An Approach Towards Greening The Digital Display System

Tarik Reza Toha[1], Alvi Md. Ishmam[2], Md. Hasanul Islam[3], Md. Abdullah Al Maruf [4],
Swarnendu Saikat Nandi[5], Amit Chakraborty[6], Salman Estyak[7],
Md. Abdullah Al Alamin[8], and A. B. M. Alim Al Islam[9]
Department of CSE, Bangladesh University of Engineering and Technology,
Dhaka-1000, Bangladesh
Email: {[1]1205082.trt, [2]1305092.am, [3]1205096.mhih, [4]1205090.maam, [5]1205108.ss, [6]1205086.acd, [7]1105094.mse }@ugrad.cse.buet.ac.bd,
[8]mdabdullahalalaminp@gmail.com, [9]alim_razi@cse.buet.ac.bd

***Abstract*—Signage display, which is used to convey message or information, has evolved from conventional to digital display. Conventional signage which may be hand written or printed papers are being wiped out by digital displays used by industries because of its attractive features of efficient involvement of consumers. However, extensive use of digital signage displays contributes a notable amount of power consumption (about 1000W for a $14inch \times 48inch$ display) of a region. In this literature, we have devised a novel approach for reducing power consumption of digital signage as well as satisfying human visibility by exploiting duty cycle. Our proposed technique is capable of relinquishing a significant amount (about 14.54% in comparison with existing display system) of power consumption occurred by digital display by keeping an eye on expected human vision.**

I. Introduction

Digital displays stand for one of the symbols of modernization of cities. It has numerous usage such as displaying information on electronic equipment and instrumental panels or advertisement on billboard, etc. From multinational big companies to local industries, from large tech giant to local electronic workshop are taking new form advertisement technique through digital signage instead of traditional static form advertisement technique like banner, placard, non-electronic billboard, etc. A study [1] indicates that about 70% of American people who notice a digital video display, among 47% of them can specifically recall them. Therefore, a digital display can bring impression enough to be engaged in it. So, it is a foregone conclusion that, advertisers will choose digital display more than anything else. It is a obvious choice from indoor small bulb to large commercial digital signage, people are using LED driven lighting technology. A study [1] shows that, the market of digital signage is set to grow at 8.94 percent of annual growth rate by 2020.

As the usage of digital display have reached a significant rate, then there arises a question of energy consumption. A digital display is one of the components which have the highest percentage of total energy consumption [2], [3]. The study in [4] concludes that a digital billboard consumes up to 30 times than an American home. According to US Department of Energy, a Light Emitting Diode (LED) glows more brightly than fluorescent, incandescent or halogen bulbs [4]. As a result, LED based displays are dominating over all kind of digital displays. Determination of the power consumption rate of digital billboard depends on different factors like size, resolution(diode density), how many LEDs are in each pixel, the color capabilities of board, the image being displayed, time of operation (day time operation requires more power than night time operation). In addition to,the power consumption of controller and cooling system of the display should be taken into account [4]. For example, a typical $14inch \times 48inch$ LED billboard consumes 162,902 KWh per year [4] which consists of about 10000 diodes. A pixel may consist of more than one LED. If we consider that a pixel consists of just one LED and each LED pixel operates [5] at 5 V and 20 mA current, so it requires $5V \times 20mA = 0.1W$ to operate a pixel. Therefore, if we want to illuminate 10000 pixel simultaneously, it consumes about $10000 \times 0.1W = 1000W$ power. As a result,people of different fields are using LED driven lighting system for its attractive features and these digital displays are contributing a significant amount of the total energy consumption of a territory.

Researchers have shown their interest to get over the challenges faced by power consuming LED based digital lighting system. The challenging task is to reduce the amount power consumption as well as satisfying human visibility. However, no significant attempt have been addressed yet that compromise between power consumption and satisfying human visibility.

As a remedy of this problem, in this literature, we have proposed a novel methodology that leads us to determine a optimal operating point of LED driven digital display by varying duty cycle. This optimal operating point not only reduces the total energy consumption but also makes our display visible enough to the spectators. Our proposed design is simple enough and through rigorous experimentation we have determined the best combination of power consumption and expected visibility which is the primary concern of digital signage.

Based on our work, we make the following set of contributions in this paper:

- Our main focus is to find out the best optimal operating

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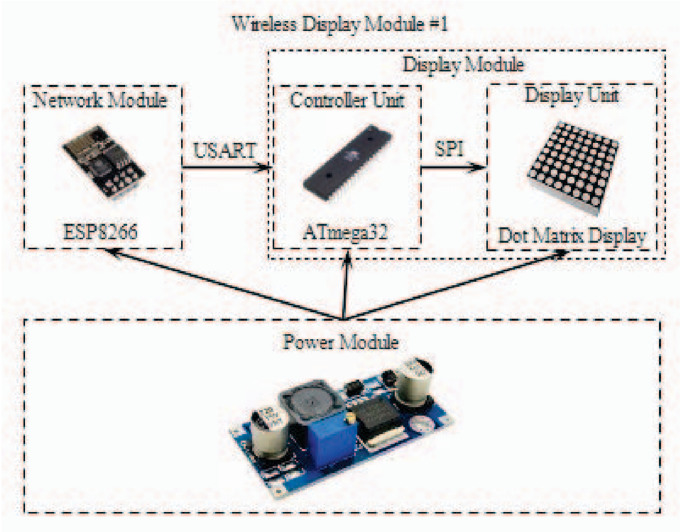

Figure 1: Block Diagram

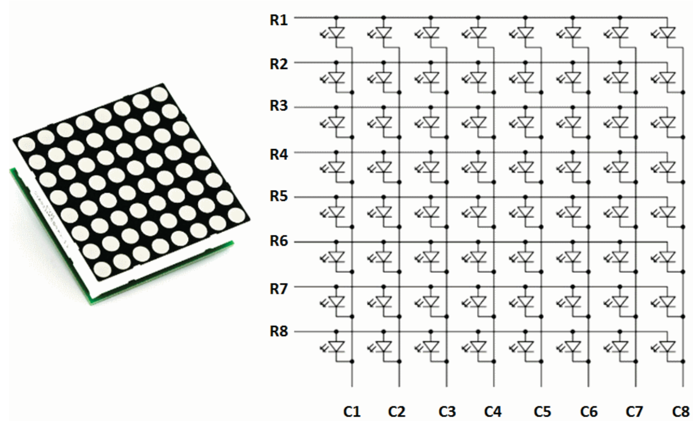

Figure 2: LED (8x8) dot matrix

point of display module without altering any major design issue of existing LED display system. Our proposed optimal point is suitable with respect to power consumption and human visibility and it is achieved by varying duty cycle.

- We have exploited three fundamental parameters of LED lighting system especially LED dot matrix display for high efficiency to achieve our goal and that lead us to gain optimal power consumption.
- We have managed the least power consumption of the controlling unit as well as data feeding component of the digital display which is also responsible for consuming a considerable amount of energy for large displays.

II. Related Work

LED driven digital displays are replacing traditional fluorescent and incandescent bulbs because of its low life expectancy, high energy consumption, high cost and high maintenance. However, due to excessive use of these LED driven displays, the total power consumption of these displays are not tiny amount now rather have become a large amount to be dealt with. In various literature, researchers have shown keen interest about designing new kind of LED driven lighting system. A low voltage DC (LVDC) grid powered LED lighting system was proposed here [9]. About 44.2% energy saving is possible in this proposed system which is a perfect dominance over AC fluorescent system.

Researchers have been trying to find out different ways to reduce the consumption of energy of LED lights by following various dimming methodology of LED lights since light dimmers save energy by reducing the flow of electricity to the bulb and allowing light to operate with lower power outputs [6]. Varying Pulse Width Modulation (PWM) is considered as the best dimming strategy [7], [8] rather than variation in DC current in LED source. However, no optimal point of power consumption is addressed and the impact of power consumption reduction on human visibility is not discussed which is a fundamental issue for large digital display. Luminance distribution and panel refresh rate are used to reduce the flickering of dot matrix display [9]. However, the power consumption rate and expected visibility of dot matrix are not discussed here.

III. System Design

Our system consists of three modules–network module, display module and power module. The display module has just one Wi-Fi component ESP8266 connected with the power module. The display module consists of two units named control unit and display unit. The atmega32 avr microcontroller and LED (8×8) dot matrix are named as control unit and display unit respectively. The power module consists of external power supplying device. The block diagram of our system is shown in Fig.1.

A. Network Module

The network module stands for just data feeding to the display module. Therefore, our digital display can be controlled from any part of the world acting as a remote display. The communication is established through USART (Universal Synchronous/Asynchronous Receiver/Transmitter) with the help of atmega32 avr microcontroller. We are not concerned about how the communication between display module and network module is established because it is out of the scope of this literature.

B. Display Module

The key component of display module is 8×8 bi-color LED dot matrix acting as a display unit. Atmega32 avr microcontroller is used as the controller unit of the display module. Firstly, we need to know the functionality of dot matrix to understand our system architecture.

1) LED dot Matrix (8×8): In a dot matrix display, multiple LEDs are wired together in rows and columns. This is done to minimize the number of pins required to drive them. For example, a 8×8 matrix of LEDs shown in Fig.2 need 64 I/O pins, one for each LED pixel. By wiring all the anodes

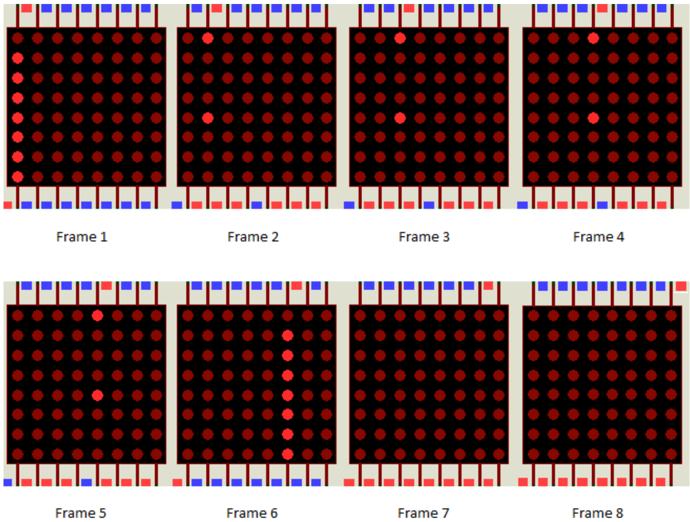

Figure 3: Framing along column

together in rows (R1 through R8), and cathodes in columns (C1 through C8), the required number of I/O pins is reduced to 16. Each LED is addressed by its row and column number. In the Fig.2, if R4 is pulled high and C3 is pulled low, the LED in fourth row and third column will be turned on. Characters can be displayed by fast scanning of either rows or columns.

2) Displaying A Character: A character needs to be fragmented into several frames. The framing should be at such rate so that it can deceive human perception of vision which is approximately 0.1 second. That means we need to turn on one LED after another within 0.1 second. As a result, it seems that all the LED dot are illuminated simultaneously. Fragmentation can be done along the column or along the row. Considering a column anode/row cathode matrix display, to display a character alphabet ‘A’, this character can be fragmented into columns to get frames, as shown in Fig.3. The communication between atmega32 and LED matrix is established through SPI (Serial Peripheral Interface) which is a data feeding technique to the display unit.

3) Registers and IC: We used shift register(74HC595) instead of traditional MUX and dot matrix driver circuit to make our displays more robust and cheap.

C. Power Module

We used external power module and darlington transistor arrays to meet up power hungriness of dot matrices. Shift registers and darlington transistor arrays are used to reduce the power consumption of LED dot matrix.

IV. Proposed Methodology

In this literature, we have selected three fundamental factors i.e duty cycle, frame rate, system frequency to green the digital display i.e LED dot matrix by reducing amount of power consumption.

- Duty Cycle: Duty cycle is the proportion of time during which a component, device or signal is operational. In other words, it is a fraction of time of period of a signal. Duty cycle can be expressed as a ratio or as a percentage. Suppose a disk drive operates for 1 second, then it is shut off for 99 seconds, then is run for 1 second again, and so on. The drive runs for one out of 100 seconds, or 1/100 of the time, and its duty cycle is therefore 1/100, or 1 percent.
- Frame Rate: Frame rate determines how fast LEDs are illuminated. If frame rate is high, the time interval between the illumination of two LEDs, that means frame period is low and vice versa. As discussed earlier, to illuminate a character or pattern, we cannot animate all the corresponding LEDs at once but to animate column by column shown in Fig.3. This animation process must be at a speed that that can deceive human eye. Therefore, in order to avoid flickering, frame rate should be at an expected rate.
- System Frequency: System frequency is the frequency of our atmega32 microcontroller. We examined couple of system frequency to find out least power consumption rate.

Figure 4: Snapshot of our display module

According to the definition of duty cycle, we get the following equation–

$$P_{avg} = P_{peak} \times dutycycle \tag{1}$$

If duty cycle is 100 percent, that means the device is operational fully in its time period and LED matrix will consume maximum power. Equation (1) can lead us to a conclusion that, the more we can reduce the duty cycle, the more we can reduce power consumption. However, in real life digital signage becomes operational for about 24 hours in a day. Therefore, we are pretty much less privileged to reduce duty cycle to a great extent.

While displaying character on LED dot matrix by row wise, we have to select corresponding column of that row in every frame period to illuminate the corresponding pattern of that frame.

Therefore, every frame period requires power to display the frame. Now, we can exploit duty cycle for every frame period. Reducing duty cycle at a considerable rate (say 95 percent duty cycle) does not lessen the brightness of the

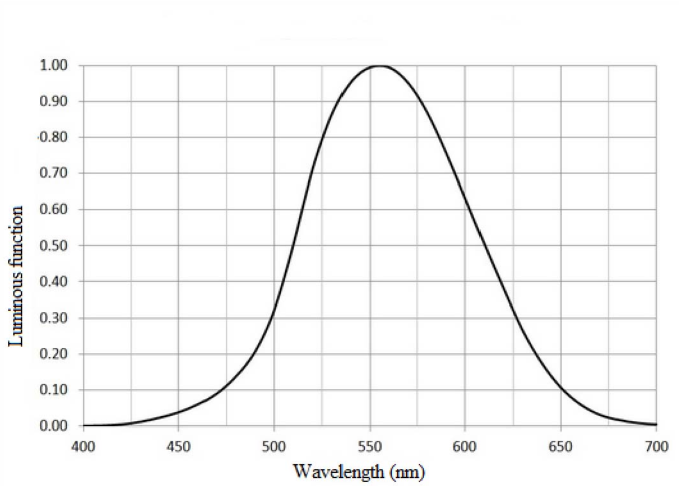

Figure 5: Spectral response of human eye versus wavelength of light

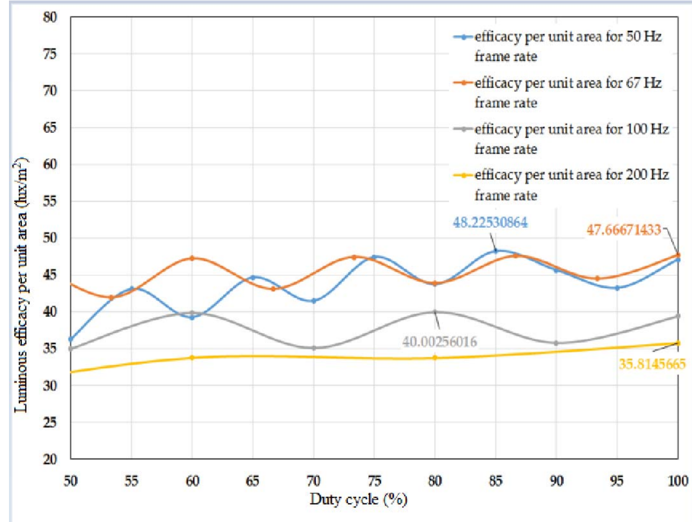

Figure 6: Duty cycle versus luminous efficiency per unit area at 16 MHz system frequency

display significantly but reduces overall power consumption of the matrix for the dimming period.

Additionally, the reduced system frequency can lead to reduced current consumption of LED matrix. Reduced frame time or high frame rate is also required for the reduction of power consumption.

While reducing the power consumption, we should always be concern about luminous efficacy which indicates how well a light source produces visible light. Since all wavelengths of light are not equally visible or equally effective at stimulating human vision due to spectral sensitivity of human eye, we need to be concern about the illuminance of visible light. Luminous efficacy determines how well the emitted radiation is detected by our eye. The response of human eye presented as luminous function which is a function of wavelength and the wavelength of visible light is presented in Fig.5. It is clear to us that, the response of human eye also varies with respect to the wavelength of visible spectrum.

Therefore, we need to find out the best combination of duty cycle, frame period and system frequency so that we can reduce power consumption. However, in the meantime, luminous efficacy per unit area must be at expected rate that is suitable for human vision. In order to pursue our goal, we need to find out luminous efficacy per unit are by varying duty cycle at different frame period and system frequency.

V. Experimentation and Findings

We have investigated the impact of duty cycle change on luminous efficacy in a 2×4 LED dot matrix display. A 2×4 dot matrix is comprised of total 8 LED matrices in a 2×4 (16×32) pixel set up shown in Fig.4. In Fig.4 there are 8 LED matrices arranged in 2 rows and 4 columns and each LED matrix is displaying character 'A'. This display module is controlled by atmega32, whenever we want to change the character or pattern we just need to flush the character or pattern through atmega32 and for character flushing we used Wi-Fi module ESP8266.

After the completion of instrumental setup, we started varying the duty cycle and started measuring luminous efficacy of per unit area of our LED matrix. Illuminance is measured by lux meter and luminous efficacy per unit area is evaluated by the following formula–

$$Efficacy(perunitarea) = \frac{Illuminance}{Powerconsumedbydisplayunit} \tag{2}$$

For example, if illuminance is 7 lux and power consumed by display module is 145.152 mW, luminous efficacy per unit area = $\frac{7lux}{145.152mW} \times 1000$=48.22530864 lux/m^2 which is the maximum luminous efficacy at 50 Hz frame rate shown in Fig.5 according to equation (2).

In our experiment, we have chosen two system frequencies i.e 16 MHz and 8 MHz. For 16 MHz system frequency we have selected 4 frame rate i.e 50 Hz, 67 Hz, 100 Hz, 200 Hz. We found different luminous efficacy by varying duty cycle (from 50% to 100%) at 50 Hz, 67 Hz, 100 Hz, 200 Hz frame rate shown in Fig.5 and at 100 Hz, 200 Hz frame rate shown in Fig.6. For both of the Fig.5 and Fig.6, we have calculated luminous efficacy from 50% duty cycle to 100% duty cycle since operating the display below 50% duty cycle reduces the brightness of the display too much. As a result, the character or pattern written in the display will not be clearly visible or dimly visible.

A. For 16 MHz System Frequency

The maximum luminous efficacies are 48.22530864 lux/m^2, 47.66671433 lux/m^2, 40.00256016 lux/m^2, 35.8145665 lux/m^2 for corresponding 50 Hz, 60 Hz, 100 Hz, 200 Hz frame rate shown in Fig.5. The duty cycles for 50 Hz, 67 Hz, 100 Hz and 200 Hz are 85%, 100%, 80% and 100% respectively. We

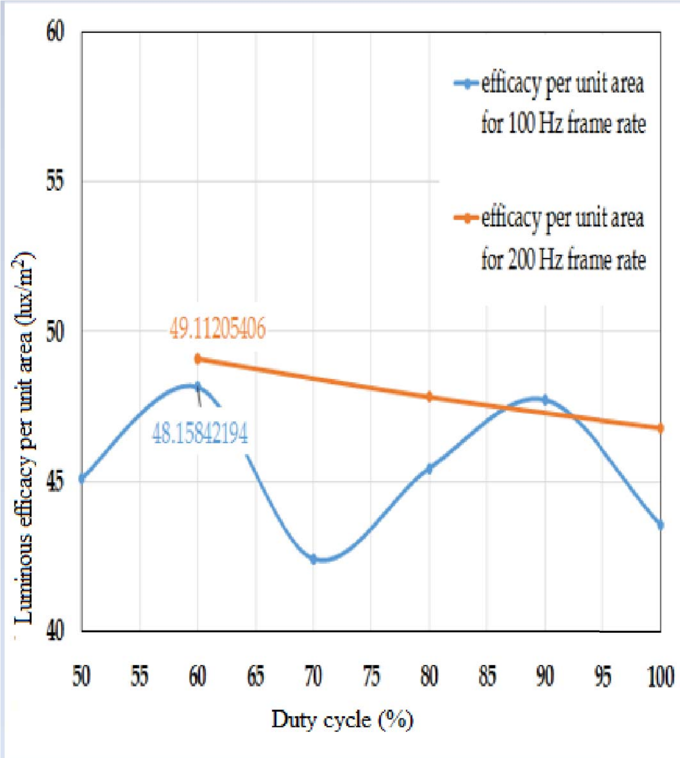

Figure 7: Duty cycle versus luminous efficiency per unit area at 8 MHz system frequency

have gained these luminous efficacies by following equation (2).

B. For 8 MHz System Frequency

The maximum luminous efficacies are 49.11205406 lux/m^2 and 48.15842194 lux/m^2 for frame rate 100 Hz and 200 Hz shown in Fig.6. The duty cycles for 100 Hz and 200 Hz are 60% and 50% respectively. We have gained these luminous efficacies by following equation (2).

VI. Analysis of Experimental Findings

We have found out that with the decrease of duty cycle, frame period and system frequency, illuminance of the display decreases. If we take a large system frequency such as 16 MHz rather than 8 MHz, we can use a wide range of frame rate i.e 50 Hz, 67 Hz, 100 Hz, 200 Hz since the minimum frame rate to avoid flickering is 50 Hz (In Fig.5). Taking frame rate less than 50 Hz cannot deceive human's perception of view (0.1 second) and we can differentiate the flickering of LED matrix.

In case of 8 MHz system frequency shown in Fig.6, the minimum frame rate to avoid flickering is 100 Hz since taking frame rate less than 100 Hz cannot deceive our perception of view. Multiple flickering can come within 0.1 second and we may see a blinking LED matrix rather than continuous illumination if we take frame rate less than 100 Hz.

A. For 16 MHz System Frequency

Power savings rate and brightness of signage display for 8 MHz system frequency are discussed below–

1) Power Savings Rate: When duty cycle is 100%, our measured current is 33.7 mA and measured voltage is 5.04 V. Therefore, power consumed by display unit or by the LED matrices is $33.7mA \times 5.04V = 169.848mW$ which is the maximum amount of consumed power by our LED dot matrix display. Here 5.04 V comes from the power module to operate display unit.

Now, we notice that, our maximum luminous efficacy is 48.22530864 lux/m^2 at 85% duty cycle. The amount of power consumtion is $0.85 \times 169.848mW = 144.3708mW$ (according to equation (1)).

At 85% duty cycle, the measured current is 28.8 mA. Therefore, power consumed by display unit is $28.8mA \times 5.04V = 145.152mW$, which is very close to 144.3708 mW. We know that–

$$powersaving = \frac{maximumpower - obtainedpower}{maximumpower} \times 100\% \tag{3}$$

According to equation(3) we find that–
power saving = $\frac{169.848-145.152}{169.848} \times 100\% = 14.54\%$

2) Brightness Reduction Rate: When duty cycle is 100%, our measured illuminance is 8 lux which is the maximum illuminance. When duty cycle is 85%, illuminance is reduced to 7 lux. We know that–

$$brightnessreduction = \frac{maximum - obtained}{maximum} \times 100\% \tag{4}$$

Therefore, according to equation (4) brightness reduction = $\frac{8-7}{8} \times 100\% = 12.5\%$

B. For 8 MHz System Frequency

Power savings rate and brightness of signage display for 8 MHz system frequency are discussed below–

1) Power Savings Rate: When duty cycle is 100%, our measured current is 31.9 mA and measured voltage is 5.04 V. Therefore, power consumed by display unit or by the LED matrices is $31.9mA \times 5.04V = 160.776mW$ which is the maximum power consumption of our display unit.

Here our maximum luminous efficacy is 49.11205406 lux/m^2 when duty cycle is 60%. Power is consumed $0.6 \times 160.776mW = 96.4656mW$ (according to equation (1)).

At 60% duty cycle, the measured current is 19.5 mA. Therefore, power consumed by display unit is $19.5mA \times 5.04V = 98.28mW$, which is close to 96.465 mW. Therefore, power saving is $\frac{160.776-98.28}{160.776} \times 100\% = 38.87\%$ according to equation (3).

2) Brightness Reduction Rate: When duty cycle is 100%, our measured illuminance is 8 lux which is the maximum. When duty cycle is 60%, our measured illuminance is 5 lux. Therefore, brightness is decreased $\frac{8-5}{8} \times 100\% = 37.5\%$ according to equation (4).

C. Comparison Between 16 MHz and 8 MHz System Frequency

Considering system frequency as 16 MHz and 8 MHz we can get the following key points–

- From Fig.5 and Fig.6 we see that overall maximum luminous efficacy per unit area is gained for 8 MHz and it is 49.11205406 lux/m^2 at 200 Hz frame rate.
- We also find that power savings are 14.54% and 38.87% at maximum luminous efficacy per unit area for 16 MHz and 8 MHz respectively.
- However, in case of 16 MHz brightness is decreased 12.5% while for 8 MHz, brightness is decreased 38.87%. This type of reduced brightness is not excepted for large digital signage or billboard because at daylight, displays will not be clearly visible from long distance. Therefore, we cannot take this as our expected optimal point.
- Considering the visibility issue, our optimal operating point is 85% duty cycle while frame rate is 50 Hz and system frequency is 16 MHz. The brightness is 87.5% where luminous efficacy is 48.22530864 lux/m^2 at these duty cycle, frame rate and system frequency.

VII. Future Work

We have experimented our system on people who have proper eyesight. Our proposed system will gain more credibility if we can analyze the impact of our proposed optimal result on people of different ages of different eyesight. We plan to gain more accuracy by exploring different human eyesight factors such as angle of vision, short eyesight (myopia), long eyesight (hypermetropia), etc. Moreover, it is yet to be addressed that our experimental findings will be worthy of running commercial large multi-color signage display. We have conducted our experiment over LED dot matrix display which is the most popular for its efficiency and widely used as signage display. However, it is yet to be addressed that our proposed method is equally effective in LCD based display.

VIII. Conclusion

In this literature, we have presented a novel approach of power consumption of digital display by exploiting duty cycle, frame period and system frequency. The challenging part of our proposed methodology is not only the reduction of power consumption but also the visibility of the display to be remained at a expected point. For this reason, while reducing power consumption at different frame rate and at different system frequency, we have considered the level of brightness of the display that leads us to find the optimal operating point of the display. Another point is that we have not made any major change in LED lighting system but used three existing parameters that are essential for lightening a display to attain our goal. Besides, these three parameters, there are some contributing factors e.g LED temperature which can make our system more greener. The impact of those parameters along with these existing three parameters is yet to be addressed in our future work. In our presented system, we have experimented the visibility of the display over the people whose eye vision are well enough. Therefore, it is yet to be addressed that our proposed system works as good as on the people who have some eye sight problems or color blind people.

References

[1] http://www.sixteen-nine.net/2016/01/27/18-surprising-statistics-about-digital-signage/ Accessed: Aug. 25, 2017

[2] Carroll, A. and Heiser, G., 2010, June. An Analysis of Power Consumption in a Smartphone. In USENIX annual technical conference (Vol. 14).

[3] Pitt, M.G., Zehner, R.W., Amudson, K.R. and Gates, H., 2002, May. 53.2: Power Consumption of micro-encapsulated Display for Smart Handheld Applications. In SID Symposium Digest of Technical Papers (Vol. 33, No. 1, pp. 1378-1381). Blackwell Publishing Ltd.

[4] Young, Gregory. "Illuminating the Issues Digital Signage and Philadelphia's Green Future." (2010).

[5] https://ledsignsolution.com.au/led-signs-basics/led-sign-power-consumption-electriciy-cost Accessed: Aug. 25, 2017

[6] :https://www.saveonenergy.com/energy-saving-tips/dimmer-switch/ Accessed: Aug. 25, 2017

[7] Rodrigues, W.A., Morais, L.M.F., Donoso-Garcia, P.F., Cortizo, P.C. and Seleme, S.I., 2011, September. Comparative analysis of power LEDs dimming methods. In XI Brazilian Power Electronics Conference (pp. 378-383). IEEE.

[8] Garcia, J., Dalla-Costa, M.A., Cardesin, J., Alonso, J.M. and Rico-Secades, M., 2009. Dimming of high-brightness LEDs by means of luminous flux thermal estimation. IEEE transactions on Power Electronics, 24(4), pp.1107-1114

[9] L. H. Koh, Y. K. Tan, Z. Z. Wang and K. J. Tseng, "An energy-efficient low voltage DC grid powered smart LED lighting system," IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society, Melbourne, VIC, 2011, pp. 2883-2888.

[10] M. Firoz Pervez , Abdul Al Mortuza , Md. Hasan Ali , M. A. Sayid Haque , H. K. Ghosh , Mahbubul Hoq , Novel Scanning Technique for LED Dot-Matrix Display to Reduce Flicker, Electrical and Electronic Engineering, Vol. 6 No. 2, 2016, pp. 19-24. doi: 10.5923/j.eee.20160602.01.