Advanced Multi-Field-Driving Method
for Low Power TFT-LCDs

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Abstract An advanced multi-field-driving method that reduces not only the dynamic power consumption, but also the static power consumption of LCD driving circuits has been developed. The applicability of this method was confirmed by using a 9.5" VGA TFT-LCD. Total driving circuit power consumption was reduced to less than half that of a conventional 60 Hz driving method for all displayed images. In addition, the displayed images obtained were sufficient for practical use and had no visible image degradation, such as flicker and crosstalk.

1. Introduction
Progress in low-power TFT-LCD technologies has enabled the realization of portable notebook-type personal computers. These technologies have mainly focused on backlighting system or pixel structure for high transmittance efficiency\(^{(1)}\). Novel pixel structures technologies, such as an integrated black matrix on TFT-LCD\(^{(2)}\), a shield-electrode structure\(^{(3)}\), and a completely self-aligned TFT\(^{(4)}\), made it possible to enlarge aperture-ratio from 40% to 60%. The power consumption of backlighting system has been reduced to 67% theoretically by these technologies. On the other hand, a driving system which enables LCDs to perform as high-definition, full-color displays is demanded, because many window images including still images and moving images are displayed at the same time. The frequency of a driving circuit for moving images is higher than that for still images in order to operate video signals. Therefore the power consumption of driving circuits is approaching that of backlighting system. In addition, the reduction of driving circuit power consumption is more effective for reflective-type LCDs because driving circuit power consumption accounts for a large percentage of total module power consumption. It is said that a technology to reduce driving circuit power consumption is needed especially for portable notebook-type personal computer with VGA or SVGA TFT-LCDs.

Low-voltage driver ICs have been developed as a method to reduce the power consumption of driving circuit\(^{(5)-(7)}\). However, these methods are not yet satisfactory and further low-power consumption methods are required. We have reported a novel driving method, called the multi-field-driving (MFD) method, in which the power consumption was reduced by decreasing the driving frequency.
This paper presents an advanced MFD method which further reduces the total power consumption of a driving circuit, compared to the conventional MFD method. We also evaluated image quality and confirmed the applicability of this technology by applying it to a 9.5" VGA TFT-LCD.

2. Analysis of power consumption

2.1 General analysis

The total power consumption (TPC) of driving circuits is the sum of the static power consumption (SPC) and the dynamic power consumption (DPC). SPC mainly consists of the bias current of the gray scale voltage source which generates the gray scale voltages and consumes power continuously. DPC is proportional to the image signal frequency and the system clock frequency. For example, a high image signal frequency means a low correlation between signals of pixels, such as a checkered pattern. On the other hand, a low image signal frequency means a high correlation between signals of pixels, such as a raster image. We analyzed TPC in more detail and TPC was divided into 5 components as shown in figure 1.

(1) Control circuit

Power consumption of control circuit consists of 2 components.

\[ P_{\text{clk-cc}} = C_{\text{clk-cc}} \times F_{\text{clk-cc}} \times V^2 \]  

(2) Data driver

Power consumption of data driver consists of 2 components.

\[ P_{\text{clk-dd}} = C_{\text{clk-dd}} \times F_{\text{clk-dd}} \times V^2 \]  

(3) Panel

Power consumption of LCD panel depends on the number of horizontal pixels (Nh).

\[ P_{\text{sig-panel}} = C_{\text{sig-panel}} \times F_p \times V^2 \times Nh \]  

(4) Scan driver

Power consumption of scan driver was shown as follows.

\[ P_{\text{clk-ad}} = C_{\text{clk-ad}} \times F_{\text{clk-ad}} \times V^2 \]  

(5) Gray scale voltage source

Power consumption of gray scale voltage source was the static power consumption.

\[ P_{\text{gs}} = \frac{V^2}{R_{gs}} \]  

C and F indicates an intrinsic capacitor and a driving frequency respectively as shown in figure 1. The sum of \( P_{\text{clk-cc}}, P_{\text{clk-dd}} \) and \( P_{\text{clk-ad}} \) consumed by clock is indicated as \( \text{DPC}_{\text{clk}} \), and the sum of \( P_{\text{sig-cc}}, P_{\text{sig-dd}} \) and \( P_{\text{sig-panel}} \) consumed by image signal is indicated as \( \text{DPC}_{\text{sig}} \). In short, TPC is expressed as Eq. (8).

\[ \text{TPC} = (P_{\text{clk-cc}} + P_{\text{clk-dd}} + P_{\text{clk-ad}}) + (P_{\text{sig-cc}} + P_{\text{sig-dd}} + P_{\text{sig-panel}}) \]
Measuring various kinds of LCD, we found the following three results.

1. The maximum of DPC (DPC\textsubscript{max}) is about 3 times larger than the minimum of DPC (DPC\textsubscript{min}).
2. DPC\textsubscript{min} is nearly equal to DPC\textsubscript{clk}.
3. SPC is one third of DPC\textsubscript{max}.

Therefore the ratio of DPC\textsubscript{clk}, DPC\textsubscript{sig} and SPC is expressed as follows.

\[
\text{DPC\textsubscript{sig}} : \text{DPC\textsubscript{clk}} : \text{SPC} = 2 : 1 : 1
\] (9)

### 2.2 Conventional multi-field-driving method

Figure 2 shows the principle of MFD and the flicker compensation mechanism using MFD. In the MFD method, one frame is divided into several interlaced sub-field images \((2N+1)\), and only one \((2N+1)\) th of the scanning lines is driven in each sub-field. The phase of flicker at the scanning lines differs from the phase of flicker at the other lines, so sub-field flicker of the scanning lines is compensated by the flicker of adjacent lines. As a result, the average intensity of the flicker was reduced to one third and the compensated flicker frequency was increased to three times compared to that with the conventional method as shown figure 2.

The conventional MFD method achieves a lower driving frequency operation of TFT-LCD, which reduces the DPC component. In figure 1 which shows 9.5" VGA TFT-LCD driving circuit block diagram for power analysis, a hatching area and a dot marked area indicate DPC\textsubscript{clk} and DPC\textsubscript{sig} respectively. Dynamic power is consumed in digital integrated circuits, and therefore the image and the clock signals were converted by the conventional MFD in the control circuit. Figure 3 shows a driving circuit diagram and figure 4 shows the image and the clock signal waves for the driving circuit. Interface circuit for MFD (I/F MFD) convert image signal and clock into the control circuit. Figure 4 indicates that outputs of image signal and clock from the control circuit are turned off for nonselected-line period.

In the conventional MFD method, DPC was reduced to one \((2N+1)\) th of the conventional 60 Hz driving method. Therefore TPC with the conventional MFD was expressed as follows.

\[
\text{TPC}_{MF} = \text{DPC} / (2N+1) + \text{SPC}
\] (10)

Though in the case of DPC\textsubscript{max}, TPC can be reduced to half, in the case of DPC\textsubscript{min}, TPC can be reduced to only 67% compared to that with the conventional 60 Hz driving method, because of Eq. (8) ~ (10) (N
Therefore, we found that reduction of SPC was important to improve the performance of the MFD method further.

3. Advanced multi-field-driving method

Gray scale voltage source which is analog integrated circuit and consumes static power is working continuously in the conventional MFD. The advanced MFD (A-MFD) method, however, includes a reduction in the SPC component in addition to the conventional MFD method. By adding new switching circuits, as shown in figure 5, the power of the gray scale voltage source (unmarked area) in figure 1 is further reduced. In the A-MFD method, the switching circuits of the power supply are turned off for the nonselected-line period. The sequence of the switching circuits was composed so that no image degradation was caused. As a result, the total power consumption \( TPC_{MF} \) can be written as follows:

\[
TPC_{A-MF} = \frac{TPC}{2N+1} \quad (11)
\]

This equation means that \( TPC_{A-MF} \) is inversely proportional to the number of sub-fields.

4. Experimental results

4.1 Power consumption

The A-MFD method was applied to a 9.5” VGA TFT-LCD. Figure 6 shows the typical power consumption as a function of the sub-field number \((2N + 1)\) when the displayed image was a typical window image shown in figure 10 in which DPC is nearly minimum. TPC was reduced to 49 %, which was less than 20 % compared with the conventional MFD method \((N=1)\). Figure 7 corresponds to the image of a checkered pattern in which DPC is maximum. In this case, TPC was reduced to 40 % compared with that of the conventional 60 Hz driving method. Table 1 shows the power consumption ratio of DPC and SPC at DPCmax for the A-MFD method. This indicates that SPC was not actually always inversely proportional to the sub-field number because there was some power loss in the swit-
ching circuit of the power supply. Further reduction of SPC can be accomplished by optimizing the switching circuit.

4.2 Contrast

The V-T curve in the MFD method was slightly shifted to higher voltage at about 50% transmittance, as shown in figure 8. Defining brightness shift as

$$ Brightness\ shift = \frac{(B_{MFD} - B_{60})}{B_{60}} \times 100 \quad (12) $$

where $B_{MFD}$ = Brightness with the MFD

$B_{60}$ = Brightness with the 60 Hz driving

It was about 4.7% and it wasn't a problem for practical use. It suggests that the brightness shift was caused by the TFT off-leakage current, depending on the nonselected-line period. However, this current was not so much as to affect the display properties of the panel, such as the contrast ratio.

4.3 Crosstalk

The crosstalk ratio for the MFD method ($N=1$) and the conventional 60 Hz driving method are shown in Table 2. Here, the crosstalk ratio is defined as Eq. (13).

$$ Crosstalk\ ratio = \frac{B_w - B_r}{B_r} \times 100 \quad (13) $$

where $B_r$ = Brightness (V=3.2V)

$B_w$ = Brightness with a window

$B_r$ = Brightness without a window

The signal voltage within a window area was 5 V, which displays a black window. Assuming that the crosstalk ratio is proportional to the sub-field numbers, the crosstalk ratio is 3 times larger than the conventional 60 Hz driving method. The crosstalk ratio for the MFD method ($N=1$), however, was less than the expected value. The result was due to the mechanism of TFT off-leakage current. Figure 9 shows the signal-line voltage waveform and voltage waveforms of pixels located above and below the black window. The signal-line voltage is inverted for each sub-field by the column inversion method. The voltage polarity at the pixel above the window was the same as the polarity of the signal-line for two thirds of the holding time. On the other hand, the voltage polarity at the pixel below the window was the same as the polarity of the signal-line for one third of the holding time. Therefore, the voltage change of the pixel above the window was smaller than that below the window, and both were less than 3 times that of the conventional 60 Hz driving method.
Even in the case of the MFD method, the cross-
talk was less than 1%, and therefore invisible.

4.4 Image evaluation

Figure 10 shows displayed images for each
method. There is no image degradation with the A-
MFD method.

Moreover, we confirmed that the sub-field flicker
was compensated perfectly, and no visible flicker
was caused by the A-MFD method. Now we con-
sider a line crawling which is caused by a line
flicker. A line flicker which depends on TFT off-
leakage current caused a brightness difference
between a selected-line and a nonselected-line.
Whether the line crawling is visible or not depends
on spatio-temporal frequency response of human
vision. When the A-MFD is applied to 9.5" VGA
TFT-LCD, a viewing distance is assumed to be
11.4" which is equal to the twice height of LCD
panel. The spatial frequency \( f_{sp} \) and the speed of
a line crawling (\( v \)) are 5.7 cpd (cycle per degree)
and 1.75°/s (degree per second) as Eq. (14) and Eq.
(15) respectively (\( N=1 \)).

\[
f_{sp} = \frac{2HP_e \tan 1'}{HN} \tag{14}
\]

\[
H = \text{Height of LCD panel}
\]

\[
P_e = \text{Number of vertical pixels}
\]

\[
v = \frac{\tan \left( \frac{0.5H}{2H} \right)}{P_e \times (1/60)} \tag{15}
\]

The spatio-temporal frequency contrast sensitivity
of human vision has been investigated by H. Sakata
et. al. A contrast sensitivity at spatial frequency
of 5.7 cpd was about -32 dB in its investigation and
the experimental result of the line flicker in our LCD
panel was less than that. Therefore no visible line
crawling occurred.

These results indicate that the displayed image is
sufficient for still images.
On the other hand, when moving images are displayed, an image degradation like image-lag occurs. We can resolve this problem by decreasing the sub-field number (or increasing driving frequency) in accordance with a moving quantity of image signal. When many window images including still images and moving images are displayed at the same time on a larger and higher resolution LCD, the sub-field number is changeable partially. A-MFD method is, however, useful for low power consumption, because still images are displayed generally more frequently than moving images.

5. Conclusion

An Advanced-MFD method has been developed to reduce the power consumption of a TFT-LCD. A applicability of the new method was confirmed by applying it to a 9.5" VGA TFT-LCD. The total power consumption was reduced to less than half for all displayed images because the static power consumption, as well as the dynamic power consumption, was reduced by adding new switching circuits.

The performances of the displayed images were acceptable for practical use, as determined by the V-T curve, contrast ratio, and crosstalk ratio.

This method improves the operation time of a battery-driven PC. Moreover, the reduction of power consumption will be even greater for larger and higher-resolution LCDs than conventional LCDs.

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(References)


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