Review : Power Saving Techniques for Display of Electronic Gadgets

Mr. Ravindra R. Latthe
Department of E & TC,
STES's SKNCOE, Vadgaon (BK),
Pune, India

Dr. A. D. Kumbhar
Department of E & TC,
STES's SKNCOE, Vadgaon (BK),
Pune, India.

***Abstract*—Mobile phones of 3rd generation are dominating the market of cellular communication system. But power consumption is a critical concern for battery driven mobile devices. Due to numerous functions and applications in smart phone, they need more power. Battery which is main power supplier for such devices has limited capacity. In this paper we focus on the latest noticeable low power techniques based on display system. We categories these techniques into four groups Low power technique with: 1) backlight dimming 2) dynamic voltage scaling 3)software based low power techniques 4) hardware based low power techniques. We elaborate each category and review each technique in brief. Between all the methods efficient image compensation technique in light emitting diode (LED) backlit display system achieved the largest power saving ratio by up to 40% of total system power with small distortion level.**

Keywords—Mobile devices, backlight structures, backlight dimming, image compensation, display system.

I. INTRODUCTION

The latest mobile phones have been provided with better hardware and are becoming more powerful gradually and steadily. Music and video players, in built satellite navigation system, high speed internet connection, and high resolution cameras are just few examples of what mobile phones can cover. But the energy limitation is related to the operational time, which is one of the most important issues for customers buying a new mobile handset or any such battery operated electronic gadgets. Therefore energy consumption in smart phones is very important for mobile manufacturers, as the mobile device itself is more energy demanding and at the same time the customer asks for longer operational times. Currently, most smart phones are powered by lithium-ion batteries and at the moment the typical way to create more powerful batteries is to make them bigger. But this does not match well with the evolution of mobile which have less room for battery. This paper focuses on recent noticeable low power display techniques based on Liquid Crystal Display (LCD) systems, specially associated with an LED backlight unit as its light source. Fig. 1 shows a typical architecture of the LCD controller and panel. The LCD controller receives the video data and determines a proper grayscale i.e., transmittance [1] for each pixel based on its pixel value. The focus of the technological development is to design a device with a higher

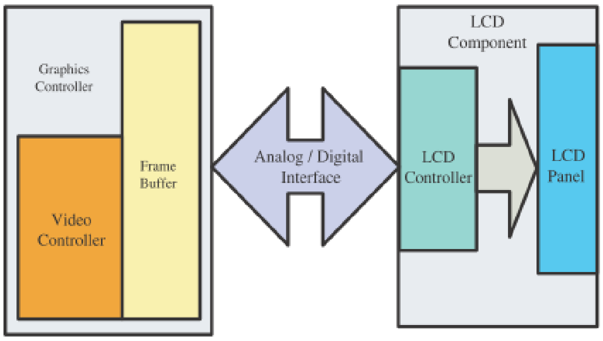

Fig. 1. LCD system architecture.

quality in terms of better brightness uniformity, less unevenness, lower colour washout and higher colour saturation. Additional features like lighter weight and lower cost are also desired. The important requirement is rapid switching or rapid scanning with wide brightness and contrast adjustment ranges is also essential parameter. Finally smart functions like auto adjusting the brightness and finer local dimming and more smart functions are the benefits of technology. An ideal BLU can almost be realized with LEDs and LEDs are able to meet the requirements of any application.

For portable devices, power saving can be achieved by using: 1) power-aware IC circuit design of controllers; 2) low-power digital/analog interface between the graphics controller and the LCD controller; and 3) efficient control of the light source of liquid crystal display. The first approach gives importance to increasing the efficiency of dc/ac power inverters, working with low and safe voltage and frequency, ultimately limiting the power consumption in the idle mode, and shutting off unused digital/analog circuits. The second approach uses encoding schemes that minimize the switching traffic of the electrical bus during transmission to reduce power consumption. The third approach focuses on controlling the backlight of LCD to lower the power consumption of display system. Since the light source of LCD accounts for a significant percentage of the total power consumption, reducing the intensity of backlight can effectively extend the battery life. This paper is organized as follows. In Section II, we give an overview of LCD system, especially the one using LED as a backlight source. From Section III to VI, we combine together different low power display techniques into various categories and look into detailed techniques belonging to each category: Backlight dimming, dynamic voltage scaling, software based and hardware based approaches. Finally section VII concludes our work and presents future works.

II. BACKGROUND

A. LCD system

LCD is widely used in various display applications such as cellular phones, PC monitors, televisions (TVs), and multimedia products. An LCD backlight module usually includes backlight source, a light-diffusion plate, a reflector, a brightness-enhancement film (BEF) and a light-guide plate (LGP). The latest LCD module use LED as a backlight source instead of conventional cold cathode fluorescent lamps (CCFLs). LED backlight source provides longer battery life, higher luminance and less light attenuation than CCFL. Also they have simple driver circuitry which works with low and safe voltages.

The shift from CCFL to LED in BLUs is an important issue in the development of LCD systems. A noticeable observation is that the use of LED has significant influences in developing new low-power techniques. Starting from the original behavior, which can produce enough luminance with lower power consumption than a CCFL does, LED is becoming a good alternative to CCFL. This is the reason why we focus on the techniques employing LED-backlit LCDs and we also try to adapt CCFL-based approaches to LED-backlit LCDs. There are four LED BLU structures for LCDs differentiated by the position of the light source and by their structural characteristics; edge-type, direct-type, hollow-type and folded-mixing-light guide plate (LGP)-type. Schematic diagrams of each type are shown in figures.

B. LED BLU Structures:

1. Edge-type structure: An edge-type structure has at least one LED light bar located at an edge of the LGP of the LCD device, as shown in Fig. 2. Through the light guide light is transmitted by means of total internal reflection. The edge type structure is made up of LEDs, an LGP with a micro-structure or dots, diffusers and a back reflector. In order to meet the requirement for low power consumption, a brightness enhancement film (BEF) or dual brightness enhancement film (DBEF) needs to be used in the BLU.

2. Direct-type structure: As shown in Fig. 3 a direct-type structure has LEDs positioned below the LCD panel. A typical direct-type backlight device consists of; several LEDs placed above a metal core printed circuit board (MCPCB), a diffusion plate, a reflector and some optical function films. This structure is suitable for local dimming. This structure has also

This structure is easier for local dimming. This structure also has the advantages of a large backlight, high brightness and light weight.

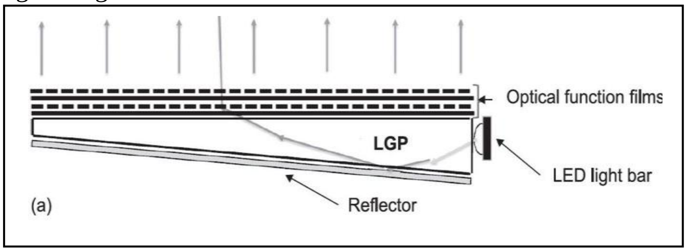

Fig. 2. Edge type backlight structure for LCDs.

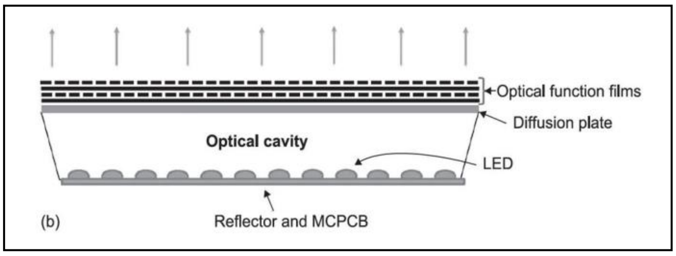

Fig. 3. Direct type backlight structure for LCDs.

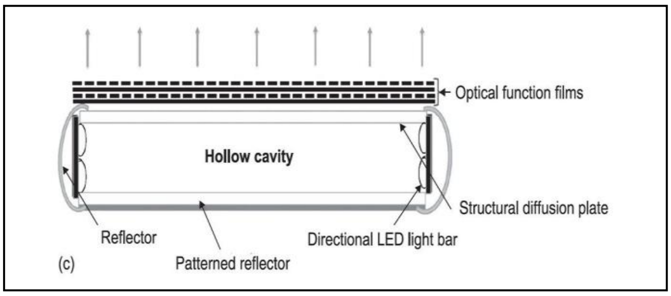

Fig. 4. Hollow type backlight structure for LCDs.

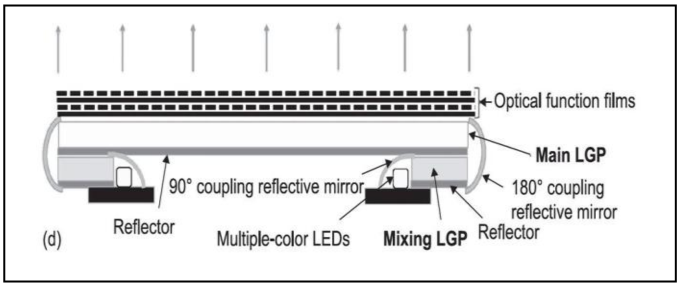

Fig. 5. Folded mixing LPG type backlight structure for LCDs.

the advantages of a large backlight, high brightness and light weight. The direct type BLU is thicker than an edge type BLU. Reason for this is to maintain a uniform brightness, a light-mixed cavity is necessary between the light sources and the diffusion plate.

3. Hollow-type structure: As shown in Fig. 4 hollow-type structures have two directional LED light bars located at the two edges of the hollow cavity of the BLU. A hollow-type structure BLU is composed of at least two LED light bars, a

hollow cavity, a patterned reflector placed at the bottom of the cavity, a structural diffusion plate and some optical films. The serious drawback of this type is poor brightness uniformity.

4. Folded-mixing-LGP-type structure: As shown in Fig. 5 a folded-mixing-LGP-type structure has at least one folded mixing colour LGP and several multiple-colour LEDs, typically RGB LEDs, positioned below the main LGP. Its main components comprise; high- power multiple-colour LEDs, a folded mixing LGP, a main LGP placed behind the LCD panel, a 90° coupling reflective mirror and a 180° coupling reflective mirror.

The edge-type backlights are mostly used for small size LCDs panel including cell phones, notebooks and monitors. This type is of compact shape and consumes lower power, so it is suitable for notebook PCs and personal digital assistant (PDA) products. And direct type backlights are usually used for LCD TVs i.e. for large screen. Now we will look into detail classification [2] of low power techniques for LED backlight unit based LCD systems. Obviously, the methods discussed below are using edge type backlight structures for LCDs. Table I shows the classification of low power techniques.

There are many techniques available for low-power display systems, and we need to choose those that are most appropriate. We elaborate each technique one by one.

TABLE I. CLASSIFICATION OF LOW POWER TECHNIQUES FOR LED BACKLIGHT UNIT BASED LCD SYSTEMS

Sr. No.	***Category – Low power techniques with***	***Techniques***
1	Backlight dimming	a. Content based backlight dimming b. Efficient Image compensation c. Segmentation based clipped error control algorithm d. Histogram equalization for backlight scaling e. Backlight local dimming f. Backlight global dimming e. Partitioned light guide backlight LCD for mobile devices
2	Dynamic voltage scaling	a. Variable duty ratio refresh b. Advanced DVS
3	Software based	a. Dynamic color depth control b. Liquid crystal orientation shift
4	Hardware based	a. Use of LED instead of CCFL b. Use of advanced light guide

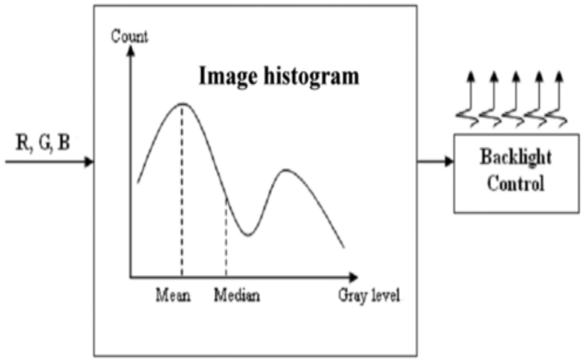

Fig. 6. **Block diagram for NBDA.**

III. LOW POWER TECHNIQUES WITH BACKLIGHT DIMMING

This is the most popular group among low power techniques, which uses BLU dimming as a main approach. We will survey all the techniques related to CCFL as well as LED. This is because the techniques which still use CCFL as their backlight source can also be applied in an LED backlit BLU. Aim of all the techniques is to find the best method in dimming the BLU with minimum distraction for users.

A. Content based backlight dimming

In [3] the authors introduced new backlight dimming algorithm (NBDA) that selects the backlight current level. This algorithm gets a display image from Host and then sends it to NBDA to analyze the image histogram. First, RGB is transformed to YC_bC_r, and Y (luminance) is regarded as gray-level. By using a statistical analysis of the image histogram, NBDA calculates the mean value and median value of the displayed image. A high mean value indicates that the backlight will be controlled to select a low current to save the system power based on different backlight current levels. Fig. 6 shows the NBDA block diagram to control backlight by histogram analysis. The image histogram represents the distribution of the gray level. The definitions of the mean and the median of the image histogram are as follows,

$$Mean = \sum_{Y(i,j)=min}^{Y(i,j)=max} \mathrm{X(i,j)} * \mathrm{p(x)}$$

$$= \sum_{Y(i,j)=min}^{Y(i,j)=max} \frac{\mathrm{X(i,j)} * \mathrm{count}}{Total\_count} \quad (1)$$

Median=the middle value of X (i, j) after sorting (2)

Level=floor (Mean (i, j)/0x20) (3)

where X(i, j) is the luminance value from the RGB to YC_bC_r color space, and p(x) is the probability density function. According to (1) and (2), the static values of the histogram can be estimated. Otherwise, a different backlights current level according to (3) can be selected. If the absolute difference between the mean value and the median value is greater than 60, the NBDA will not change the LCD backlight current because of the image fidelity issue, and original settings are kept. The NBDA adopts the content-based histogram analysis to select the corresponding TFT LCD backlight current and decreases power consumption.

B. Efficient image compensation

This method represents backlight power reduction scheme using an efficient image compensation algorithm that scales discrete cosine transforms (DCT) coefficients of image in the compressed domain [4]. To compensate the luminance and contrast degraded by backlight dimming, image compensation techniques can be used. In these techniques, the intensity of each pixel is scaled using a given mapping function. However, such pixel based enhancement methods increase the computational load in the system. To reduce the computational burden, the best way is to process only dominant DCT coefficients of images using a mapping function in the DCT domain. Intensity mapping functions are widely used to enhance the image due to simplicity. The monotonically increasing mapping function used in this method is given as,

$$f(x) = \frac{log(k \cdot x + 1)}{log(k + 1)} \tag{4}$$

where x represents the input pixel intensity and k is a scaling factor by which the slopes of the curves can be controlled. The average luminance of the image can be increased twice as that of the original image by using the mapping function in equation (4). And to display enhanced image will require less backlight levels, which will reduce current consumption by 20 to 40%. Fig. 7 shows the basic block diagram of image compensation in DCT domain. This is the low complexity image compensation algorithm performed in the DCT domain. The main advantage of this algorithm is that does not require significant memory occupancy and computational load for the image brightness and chrominance enhancement.

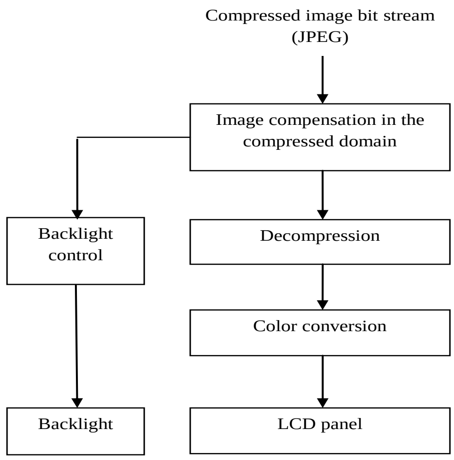

Fig. 7. Block diagram for image compensation in DCT domain.

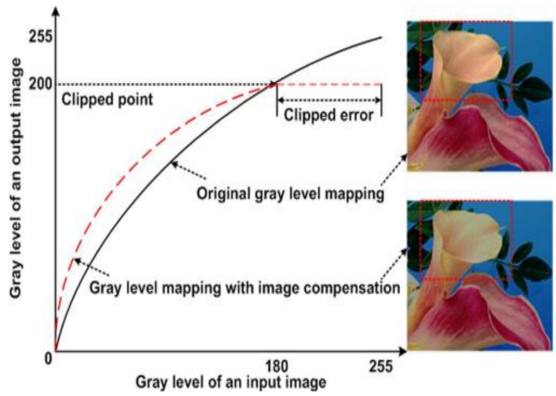

Fig. 8. Example of gray level mapping between input and output images.

C. Segmentation based clipped error control algorithm

The authors of [5] presents a backlight dimming method that applies segmentation based clipped error control to LCDs. This algorithm considers the exact local distribution of image using image segmentation, which enhances the image quality compared with existing methods. This algorithm is used for global backlight dimming. In global backlight dimming, first analyze the characteristics of an input image and determine the dimming rate, which is a ratio of the decreased brightness to the original brightness. Then second step is backlight modulation, which reduces the backlight brightness via the dimming rate. And final step is image compensation.

This compensates for the dimmed brightness by increasing a gray level of pixels in an input image. If the dimmed backlight brightness exceeds the compensation limit, the pixels in the dimmed backlight cannot be compensated by increasing gray levels, so the gray levels of these pixels are saturated. This error is known as a clipped error and the gray level of a starting point of the clipped error is known as a clipped point. Fig. 1 shows an example of gray level mapping between input and output images when image compensation is applied. Although a gray level is increased by over 180 in the input image, an output gray level cannot exceed 200, which is a clipped point. For the gray levels from 180 to 255, the clipped error occurs in the flower petals as shown in Fig. 8.

To reduce the power consumption aggressively, the clipped error is allowed in a range that humans cannot recognize. However, the image quality is reduced if this error is too large. Thus, the selection of the clipped point is very important.

The segmentation based clipped error control algorithm enhance the image quality by analyzing the exact local distribution of the clipped pixels in the images. But this method slightly increased the power consumption compared with the conventional method.

D. Histogram equalization for backlight scaling

HEBS works on an image histogram and a transformation function which transform an original histogram into a new uniformly distributed one with a specified minimum dynamic range [6]. Dynamic range is a ratio or range between the brightest and the darkest available pixel values in an image. A new histogram should be different minimally from the original one of a backlight-scaled image. After they get the histogram transformation function, they define a dynamic linear function to transform an original image to a desired resultant one.

Practically, since it is difficult to measure a distortion degree, this technique needed a number of experiments to get a mapping table of dynamic ranges to distortion ratios from some benchmark images. The results are then used to specify the minimum dynamic range in a new uniform distribution histogram.

E. Backlight local dimming

Backlight dimming is classified as local backlight dimming and global backlight dimming. Local backlight dimming controls the brightness and darkness in certain areas of a screen by turning on or off groups of light sources depending on the image characteristics. Fig. 9 shows the image regions and LED blocks in local dimming system. Local dimming method has more flexible control to the backlight and can get much more static contrast improvement than global dimming method. However, there are several critical problems for local dimming which should be dealt with modestly. These problems may lead to serious visual artifacts of image quality if local dimming algorithm is not designed skillfully.

The local backlight has three major drawbacks. First critical problem is how to decide the luminous intensity of each LED block according to the image contents. The second latent problem of local dimming is the nonuniformity artifact. Another annoying artifact may caused by local dimming is screen flicker. Also these local backlight dimming techniques did not focus on power saving. Thus, they did not report the power saving achievement. Hence this method is very less preferred for use in backlight dimming.

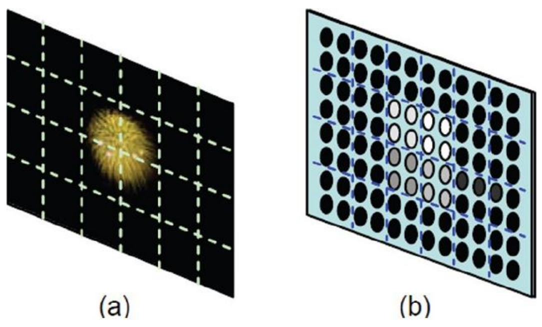

Fig. 9. Backlight local dimming system (a) Image blocks (b) LED regions.

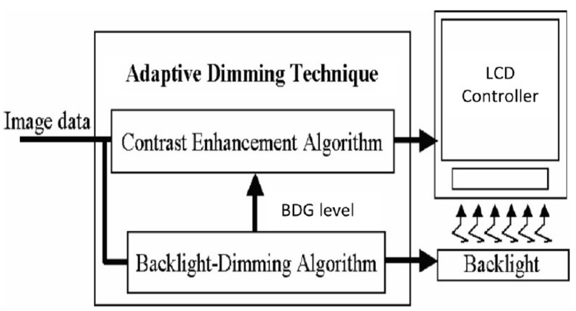

Fig. 10. Backlight global dimming system

F. Backlight global dimming

Global backlight dimming controls the brightness and darkness in all areas of a screen by turning on or off all light sources depending on the image characteristics. It can be used with all types of backlights; hence, it is more popular than local backlight dimming, although its performance is inferior. Thus, the authors of [7] tried to make improvement by executing an effective backlight-dimming algorithm and a contrast enhancement algorithm simultaneously. This technique defines a value from an image histogram, where 75% of pixel values in a histogram are below it. Then, it uses a value called backlight dimming gray (BDG) level to calculate a proper backlight dimming ratio in order to reduce the backlight luminance. For the contrast enhancement, first it transforms the signals in an RGB space into an YC_bC_r space. The algorithm is simply illustrated simply as seen in Fig. 10.

Then, it uses a BDG value to set the movement of YC_bC_r curve's turning point, and it obtains a contrast factor to be used in modifying original RGB values into compensated RGB values. The authors claimed that this technique does not cause image distortion in terms of hue and saturation, and it can achieve power reductions by up to 50% of the total system power.

G. Partition light guide backlight LCD for mobile devices

There are two major LED backlight structures in LCD, which are divided into two categories: direct type and edge type. The edge type backlight LCD is much thinner than direct type backlight LCD, hence only edge type backlight LCD can be applied into mobile devices. Structure of edge type partitioned light guide LCD is shown in Fig. 11.

The author of [8] presented a novel backlight structure called Partitioned Light Guide (PLG). In the PLG backlight module, a conventional light guide module is partitioned into several blocks of the light guide plane. Each PLG is coupled with an individually controlled LED light source. Reflection coatings at the vertical edges of each PLG plane are used to avoid light leakage. PLG convert the point light source at the edge into surface emission in each backlight block and restrict light in a local area.

Therefore, luminance of backlight blocks can be controlled independently. PLG backlight has better local uniformity of light luminance distribution and higher luminance in each backlight block. The high uniformity of light luminance distribution in PLG can greatly reduce the complexity of the dimming algorithm. Furthermore, the more the PLG blocks are divided, the higher power efficiency the system achieves.

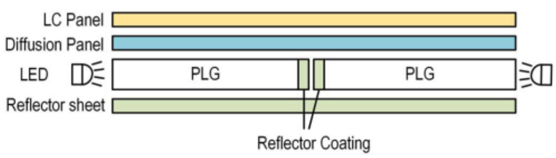

Fig. 11. Cross section of edge type partitioned light guide LCD.

This PLG LCD prototype showed that local backlight dimming can perform effectively in the edge type LCD and greatly improve the power saving ratio when compared with the global dimming. The major disadvantages of PLG are higher manufacturing cost than conventional light guides and a slight leakage at the boundary.

IV. LOW POWER TECHNIQUES WITH DYNAMIC VOLTAGE SCALING

In a Complementary Metal-oxide-semiconductor (CMOS) based circuit, the dynamic power is known to be proportional to the square of an applied voltage. This is the main approach in the second group that is utilizing dynamic voltage scaling.

Thus, considerable power saving may be obtained if the voltage goes low. But, this will accompany a certain degree of a propagation delay. Of course, the voltage scaling here does not occur in a backlight driver, but in other significant components like CPU or LCD, which can affect the overall power consumption.

A. Variable duty referesh ratio

The authors of [9] created a detailed energy model of a handheld embedded system with a high-quality LCD, as shown in Fig. 12. The part surrounded by a dashed line shows a display system. This model is based on the measured power consumption of each component in the device and can show display system is a big power consumer in an embedded system. They introduced a technique called variable duty+-ratio refresh, to reduce LCD power consumption. To make flicker invisible to viewer's eyes, they set LCD refresh rate to a minimum level. This modification is implemented using a Display Timing (DTMG) signal, and it can achieve power saving by up to 8% with an optimum display result. This technique was considered ineffective because it requires additional hardware, and it cannot gain more significant power savings since it does not allow a complete shutdown of a display controller.

B. Advanced dynamic voltage scaling

Another technique involving DVS in the method can be seen in. The authors focus on reducing the system power. From their observations, the authors found that the CPU's frequency and voltage determine the LCD's frequency and voltage and there are some special points where LCD's frequency does not increase even when CPU's frequency increases. As shown in Fig. 13(b). Thus they try to keep the CPU frequency and voltage as low as they can in order to reduce the LCD voltage and to keep the display quality from degradation at those special points. The display quality is preserved by adjusting the brightness and contrast. This technique is designed to eliminate the unnecessary independent control of the LCD's frequency as shown in Fig. 13(b), referred as a conventional DVS method.

At the special points where the LCD's frequency does not increase even when CPU's frequency increases, the pixel clock of LCD, which can determine the display quality, is reduced. Consequently, to ensure the display quality, they enhanced the brightness of backlight and contrast of LCD at

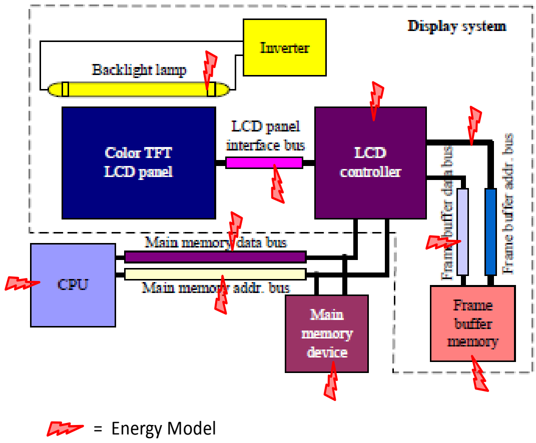

Fig. 12. **Block diagram of mobile embedded system with LCD.**

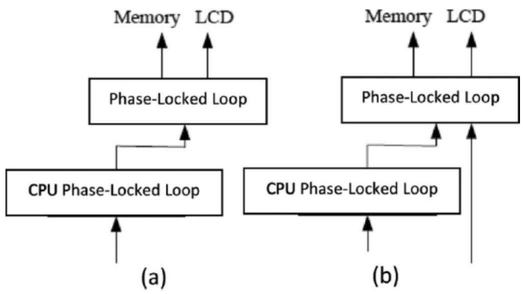

Fig. 13. LCD frequency architecture (a) Interlocking (b) Independent.

those points. The authors reported saving power by up to 41% in comparison with the conventional DVS method. But they did not explain further about the method for adjusting the brightness and contrast.

V. LOW POWER TECHNIQUES: SOFTWARE BASED

The third group employs software-based methods as their main approach including modification of pixel organization in a frame buffer.

A. Dynamic color depth control

According to [9], most modern commercial color display systems allow us to modify a color depth. For example, the authors of [9] reduced the color depth from 16 to 8 bits. Under a normal condition, this reduction does not contribute a significant power saving. Thus, they tried to change this reduction into a power saving by modifying the pixel organization in a frame buffer. This modification divides bytes into Least Significant Device (LSD) and Most Significant Device (MSD), as shown in Fig.14. When they reduced the color depth to 8 bits, they just shut down the LSD part. In this case, they powered down an SDRAM chip, leading to power reduction. The power saving was around 8% of the total system power, which is not large enough according to [9].

Further, we should consider that this technique is only applicable to high-end displays with a large number of colors.

B. Liquid crystal orientation shift

The previous work creatively proposed a power saving method which utilizes the benefit of low energy consumption in displaying an LCD screen's default colors. They encouraged applications to shift the color of inactive or insignificant screen regions toward white in a normally white LCD. As we know, in a normally white LCD, the color of white will naturally appear when no voltage is applied.

This method relies on the capability of their OS driver to dynamically specify a set of rectangular areas which will be shifted toward white. It claimed to achieve total power reduction by up to 15.3% when displaying a full white image in comparison with a full black one.

VI. LOW POWER TECHNIQUES: HARDWARE BASED

The last group depends on hardware components to reduce power consumption. In recent years, the advanced technologies have invented many enhanced hardware display components with more powerful capabilities than the standard one. However, the use of these components still leaves many issues to investigate in the aspect of power.

A. Use of Light Emitting Diode instead of Cold Cathode Fluroscent Lamp

The shift from CCFL to LED in BLUs is an important aspect in the development of LCD systems. A noticeable observation is that the use of LED has significant influences in developing new low-power techniques. Starting from the original behavior, which can produce enough luminance with lower power consumption than a CCFL does, LED is becoming a good alternative to CCFL. This is the reason why we focus on the techniques employing LED-backlit LCDs and we also try to adapt CCFL based approaches to LED to backlit LCDs.

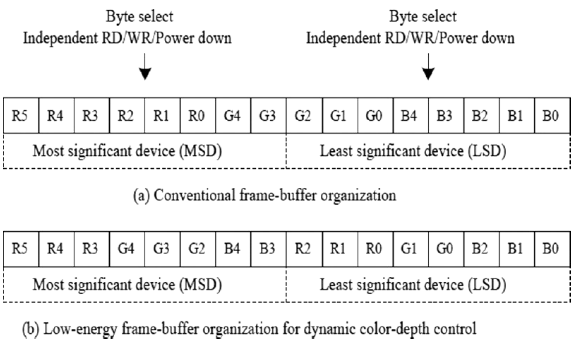

Fig. 14. Low energy frame buffer structure for dynamic color depth control.

In addition, a CCFL also needs a high-voltage power supply to work and thus requires an inverter to transform a direct current (DC) from batteries to an alternating current (AC). Due to these facts, the industries have begun to use an LED as a substitution for a CCFL. An LED offers some advantages over a CCFL, such as a smaller factor size, lower production cost, lower power consumption, wider color gamut, and is mercury-free. These merits should be considered by researchers when they want to make researches on a low-power LCD display system. They also stated that the development of surface-emitting LEDs increased the efficiency of traditional edge-emitting LEDs through a "flip-chip" bonding technique. A surface-emitting LED does not employ a reflector to emit the light in the forward direction (since a traditional LED needs to be packaged in forwarding the light like a surface emitter), but it extracts the light more efficiently after the removal of the electrode's contact pad, which resides on the top surface of a traditional LED and application of surface roughening [Figure 15]. This treatment can increase the light extraction level by up to 50%.

The author is also concerned about LED limitations. Since LEDs are not identical in their electro-optical characteristics, the manufacturers usually do a binning process to solve this problem. Also, there is a need for an LED drive circuit to employ temperature sensors and color sensors to help itself in stabilizing the color gamut of an LED and preventing its life and brightness degradation.

Also, there is a need for an LED drive circuit to employ temperature sensors and color sensors to help itself in stabilizing the color gamut of an LED and preventing its life and brightness degradation. These should be faced because an LED can suffer changes in spectrum shifts, chromaticity, brightness, luminous efficiency, and degrades its life in a junction temperature of 60°C.

B. Use of advanced light guide

A backlight module typically consists of a lightening device within a light guide, whose purpose is to distribute the light equally to the next layer. Now we all know that LCD needs a light source, and most LCD use a backlight as their light source. This light source is placed on the top and/or on the bottom of the light guide.

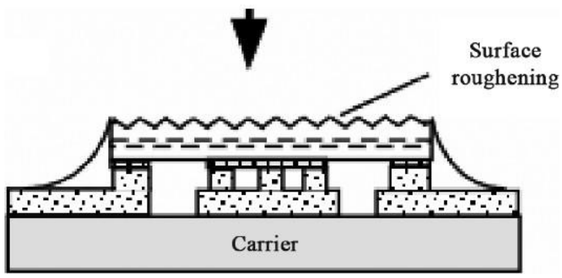

Fig. 15. Surface emitting LED based on flip flop technique with surface

C. Use of advanced light guide

A backlight module typically consists of a lightening device within a light guide, whose purpose is to distribute the light equally to the next layer. Now we all know that LCD needs a light source, and most LCD use a backlight as their light source. This light source is placed on the top and/or on the bottom of the light guide.

The authors of [10] suggested some enhancement in a light guide such as a thinner form factor, the use of one micro lens film which is sufficient enough. And to achieve adequate lighting for mobile display, small amount of white LEDs are enough. The light guide can be used in two ways. One is edge lit backlight lighting scheme, in which LEDs are placed on the edge of a light guide and another is direct lit backlight scheme where LEDs are placed on the bottom of a light guide. To reduce the cost of an edge lit backlight lighting scheme, a double grooved prism is used, which is substitute for a prism sheet and a pattern reflector. The edge lit backlight schemes fulfill 200-300 nits luminance requirements and direct lit backlight scheme fulfill 300-500 nits luminance requirement efficiently.

VII. CONCLUSION

In this paper we reviewed recent noticeable low power techniques based on display system. Edge type backlight structure is more suitable for mobile display because of its compact shape and low power consumption. We found that these techniques can be categorized into four groups mainly as backlight dimming, DVS, software based and hardware based approaches. Among the all other methods, the largest power saving ratio comes from the efficient image compensation technique in LED backlight display system, gain up to 40%. We also come to know that backlight dimming approach is likely to be significant power saver. From the DVS group, the advanced DVS method achieves second largest power saving ratio up to 25%. From the software based group, a power saving ratio of up to 15% comes from the liquid crystal orientation shift method. From hardware based group, they did not explicitly show their considerable power savings ratio. On the other hand implementation cost of hardware based techniques is considerable. So we should try to develop low power technique and renew the old ones to fit the advanced hardware technologies such as incoming LED BLU-based LCD system.

REFERENCES

[1] Pei-Shan Tsai, Chia-Kai Liang, Student Member, IEEE, Tai-Hsiang Huang, and Homer H. Chen, Fellow, IEEE. “Image Enhancement for Backlight-Scaled TFT-LCD Displays”, IEEE Transactions On Circuits And Systems For Video Technology, Vol. 19, No. 4, April 2009

[2] Aldhino Anggorosesar, Young-Jin Kim, & Kee Wook Rim, “A Survey of Low power Techniques for LCD systems with Light Emitting Diode Backlight Units” IETEJournals, March 2012.

[3] Yeong-Kang Lai, Yu-Fan Lai, and Peng-Yu Chen, “Content Based LCD Backlight Power Reduction with Image Contrast Enhancement using Histogram Analysis.” Journal of Display Technology, Vol.7 No.10. October 2011 IEEE.

[4] Tae-Hyun Kim, Kang-Sun Choi, Member, IEEE, and Sung-Jea Ko, Senior Member,IEEE “Backlight Power Reduction Using Efficient Image Compensation for Mobile Devices” IEEE Transactions on Consumer Electronics, Vol. 56, No. 3, August 2010. pp 1972-1978.

[5] Suk-Ju Kang, Member, IEEE, and Young Hwan Kim, Member, IEEE. “Segmentation Based Clipped Error Control Algorithm for Global Backlight Dimming” Journal of Display Technology, Vol. 10, No. 7, July 2014.

[6] Ali Iranli, Hanif Fatemi, Massoud Pedram “HEBS: Histogram Equalization for Backlight Scaling” Proceedings of the conference on Design, automation and Test in Europe – Volume 1 PP 346-351, March 2005

[7] Chih-Chang Lai and Ching-Chih Tsai. “Backlight Power Reduction and Image Contrast Enhancement Using Adaptive Dimming for Global Backlight Application.” IEEE Transaction on Consumer Electronics, Vol. 50, No. 2 May 2008. PP 669-674.

[8] Yang Li, Member, IEEE, Pei Chu, Jia Liu, and Sidan Du, Member, IEEE. “A Novel Partitioned Light Guide Backlight LCD for Mobile Devices and Local Dimming Method With Nonuniform Backlight Compensation” Journal of Display Technology, Vol. 10, No. 4, April 2014.

[9] I. Choi, H. Shim and N. Chang School of Computer Science & Engineering, Seoul National University, Korea. “Low-Power Color TFT LCD Display for Hand-Held Embedded Systems”. in Proceedings of the 2002 International Symposium on Low Power Electronics and Design, California, pp. 112-7, 2002.

[10] M. Anandan, "LED backlight for LCD," in Proceedings of the 27 th International Display Research Conference, Moscow, pp. 7-10, 2007.