P-49: A Programmable Gamma Reference Buffer with Integrated Backlight Control

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Abstract
Backlight modulation, when coupled with gamma remapping, can significantly increase the performance of a TFT LCD panel in terms of contrast ratio, black level and power consumption. A programmable gamma reference buffer with integrated backlight control has been developed to support dynamic gamma control in conjunction with backlight control to enable performance enhancements in notebook computers and LCD televisions.

1. Introduction
Two seemingly independent trends have led to the understanding that backlight modulation and gamma compensation must be linked in order to achieve the maximum benefit from each of them.

The first is driven by early work in histogram-based contrast enhancement schemes such as Dynamic Gamma Control (DGC). In DGC, the image to be displayed is analyzed on a frame-by-frame basis, and the gamma curve is remapped to use more of the available contrast in the range of pixel codes that contain the majority of the pixels in the image. This technique increases the contrast in the image but also can produce an unwanted boost in image brightness that appears as flicker in image sequences. This deficiency in histogram equalization-based contrast enhancement methods is well known. The solution is to modulate the backlight dependent upon the modification of the gamma curve. By modulating the backlight the scene brightness can be maintained while enhancing the contrast of the image. Additionally, reducing the backlight with DGC control improves the display's black level, a well know weakness of LCDs when compared to CRT or plasma displays.

The second trend in mobile electronics is the automatic dimming of the backlight based upon the ambient light level to reduce power consumption. As the image brightness is reduced, however, the eye's ability to perceive small luminance differences is also reduced. This renders some pixel values indistinguishable from their neighbors in intensity and loses image detail especially in the dark areas. Modifying the gamma curve while reducing the backlight insures that detail can be perceived throughout the displayed pixel value range. This method is especially effective when one is viewing video, which tends to be concentrated at the lower pixel values.

2. Objective
Modifying the gamma curve and the backlight settings can be done either in the software domain by pixel data manipulation or in the hardware domain by adjusting the gamma reference voltages applied to the column drivers. While severe contrast stretching in the software domain can greatly limit the number of levels available for display, hardware manipulation does not suffer this loss. Nevertheless, hardware control over the backlight and gamma reference voltages using Digital-to-Analog (DAC) based architectures has been limited by the limited precision and high cost of such solutions. The objective of this project was to develop a low-cost, standalone device that can store and output sets of gamma reference voltages as well as backlight intensities. Nonvolatile memory technology is used to store the different voltage levels which allows the device to operate in a stand-alone mode without the need of external control. The device can replace the current resistor string and buffer without other modifications to the panel architecture. The selection of the "sets" can be done either from hardware or software, and since the device is programmable, the gamma reference voltages can be fine-tuned in panel testing to provide a tighter distribution of gamma variation from panel to panel. The device is pre-programmed to the nominal values for a particular panel, eliminating the need for adding a programming step to the panel manufacturing process. VCOM trimming is also provided with a dedicated programmable VCOM output. The programming interface could also be made available to panel integrators or end customers to allow for precise gamma calibration during the operating life of the panel. The device has been integrated into a variety of panels to study the effectiveness of DGC and Backlight Control to address power consumption in notebook panels, and contrast enhancement in LCD television panels.

3. Architecture
The architecture of the AGB1818 was developed to allow fast, easy switching between pre-programmed sets of reference voltages. Each set of reference voltages provides up to 18 voltages of a gamma curve and an associated backlight intensity voltage.

The block diagram in Fig. 1 shows the architecture of the AGB1818. Eighteen gamma voltages, VGMA0 through VGMA17, a single backlight control voltage DIM_{ADJ}, and a trimmed VCOM voltage, $VCOM_{OUT}$, are output from summing circuits on the right of the figure. The analog memory array and summing circuits were described previously at SID 05 in the paper titled "A Programmable Reference Memory for Adaptive Gamma Correction" [1] and will not be repeated here. Programming accuracy is valid over the complete range of gamma voltages and thus provides an overall accuracy of 0.03% over 18V. Each output channel features a sample and hold circuit which outputs the current voltage level during the programming of a new value. This minimizes the flickering effect that could be generated by large transitions on the gamma reference or VCOM voltages during trimming or programming operations.

Only one of the 8 banks is selected at any one time and the 19 control voltages are output in parallel to the summing circuits. 18 stored voltages are used to drive the Gamma References on the column drivers, while the 19^{th} voltage is used to output the DIM_{ADJ} and has a voltage range of 0.2V to 5V. DIM_{ADJ} is used by the panel backlight circuits to control backlight intensity. In

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addition, a programmable VCOM output is provided which allows a trim range of +/-2 volts from the nominal VCOM input. (Alternatively, if the VCOM input is floated, the nominal VCOM will be internally generated as AVDD/2).

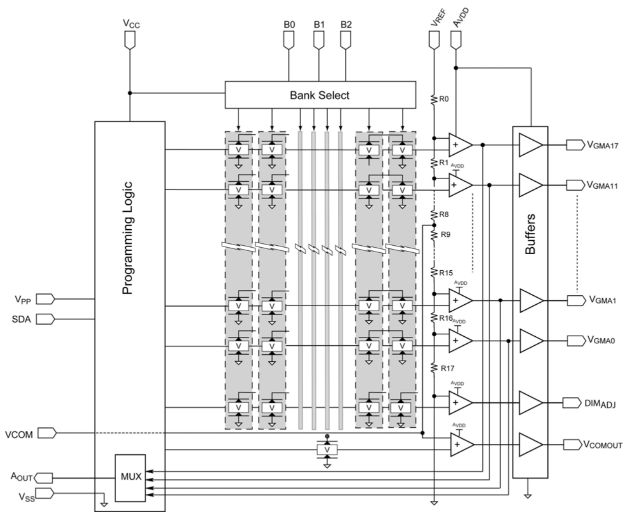

Fig. 1 AGT1818Block Diagram

Programming the references for the gamma voltages and backlight is performed on the Alta Analog PC-based programming system that is supplied by the company. Gamma voltages and backlight control voltages that have been optimized for improved display quality and reduced power consumption are entered into the programming system and then transferred to the AGB1818 via the serial bus (SDA, Vpp and Aout). The desired voltages are entered into the programmer as numerical voltages and the analog memory is programmed automatically through the serial interface.

Bank selection is performed by applying a simple bank address B[2:0] into the Bank Select block, shown at the top of Fig. 1. The address is decoded and the corresponding bank of reference voltages is sent to the output circuits. Since the outputs switch simultaneously, the gamma voltages and the associated backlight intensity change at the same time. Switching time between banks is less than 4µsec.

Thus, the AGB1818 provides a very convenient platform for the simultaneous control of gamma voltage and backlight intensity. Figure 2 shows an applications example of the AGB1818 in an LCD panel.

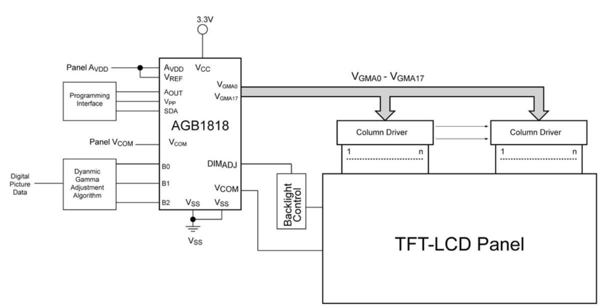

Fig. 2 – AGB1818 Application

4. Gamma and Backlight Optimization

DGC uses the image histogram to remap pixel values within the image to increase contrast in the pixel code region that contains the majority of the image data. Since video is usually dark, i.e., the majority of the pixel codes are below ½ scale, DGC has been used to enhance the contrast of LCD panels used in televisions. The problem, inherent to this technique, is that the brightness of the image will also increase in images that are strongly contrast enhanced and where most of the pixel values are near the bottom of the brightness range. As an example [2] it has been shown that boosting the dark regions contrast results in a 3X improvement in Contrast Ratio and a 1.7X increase in brightness. This brightness increase creates a problem by changing the brightness dynamics of the film content. It can also create visible brightness changes if the histogram analyzer is "fooled" into thinking a scene change has occurred during a camera pan or zoom sequence.

Adjusting the backlight intensity retains the average brightness of the scene and reduces the possibility that the contrast enhancement will produce unwanted banding artifacts. Reducing the backlight on the dark scenes makes the blacks blacker, further improving the contrast ratio.

The best implementation for Dynamic Gamma Control will utilize gamma optimization as well as backlight modulation to increase image detail, improve black levels, and increase the overall contrast ratio of the panel while allowing the panel to support a variety of image formats and sources.

In portable applications, such as personal DVD players, a large portion of the overall system power budget is consumed by the backlight. Reducing the backlight to the minimum required for acceptable image quality can greatly increase the battery run time. Many systems employ an ambient light sensor to reduce the backlight in concert with a reduced ambient.

A TFT LCD panel is a spatially programmable non-neutral density optical filter so changing the backlight intensity scales the entire image proportionally. As the backlight is reduced the eye loses its ability to discriminate between the gray levels in the darker pixel codes, and more and more detail is lost in the perceived image. This effect is often evident with video content, which resides in the lower pixel ranges and where the gamma tends to be very flat.

The dependency of the eye upon brightness, contrast and spatial frequency to extract details in the image is well documented in the human vision research literature. Van Nes and Bouman (1967) [3] measured the contrast sensitivity function (***csf***) of the eye by finding the contrast of bar gratings of varying bar widths and brightness levels that were just noticeably bar gratings as opposed to gray fields. Using this method they determined the threshold contrast for seeing the bars as a function of brightness and spatial

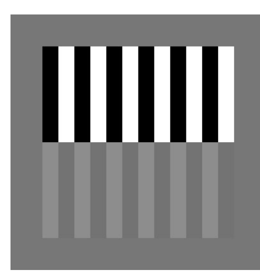

Fig. 3 Bars of the same spatial frequency and approximate average brightness with two different contrasts.

The optimal spatial frequency for seeing bar patterns occurs between 2 and 4 cycles per degree visual angle. Fig. 3 contains a bar pattern which when viewed in hard copy at typical reading distance is at approximately 2 cycles/deg visual angle. The bars on top are high in contrast and those on the bottom lower in contrast. By lowering your reading light you can titrate the brightness threshold for each contrast. As the illumination level decreases the low contrast bars become indiscernible sooner than the higher contrast bars. Increasing the viewing distance increases the spatial frequency of the bars also making their pattern less visible. It is evident from these observations that both feature size, i.e., spatial frequency, and brightness, directly impact visibility. Lowering brightness or increasing spatial frequency beyond the peak of the ***csf*** lowers the eye's sensitivity to image features. Therefore lowering the backlight with invariant image contrast reduces image feature visibility.

Reducing the backlight lowers the average level of each image and improves the blacks by making them darker. This last effect is not trivial. Unlike CRTs, liquid crystal displays leak light even when set to black. The liquid crystal display's "dark light" reduces the overall contrast that can be produced on the display.

Liquid crystal panels have an inherent contrast determined by the ratio of the maximum and minimum light attenuation through the panel. This contrast, C_P, cannot be increased without changing the physical properties of the panel. Modulating the backlight, however, multiplies the panel's contrast by a factor, C_B, equal to the ratio of backlight intensities. The display contrast, C_D, becomes $C_D = C_P \times C_B$. If the image content, i.e., the mean luminance of individual frames, is used to lower the backlight and the panel attenuation is remapped appropriately, the overall contrast performance of the display can be increased.

The majority of video content frequently resides in the lower half of pixel codes. A pixel code of 190 is typically near the display's half brightness level, so video content resides at luminance levels well below the panel's half brightness point. Without contrast enhancement the available panel contrast to portray the video scene is therefore as little as a third of the panel's range. It is not surprising that image details are lost to the eye. Remapping the panel's attenuation improves amplitude modulation within the rendered image. Remapping the signal without changing the rail voltages on the drivers forces the new gamma to use the same attenuation factors that are applied at full brightness, thus the level spacing is highly constrained. Changing the rail voltages allows arbitrary level spacing providing an additional benefit of not requiring a loss of levels through pixel level sub sampling, the typical DSP solution to contrast enhancement.

Remapping The Tonescale We have implemented this system on a standard laptop computer. The native and modified transfer functions for this display are shown in Fig. 4. In this case the single modified transfer function was optimized for image content in the lower half of the display's brightness range. This optimization was done to improve video image quality while reducing the backlight to minimize power consumption

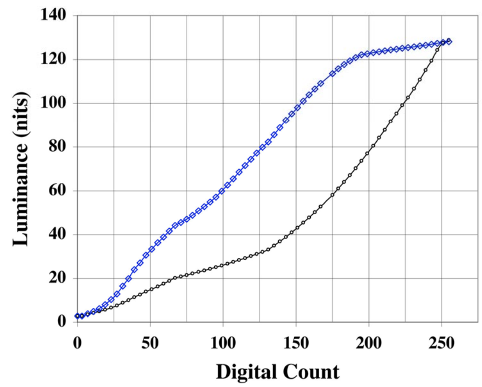

Fig. 4 Panel luminance as a function of the digital count is shown for two transfer functions. The function on the bottom is the gamma function that was delivered with the laptop. The transfer function on the top is the modified function that expands the contrast range of pixels assigned digital count values below 200.

The transfer functions in Fig. 4 were measured with the backlight on the brightest setting. Almost the entire attenuation range of the panel is achieved by digital count 200 in the upper curve. Another way to see this is in a log luminance plot of brightness versus digital count values. Fig 5 shows the pixel luminance values on a log luminance axis and with the backlight reduced when the modified transfer function has been selected.

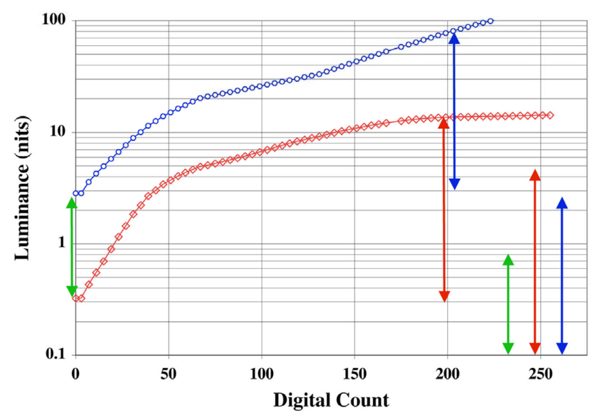

Fig. 5. Displayed luminance as a function of digital count values for two backlight settings and two transfer functions is shown this figure.

The upper curve in Fig. 5 is the standard gamma. The lower curve is the result of lowering the backlight and using the modified gamma. The green arrow on the left represents a factor of 5 improvement in black level made possible by dimming the backlight. The red arrow is the dynamic range or contrast obtained with the modified gamma. The blue arrow is the comparable contrast for the nominal panel settings. All three arrows are shown to the right in the figure and show the relative improvements in black level and displayed image contrast as the relative length of the arrows.

5. Performance

Fig. 6 A video scene rendered on a prototype display with 3 different setting combinations.

Fig. 6 shows the impact of this technique on a frame from a video sequence. The top image in the figure is a photograph of the screen with nominal gamma and full backlight, the middle image is a photograph of the same scene with the backlight reduced to one tenth of the full range, and the bottom photograph is of the scene with backlight reduced to one tenth full brightness and a modified gamma. One can clearly see the increase in detail and improvement in the black level over the original gamma with full backlight while consuming $1/10^{th}$ of the power. Clearly, this technique could dramatically extend battery life in portable video applications. Adding a simple image classification scheme would allow the display to compensate for different image characteristics similar to that of DGC. An alternative approach would allow the system to be applications and operating environment aware and switch between different gamma and backlight setting for video or PC generated content, ambient light level and power source. The current device has 8 different programmed sets to facilitate such optimization.

6. Conclusions

We have implemented a low-cost, programmable solution for controlling gamma reference voltages in conjunction with backlight intensities. Initial results show that the combination of these two functions can increase contrast and black level in LCD televisions as well as reduce power consumption while improving color performance in portable video applications. The device also allows gamma calibration as well as automated VCOM trimming to be added to the LCD panel test operation to compensate for panel to panel variation.

7. Acknowledgements

The authors would like to thank Dick Simko for his technical support and contributions during the development of the AGB1818.

8. References

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