62, are reduced in brightness by dimming corresponding light sources of the backlight, to compensate for their higher panel transmission.

[0036] For example, when in an image of grey video at 100% luminance, the video-data related to one segment comprises an area with a bright saturated red colour, its local brightness may be 25% below the required value, due to the smaller aperture of the red sub-pixels of a RGBW pixel. Here, the local backlight luminance at the pixel position needs to be increased to 125% to be able to correctly reproduce the colour.

[0037] To achieve the extra 25% luminance for a 1-Dimensional (1 D) dimming backlight, the backlight luminance of the segment is increased to 150%, as half the extra light leaks to both neighbouring segments. Also, to preserve the local brightness of the neighbouring segments, the neighbouring segments are controlled to create about 12% less light (assuming a 1D luminance profile along the segments of 25%-50%-25%).

[0038] To achieve the extra 25% luminance for a 2-Dimensional (2D) dimming backlight, the backlight luminance of the segment should preferably be increased to 200%, as three-quarters of the extra light leaks to the eight neighbouring segments. Also, to preserve the local brightness of the neighbouring segments, the neighbouring segments are controlled to create about 25% less light (assuming a 2D luminance profile as follows: 7%-12%-7% (Upper Row), 12%-24%-12% (Middle Row), 7%-12%-7% (Lower Row))

[0039] As all the light is created at a location where it is needed, no energy is wasted. When the local brightness cannot be doubled, the adjacent segment will be dimmed less to help providing sufficient light at that location.

[0040] Furthermore, the backlight of all segments driving only grey pixels can be reduced by 30% due to the larger transmission property of the pixels of a

[0041] RGBW pixel. Significant power is saved by dimming the LEDs of these backlight segments, as the average content of image-data typically contains many pixel driven with unsaturated colours. Boosting the luminance of backlight segments also enables a larger modulation of the effective light level between segments. As a result, deeper dimming of segments is possible, while still preserving the luminance of the brighter neighbouring segments.

[0042] As a further example, when in an image of mid-grey video, the video-data of one 1D segment needs to be increased by 20%, the backlight of this segment should be increased by 40%, as half the extra light leaks to both neighbouring segments. Also, to preserve the local brightness of the neighbouring segments, the neighbouring segments are controlled to create about 10% less light each (assuming a 1D luminance profile along the segments of 25%-50%-25%).

[0043] Further, when in an image of mid-grey video, the video-data of one 2D segment needs to be increased by 20%, the backlight of this single segment should be increased by 80%, as three-quarters of the extra light leaks to all its eight neighbouring segments. Also, to preserve the local brightness of the neighbouring segments, the neighbouring segments are controlled to create about 15% less light each.

[0044] Boosting light sources can create the requested 80% extra light on top of the initial 50% light and drive 130%, as the temperature is far from its maximum, and the overall dissipation is this region is not very high. The dimming of the neighbouring segments saves almost the total amount of power needed for the extra local brightness (4x10%+4x5%). Power is saved as the 130% driven light source actually consumes about 70% energy.

[0045] If boosting would not be possible, the brighter segment would be driven to 100%, and all the adjacent segments would be required to create about 5% extra light each to generate the locally desired luminance. The extra light provided by the neighbouring segments also consumes energy (4*15%), which comes on top of the power consumed by the local segment (100%), and there is hardly any compensation anymore for all the light which is created at a location where it is not needed. Some power is wasted as the 130% driven LED actually consumes about 160% energy (assuming a 2D luminance profile along the segments of: 7%-12%-7% (Upper Row), 12%-24%-12% (Middle Row), 7%-12%-7% (Lower Row)).

[0046] Since the boosting part of the algorithm is based on the required brightness of the dimming algorithm, this feature may require some extra processing power on the video content, as both the dimming properties, combined with the optical profiles of the segments may be needed to determine the actual video data. The local brightness and contrast for most of the pictures are increased, without increasing the amount of "installed light", hence without increasing the system cost.

[0047] The system cost can be reduced by omitting light sources and drivers and maintaining the original local peak brightness. It should be noted that the maximum brightness for a highly saturated colour image on an LCD device according to an embodiment, yet a power limiting function is a common feature for TV applications and is generally always active in Plasma Display Panel (PDPs) and Cathode Ray Tube (CRT) TVs.

[0048] To prevent the local (LED) backlight segments from overheating, a temperature feedback control is preferred.

[0049] When the control process monitors the driving levels of the light sources, it can simulate the temperature of the light source (i.e. the temperature of an LED junction). Using the known relation between these driving levels, and their related power consumption, the generated power can be integrated into energy and applied to a thermal model of the LED packages and backlight system.

[0050] When the estimated temperature is lower then a maximum allowed temperature, the light sources are allowed to be driven at a higher current, to create more light output. When the estimated temperature is higher than the maximum allowed junction temperature, the light sources should be driven at a lower current, creating less light output. Thus, the system is arranged in a way that the temperature of the light sources matches the maximum allowed temperature when all the backlight light sources are driven continuously at their nominal current (i.e. the current which corresponds to the segment being driven at nominal 100% luminance).

[0051] When one of the light sources is not driven at nominal luminance of 100%, e.g. due to dimming, the remaining light sources can be driven beyond 100%. Typically, the bottom and corners of a backlight system will meet these requirements, as they have better cooling properties.

[0052] Figure 7 shows an exemplary illustration of a thermal gradient of a backlight system after being operated for a time period of one hour at a nominal 100% luminance. It will be appreciated that the bottom and side parts of the backlight will generally be cooler than the centre and top parts of the panel.

[0053] At nominal 100% brightness, the junction temperature of the LEDs is about 20°C (degrees Celsius) above the temperature of the back-plate. The specified maximum temperature of the LEDs is, for example, 80°C (degrees Celcius).

[0054] Having knowledge of the backlight temperature gradient, the thermal design can be optimised by adding additional (passive or active) cooling provisions on the hotter parts of the system, creating headroom for a higher nominal luminance level (more then the initial 100%). However cooling provisions may be relatively expensive.

[0055] Alternatively, the LEDs in the cooler parts of the system have headroom for boosting the luminance to a significant higher level. Hence the 2D local dimming and boosting can be performed with more luminance modulation, using a more accurate spatial control, thereby saving power.

[0056] A further option is to reduce the amount of LEDs in the cooler parts of the backlight system, since these LEDs can be driven at a higher current, creating more light per LED, without exceeding the maximum die-temperature. Investigations have shown that at 200% brightness the junction temperature of the LEDs is about 35°c above the temperature of the back-plate.

[0057] When the control process uses a sensor to measure the temperature of ambient the temperature of the centre of the back-plate the simulation model may be more accurate. Preferably, the temperature is sensed by an array of sensors. The temperature behaviour of an LED junction can then be accurately determined independent of the thermal design and modelling of the backlight system. However, provisions for accurately measuring a plurality of temperatures may be expensive. Also, the difference between local back-plate temperature and internal junction temperature of the LEDs may still require the use of a simulation model.

[0058] By equipping the LED drivers with the appropriate integrated circuitry, a cost-effective method for determining the junction temperature of each individual LED segment can be implemented, therefore enabling the LED segments to be overdriven for high performance without exceeding the specified maximum junction temperature. Further, accurate temperature models of the backlight system will not be required, since the delta Vt corresponds linearly with the junction temperature variation.

[0059] Referring to Figure 8, there is illustrated an integrated driver circuit for an LED light source of a backlight according to an embodiment of the invention.

[0060] The LED 80 is driven by a Pulse Width Modulated (PWM) 50mA current source 82. The output luminance of the LED is varied by a PWM control unit 84 that is connected to a timing unit 85 and adapted to modulate the dutycycle of the PWM current source 82 according to input signal LUM_{TARGET} which represents a target luminance value.

[0061] During the inactive part of the duty cycle, a 20 pA sense current source 86 (20 pA) is driven via a Vt sense control unit 87 towards the LED 80, and at the same time the forward voltage Vt of the LED junction is measured by a Vt sensing unit 88. The sense current does not generate any output luminance from the LED 80.

[0062] The measured voltage Vt is provided by the Vt sensing unit 88 to a display controller (not shown), which can then take appropriate action depending on the measured voltage Vt, for example by changing the value of the input signal LUM_{TARGET} provided to the PWM control unit 84

[0063] Thus, the measured voltage Vt is used to control the output luminance of the LED by modulating the value of the PWM current source 82. When Vt decreases, the duty cycle of the current source 82 is increased, whereas, when Vt increases, the duty cycle of the current source 82 is decreased. In this way, the output luminance of the LED 80 can be stabilised.

[0064] At time T=0, the system can be calibrated such that the luminance (and colour) are of a desired value and uniformity. When the measured Vt changes, due to temperature variations for example, corrective action can be taken to maintain the desired initial luminance level.

[0065] The measured voltage Vt can also be used to control the boosting of the output luminance of the LED. When the requested luminance is driven beyond 100%, the value of the PWM current (or PWM duty-cycle) is increased accordingly. Yet, the maximum temperature of the LED junction is limited by reducing the boosting PWM current (or PWM dutycycle) accordingly when the measured voltage Vt increases. When the measured voltage Vt decreases, the current (dutycycle) limitation is decreased.

[0066] Such a feedback arrangement embedded in a LED driver integrated circuit enables the following features:

- Stabilisation of the LED flux output, enabling a more uniform backlight luminance and colour.
- Boosting of the LED flux output, creating a higher local brightness and contrast, and reducing the average backlight power consumption for local dimming backlight systems.

[0067] When the boosted LED output is limited by the LED driver due to the temperature constraints, this is signalled back to the display processor unit. The display processor may take appropriate action, including the following:

(i) No action, hence accepting some luminance limitation artefacts;
(ii) Drive extra luminance from adjacent LEDs to secure the locally requested light output (2D dimming algorithm), hence resulting in a small increase of halo artefacts;
(iii) Drive extra luminance from video-data (gain) to obtain the locally requested light output, hence allowing for some clipping artefacts in the video-data;
(iv) Reduce saturation of saturated video-data to allow for more light output via the white sub-pixels of the RGBW display panel, thus allowing for some reduced saturation in some of the saturated parts of video-data.

[0068] The LED driver can also detect an open and/or short circuit of an LED string and signal this information back to the display control processor. In response to this, the display control processor may take appropriate action, including the following:

(i) No actions, hence accepting some luminance limitation artefacts;
(ii) Drive extra luminance from adjacent LEDs to obtain the locally requested light output (2D dimming algorithm), thus resulting in a small increase of halo artefacts;
(iii) Drive extra luminance from video-data (gain) to secure the locally requested light output, hence allowing for some clipping artefacts in the video-data.
(iv) Reduce saturation of saturated video-data to allow for more light output via the white sub-pixels of the RGBW display panel, hence allowing for some reduced saturation in some of the saturated parts of video-data.

[0069] Thus, with only a few minor adaptations to the proposed local Vf measurement circuitry:

- The LED driver can enable a more ideal light source, as for the lower brightness levels the flux output is stabilised (as already proposed).
- The LED driver can enable a more powerful light source, as for the saturated high brightness levels the flux output is boosted, yet limited by the maximum LED temperature.

[0070] Turning now to Figure 9, there is shown a schematic cross sectional view of a Liquid Crystal Display (LCD) device according to an embodiment of the invention. The LCD device comprises a housing 100 within which a backlight unit 105 is positioned below an array of liquid crystal (LC) cells 110, and a glass 115 panel is positioned above the array of LC cells 110. Each LC cell 110 corresponds to a display pixel, the voltage across which determines the LC cell's transmittance of light. The operation of the display so as to display an image is similar to that of a conventional LCD device and well known to a person skilled in the art of display devices. Accordingly, a detailed description of its operation will be omitted, although a description of the backlight will now be provided.

[0071] The backlight unit comprises a plurality of light source units 120 arranged in a matrix form, a light source controller 125, and a plurality of light source drive units 130. Each light source unit 120 comprises a plurality of LED light sources (not shown) and each drive unit 130 comprise a respective plurality of LED drive circuits (not shown) such as that shown in illustrated in Figure 8.

[0072] The light source controller 125 is adapted to supply a control signal for controlling a brightness of the light source units 120, and the light source drive units 130 are adapted to supply different driving signals to different light source units 120 based on the control signal. Here, a requested backlight profile BP representing a target brightness level for each of the plurality of light sources is provided to the controller light source controller 125. The light source controller then generates a control signal according to the requested backlight profile BP.

[0073] In accordance with the embodiments described above, the light source controller also comprises an image signal $IMAGE_{IN}$ classification unit 150 which is adapted to classify the image signal based on a luminance and saturation of the image signal $IMAGE_{IN}$. Specifically, the classification unit 150 determines if an image signal contains pixel information denoting that a pixel is of a bright saturated colour outside of the output colour gamut of the display device. If a pixel is determined by the classification unit 150 as being a bright saturated colour outside of the output colour gamut of the display device it is classified as being an improvement target. For such an improvement target, the display device will not generate sufficient brightness, and so extra light is determined to be desired. According to embodiments, such extra light is provided by driving one or more light sources of the backlight beyond a nominal brightness to produce more light in a location corresponding to the improvement target pixel.

[0074] Thus, if a pixel of the image signal $IMAGE_{IN}$ is classified as being an improvement target, the light source controller 125 is adapted to modify the control signal so as to increase a brightness first light source 120a in a location corresponding to the improvement target. Also, the light source controller 125 is adapted to modify the control signal so as to decrease a brightness of second 120b and third 120c light sources neighboring the first light source 120a. Hence, the extra luminance provided by the first light source 120a is compensated for by conditionally dimming neighboring light sources 120b and 120c of the backlight to produce less light and hence consume less energy.

[0075] Embodiments can be implemented in conjunction with direct-lit backlight systems, as well as white-backlight systems and side-lit backlight systems.

[0076] Embodiments provide realistic colour reproduction on power efficient RGBW display panels. Use of dimming and boosting backlight enables backlight and video brightness modulation based on image content.

[0077] Improved colour reproduction of RGBW pixels driven with bright, saturated colours is realised by providing more backlight brightness at the area(s) of the backlight corresponding to the pixel(s). Further, creating less local backlight for RGBW pixels not driven with bright, saturated colours brightness reduces power consumption.

[0078] Boosting light sources (by driving beyond a nominal 100% luminance) in a backlight system provides a significant benefit in cost, power and performance. Uncontrolled light sources, such as LEDs, would otherwise all be driven at defined safe currents, these currents being defined by the weakest light sources in a backlight for example.

[0079] Embodiments therefore attain maximum performance of the backlight system. Luminance can be stabilized to improve uniformity, whilst costs associated with alternative uniformity efforts like binning and thermal design are avoided.

[0080] One can make a continuous trade-off: more homogeneity vs. more luminance, there is no need for any margins related to the overall system, as this is controlled by a feedback loop.

[0081] For 2D dimming systems, the impact of boosting cost-effective white LEDs provides a significant advantage, as due to spatial and temporal dimming, the temperature of dimmed light sources will decrease, creating more headroom for boosting/over-driving light sources as required.

[0082] As the boosting feature can use embedded Vf measurements and a feedback control loop, it can be implemented without added cost.

[0083] Boosting the luminance of backlight segments enables a higher local light level to be achieved. The adaptively controlled luminance enables more local brightness to be provided for pixels driven with bright saturated colours, preserving the luminance of such RGBW pixels.

[0084] It should be noted that the above-mentioned embodiments are presented purely by way of example and that numerous modifications and alterations may be realised by those skilled in the art while retaining the teachings of the invention.

[0085] For example, embodiments may be implemented in Field Sequential Colour (FSC) displays wherein colour reproduction is achieved by flashing coloured pulses from the backlight sequentially in time for each pixel which are then mixed by the human eye. Thus, in FSC displays, the pixels do not have sub-pixels or colour filters.

Claims

1. A backlight unit (105) for a display device comprising:

a plurality of spatially arranged light sources (120); and

a light source controller (125) adapted to supply a control signal for controlling a brightness of the light sources (120),

wherein, when the control signal is adapted to control the plurality of light sources (120) to output a maximum uniform brightness for the backlight unit (105), the luminance value of each of

the plurality of light source units is substantially equal to a nominal 100% luminance value,
and wherein the light source controller (125) is adapted modify the control signal so as to control the luminance value of one or more first light sources (120a) to be greater than the nominal 100% luminance value and to control the luminance value of one or more second light sources (120b) to be less than the nominal 100% luminance value.

2. The backlight unit of claim 1, wherein the backlight unit (105) comprises an image signal classification unit (150) adapted to determine if an image signal contains pixel information denoting that the colour of a pixel is outside of the output colour gamut of the display device, and to classify a pixel as an improvement target if the colour of the pixel is determined to be outside of the output colour gamut of the display device,
and wherein the light source controller is (125) adapted to modify the control signal based on whether a pixel is classified as an improvement target.

3. The backlight unit of claim 1 or 2, wherein the light source controller (125) is adapted to modify the control signals in accordance with at least one of: a target brightness value; a target power consumption value; target luminance values for the light sources; temperature limitations of the light sources; and a target dynamic range value.

4. The backlight unit of claim 3, when dependent on claim 2, wherein the light source controller (125) is adapted to reduce at least one of the saturation and the brightness of the pixel data if a target value cannot be achieved.

5. The backlight unit of any preceding claim, wherein the control signal is generated according to a requested backlight lighting profile for the backlight, the requested backlight profile representing a target brightness level for each of the plurality of light sources.

6. The backlight unit of any preceding claim, further comprising a driver feedback unit adapted to calculate the brightness of the backlight at the position of the subsegments and to provide a feedback signal to the controller based on calculated brightness,
and wherein the light source controller (125) is adapted to modify the control signal based on the feedback signal.

7. The backlight unit of claim 6, wherein if the feedback signal indicates that the calculated brightness of a first light source is not within a predetermined range of a target value, the light source controller (125) is adapted to modify the control signal to change the brightness of one or more neighbouring light source units of the first light source unit (120a).

8. A display device comprising the backlight (105) of any one of the preceding claims.

9. The display device of claim 8, further comprising:

an LCD panel having a matrix of pixels (110), each pixel comprising one or more wavelength filtered sub-pixels and one or more transparent sub-pixels; and
an image rendering unit adapted to convert input pixel red, green and blue, RGB, data into a corresponding set of red, green, blue and white, RGBW, sub-pixel transparency values corresponding to the colours of the sub-pixels, wherein transparency values larger then 100% are permitted.

10. The display device of claim 8, further comprising:

an LCD panel having a matrix of pixels (110); and
an image rendering unit adapted to convert input pixel RGB data into a corresponding set of RGBW data.

11. A control method for a backlight unit comprising a plurality of spatially arranged light sources, wherein the method comprises the steps of;
generating a control signal for controlling a brightness of the light source units, wherein, when the control signal is adapted to control the plurality of light sources to output a maximum uniform brightness for the backlight unit, the luminance value of each of the plurality of light source units is substantially equal to a nominal 100% luminance value;
modifying the control signal so as to control the luminance value of one or more first light sources to be greater than the nominal 100% luminance value; and
modifying the control signal so as to control the luminance value of a one or more second light sources to be less than the nominal 100% luminance value.

12. The method of claim 11, further comprising the steps of:

determining if an image signal contains pixel information denoting that the colour of a pixel is outside of the output colour gamut of the display device; and
classifying a pixel as an improvement target if the colour of the pixel is determined to be outside of the output colour gamut of the display device,
wherein the step of modifying the control signal

is based on whether a pixel is classified as an improvement target.

13. The method of claim 11 or 12, further comprising:

calculating the brightness of one or more of the plurality of light source units;
providing a feedback signal to the controller based on the calculated brightness; and
modifying the control signal based on the feedback signal.

14. A computer program comprising computer program code means adapted to perform all of the steps of any of claims 11 to 13 when said program is run on a computer.

15. A computer program as claimed in claim 14 embodied on a computer readable medium.

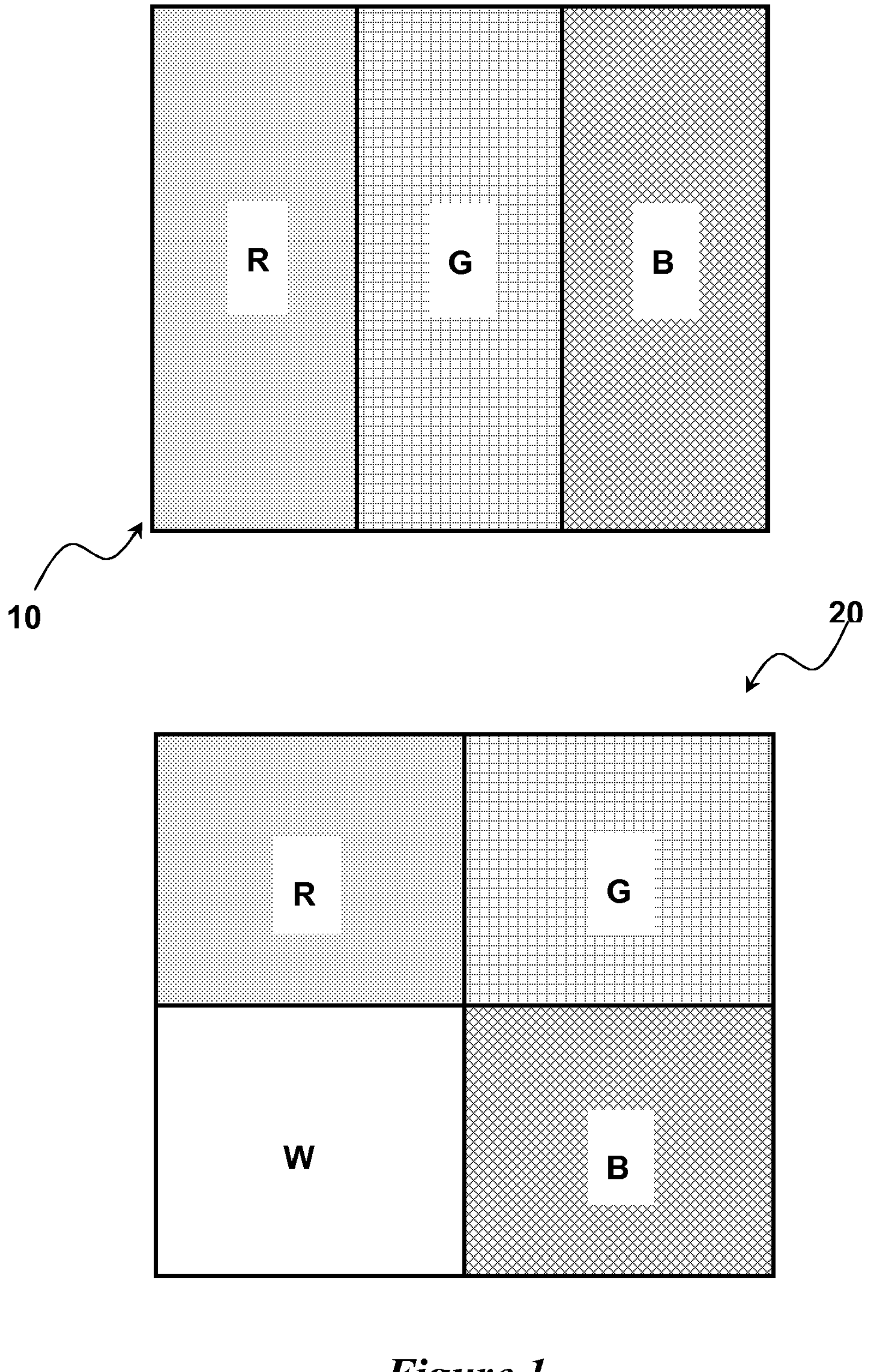

Figure 1
(Prior Art)

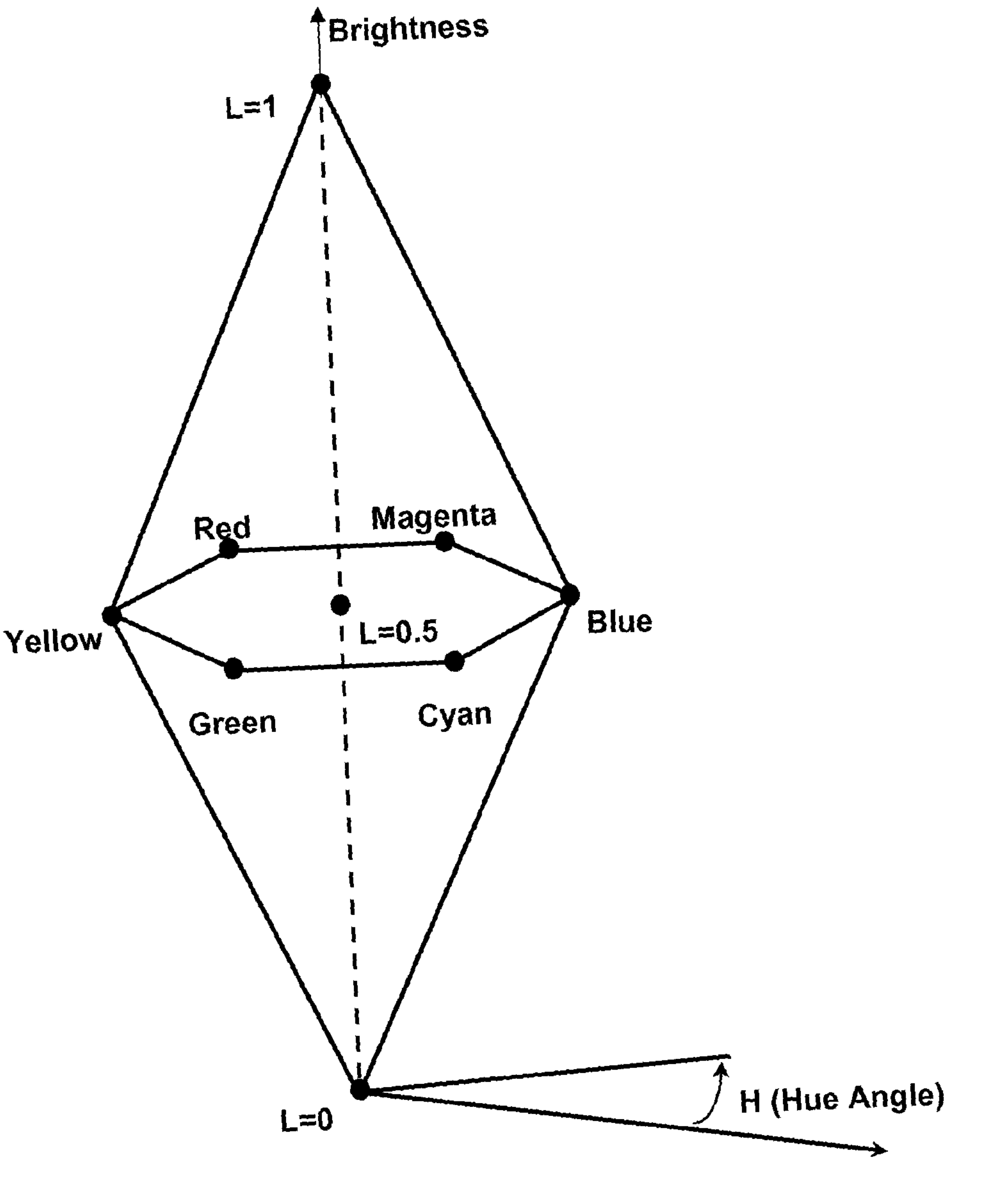

Figure 2
(Prior Art)

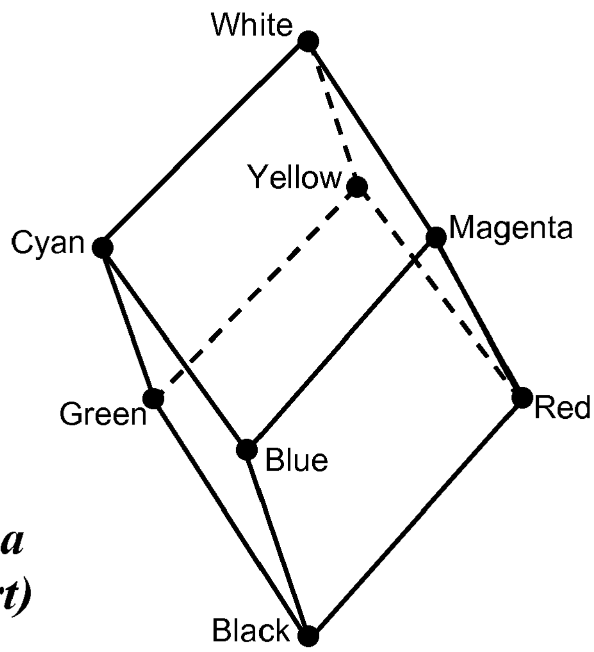

Figure 3a
(Prior Art)

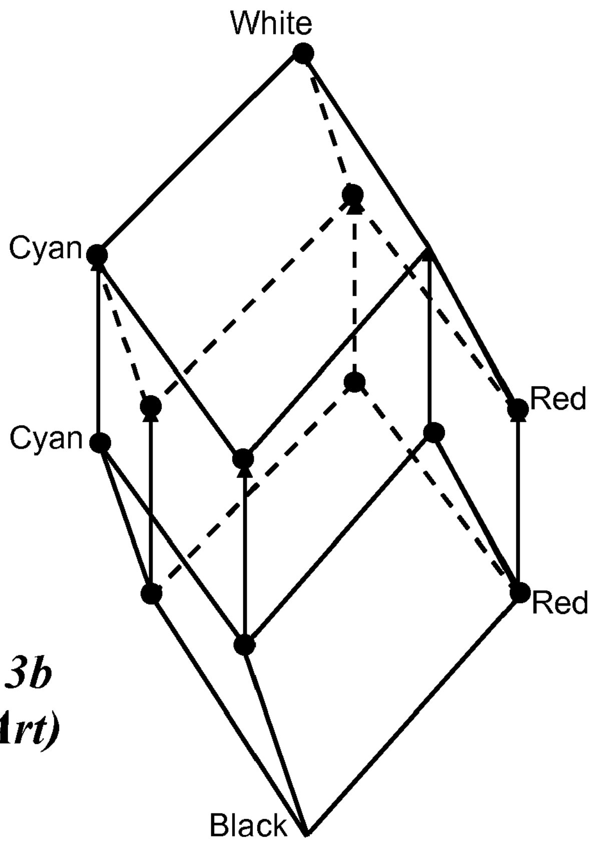

Figure 3b
(Prior Art)

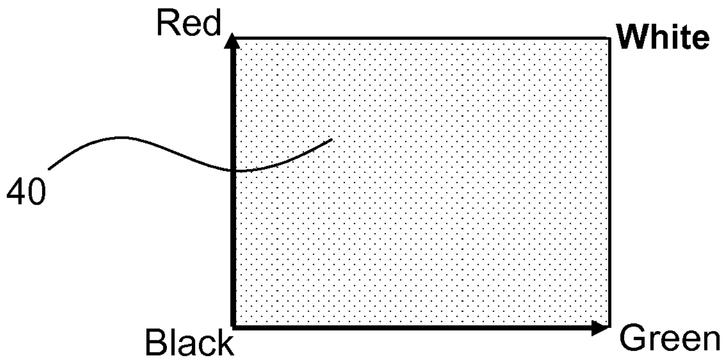

Figure 4a
(Prior Art)

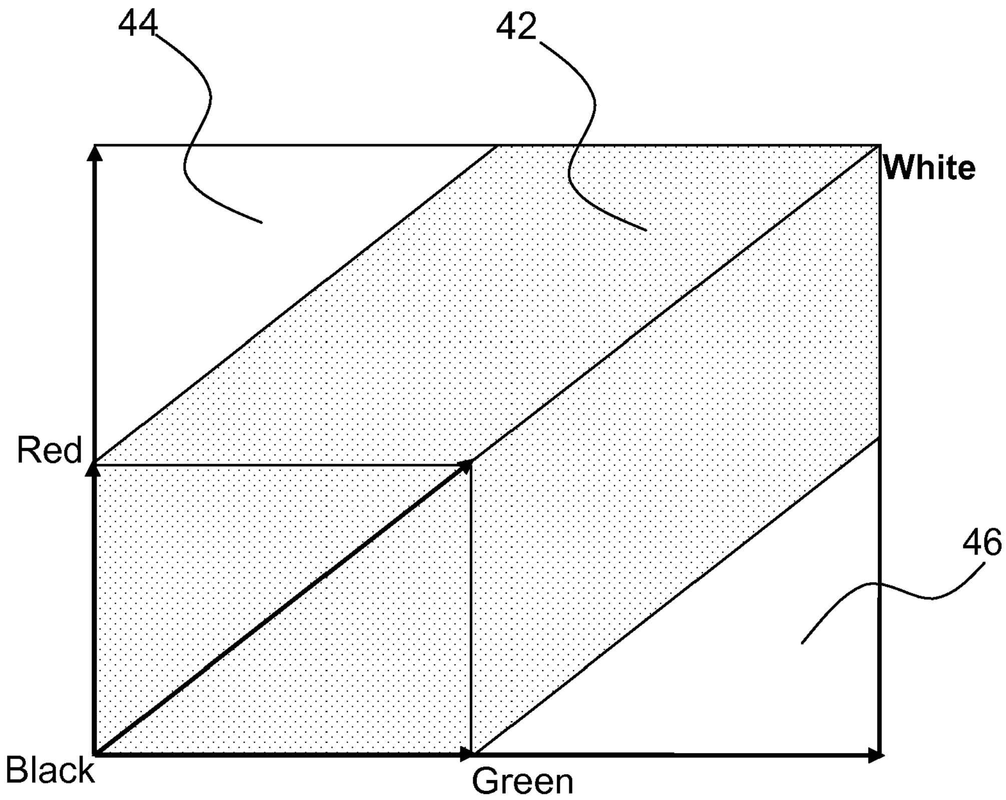

Figure 4b
(Prior Art)

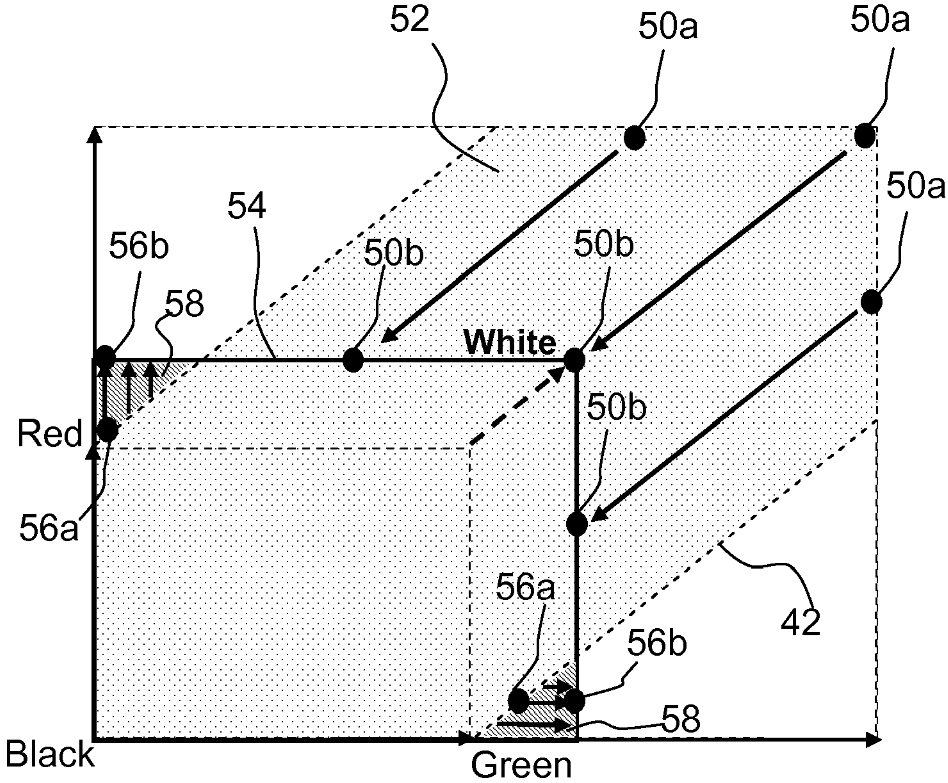
52
50a
50a
50a
54
56b
50b
50b
58
White
50b
Red
56a
56a
42
56b
58
Black
Green

Figure 5

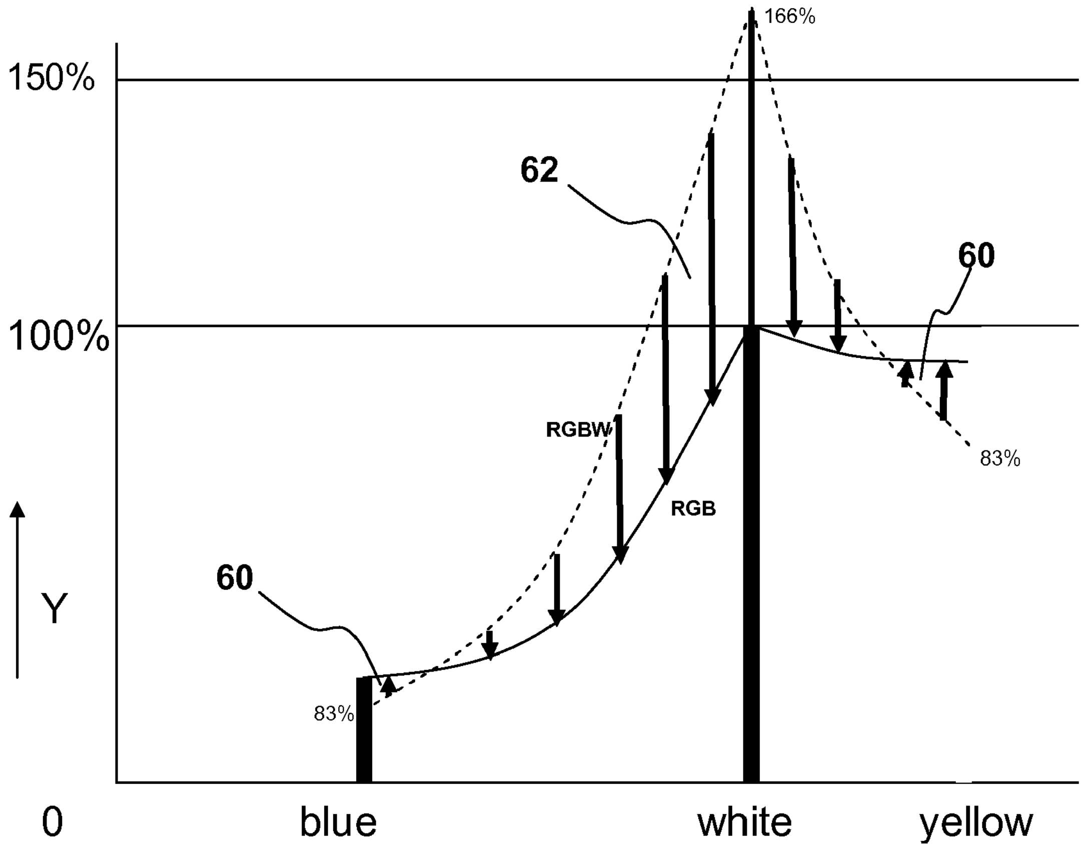

Figure 6

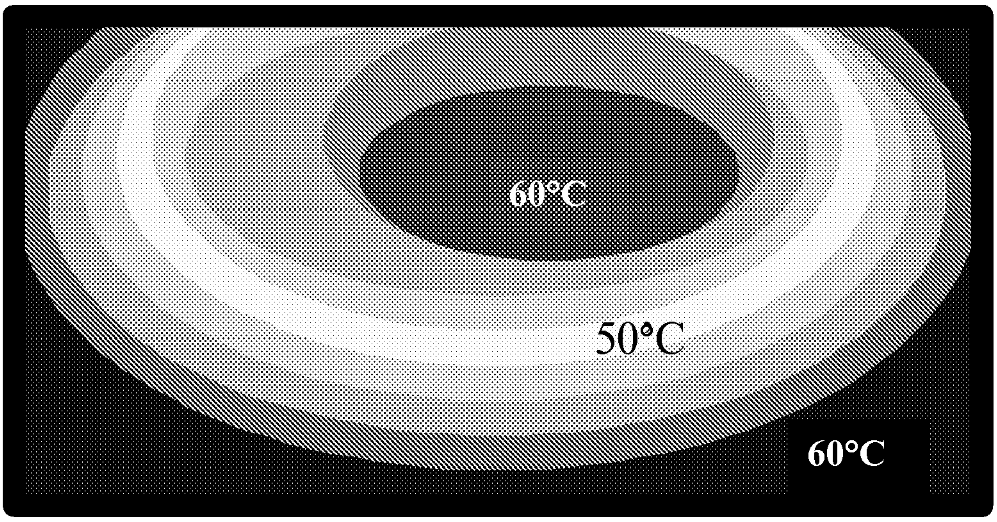

Figure 7

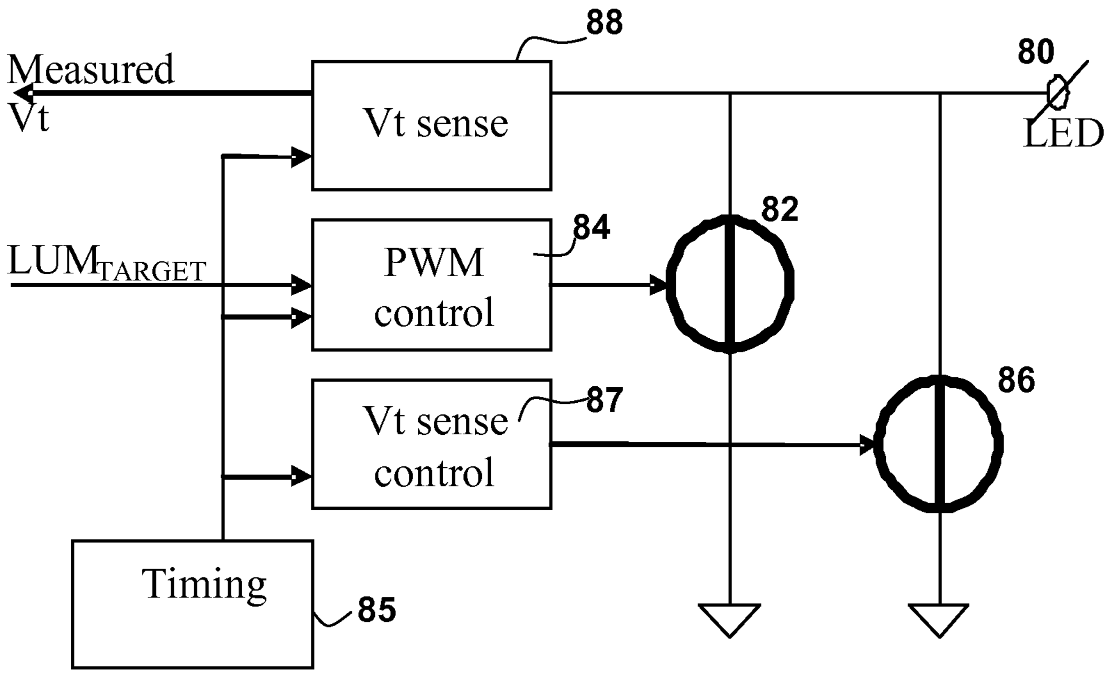
Measured
Vt
88
80
Vt sense
LED
LUMTARGET
84
PWM
control
82
87
Vt sense
control
86
Timing
85

Figure 8

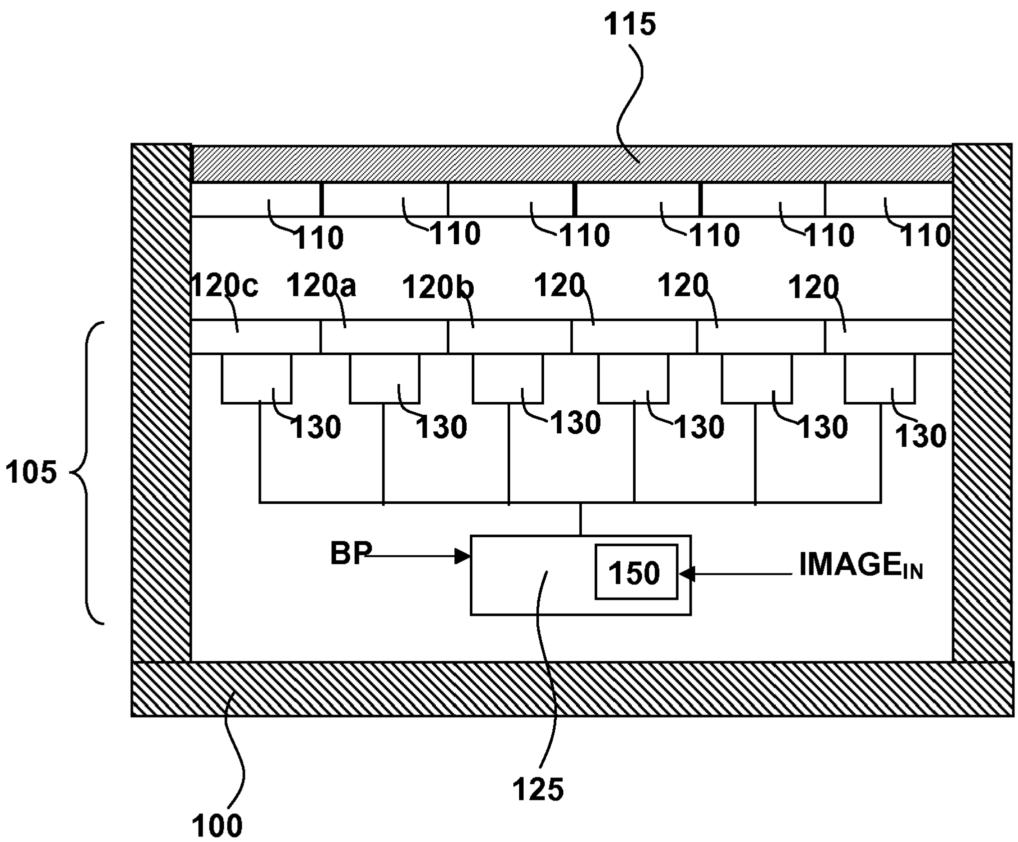
115
110
110
110
110
110
110
120c
120a
120b
120
120
120
130
130
130
130
130
130
105
BP
150
IMAGE_IN
125
100

Figure 9

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EUROPEAN SEARCH REPORT

Application Number
EP 09 16 9185

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Y		6,7,13	
A	EP 2 061 288 A (SHARP KK [JP]) 20 May 2009 (2009-05-20) * paragraphs [0004], [0032] - [0034], [0042] *	5	
Y	PIERRE DE GREEF AND HENDRIEK GROOT HULZE NXP SEMICONDUCTORS (FOUNDED BY PHILIPS) ET AL: "39.1: Adaptive Dimming and Boosting Backlight for LCD-TV Systems" 20 May 2007 (2007-05-20), SID 2007, 2007 SID INTERNATIONAL SYMPOSIUM, SOCIETY FOR INFORMATION DISPLAY, LOS ANGELES, USA, PAGE(S) 1332 - 1335 , XP007013259 ISSN: 0007-966X * the whole document *	6,7,13	TECHNICAL FIELDS SEARCHED (IPC) G09G
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	5 October 2009	Pichon, Jean-Michel

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EUROPEAN SEARCH REPORT

Application Number
EP 09 16 9185

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	5 October 2009	Pichon, Jean-Michel

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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