# SXGA Microdisplay Application Note

This note provides an update on certain application information for the Rev3 version of the eMagin SXGA microdisplay. Specifically the following topics are covered:

- Regulated luminance control
- Automatic gamma correction

The following system components are required for these features to be fully activated:

- SXGA microdisplay Part# A04-500463-01
- DRK Board Rev.2
- SXGA Firmware V3.1
- SXGA Interface Software V1.7

## 1 Luminance Control

The automatic temperature compensation feature (activated when in Auto VCOM mode) enables a relatively constant output luminance from the display over a wide operating temperature range. It also provides for accurate setting of brightness using the control registers IDRF and DIMCTL. When in this mode the microdisplay will start instantly and repeatedly at the luminance set by the control registers and remain constant over time as the part warms up or the ambient temperature changes.

### *1.1 Brightness Setting*

To activate the automatic temperature mode set VCOMMODE = 00h (default level).

The brightness level for the display is then set using registers DIMCTL, IDRF, and DAOFFSET as described below.

Linear control of brightness is provided by the decimal value of register DIMCTL over a 1 to 127% range in steps of 1% according to the following expression:

$$L_B = L_{MAX} * \frac{DIMCTL(dec)}{100} \qquad \text{for } 0 \leq \text{DIMCTL} \leq \text{1Fh}$$

where $L_B$ is the display brightness and $L_{MAX}$ is the brightness at the default setting for DIMCTL (64h). A typical dimming response measurement is shown in Figure 1.

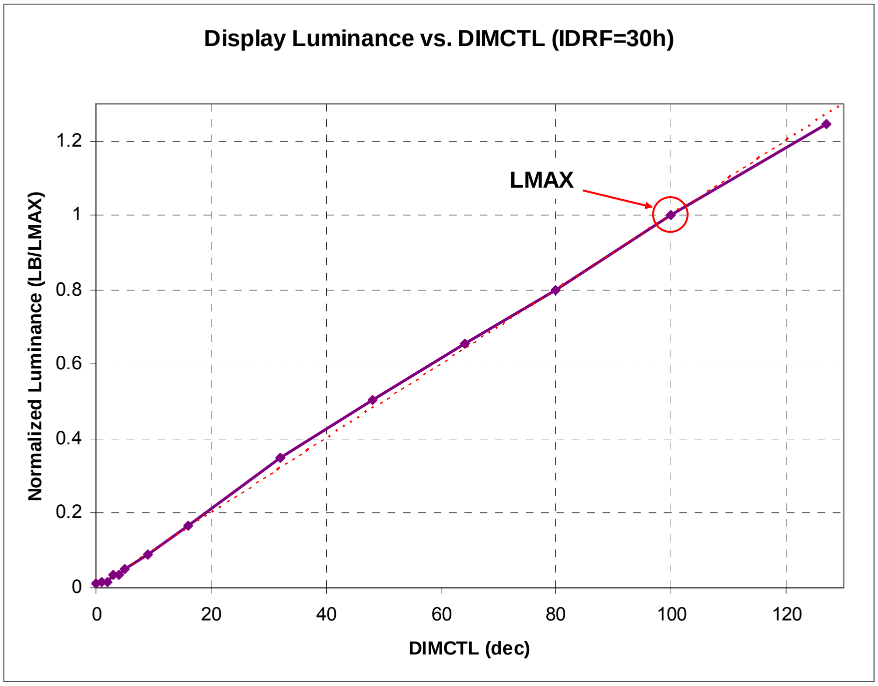


Figure 1: Display brightness as a function of DIMCTL

The IDRF register is used to set the brightness level, $L_{MAX}$, produced at the default setting for register DIMCTL. The dependence of parameter $L_{MAX}$ on the decimal value of IDRF is given by the following relationships:

$$L_{MAX} = L_{DEF} * F_{IDRF}$$

where the factor $F_{IDRF}$ is given by:

$$F_{IDRF} = \frac{IDRF(dec)}{32} \qquad \text{for } 0 \le \text{IDRF} < \text{20h}$$

$$F_{IDRF} = \frac{IDRF(dec)}{32} - 0.5 \qquad \text{for 20h} \le \text{IDRF} \le \text{C0h}$$

and $L_{DEF}$ is the display luminance level at the default settings IDRF=30h and DIMCTL=64h. An example of the brightness dependency on IDRF is shown in Figure 2 for measured and calculated cases with DIMCTL = 64h.

Using these control registers, the minimum brightness level that can be achieved is about 0.7fL for a color display and about 2fL for a monochrome white display.

Abrupt changes to the brightness level via the registers should be limited. The display should only be started at the default settings (IDRF=30H, DIMCTL=64H) or at register values corresponding to a lower brightness. To attain a higher brightness after startup, the register values should be increased gradually. For example, it has been found that IDRF should be increased at no more than 8h per write cycle via the $I^2C$ bus to avoid a potential disturbance to the display. On the other hand, there is no limitation on decreasing the register values to reduce the display brightness.

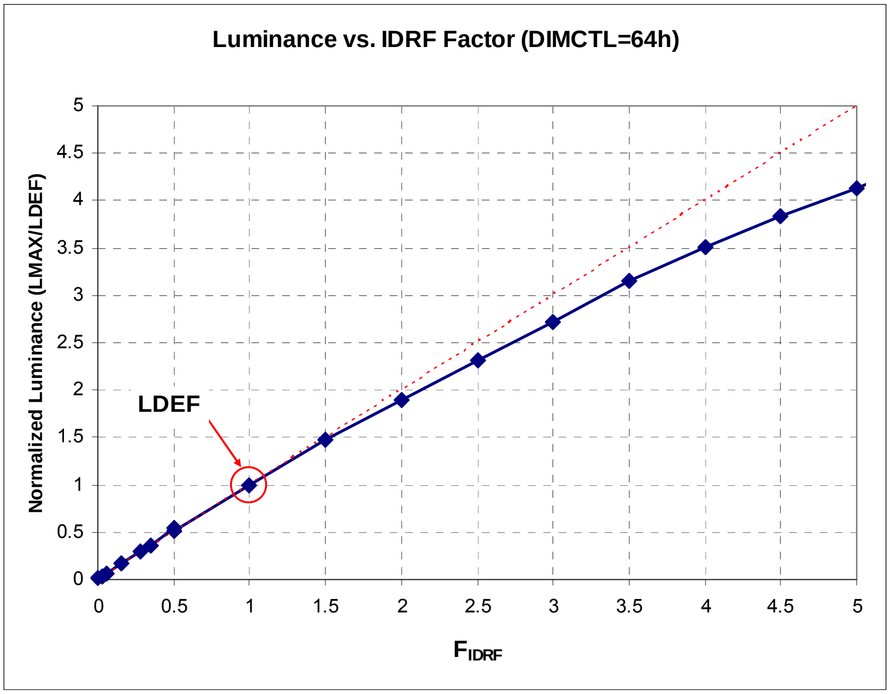


Figure 2: Default brightness as a function of IDRF

### *1.2 Luminance Calibration*

The default luminance level $L_{DEF}$ is adjusted by the DAC offset calibration register DAOFFSET. Each display must be calibrated using DAOFFSET in order to have consistent output brightness. Once DAOFFSET is correctly set, the value of $L_{DEF}$ for a color display is typically equal to:

$$L_{DEF} \approx 84 \frac{cd}{m^2}$$

Determination of the optimum DAOFFSET setting for a particular device is carried out using the following procedure. First, the luminance for a flat white field (all pixels on at full white) is measured for a range of continuous settings of the DAOFFSET register. Registers IDRF and DIMCTL should be at their default settings. Next, the optimum value of DAOFFSET is extracted from the measured curve.

A typical response of the luminance to changes in the DAOFFSET register is shown in Figure 3. The register setting, which is converted to decimal values, is plotted along the x coordinate using the following expression:

DAO(d) = DAOFFSETH(dec) – DAOFFSETL(dec)

| **DAOFFSET** | F0 | E0 | D0 | C0 | B0 | A0 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | 0C | 0D | 0E | 0F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DAO(d)** | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -10 | -11 | -12 | -13 | -14 | -15 |

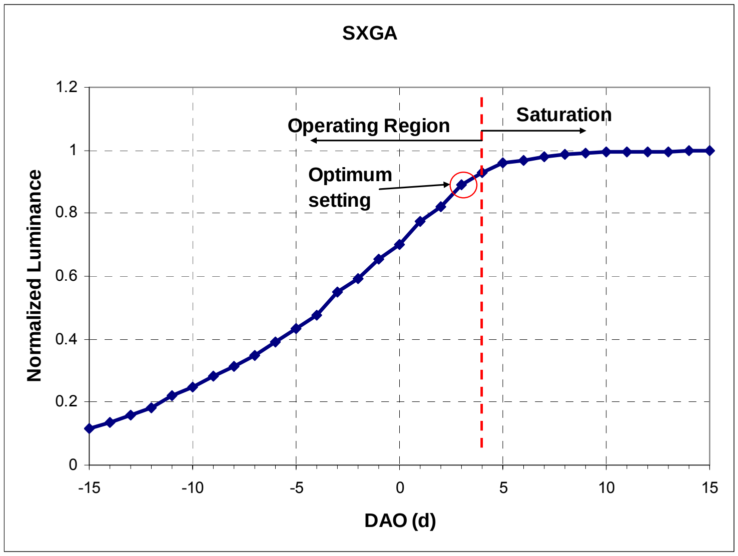


Figure 3: Typical response of luminance to DAOFFSET value

The measurement shows a region of saturation to the right of the dotted red line, and a region of slope to the left of the red line. The optimum setting for DAOFFSET is for a luminance of about 88% of the saturated value, as highlighted by the circle in Figure 3. This point will vary from part to part due to manufacturing tolerances and must be calibrated for each individual display.

## *1.2 Measured Results*

Figure 4 shows the brightness regulation for a typical device in the automatic VCOM mode measured over a wide temperature range. There is some reduction in luminance at the low and high temperature ends for a fixed DAOFFSET setting. The full temperature regulation can be further improved by programming one of the brightness setting registers, such as DAOFFSET, to compensate for the temperature dependency.

In automatic VCOM mode the display will start immediately at the brightness level determined by registers DIMCTL, IDRF, and DAOFFSET, and will remain constant over time. An example of the brightness behavior on startup is shown in Figure 5.

Figure 6 shows the distribution of brightness for a sample of 32 displays following calibration via the DAOFFSET register. The distribution had a mean value of 84cd/m$^2$ with a standard deviation of 4%.

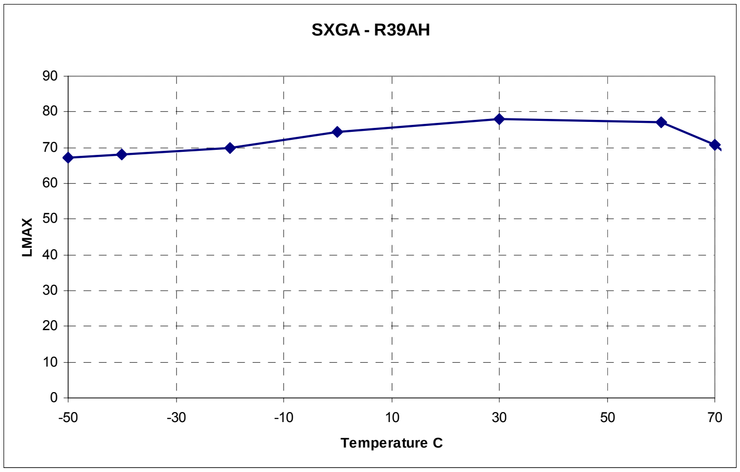


Figure 4: Luminance regulation over temperature in Auto Temp Mode

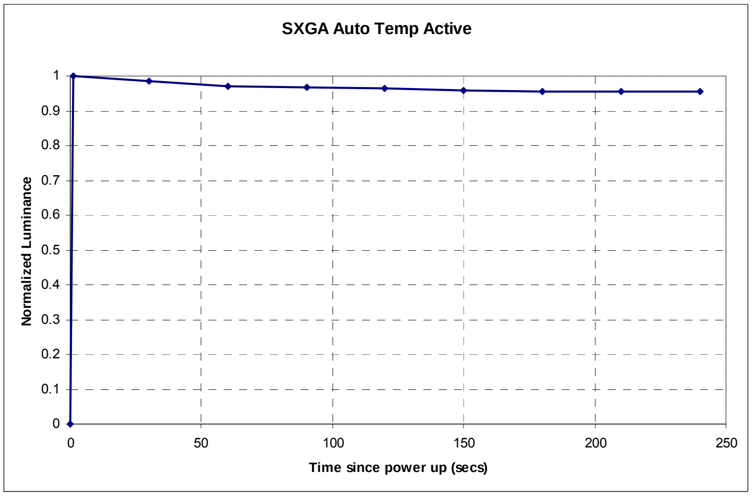


Figure 5: Brightness at startup

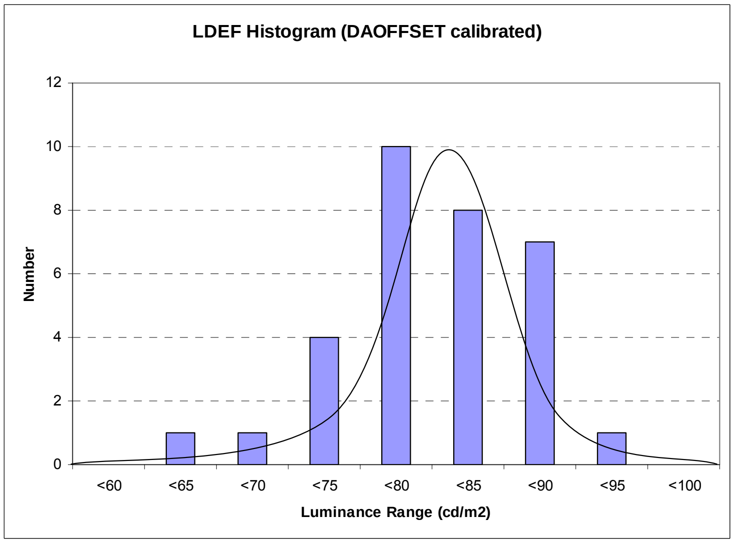


Figure 6: Brightness distribution after calibration

## 2 Automatic Gamma Correction

Due to the non-linear electro-optic characteristic of the OLED pixel, a gamma correction signal must be applied to the video input signal to achieve a linear system response for the display. Since the optimum gamma curve will vary with temperature and luminance, it should also be regularly updated to account for changes in operating conditions. The color balance for the display can be modified by controlling the gamma individually for each of the three color data channels. Figure 7 illustrates the behavior of different components of the SXGA display system. The OLED response curve shown in the figure is an example of the typical optical response to input data of the microdisplay and demonstrates its highly nonlinear behavior. The Gamma Correction function shown in the figure is obtained by directly inverting the OLED response function. As confirmed by the measured system response curve in the figure, the overall system display response becomes linear when the source video data is modified by the Gamma Correction function before being applied to the SXGA.

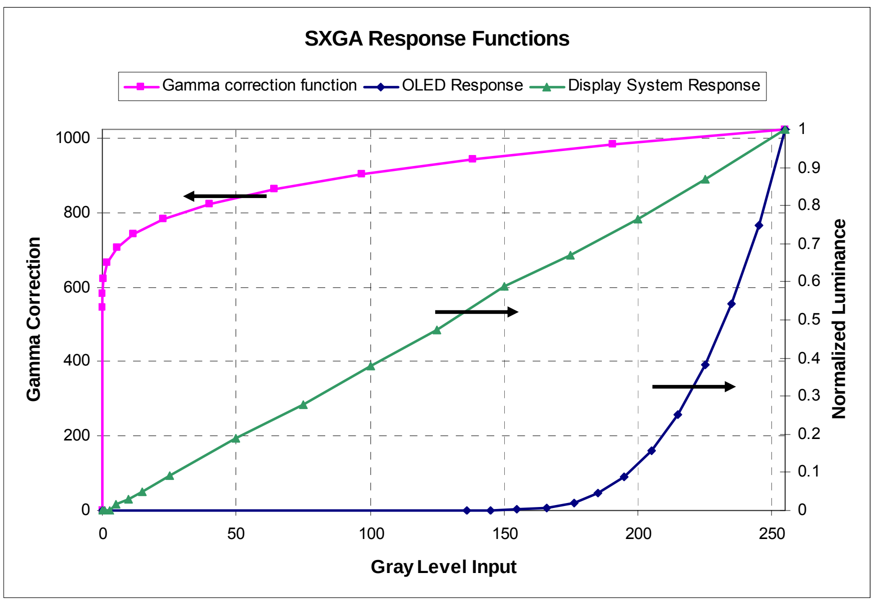


Figure 7: Gamma corrected system response characteristic

As shown in Figure 8, a typical SXGA application will include a 256x10-bit look-up-table for each color channel located in the data path between the video source and the display. The LUT, which is contained in an external FPGA, converts the 8-bit data byte for each color of the video source into a 10-bit output data word for driving the microdisplay. The LUT is programmed with the gamma correction function required to linearize the system for the current operating conditions. Due to the non-linear characteristic of the OLED display, a 10-bit input to the SXGA is used to ensure a linear

8-bit optical response with better than 1-lsb accuracy. The LUT data must be in Gray Code format as described in the datasheet.

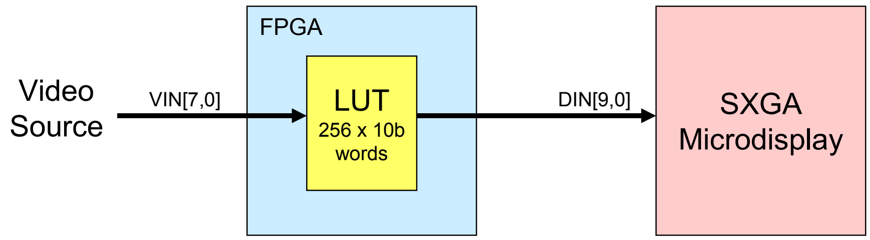


Figure 8: Gamma correction using a look-up-table (LUT)

On-chip support for generating the gamma correction function in the form of an 8-segment piecewise-linear function is provided by the SXGA display chip. As shown in Figure 9, a total of 8 data points (Q1…Q8) that lie on the gamma curve can be determined from the gamma sensor signal available at the VGN pin, and used to construct a piece-wise linear approximation of the ideal gamma correction function. The external microcontroller can use this information to generate intermediate data points for the entire 256 point curve by linear interpolation.

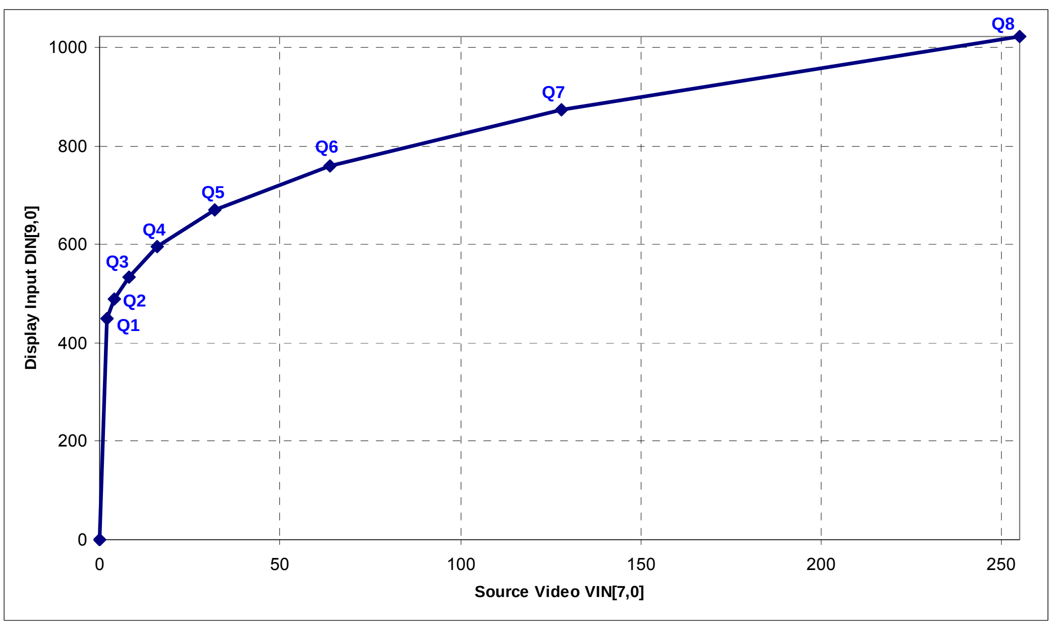


Figure 9: Typical SXGA gamma correction function

## *2.1 Timing Requirements*

In the DRK board the full-scale reference for the A/D converter is fixed at VAN/2 (or 2.5V) and the output range for VGN is set to 0 to 2.5V by using GAMMASET values of 8h to Fh. The VGN signal should be low-pass filtered before passing to the input of the A/D converter in order to minimize high-frequency noise. Figure 10 shows the implementation of the RC filter used on the Rev.2 DRK board:

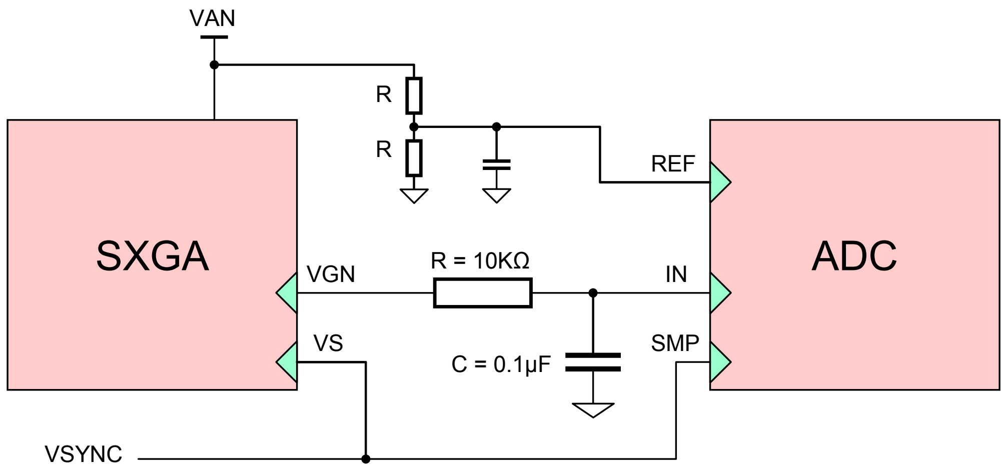


Figure 10: Recommended interface between VGN and ADC

The VGN signal should be sampled by the A/D converter during a time when data is not being transferred to the microdisplay to ensure quiet operation. This is best done by forcing the A/D converter to acquire the VGN value within the period defined by the falling edge of the VSYNC clock signal and the rising edge of DataEN as shown in the timing diagram of Figure 11. The timing requirements for the VGN sampling operation are given in Table 1. Consequently, a complete measurement of the gamma coefficients can typically be carried out within about eight video frame cycles. An interrupt driven A/D sampling scheme is currently used in the SXGA Firmware V3 in order to synchronize the VGN acquisition with the VSYNC clock. In this firmware an interval of one full frame period is provided for the VGN settling time after each change of GAMMASET before the value is sampled.

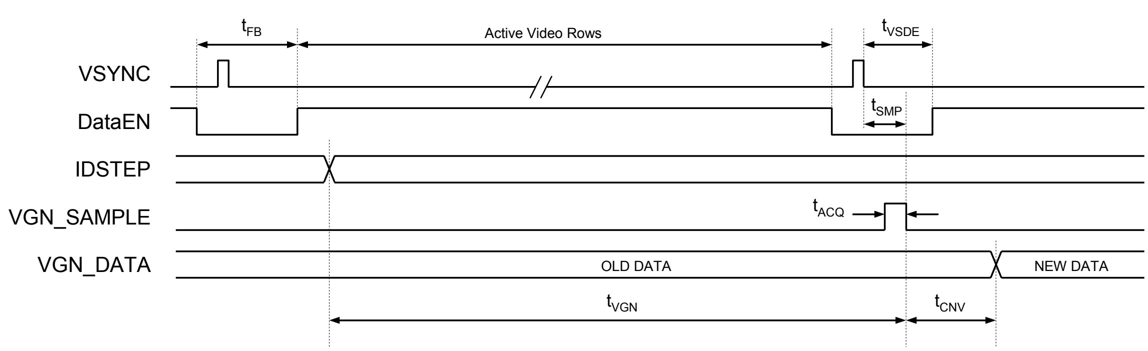


Figure 11: Timing diagram for VGN sampling operation

The duration of a full LUT update cycle depends on the VGN data acquisition time, firmware processing time, and the LUT data upload time. The implementation given in V3 of the SXGA firmware takes about a second to complete a full LUT update cycle.

Table 1: Timing requirements for VGN sampling

| Parameter | Symbol | min | typ | max | Unit |
|---|---|---|---|---|---|
| Frame blanking time (% of frame time) | $t_{FB}$ | 1 | | | % |
| VGN settling time after IDSTEP change | $t_{VGN}$ | 10 | | | ms |
| Sampling window | $t_{SMP}$ | $t_{ACQ}$ | | $t_{VSDE}$ | |
| ADC acquisition time | $t_{ACQ}$ | | | 20 | us |
| ADC conversion time | $t_{CNV}$ | | tbd | | |

### *2.2 Operational Description*

The gamma sensor is provided as an aid to generating a linear optical response from the SXGA display system. As described previously, an external 256-entry look-up-table is required to transform input video data into a gamma-corrected data signal for driving the microdisplay input port. The SXGA display generates an internal real-time representation of the gamma correction curve for the current operating conditions. This representation is in the form of an analog voltage waveform which can be sampled one point at a time at the VGN pin for eight specific values. A specific value $\boldsymbol{VGN_i}$, corresponding to one of 8 internally fixed grayscale levels $\boldsymbol{GL_i}$, is selected by setting bit IDSTEP in register GAMMASET via the serial port. The VGN signal can be selected for a full-scale output range of either VAN (default) or VAN/2 by setting bit VGNSEL in register GAMMASET. Eight sequential measurements are required to complete the gamma table. The gamma table can then be used to reconstruct an approximation of the ideal gamma correction curve using piece-wise linear interpolation, or by employing a curve fitting algorithm to achieve better accuracy if desired. This function is only available for VCOMMODE=00h.

An external A/D converter is required to convert each VGN measurement into digitized form and store the values in a microcontroller for further processing. The VGN readings are normalized and converted to a 10-bit full-scale word $\boldsymbol{DVGN_i[9,0]}$ using the following expression:

$$DVGN_i[9,0] = \frac{VGN_i}{VGN_{MAX}} * 1023$$

where $\boldsymbol{VGN_{MAX}}$ is either VAN or VAN/2 as set by bit VGNSEL. Each of these data values must be further multiplied by a correction factor $\boldsymbol{CF_i}$ to obtain the Gamma Correction coefficients as follows:

$$GC_i[9,0] = DVGN_i * CF_i$$

where the empirically determined values for factor $CF_i$ are given in Table 2.

Table 2: Correction Factor values

| CF1 | CF2 | CF3 | CF4 | CF5 | CF6 | CF7 | CF8 |
|---|---|---|---|---|---|---|---|
| 0.880 | 0.909 | 0.929 | 0.953 | 0.973 | 0.987 | 0.992 | 1 |

Using the derived values for $GC_i$ and their corresponding grayscale coordinates $GL_i$, the 8-entry Gamma Correction table consisting of data points $Q_i = (GL_i, GC_i)$ can be constructed. The outcome of a typical gamma sensor measurement and calculation procedure is shown in Table 3.

Table 3: Sample Gamma Correction Table

| ***i*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| ***IDSTEP[0]*** | 0h | 1h | 2h | 3h | 4h | 5h | 6h | 7h |
| ***$VGN_i$ (volt)*** | 1.839 | 1.876 | 1.913 | 1.964 | 2.045 | 2.159 | 2.318 | 2.500 |
| ***$GC_i$ (dec)*** | 662 | 698 | 727 | 766 | 814 | 872 | 941 | 1023 |
| ***$GL_i$ (dec)*** | 2 | 4 | 8 | 16 | 32 | 64 | 128 | 255 |

The full 256-word LUT is derived from the Gamma Coefficient Table using linear interpolation to generate intermediate data points as illustrated in Figure 12. The input to the LUT for each color of the video source is represented by the 8-bit signal VIN[7,0], and the output of the LUT (which is also the input to the microdisplay) is represented by the 10-bit signal DIN[9,0]. For example, the intermediate point Q(x, y) on the line segment formed between the gamma table points Q6 and Q7 is obtained by:

$$Y = Y_6 + (Y_7 - Y_6) * \frac{(X - X_6)}{(X_7 - X_6)}$$

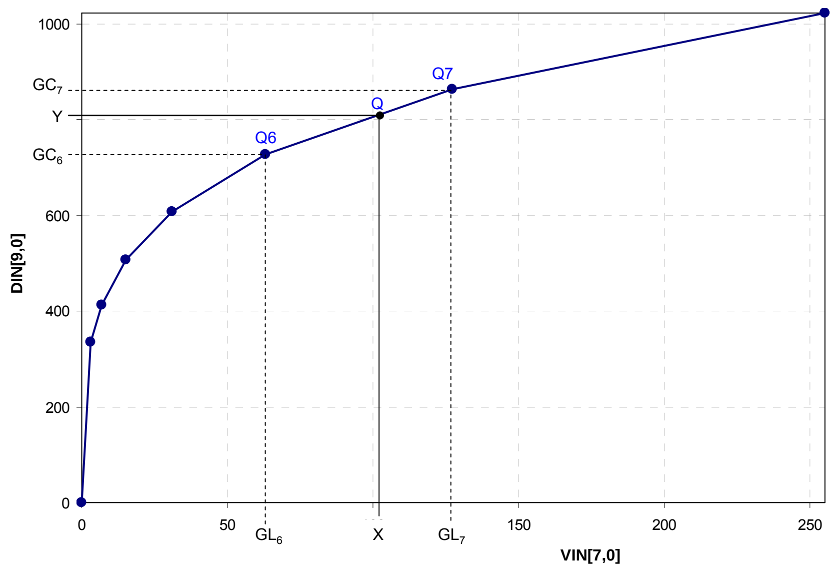


Figure 12: Generating intermediate points by linear interpolation

The intermediate points for other line segments are found in similar fashion. A software routine in the system microcontroller is used to perform the necessary calculations. The software is also used to convert the LUT data into Gray Code format before loading it into the data-path LUTs in the FPGA. A buffer LUT should be used to temporarily store the data as it is transferred from the microcontroller via the serial port. When the buffer LUT is full, the data can be rapidly transferred to the data-path LUTs during a frame blanking time to avoid disturbing the displayed image.

## *2.3 Optimizing Low-Level Gamma*

A smooth transition of the gamma curve at the lowest gray levels is essential for best performance of the display at the black end of the gray scale. Refer to Figure 13 for an illustration of how the gamma curve is calculated in the latest SXGA Firmware V3.1. The LUT data points for gray levels 1 to 4 are all obtained by linear extrapolation from the gamma points Q1 and Q2. The LUT data point for gray level 0 is set to a much lower value (e.g. 1) to ensure the best black level.

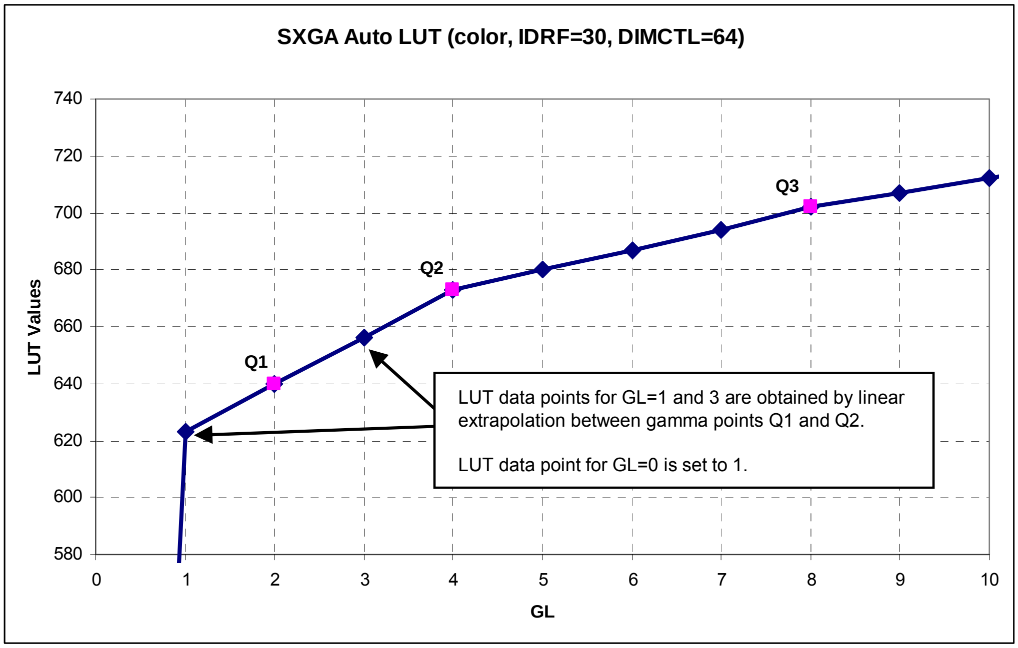


Figure 13: Gamma curve at low gray levels

## *2.4 Arbitrary Gamma System Response*

A display system response that is characterized by a system gamma other than one (sys_gamma ≠ 1) can be obtained by modifying the gamma correction table. The gamma correction coefficients for an arbitrary system response (sys_gamma = γ) are derived from the measured $VGN_i$ data as follows:

$$GC_i^{\gamma} = \left(\frac{VGN_i}{VGN_{MAX}}\right)^{\gamma} * (CF_i)^{\gamma} * 1023$$

In the case of γ = 1 this equation defaults to the relationships shown in section 2.2. An example of a gamma correction table calculated for the case of γ = 2 is given in Table 4.

Table 4: Example of Gamma Correction Table for γ=2

| ***i*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| ***IDSTEP[0]*** | 0h | 1h | 2h | 3h | 4h | 5h | 6h | 7h |
| ***$VGN_i$ (volt)*** | 1.839 | 1.876 | 1.913 | 1.964 | 2.045 | 2.159 | 2.318 | 2.500 |
| ***$GC_i$ (dec)*** | 429 | 476 | 517 | 573 | 648 | 743 | 865 | 1023 |
| ***$GL_i$ (dec)*** | 2 | 4 | 8 | 16 | 32 | 64 | 128 | 255 |

The resulting gamma curve is plotted in Figure 14 along with the curve generated for a system gamma = 1 and 1.6.

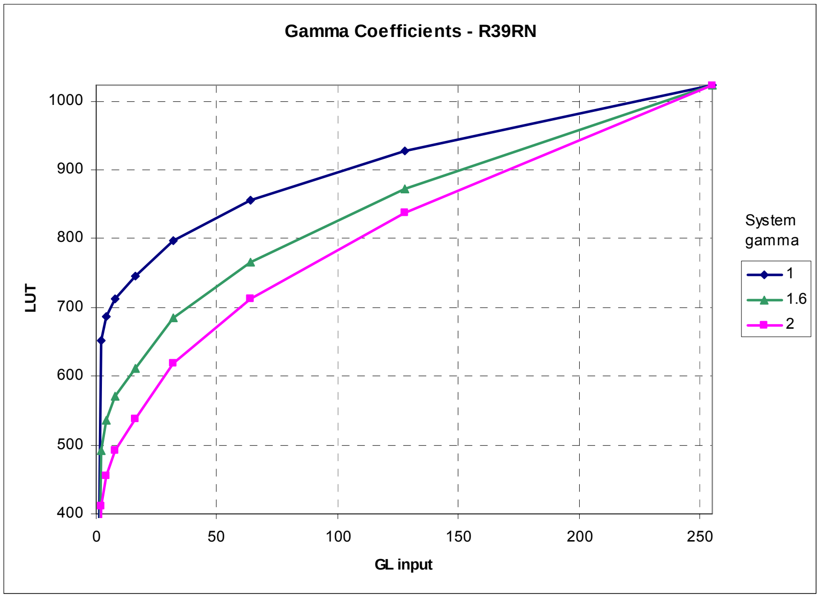


Figure 14: Comparison of Gamma Curves for 2 different system gammas

## *2.5 GUI Interface*

The interface screen for the SXGA Design Reference Kit using Software V1.7 is shown in Figure 14. Note that the VCOMMODE register has been set to “00” to activate both the Auto VCOM and Auto Gamma modes for the part under test. Also the DAOFFSET register has been set to the specific value that has been measured to be optimal for this part.

Initially, the Gamma Table is loaded with default values which are displayed by clicking on the “R” button to the right of the Gamma Table. The automatic gamma update process based on the VGN sensor is then triggered by clicking on the “Update LUT” button. After the process is completed, the new Gamma Table values can be displayed by clicking on the “R” button.

The shape of the gamma curve at different display temperatures or brightness settings can be readily observed by using the “Update LUT” feature.

The Gamma Table can also be manually updated by filling in the gamma boxes with user data and then clicking on the “W” button.

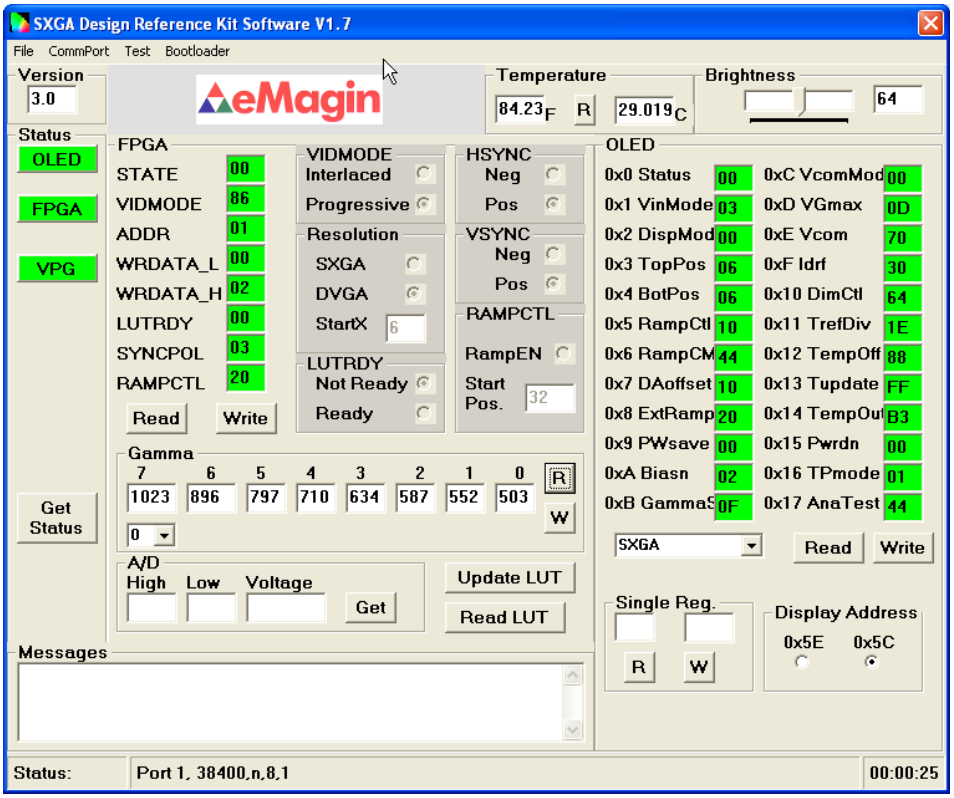


Figure 14: Software Version 1.7 GUI screen with V3.0 Firmware

## *2.6 Measured Results*

An example of measured gamma curves is given in Figure 15. These curves were taken at three different luminance levels and demonstrate the general trend in the shape of the curves as the display brightness changes.

Typical measured response curves for the SXGA R3 displays with the Automatic Gamma Correction feature activated are shown in Figures 16 and 17. The normalized display luminance as a function of input gray level, taken at room temperature and two brightness settings, is plotted in Figure 16 and demonstrates good linearity across the entire range. The display response is linear down to gray level 1 to 2 as shown by the data for low gray level response given in Figure 17.

Similar data obtained for a fixed nominal brightness (79cd/m$^2$) at both room and extreme temperatures are shown in Figure 18. These results show a slightly higher nonlinearity, mostly due to the different measurement conditions in the oven environment as compared to the room temperature setup.

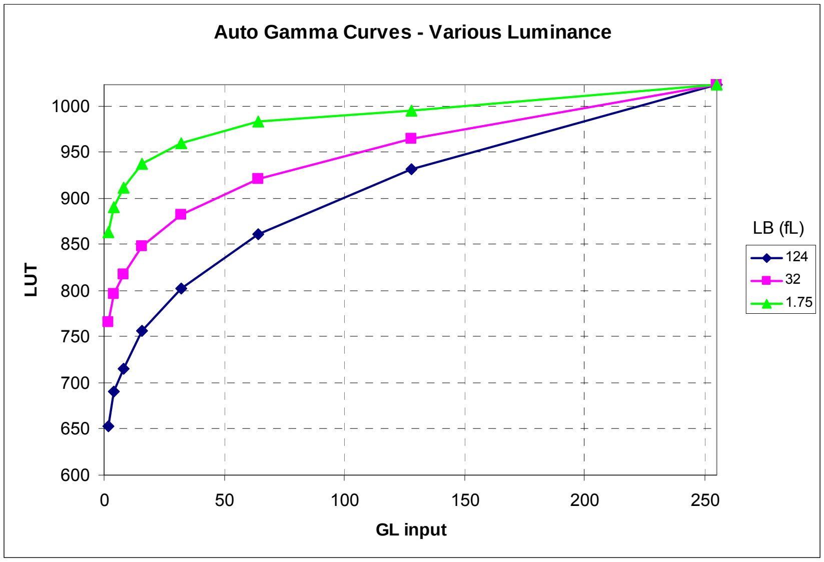


Figure 15: Typical measured gamma curves

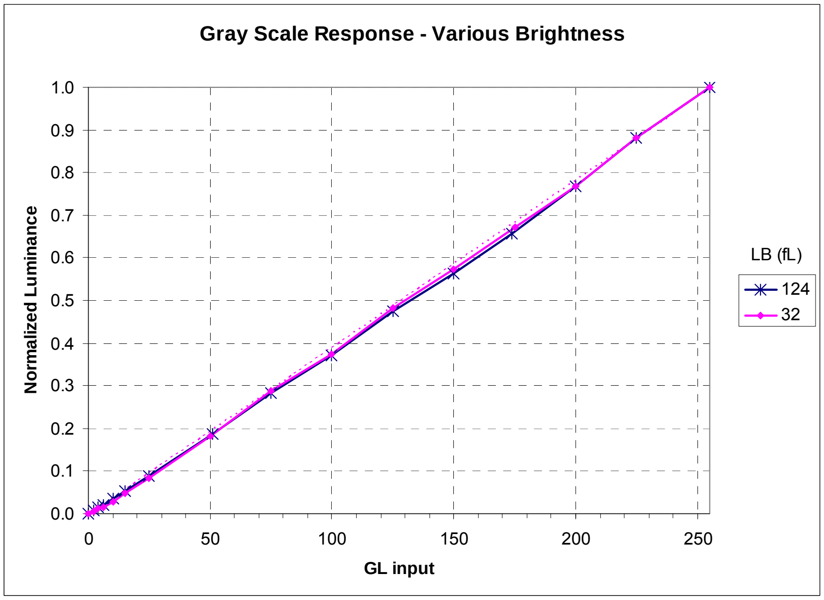


Figure 16: Display response for various brightness levels at room temperature

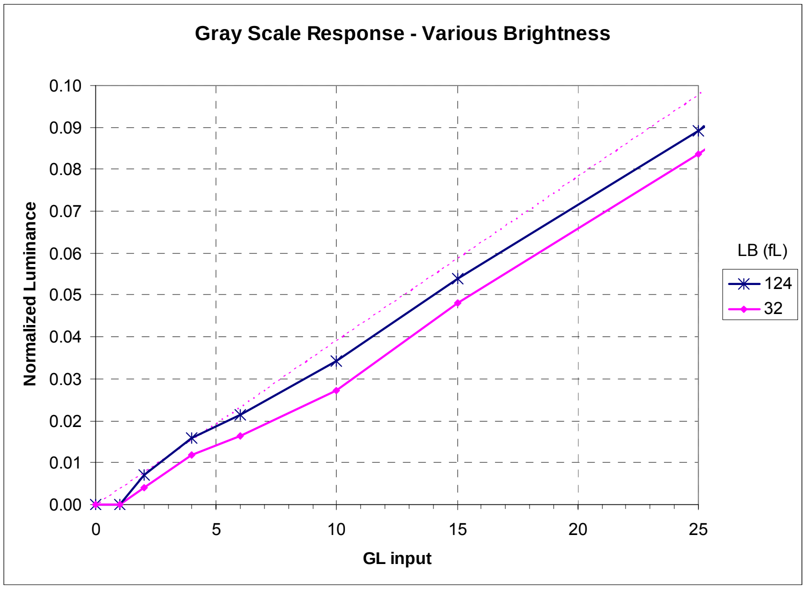


Figure 17: Display response at low gray levels

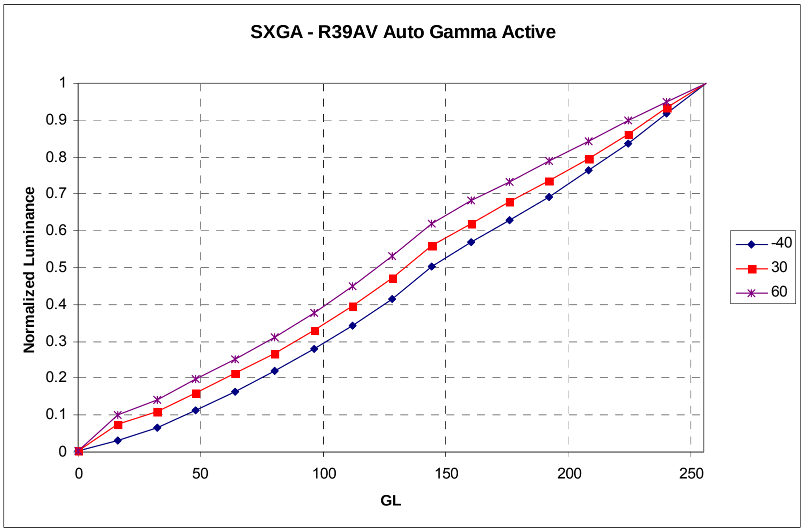


Figure 18: Display response for various temperatures at nominal brightness

Figure 19 provides measurement results of the system response for a display with the different gamma curve settings given in Figure 14. Notice that the system gamma setting of 1.6 provides a better match to the ideal gamma=2 curve at low gray levels then a system gamma of 2.

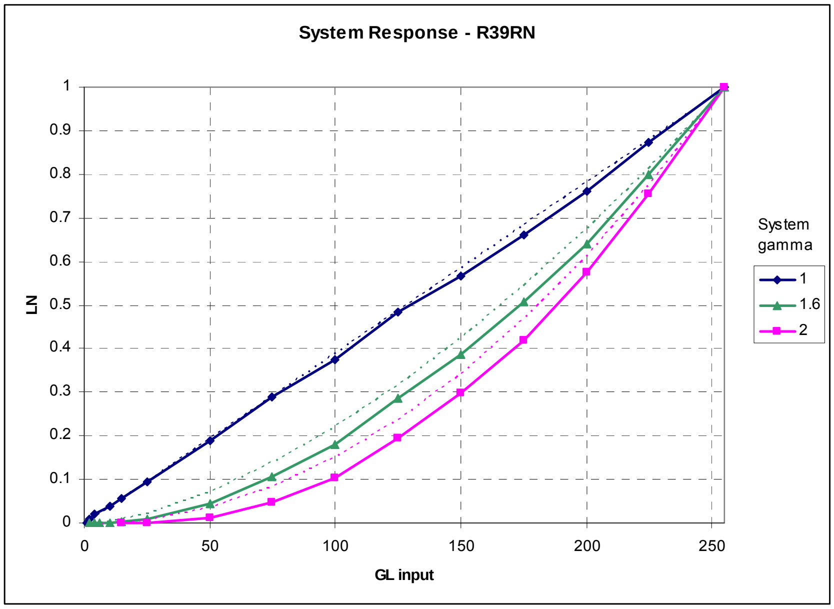


Figure 19: Display system response for various gamma curve settings