37.4: Mass-Production-Oriented Master Slice 6-bit Gamma Correction for Mobile Applications

***Hisashi Sasaki, Yoshihide Nakajima, Masaji Ueno*.**
Toshiba Corp. Semiconductor Company,
2-5-1, Kasama, Sakae-ku, Yokohama, 247-8585, Japan.

Abstract

Thoughtful distinction between programmability for prototyping and mass-production proposes "Master slice gamma correction", which gives not only programmability to adapt individual company or panel-specific gamma correction characteristic, but also both low-cost and low-power driver IC.

1. Introduction

Programmability is a desirable function in general to adapt several gamma correction characteristics for multiple companies or for multiple panels by a single source driver. However it has many aspects according to its problem as explained below.

The first problem is an exploration of specification itself. Figure 1 shows a typical configuration to perform "system design" on gamma correction. It is very problematic that it includes tentative source drivers to drive LCD panel to measure the ideal characteristic. The tentative source drivers are not tuned to the ideal, but somewhat good for driving. System engineer may expect that this tentative maybe replaced with the final one to be implemented because they need final test by using real pictures. For this case, full programmability is attractive for system designer to quest the final ideal characteristic.

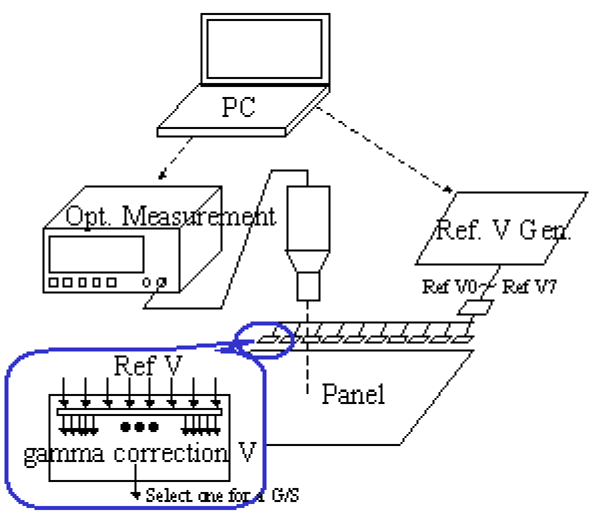

Figure 1: Typical curve exploration

The second problem is an assembling that reference voltages are not well distributed to each source drivers via PCB, especially via COG, to panel.

The third problem is accuracy. The PWL (piece-wise linear) approximation of gamma correction characteristic is a popular solution for 6-bit accuracy such as mobile application. On the other hand, TV and PC application already have 8-bit accuracy and therefore they exploit a LUT (look-up table) to assure its accuracy. Mobile application is requested to get more accuracy by expecting mobile TV. The visual 6 bit means electrical 8 bit, so that PWL requires 8-bit accuracy in order to faithfully reproduce the desired characteristic. However it is impossible to implement faithful 8-bit accuracy by PWL: the lines cannot fit the curve accurately within whole range. This is because that the VT characteristic is experimentally approximated by the certain kind of exponential called TRC (Tone Reproduction Curve). As exponential is irrational, any attempt to use fix number of boundary points of PWL is not enough.

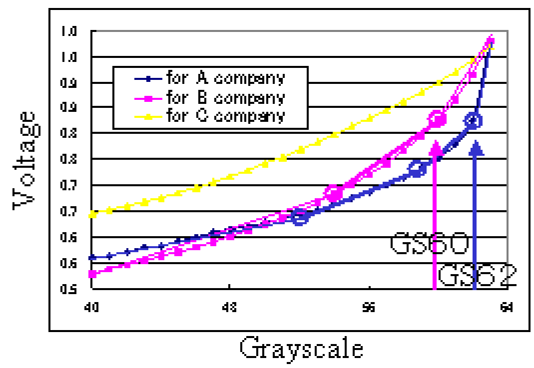

Figure 2: PWL approximation for GC Curves

The last problem is power consumption. It is very important for customers to save power and to gain long time operation especially for mobile apparatus.

As our target is mobile application, we decide that full programmability is not always prerequisite for manufacturing, so that the mater slice approach is selected. The approach supports the programmability to adapt multiple specifications of gamma correction for each company.

2. Previous works

Programmability has been studied by many approaches, which are summarized as the following figure.

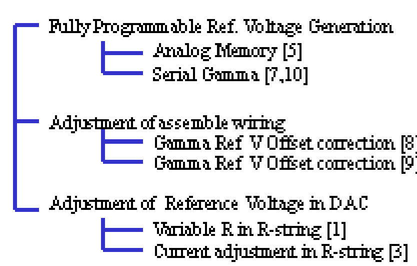

Figure 3. Previous works classified as three groups

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3. Master Slice Gamma Correction

3-1. Fundamental structure

"Master Slice Gamma Correction" (MSGC) includes both gamma reference voltage generation circuit ("pre gamma") and gamma voltage supply circuit ("post gamma"). The pre gamma generates the reference voltages, which are corresponding to boundary points of PWL approximation. The post gamma generates the voltages for all grayscale, for example 64 grayscales. The pre and post gamma consist by R-string with uniform unit of resistors. For 64 grayscales, electrically 8-bit accuracy is requested, but practically speaking, 1/250 is enough instead of 1/256. Resistors are prepared as master slice: resistors are physically placed in advance and afterwards connections will be done using metal layer such as AL. The extra preparation of resistors is desirable to attain much flexibility, for instance 250+50 = 300 resistors. The resistors are connected in zigzags. A single difference of grayscale is implemented by a group of unit resistors in serial or parallel connection. The group is represented as dashed-boxes in Figure 4. The output nodes (to take out reference voltage in the pre gamma and to feed grayscale voltages in the post gamma) are nodes reside in such as group boundaries.

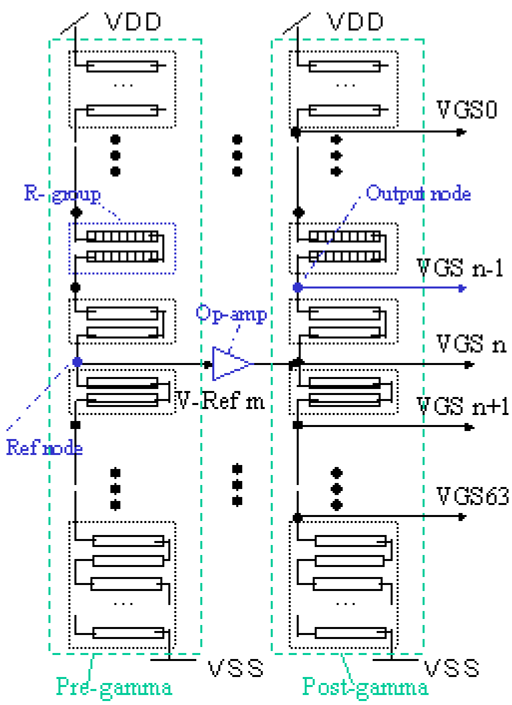

Figure 4: Master Slice Gamma Correction

The identical structure is essence for our MSGC. The property ensures the LUT accuracy for targeted gamma correction curve and the flexibility to adapt several curves. Strictly speaking, the "identity" means the ratio identity: their absolute values are to be determined by considering current consumptions for the two R-strings. As pre and post gamma will generates exactly same voltages because of the structural identity, op-amp currents between pre and post gamma will also be reduced: ideally, zero. Its current consumption is reduced as much as possible even in the case that reference voltage adjustment is occurred.

Figure 5 shows other wirings. The parallel wiring enables finer tuning of resistor ratio. In general, electrical 8-bit accuracy (=1/250) seems enough to fit for 6-bit visual perception. However, the central very linear part of PWL approximation is so sensitive, we sometimes add extra accuracy. The auxiliary layout allocations are invented by considering such a parallel connections. When changed serial connection in zigzags to parallel connection at a node, the changing will be repeated. To avoid such domino changing, resistor is set intentionally unconnected in skipping one by one. The skipped (auxiliary) resistor is prepared as parallel resistors. If further accuracy requested, skipping step may be changed to three in order to implement 1/4 parallel connection. Another choice is a serial connection of two 1/2.

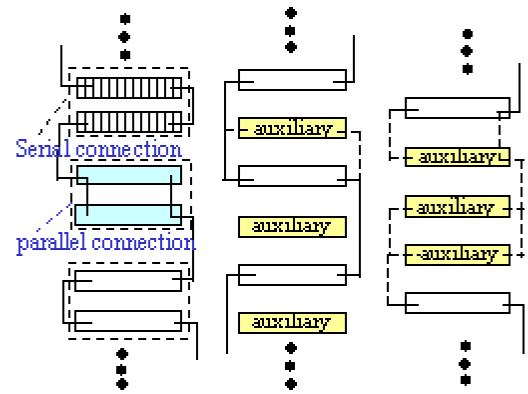

Figure 5: variations for connections

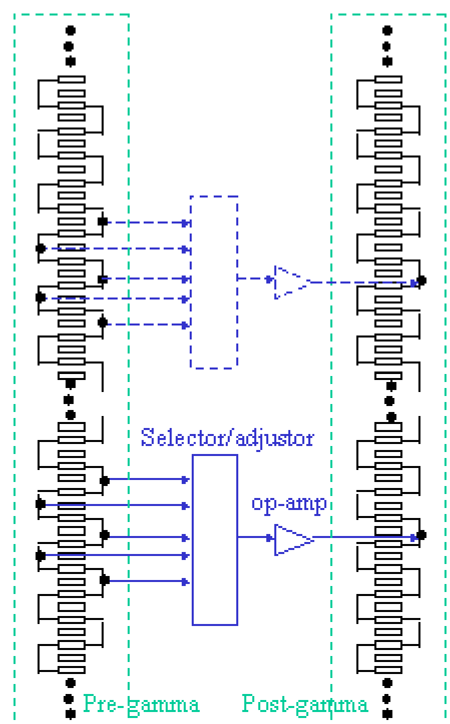

Figure 6: Master Slice Gamma Correction

Figure 6 shows the adjustment of PWL approximation. A selector chooses the nodes as reference voltage to feed into the post gamma. The candidate nodes are gathered around the center node. By this selection, we can adjust the reference voltage boundary points. If you want coarser adjustment, selected node should be selected with skipping several steps, for instance, five by five, or more. In order to establish very much coarse adjustment, these selection must be shifted as a whole: the output node of post gamma is to be shifted just as same as the pre gamma. This shift means the structural identity not only the as R-string but also as the connection between the two R-strings. In fact, the shift is not implemented as the physical move of the allocated resistors, but the implemented as the change of wiring (as master slice). That is, the corresponding pre gamma node and post gamma node have the same voltage. Therefore, op-amp has very small current flow to adjust another PWL approximation for another panel characteristic.

The master slice has the advantages that the change of wiring can treat any big change caused by another panel. If unit of resistor was updated, we should redesign mask from the beginning: the first mask layer. In our proposal, only wiring is changed, no other mask should not be updated, so that mask cost is very low, roughly speaking 1/100 times low, and the time to derivative product is also so short.

3-2. Design Flow for MSGC

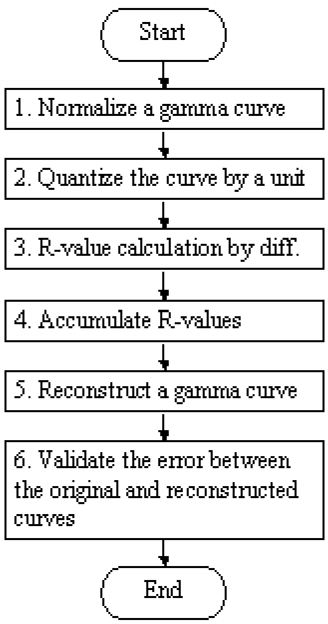

Figure 7: Design Flow for MSGC

Figure 7 shows the design procedure how to calculate resistor values (relative one, not absolute) and how to verify its soundness. The first step is a normalization of a given gamma correction curve as a specification. Its unit is supply voltage to drive liquid crystal. Figure 8 is an output for this step.

The second step is a quantization that maps the relative voltage into the integer value, which is representing the unit step of resistor. Its inter value is hopefully 1, but not limited to 1. If finer accuracy requested, 0.5 as parallel connection is also admissible. Assume we adopt 1/250 step in accuracy for instance. It is natural to adopt 1/256 for 8-bit. However, in the practical situation that plotting VT-curve to pick boundary voltages up, 1/250 is more natural than 1/256 because of its easy read-out. The 1/250 is the quarter of 1/100 scale, however 1/256 has rounding error and difficult to determine it's final rounding: rounding up or down to nearest. For this reason, 1/250 is preferable in practice. Thus interval is calculated by multiplying relative voltages by the factor 250.

The third step is a differentiation of voltages, which gives the resistor values for each grayscale.

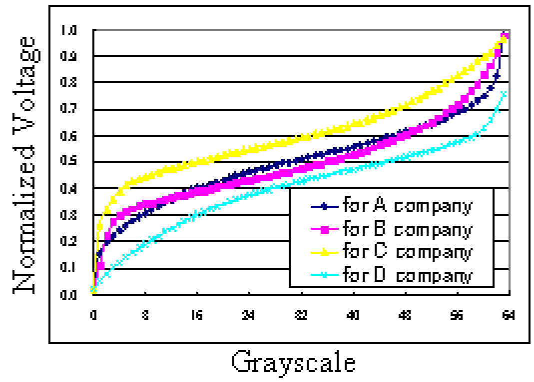

Figure 8: Normalized Gamma Correction Curves

The rest three steps are the verification. As the center portion of curve requires accuracy, parallel connection is allocated intensively for these center portion, so that the count of parallel connection is reduced as small as possible. For instance, for the curve of B, 8 to 38 grayscales have parallel connections, 0 to 7 and 39 to 63 grayscales have no parallel (serial) connections only. By this allocation, count of resistors is reduced also 326 = 256+76 to 296 = 256+46: 46 parallel connections for the center portion. Then we conclude that 300 resistors are enough to prepare as extra supplements. In fact, our additional experiments show that 330 are good for almost case.

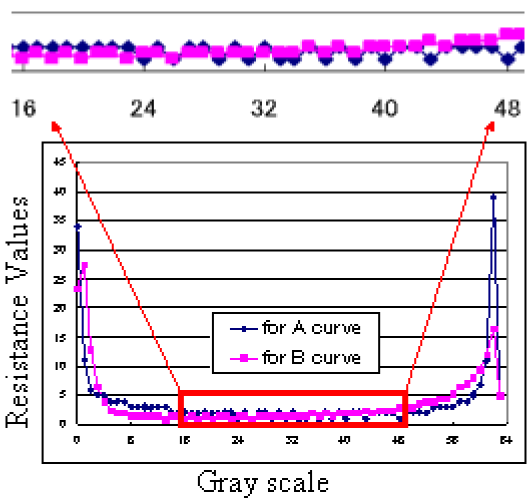

Figure 9: Normalized Reconstructed Resistor Values

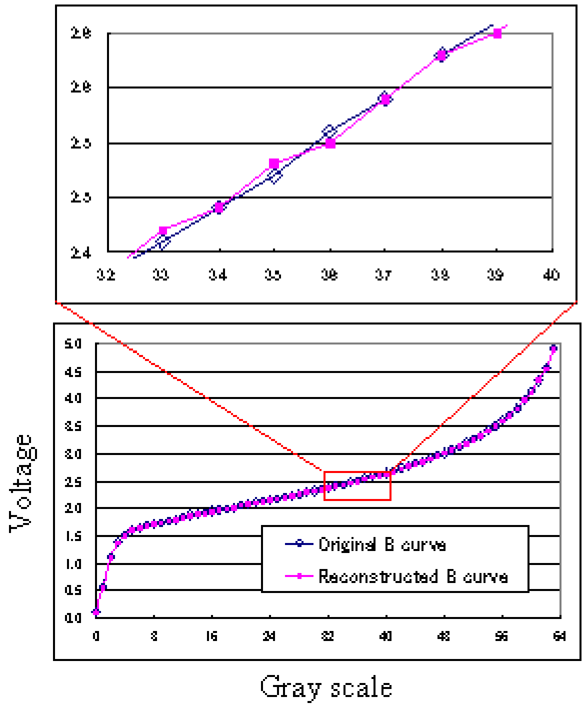

Figure 10: Comparison between Reconstructed and Original

The summing step calculates the relative voltages by summing the quantized resistor values. Multiplying relative voltage by supply voltage gives the absolute values of resistors. Figure 10 compares the resultant reconstructed gamma correction curve with the original specification. The zoomed two curves show that the reconstruction errors are within 1/500: the errors are confined locally, and it has no global accumulation. The last verification step validates the voltage difference as numerical quantity to compare the original with the reconstructed.

As described above, two R-strings of the pre and post gamma have identical structure. The pre gamma's primary role is the generation of reference voltages to be fed to op-amps, with no need of large current to drive. On the other hand, the post gamma must supply somewhat sufficient current to drive LC cells, with aiming as low power as possible simultaneously. Therefore, the ratio is exactly identical but their absolute values could be different according to their values so that the units for the two R-strings are different.

4. Discussions

In this section, we will discuss the four advantages of MSGC: (1) mass production oriented, (2) no wire assembling issue (no voltage drop), (3) no harm for prototyping on specification exploration of gamma correction, and (4) cost-reduced FRC support for mobile TV.

Our proposal is the thoughtful distinction between prototyping and mass-production. The prototyping just explores the specification of gamma correction. Once explored, lavish programmability is no more requested, but limited adjustment flexibility. Mass-production pays much more attention on implemented performances such as low power consumption, low production cost and good statistical yield. For this reason, additional circuits with increasing chip area should be avoided, so we introduced the master slice approach.

Our proposal includes no bundle of reference voltages, and even no serial interface to transmit gamma data: the reference voltages are generated by pre gamma in IC drivers. So, there is no concern on assemble for wiring (unwanted voltage drop). For example, larger screen TV (however low-end TV) has long wiring, and assembling issue is important issue. In this case, the issue will be vanished when the generation of gamma reference voltages is included in IC drivers themselves.

In the system design on gamma correction, the tentative driver seems harmful at a first glance because of its non-ideal characteristics. However, its tentativeness doesn't affect the measurement of electro-optical characteristic itself. So, you should separate the measurement from the design of gamma correction, and after measurement you should understand you can always get correct LUT for any design by interpolations.

When you want to reduce bit width by FRC such as 6-bit cheaper implementation for 8-bit accuracy, our master slice approach also is a good option. Our approach has no accuracy limitation: the 1/250 accuracy means almost 8-bit accuracy, so that 6-bit output has 8-bit accuracy inherently. Therefore, mobile TV is a suitable application, and even suitable for large screen TV when it is a cost reduced low-end product with using FRC.

5. Conclusion

We have proposed the MSGC (master slice gamma correction) especially targeting mass production. It cares low cost and low power with permitting the adjustment of gamma correction by abandoning the universal programmability for specification exploration, but the metal wiring still keeps acceptable adaptability for variations caused by different company/panel-specific characteristics. Therefore, our recommendation is: you should use the Toshiba's driver with MSGC for mass-production even when you already prototyped your gamma correction by using any high-end high-cost driver with full programmability.

6. References

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