Driving and System Considerations of PM- and AM-OELDs

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Abstract

This paper will review the driving methods and issues of driving circuitry for passive matrix organic electro-luminescent displays(PM-OELDs). And it will shows the proposed one-chip and two-chip solution for driving the PM-OELDs and also the pixel structure and driving methods of active matrix (AM-OELDs). We will discuss the proper applications of OELDs with its power consumption by comparison with that of LCD.

1. Introduction

OELD(Organic Electro-Luminescent Display) has many attractive properties such as fast response time, high brightness, wide viewing angle, wide operating temperature range, self-emissive, and high contrast ratio for FPD(Flat Panel Display) applications [1-3]. There are two kinds of panel structures [1,4], which are PM-OELD(Passive Matrix OELD) and AM-OELD(Active Matrix-OELD), they are classified according to the existence of active driving transistors in each pixel. Although PMOELD has advantages such as simple pixel structure, low cost fabrication process and fast response time, it still has some drawbacks to apply to high resolution and large panel applications. Because the available time to drive each pixel decreases as the number of row lines increases, huge driving current is necessary for high resolution and large size panels to achieve adequate average brightness levels [2]. This huge driving current causes many problems such as large voltage drop on column and row lines and less lifetime. In case of AMOELD, because light is emitted during frame time, most of above problems can be solved. However, because low temperature polycrystalline silicon thin film transistor (LTPS-TFT) is used as current source in pixel, non-uniformity of gray-scale due to threshold voltage and mobility variations of TFTs can be critical problems.

In this paper, we will review the driving methods and issues of driving circuitry for PM-OELDs and pixel structure and driving methods of AM-OELDs. And we discuss the power consumption of OELDs by comparison with that of LCDs.

2. PM-OELDs

2.1. Driving Methods of PM-OELDs

The PMOELD, which has the panel structure of having no active devices in each pixel that is different from AMOELD, has the merits of simple fabrication process and low-cost. So, the PMOELDs are becoming very attractive devices for small sized displays such as mobile display electronics. But, because the power consumption of the PMOELDs is relatively high compared to the TFT-LCDs, reducing the power consumption is becoming very important issue for mobile applications.

As shown in figure 1, the electrical model of one OEL pixel is composed of a diode and a capacitor. The threshold voltage of the diode is over 6V, which means that the illumination starts when the voltage difference between anode and cathode of OEL pixels become over 6V. Each column line has large capacitive load because many pixel anodes are connected to one line. For example, the measured column line capacitances of R(Red), G(Green) and B(Blue) line of 1.8-inch 128 × 160 color PM-OELD

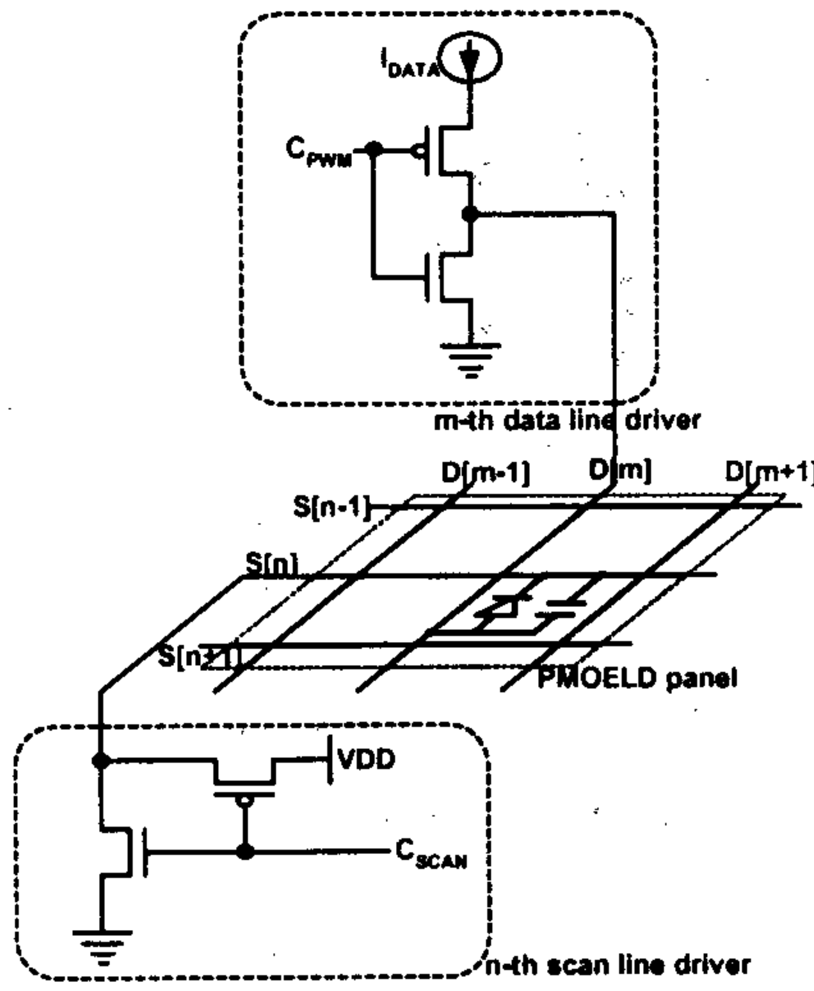


Figure 1. Schematic diagrams of driving circuits and PMOELD panel.

panel are 500pF, 300pF and 300pF, respectively [5].

Conventionally, to display images on the PMOELD panel, current-controlled PWM gray scale method, which generates the current pulses with varying pulse width but the same height, is used. But this method has a problem of nonlinear gray scale at low gray levels because charging the large capacitive load of the column line over the pixel threshold voltage takes a long time and the PWM duration is relatively short compared to the charging time at low gray level. To overcome this problem, the pre-charging method is used as shown in figure 2 [5]. The pre-charging method is that, at the beginning of the PWM pulse, high driving current is supplied to the column line for the fast charging of the column line over the threshold voltage. In PWM gray scale method with the pre-charging, if all column lines are pre-charged simultaneously, very high current is needed and it can not be supplied in battery-operated system. So, the falling-syncronous PWM gray scale method that the PWM pulses(pre-charging) begin individually and end simultaneously is adopted in order to reduce the maximum supply current. As a result of the method, linear gray scale over all the gray levels is achieved and 15 % of the power saving is also obtained because the height of the PWM pulses is lowered with the pre-charging method. Recently, sub-frame and and, by applying a multiplexed current to the column line in each sub frame, gray scale is obtained. But, the resolution and the number of gray levels are limited compared to the conventional PWM method because current driving method are introduced [6]. In this method, the whole frame is divided into sub frames one low line time is seriously reduced by the sub frames and, more over, capacitive load of column line increase proportional to resolution.

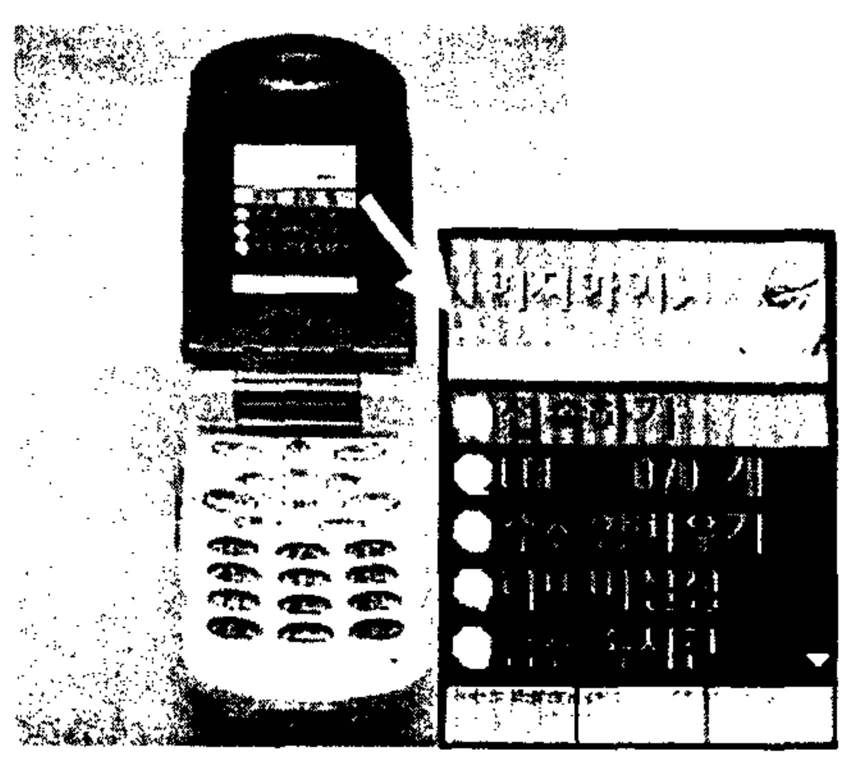
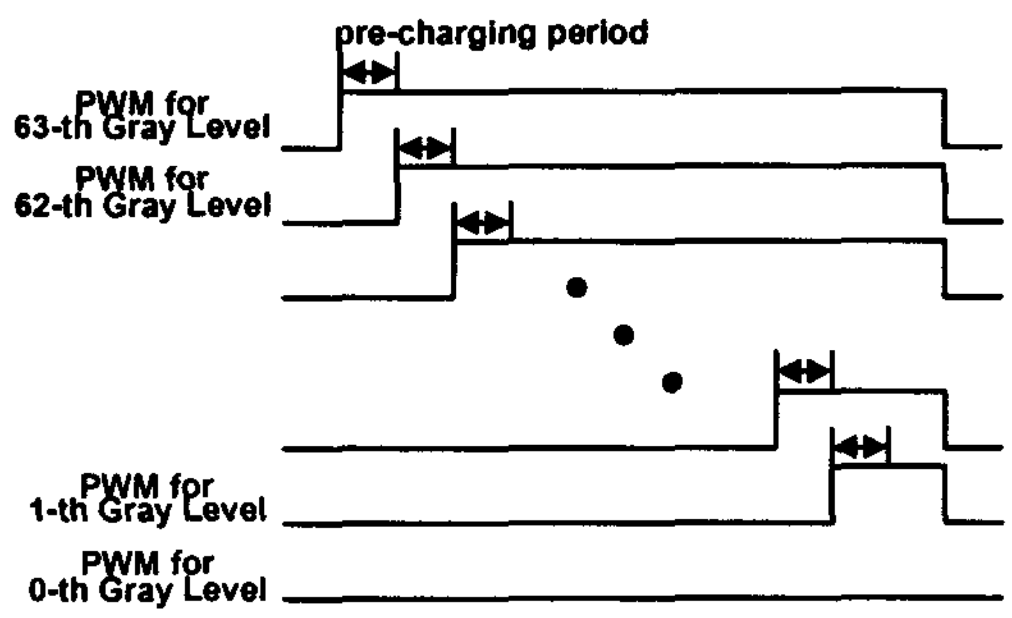


Figure 3. Fabricated color PM-OELD panel using the proposed pre-charging method [5].



the.

Figure 2. PWM voltage waveforms using the proposed pre-charging method.

2.2. Issues of Driving Circuitry for PM-OELDs

As we mentioned previously, PMOELDs is suitable for small-sized applications such as cellular phone and IMT-2000 terminals. In STN-LCDs for cellular phone application with less than 16-gray scale, one-chip solution that integrates driving circuits, timing controller and oscillator is ubiquitous for low-cost. For the same reason, power-driving circuit is also integrated on the same chip. In similar to LCDs, system for PMOELDs does so. So we mainly focus on the integration of the driving system for PMOELDs on a same-chip.

Figure 4 shows one example of driving circuits for PMOELDs. The number of output channels for data driver and row driver depend on the resolution of the panel. Usually, 128×80 plus some icons, monochrome PMOELD is used for cellular phone application and 128×RGB×160, color PMOELD is used for IMT-2000 terminal. Display data and internal commands from external units such as MCU, Image sensor and CODEC are fetched and processed in External Interface & Command Decoder block. Processed display data are stored into RAM modules through RAM Interface block and the commands are stored into internal register in Command Decoder. Timing Generator generates the control and synchronizing signals for each block by using the clock from Internal Clock Generator. Data Driver Controller fetches the display data from RAM modules according to the commands of Command Decoder and puts them into the Data Driver. DC-DC Converter generates high-voltage supply from low-voltage supply for Data Driver and Scan Driver.

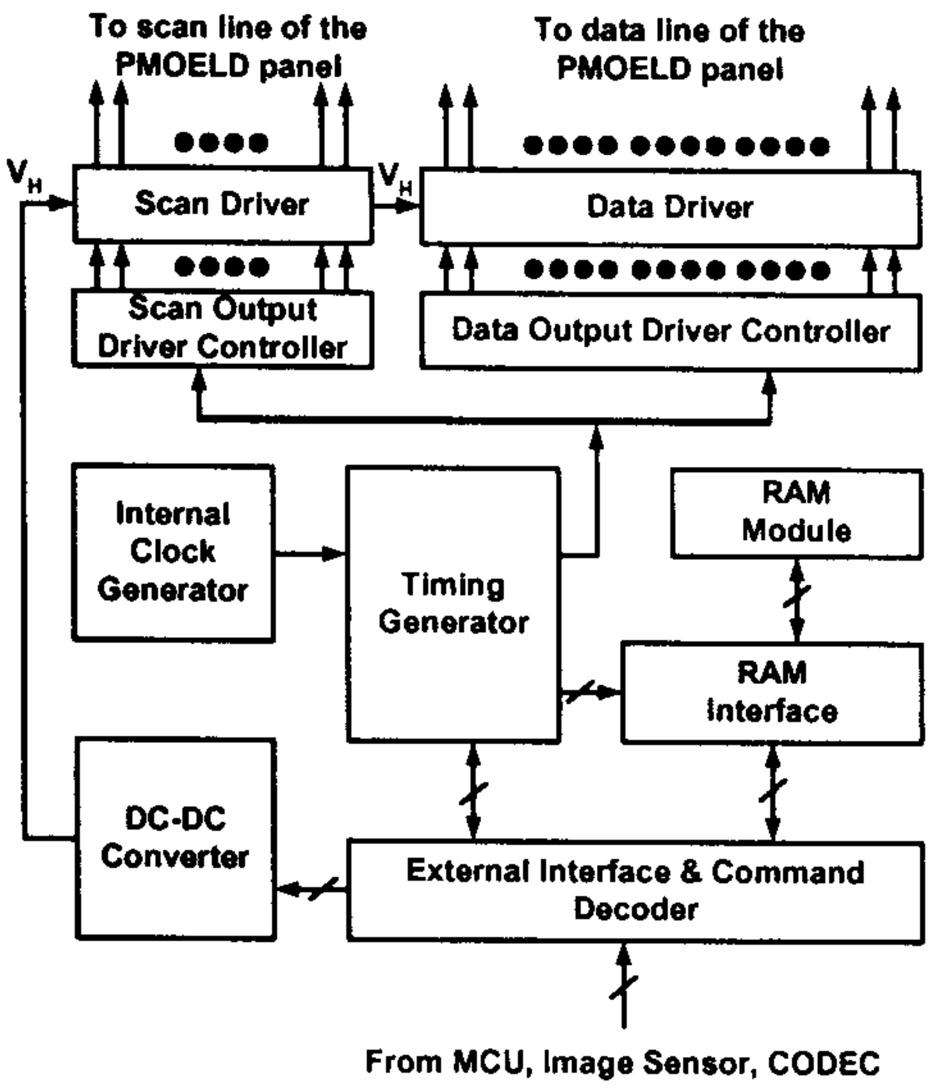


Figure 4. Block diagram of driving circuits for PMOELDs.

In this system, the integration of the driving system on a same chip mostly has two main issues; one is self-contained problems of the chip and the other is due to driving issue of PMOELDs.

Self-contained issues of the chip rely on the two factors, area and power. Area problem could be divided into two parts, core-area limitation and pad-area limitation. Firstly, the bottleneck of large core-area usually stems from RAM modules. RAM modules store frame image of display data. If additional display functions such as Picture-In-Picture(PIP) and On Screen Display(OSD) are required, the capacity of the RAM modules should be increased. For example, 128×80 resolution, monochrome device with only frame memory requires 10k bits, which is moderate for integration and successfully demonstrated [7]. As shown figure 5, one chip with 12mm× 4.17mm chip size integrates timing controller, oscillator, DC-DC converter and 10k-bit frame memory as well as data/scan drivers. But for color displays with 6-bit gray scale, 128×160 resolution plus 64×80 PIP requires over 150k-bit memory, which could not be integrated with driving circuitry in available technology. With this reason, driving circuitry such as data/scan driver is separately implemented with timing controller/RAM modules for color PMOELDs. Secondly, drastic increase of the number of chip-pads is an issue as the resolution of the panel increases. To reduce both cost and complexity of off-chip interconnection on COF(Chip-On-Film), output pads of panel driver are usually aligned along one-side. If we assume uniformly distributed chip-pads with 40 μm pitch, the number of output pads for 128×RGB×160 resolution is over 500, which is practically impossible to align.

The power problem of the chip is due to supplying capability of DC-DC converter. That is, the output current drawn by each output channel of data driver limits the integration of DC-DC converter. The output current of data driver directly influences the luminance of the OELD. So several hundreds of μA for each output channel is required for reasonable luminance. For example, total output current drawn by data driver is below 50mA for 128×80, monochrome PMOELDs and is above 100mA for 128×RGB×160, color PMOELDs. DC-DC converter in battery-operated system boosts low voltage supply, i.e. 3.3V, to high voltage supply, i.e. 16V. In this case, the efficiency of the conventional DC-DC converter with PWM control can't be over 90%, which limits the maximum current drawn from the DC-DC converter. Usually the maximum supplying current drawn from the conventional DC-DC converter can't

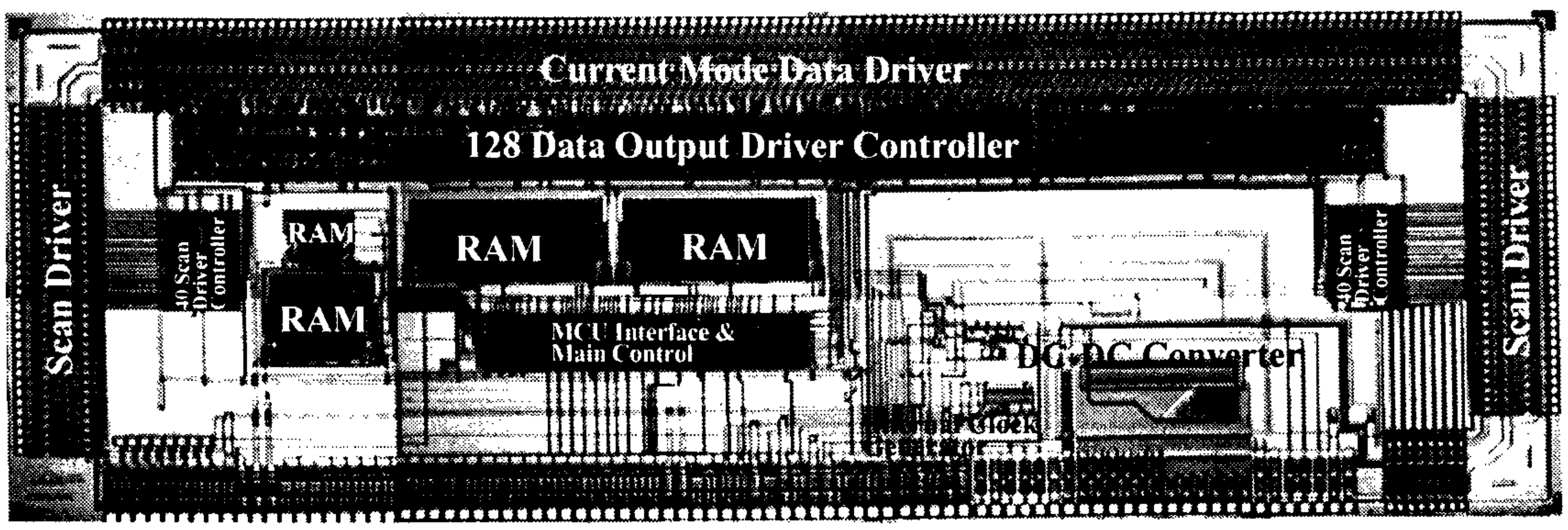


Figure 5. Chip micrograph of driving circuits of 128×80 resolution, monochrome PMOELDs for cellular phone application [7].

exceeds 100mA at 10V~16V voltage output. So in color PMOELDS for terminal application, driving circuits cannot be integrated with a DC-DC converter. To overcome this problem, a new architecture of DC-DC converter should be proposed and/or emission efficiency of OELD should be increased.

Another bottleneck of the system integration is related to driving scheme of the PMOELDs. If the size and resolution of the PMOELDs grow larger, the capacitance of data line in the panel becomes larger and the allowable charging time becomes shorter, as fore-mentioned. In 128×RGB×160, color PMOELDs case, the number of total driving chips is four. There are two data driver LSIs, one scan driver LSI and one controller. In order to charge the data line fully, we normally use the dual bank driving scheme, which use the two data driver LSIs at the upper and lower side of OELD panel. It increases the system cost. Therefore we have to use novel driving scheme that can drive the data line by using only one data driver LSI and also reduce the power consumption caused by charging and discharging the data lines. So, in this cellular phone application, we have to develop the two chip solutions. One is the combination of scan driver and controller and the other is data driver with novel driving scheme.

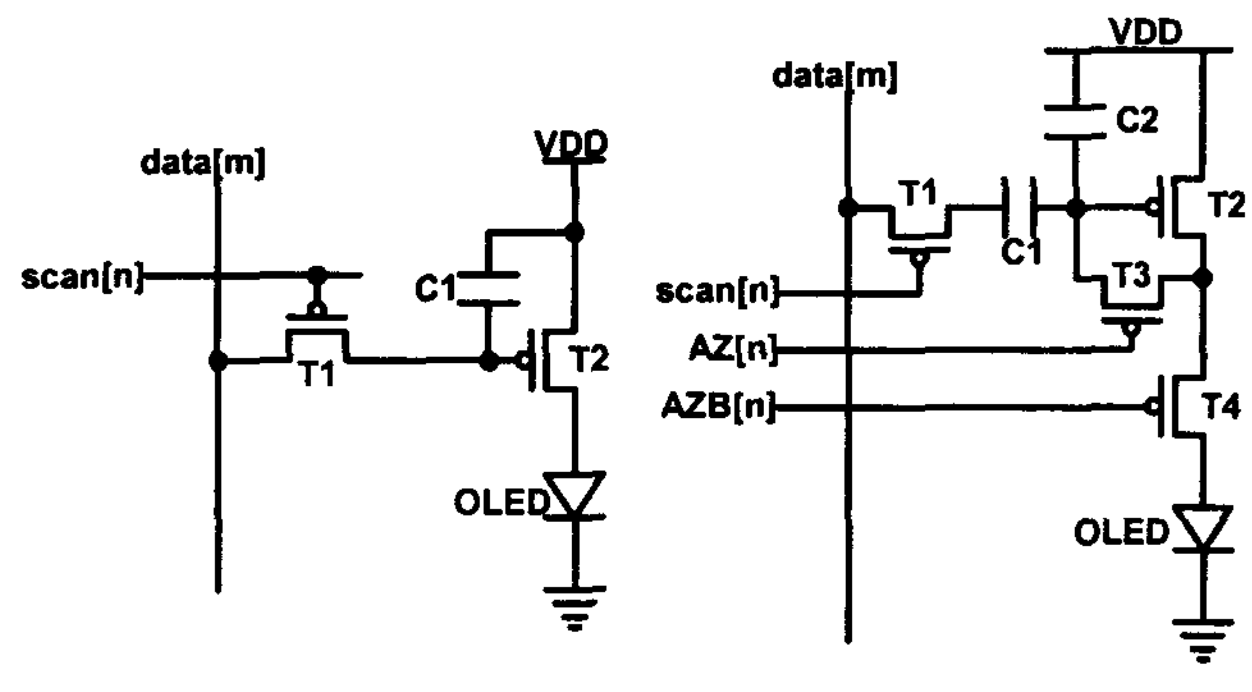
3. AM-OELDs

3.1. Pixel Structures and Driving Methods of AM-OELDs

The conventional pixel structure of AM-OELD is shown in figure 6 (a). This structure consists of two TFTs and one capacitor. T1 is a pixel switch TFT which samples data voltage, T2 is a driving TFT which draws the constant current to organic light-diode (OLED). Although this structure is simple, non-uniformity of gray-scale due to the mobility and threshold voltage variation of driving TFTs is a critical issue.

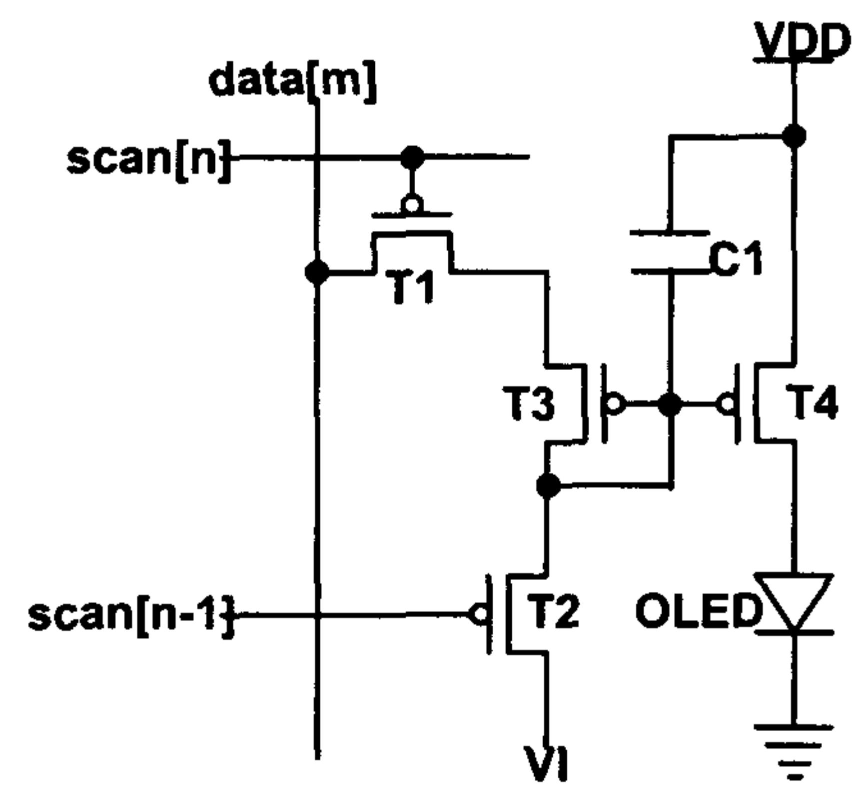
To solve the issue, there were several suggestions such as time-ratio gray-scale control (TRG) methods and the voltage programmable pixel structures, which and compensate the threshold voltage variation and the current programmable pixel structures, which can calibrate both mobility and threshold voltage variation.

The time-ratio gray-scale control methods are reported by Semiconductor Energy Laboratory Co.[8, 9]. In these methods, one frame is divided into sub-

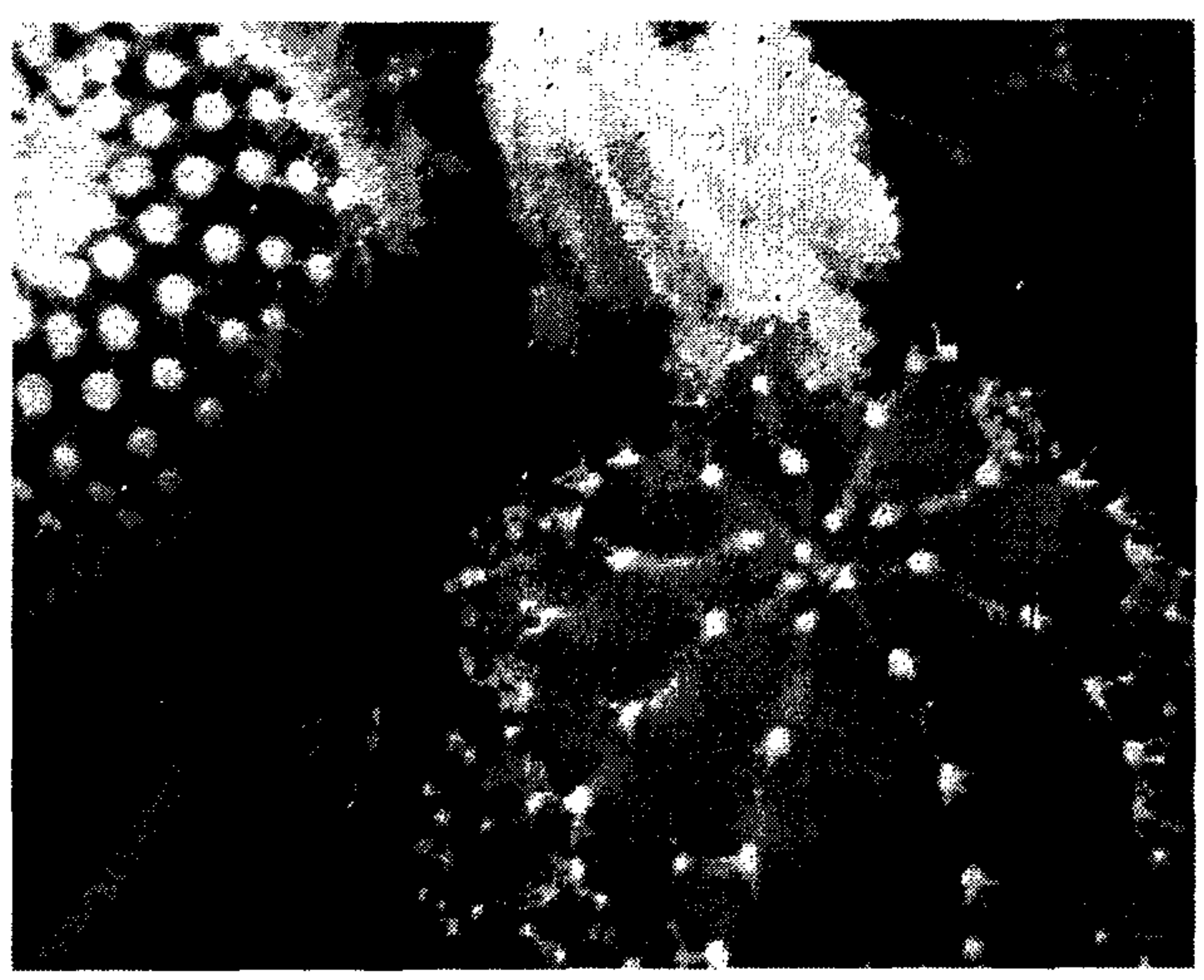


(a) (b)

Figure 6. Pixel structure with voltage driving; (a) conventional 2-TR structure and (b) voltage programmable pixel structure [10].



(a)



(b)

Figure 7. (a) Proposed pixel structure and (b) displayed image of the fabricated 3.5-inch AMOELD panel [11].

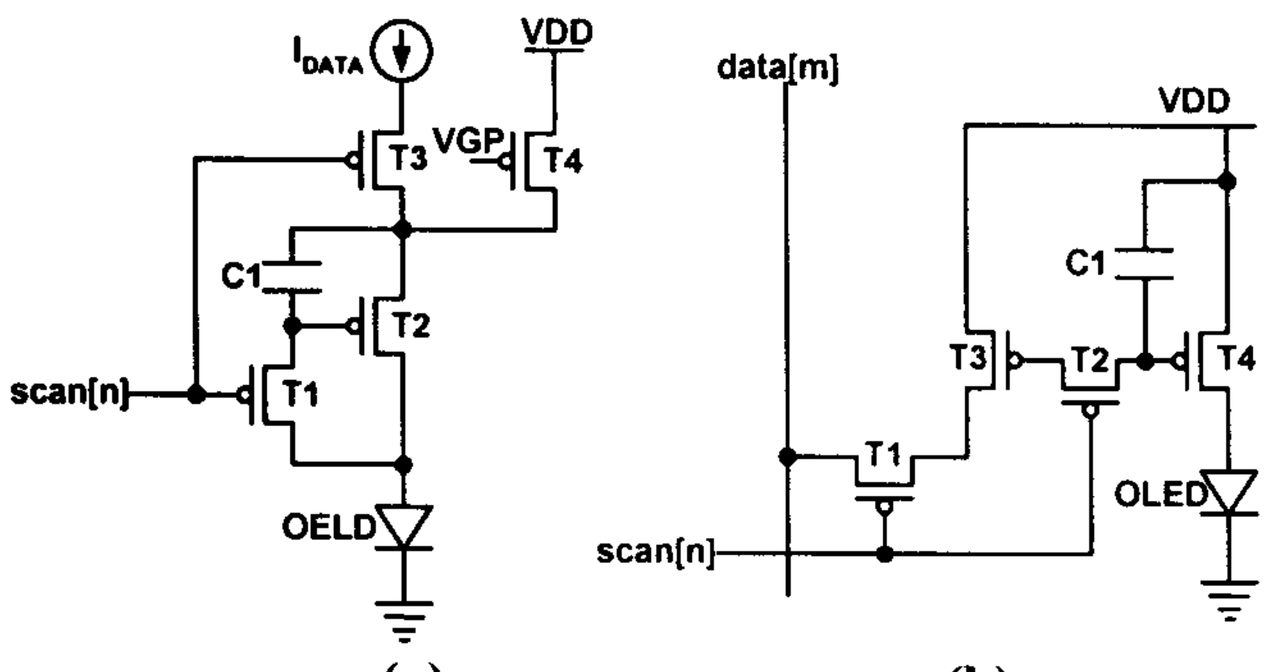


Figure 8. Current programmable pixel structure; (a) direct current programmable type and (b) current mirror type.

frames. For example in 6-bit gray scale, 1 frame consists of 6 sub-frames. One sub-frame period is divided into an addressing period and a lighting period. And brightness is controlled by adjusting the duration of light-on states. Therefore these methods can lessen the gray-scale degradation caused by the process variation of driving TFTs, with simple pixel structure. But these methods require frame memories which contain the data for sub-frame that would increase the cost and the power consumption of the driving system. And also its system clock frequency have to increase drastically since the system clock frequency is proportional to the number of sub-frames power of 2.

The voltage programmable pixel structure which compensates the threshold voltage variation of the driving TFT, is reported by Sarnoff Co. [10], as shown in figure 6 (b). The procedure of threshold voltage compensation is; first, using AZ/AZB control signals, threshold voltage of driving TFT, T2 is stored in C2. Then data is applied and there happens capacitive coupling through C1, so modulated data can compensate the threshold voltage variation of driving TFT, T2. But the pixel structure requires four TFTs, two capacitors and three control signal lines. These three independent control signals make the interconnection to each pixel and peripheral drivers rather complex.

And also we proposed a new voltage programmable pixel structure [11]. This pixel structure consists of four TFTs, one capacitor and one control signal line so that relatively high aperture ratio about 33.8% can be obtained and simplify the peripheral drivers. In figure 7 (a), T1 is pixel switch TFT and T4 is driving TFT of OELD. Additional diode connected T3 is used for detection of the threshold voltage of the driving TFT, T4. And T2 is used for initializing the stored voltage at the capacitor. The operation of this circuit is; during initializing period, previous select line (Select[n-1]) is selected and the storage capacitor, C1 is discharged by initial voltage (VI). Then during programming period, select line (Select[n]) is selected and data voltage is applied. Here the threshold voltage variation of driving TFT, T2 is compensated by diode connected TFT, T3. If the threshold voltage of T3 and T4 are same, each threshold voltage is canceled out. So it is possible to control OELD current independent of the threshold voltage of driving TFTs. Displayed image of the fabricated 3.5 inch QVGA AM-OELD panel with proposed pixel structure is shown in figure 7 (b). Measured non-uniformity of luminance of this panel is about 13%.

And there are two kinds to implement the current programmable pixel structures. One is using the current mirror types reported by LG.Philips-LCD shown in figure 8 (b) and Sony etc. [12, 13]. And the other is programming the driving current directly, which was reported by Sarnoff shown in figure 8 (a) [12]. As shown in figure 8 (a), driving TFT, T2 samples the programming current during a line time and supplies the programmed constant current to OLED for a frame time. Here, because the programming current should be same with driving current, the charging problem same as mentioned section 2.1 can be caused. In figure 8 (b), T3 samples the programming current and T4 supplies the OLED current. In current mirror type pixel structure, the charging problem can be solved using M:1 mirror(i.e. M > 1) [13], that is, the programming current is larger than the driving current, but the threshold and mobility mismatch of nearby two mirror TFTs and low aperture ratio are still drawbacks.

3.2 Issues of Driving Circuitry of AM-OELDs

The voltage programmable pixel structure can be driven using conventional LCD data driver LSIs. But because the transmittance to voltage curve of LC(Liquid Crystal) and luminance to voltage curve of OEL material are different, it is difficult to adjust the gamma-correction.

To drive the current programmable pixel structures, the current data driver using current DAC has to be developed. If the current DAC is used for every channel in data driver, the chip area, power consumption and output current uniformity can be the problems. To solve the problems, Sony suggested an integrated data current driver circuitry, which sample and hold the data current. But the integrated sample and hold circuits is made by poly-Si TFT so that the process variation of poly-Si TFT can cause the deterioration of the display uniformity [13].

Therefore, to solve above problems, a new driving circuit and driving method for current programmable pixel structure is needed.

4. The Proper Applications of OELDs

OELD has strong points of its fast response time, wide viewing angle and thin shape by comparison with LCD(Liquid Crystal Display) which is a current dominant flat panel display. However, there are three major weakness such as power consumption, life time of organic electro-luminescent material and display uniformity of OELD panel. In those of weakness, power consumption is critical characteristics to select the proper applications of OELDs.

Figure 9 shows the comparison between the power consumption of the commercialized color TFT-LCD and estimated power consumption of the color AM-OELD with three different size and resolution. The estimated power consumption of OELD consider the aperture ratio of the pixel, emission efficiency of organic electro-luminescent material. In the 2-inch, 120×160 resolution that is applicable to display unit of portable battery-operated electronic device, power consumption is linearly proportional to the operation time. Therefore both manufacturer and customer of the portable electronic device want to use LCD for its lower power consumption. And also in case of the 12.1-inch, XGA resolution, power consumption of OELD is higher than that of LCD. However in over 17-inch, SXGA resolution, the difference of power consumption between OELD and LCD becomes negligible. Moreover, OELD has merits such as higher moving picture quality and high contrast. Therefore it is expected to have possibility of high quality large size TV applications.

5. Conclusions

In this paper we have reviewed the conventional driving methods and proposed pre-charging scheme and issues of driving circuitry and system for PM-OELDs and the pixel structures and issues of two driving scheme, voltage driving and current driving for AM-OELDs. And also we discussed the proper applications of OELDs with its characteristics. As the results, it is expected to obtain much advantages for large size TV application for their attractive characteristics such as wide viewing angle, high quality moving pictures and comparable power consumption to that of LCD etc.

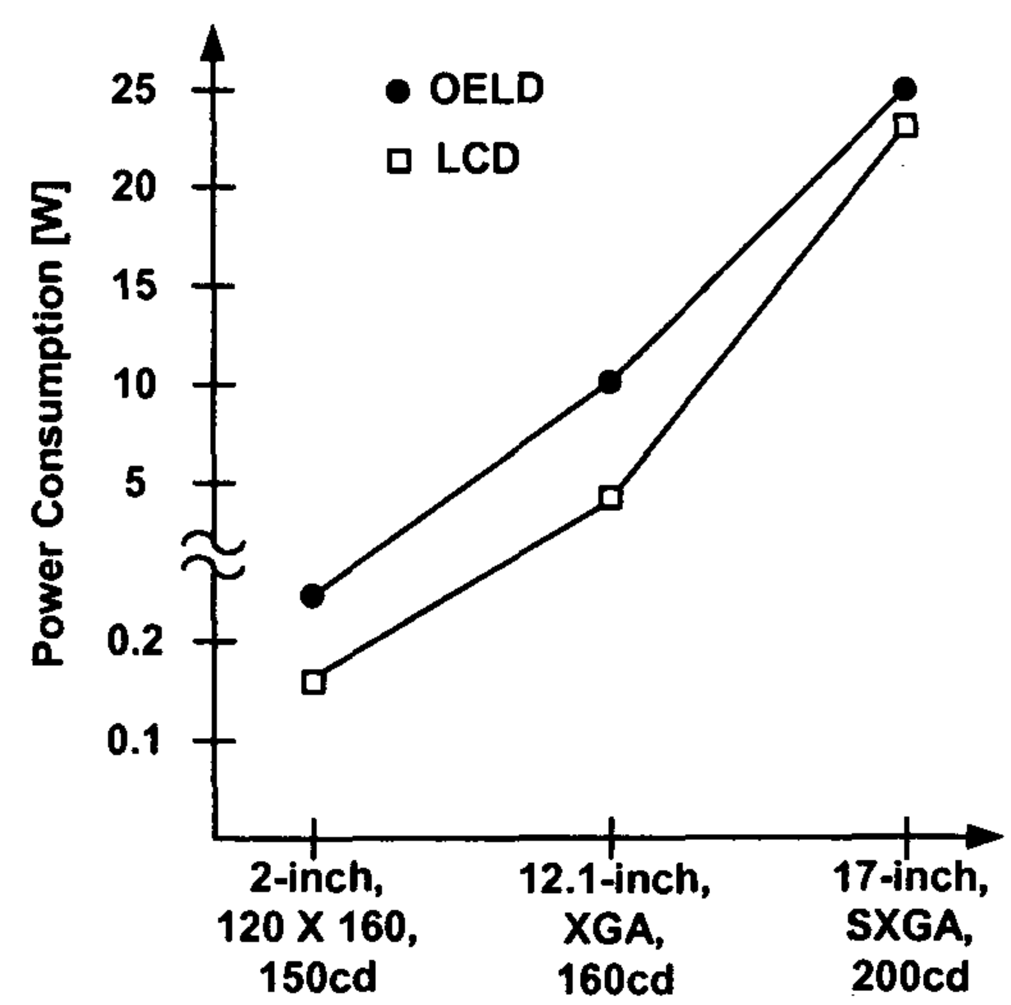


Figure 9. Power consumption comparison between LCD and OELD with various size and resolution.

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