Novel LUT Measurement Method for Response Time Compensation

***Taesung Kim*, Bongim Park**
AMLCD Business, SAMSUNG ELECTRONICS CO., LTD, San #24, Nongseo-Ri, Giheung-Eup, Gyeonggi-Do, Korea(ROK), Phone :+82-31-209-8163, E-mail : warmack.kim@samsung.com

Abstract

A new measurement scheme is proposed to generate an optimized boost table for video rate LCD response time compensation. This method, which closely follows basic theory, enables up to a 90% reduction in the lookup table creation time compared to conventional methods. Furthermore, while conventional approaches require all measurements to be repeated in order to load the entire LUT whenever key parameters such as refresh rate or boost intensity are modified, the method proposed in this paper allows the new table to be calculated by utilizing saved waveform data without the need for any repeated measurements.

1. Introduction

Recently, extensive efforts to improve the response time of LCDs have been investigated and reported. [1,2,3,4,5,6] One of the response time acceleration techniques is voltage over-drive of the LC device. In this approach, a larger voltage than the target value is applied temporarily to accelerate the LC response. A LUT (Look-Up Table) is generally employed to implement this function. This LUT is also called "boost table" in the sense that the voltage is "boosted" for a period of time. The amount of boost programmed into the LUT is a function of several factors, including luminance delta for a pixel in current and successive frames, refresh rate, characteristics of the LC material, and others. To select and load optimized LUT values, accurate and effective measurement of the display is a key factor. In this research, an optimal boost table measurement method is proposed, and numerous advantages of using this method are presented and proven.

2. Voltage Overdrive Theory

Response time acceleration (RTA) is performed based on the fact that LC response is proportional to the applied field intensity. Figure 1 shows the principle of over-drive theory. Given that G_{target} is the gray level applied to the LC pixel in the current frame and L_{target} is the target luminance level that G_{target} should achieve, the transition will occur over several frames if target voltage is a simple step function, as shown by the dotted line. However, if there is a certain higher gray (G_{bst}) by which the LC cell can achieve L_{target} at the end of current frame, we can apply G_{bst} for one frame period and then G_{target} for successive frames so that the luminance level at the end of current frame will be L_{target} and maintain the same level thereafter. The graphs in (b) are for the case of white to black transition. To implement the boost operation, the easiest way is to store one frame and compare it with incoming frame data to generate boost values. Two values, one from the previous frame and another from the current frame, can be used as row and column addresses of the LUT so that the target boost data will be selected at the intersection of the two values.[1,6]
Conventional approaches to generate the LUT have employed trial-and-error methods. Typically, an arbitrarily selected boost value is applied, and the corresponding luminance change is monitored with an oscilloscope so that the boost level which generates the best transition curve is chosen as the LUT element, as shown in Figure 2. However, this conventional measurement method has several problems in actual use.
First, it takes too much time and effort to generate one LUT. Even with interpolation, assuming a 16x16 table is used, 240 (=16x16-16) elements are still necessary in order to populate the 16x16 table. Since one boost level requires about 4 passes of trial-and-error measurement on average, we have to make 240x4=960 measurements in total. If one measurement takes about 2 minutes, 32 hours will be necessary to generate one 16x16 table. Second, because an observer has to decide which curve is best, the resultant table will be highly subjective. Also, the results will vary over time even if the same observer repeats the measurements, which means that the selected table values suffer from a lack of reproducibility. Lastly, certain parameters such as vertical refresh rate will affect the amount of boost energy required. If these parameters are changed, then these procedures have to be repeated, resulting in a lot of wasted time and effort. Therefore in this paper, we propose a new, observer-independent method to overcome these disadvantages, and we demonstrate the effectiveness of this new method.

3. Proposed LUT Measurement Method

The method proposed in this paper applies basic theory of LC response and is easy to implement. By way of example, refer to an actual gray-to-gray transition curve in Figure 3. It can be inferred from the waveform that if the intended gray is changed from one level (G_{n-1}) to another (G_n), the actual luminance (g_{fb}) that can be reached after one frame will not fully reach the target luminance level (G_n)

because of slow response time.

Let us propose an 8bit/subpixel color depth system with an 8x8 LUT format. Further, let us constrain the G_{n-1}, G_n... values to be [(integer multiples of 32)-1], i.e. 0, 31, 63,..., 255. When the intended gray is transitioned from G_{n-1} to G_n, the resultant g_{fb} level achieved from the waveform will usually occur off of the grid of 32. We can characterize the system response by measuring each of the transitions from G_{n-1} to each of the 8 possible (0, 31,..., 255) G_n values. After curve fitting based on measurements of each of the 8 possible G_n values, we can derive optimal boost levels, 8 g_{bst} values, which result in G_n luminance levels which do land on the grid of 32. Figure 4 depicts this process.

We can repeat this process for all 8 different starting levels (0, 31, 63,..., 255), then calculate the complete 8x8 boost table with optimized values for all elements. When going through this process, we measure and store all of the waveforms. In this case, in total, 56 (= 8x8-8) measurements are required.

Now let us consider the case where the frame boundary changes. If a new boost table is needed for a different refresh rate, for instance 75Hz (1/75=13.3ms), we can simply repeat the calculation procedure with the same waveforms, using the different frame boundary. By doing so, an optimized boost table at the new refresh rate can be ***calculated*** in just minutes, with no need for repeated measurements. Compare to conventional methods which require a new, full set of measurements taking tens of hours.

In general, the waveforms taken from the luminance meter contain substantial noise. Therefore, before parameter extraction is performed, some level of filtering is necessary. Figure 5 shows the waveform before and after filtering.[7] As shown in the figure, G_{n-1} and G_n are calculated by averaging over a certain time interval. The value of g_{fb} is taken as the luminance value at the frame boundary. All 64 waveforms are processed through this filtering step and three parameters (G_{n-1}, G_n, g_{fb}) are extracted. Based on these values, a two-step interpolation is applied: The first interpolation is performed to make an 8x8 boost table, and second calculated interpolation is performed to expand the 8x8 table into a 16x16 table that is the most general form of LUT size.

4. Experimental Results

Figure 6 shows the full process flow of our proposed measurement method. With a luminance meter (BM7) and a digital oscilloscope, we can measure 56 waveforms from the DUT which are then processed in a computer with MATLAB™ S/W. The filtering and averaging operations will help to extract accurate parameters from the data. The first interpolation calculates the optimal 8x8 boost table, and the second interpolation expands the table to fit the actual 16x16 LUT implementation circuit. When the boost table needs to be modified to accommodate a different refresh rate such as 75Hz, we simply repeat the process with existing data for the new frame timing, so that the new table is available in just minutes.

For comparison purposes, Figure 7 and 8 show the measured boost table applying the proposed method at 60Hz and 75Hz. Each curve represents one column in the LUT so that this graph can be considered as a two-dimensional projection of a three dimensional boost table. A greater spread over the set of all curves represents a larger applied boost intensity. Therefore, we can see the 75Hz table demands greater boost levels than the 60Hz table, as would be expected. We have also shown a table derived from the conventional method in Figure 9. It can be inferred that the conventional method has resulted in an over-boosted system so that some artifacts on the moving images are observed as can be seen in Figure 10. This experiment was done on a 32" PVA TFT-LCD panel.

5. Conclusions

We have proposed a new measurement method to derive the response time acceleration boost table. This new approach has many advantages. Unlike conventional methods which take several days and are subjective, the proposed method gathers all necessary data at once and calculates LUT elements with interpolation so as to save 90% of the time and effort in deriving the table. Additionally, the new method generates consistent results since the data is collected by instruments and the table is calculated numerically with objective criteria. If the boost intensity needs to be changed, it is possible to set a different time reference and run the calculation S/W again with the saved waveform data. We can then extract a new boost table in just minutes. This methodology will also be easy to implement in automated measurement systems in the future.

6. References

[1] Back Woon Lee, et al., IDW'00 Digest, pp. 1153~1154

[2] K. Kawabe and T. Furuhashi, SID'01 Digest, pp. 998~1001

[3] K. Nakanishi, et al., SID'01 Digest

[4] Tsutomu Furuhashi and Kazuyoshi Kawabe, et al., SID'02 Digest, pp. 1284~1287

[5] Jun Someya, et al., SID'02 Digest

[6] Richard I. McCartney, SID'03 Digest

[7] T. W. Parks and C. S. Burrus, "**Digital Filter Design**," John Wiley and Sons., 1987

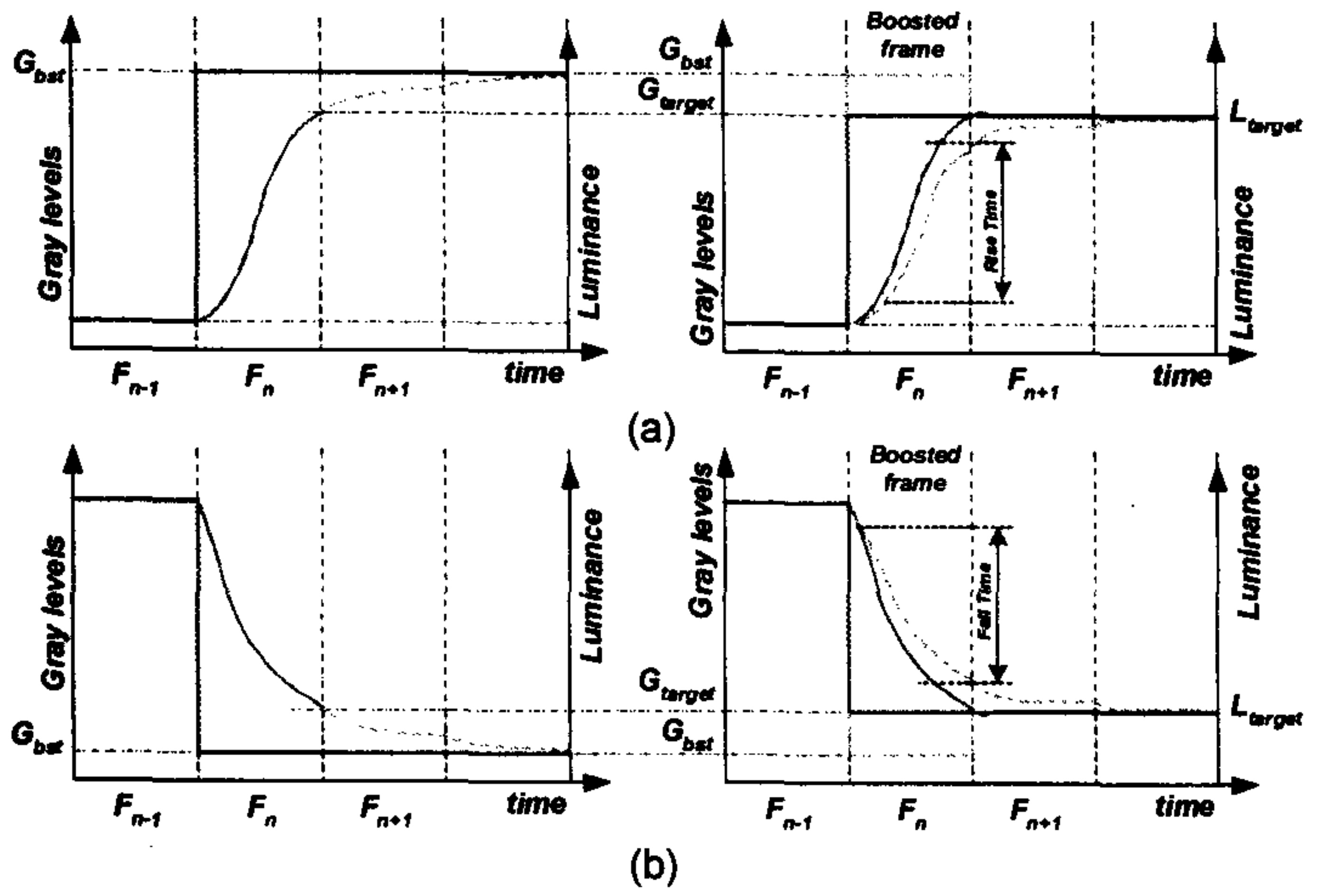

Figure 1. Voltage overdrive operations

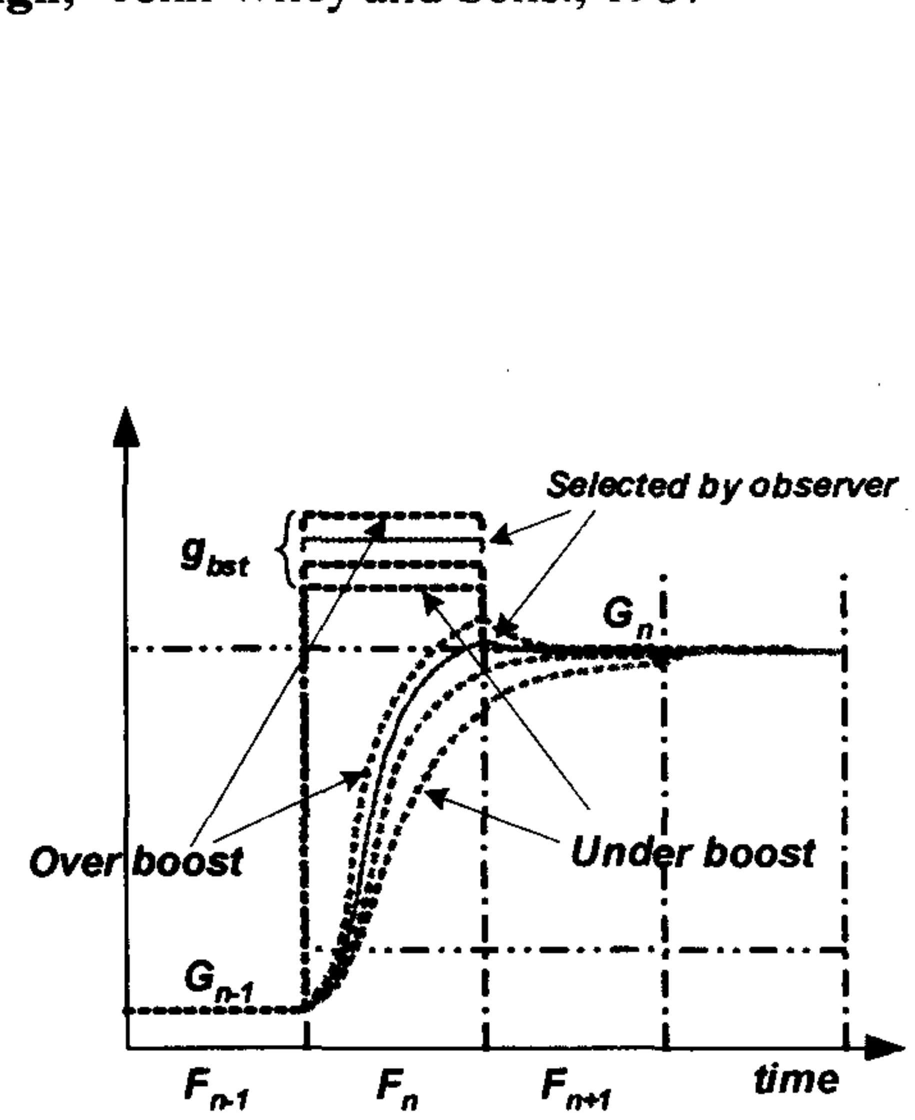

Figure 2. Conventional boost table measurement

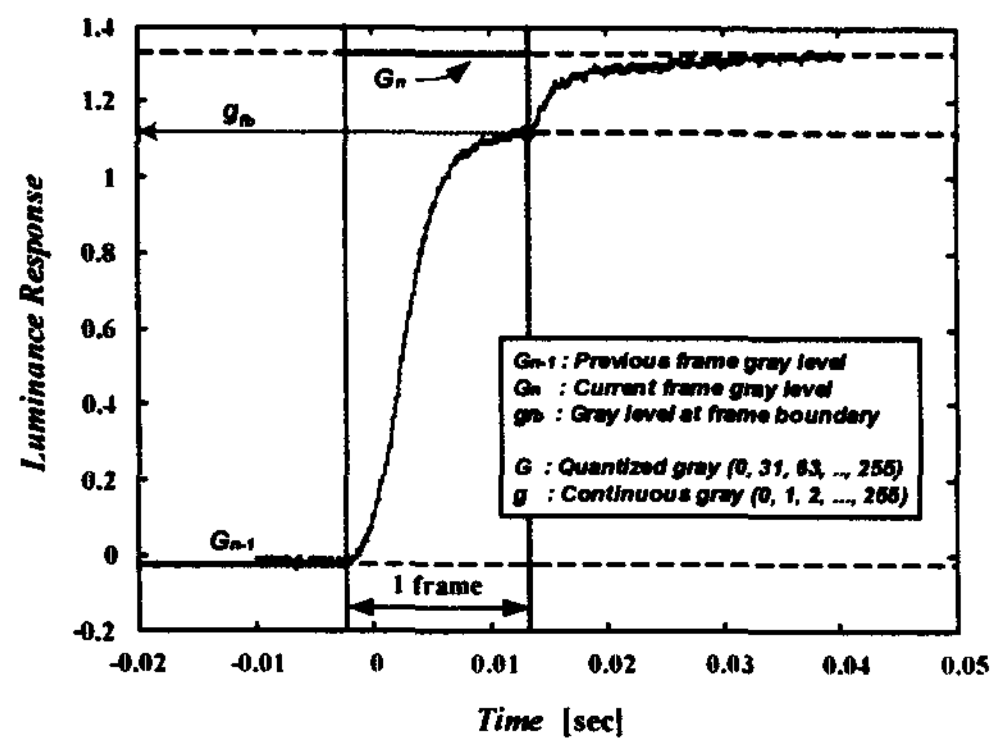

Figure 3. Luminance transition curve

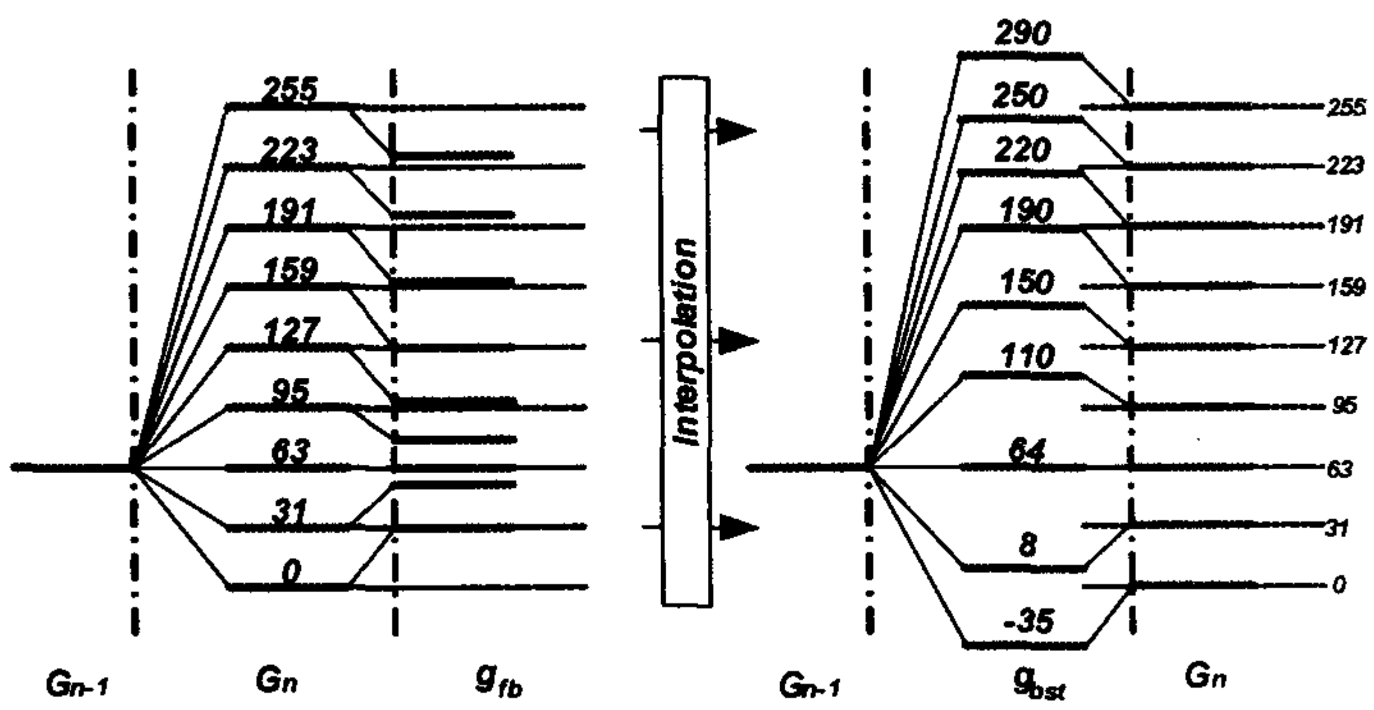

Figure 4. Interpolation process

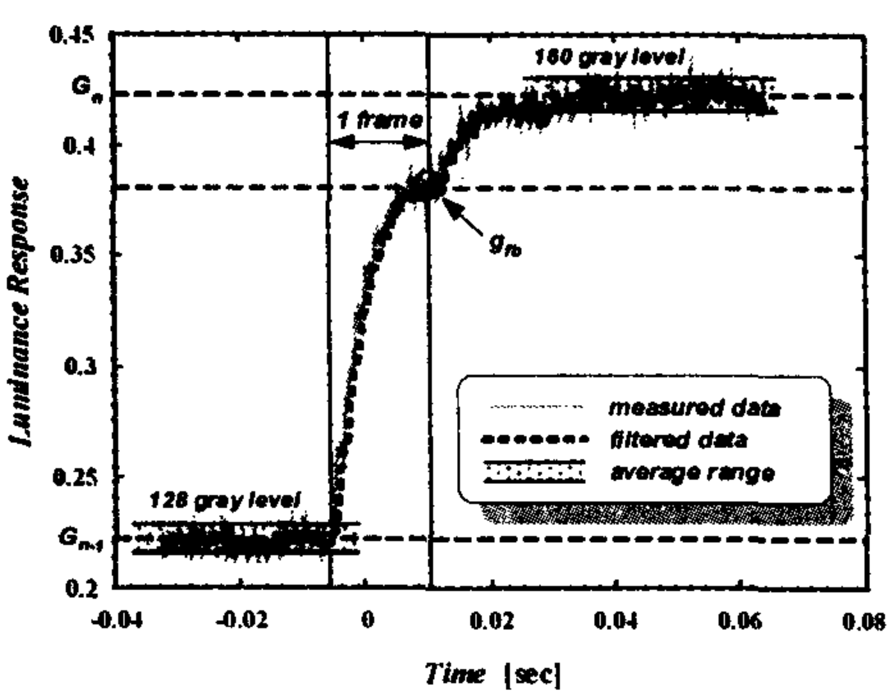

Figure 5. Filtering procedure

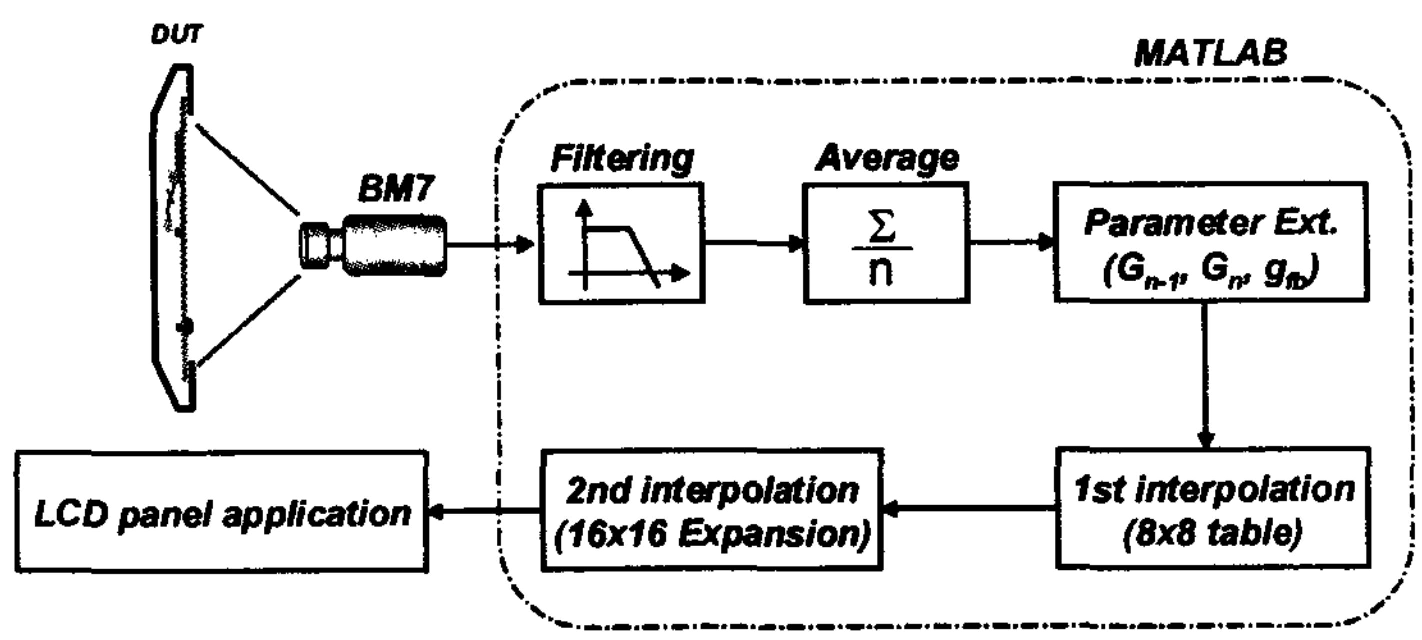

Figure 6. Full data process flow

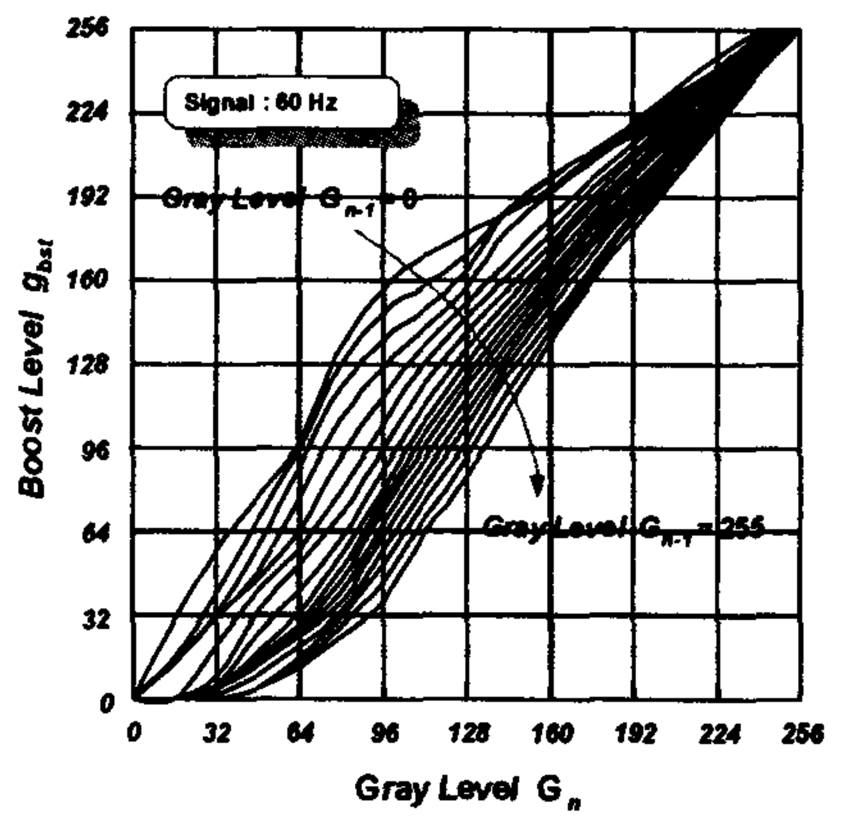

Figure 7. LUT with new method @ 60 Hz

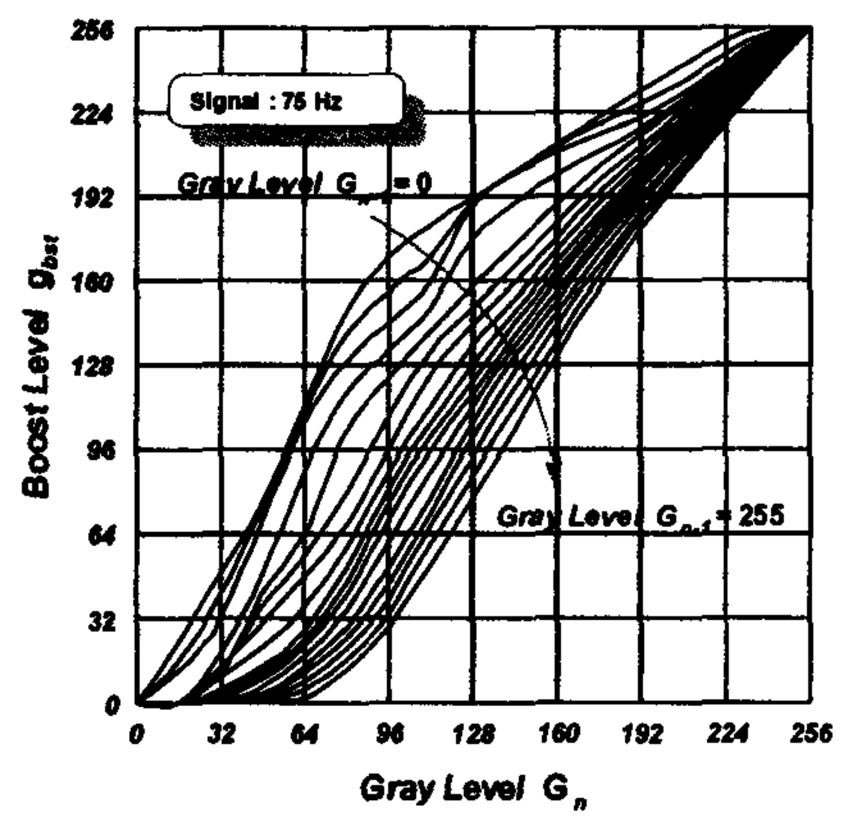

Figure 8. LUT with new method @75 Hz

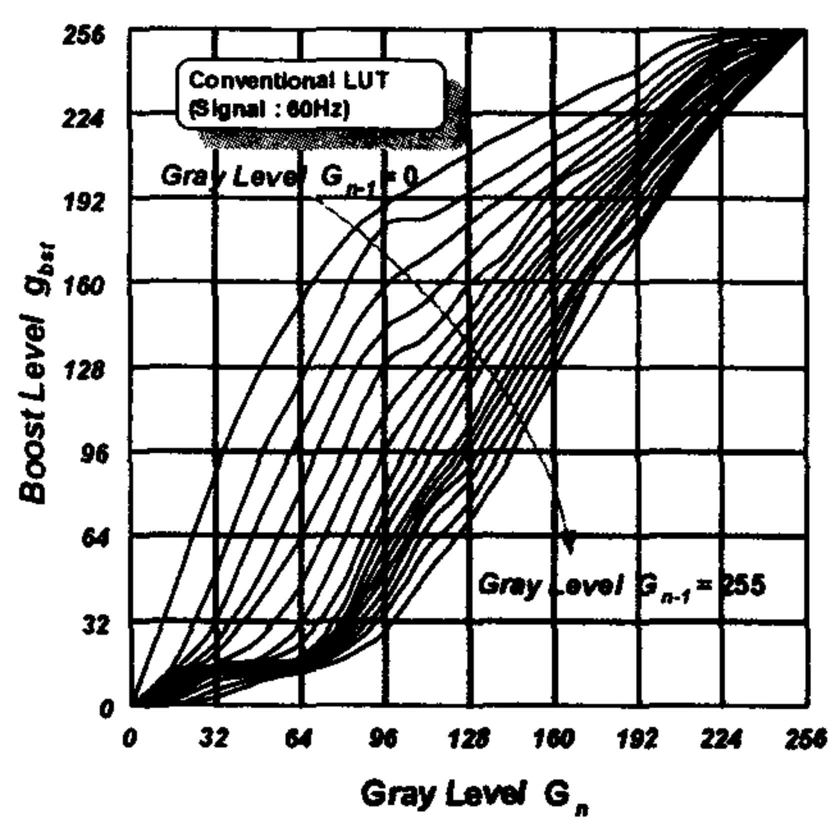

Figure 9. LUT with conventional method @60 Hz

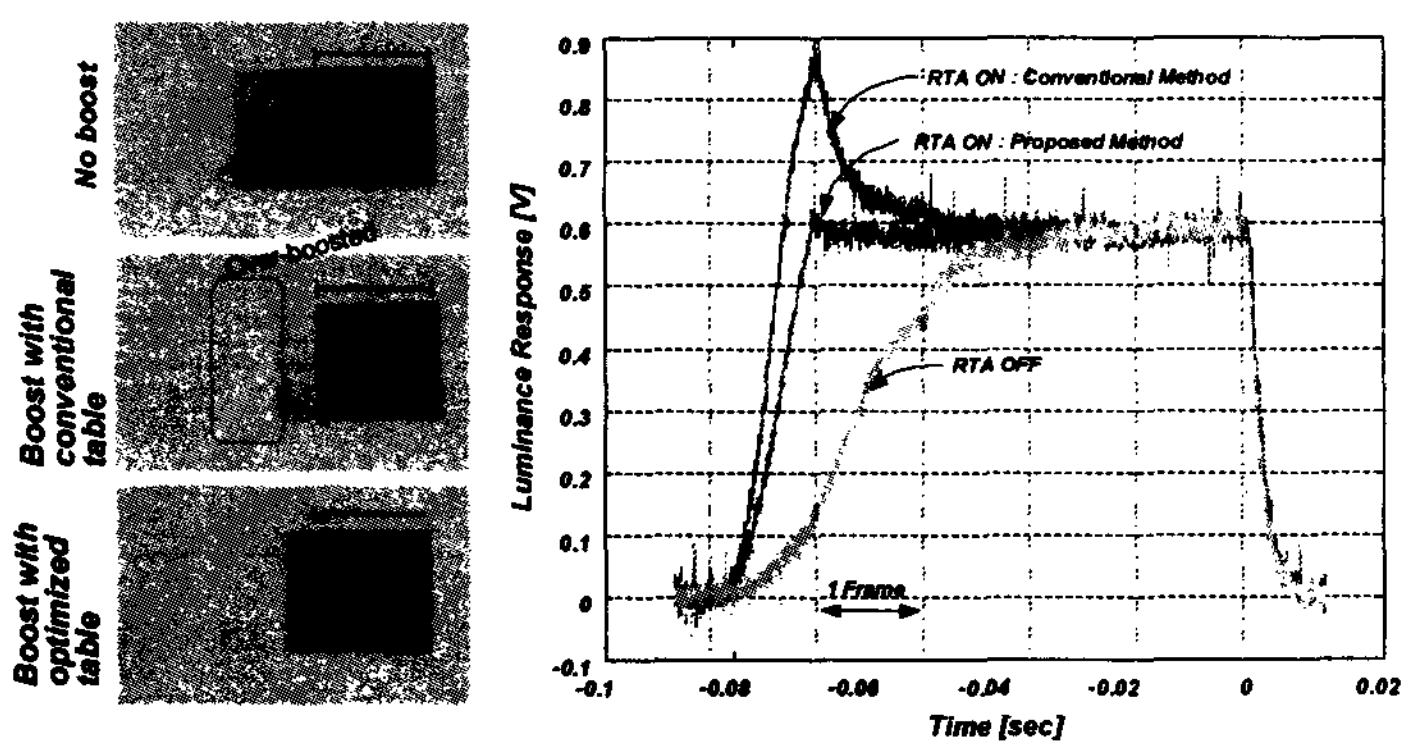

Figure 10. LC response comparison with different tables