International Journal of Computer Applications (0975 – 8887)
Volume 58– No.22, November 2012

PWM Strategies in 32-Bit Microcontroller for Interior White LED Down Panel

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ABSTRACT

This paper considers the Pulse Width Modulation (PWM), the internal module of ARM7 based microcontroller i.e. LPC2148 designed by NXP (founded by Philips), to study the illumination of a White LED down panel. This paper also shows the effect of PWM implementation on the White LED down panel using the internal module and the general purpose input output (GPIO) pins of LPC2148 microcontroller and compares both PWM implementations on the White LED down panel. They have discussed the effects of PWM waveform controlling the White LED down panel using different intermediate modules like without any LED driver, BJT transistors, relays and current driver IC (ULN2003) connected between the LPC2148 microcontroller and the White LED down panel. The comparison between the different intermediate modules that considered, are analyzed their influences on the White LED down panel.

General terms

Concept of PWM, White LED down panel, internal PWM module in LPC2148, comparison with the existing technology, strategies to implement PWM in case of LPC2148, driver circuits for White LED panel

Keywords

ARM7, LPC2148, White LED down panel, Pulse Width Modulation, LED down panel drivers

1. INTRODUCTION

The emergence of energy efficient products and systems are known to meet the demand of energy consumption of 7 billion populations of the world. Light Emitting Diode (LED) is a low energy consumption, efficient, environment friendly small bulb and produces no heat during operation. In contrast to other lighting technologies, LED light tends to be directional. This is a disadvantage for most general lighting applications, but can be an advantage for spot or flood lighting [9]. Globally, electric lighting accounts for some one fifth of all electric energy consumed [3]. Therefore any efficient electric lighting initiative is a subject of interest of all mankind. Such an initiative is dimming the LEDs in a LED panel [15] [17]. Dimming led saves energy at a roughly 1:1 ratio. This means that if you dim LEDs down to 50% of their output you will save nearly 50% of your energy usage [6] [14] [16]. Dimming LEDs run cooler than the existing tube lights and bulbs, which should extend the life of the electronic components of the driver, as well as prosper on the LEDs. Dimming of the light output of White LED down panel is done with pulse width modulation in order to maintain a consistent color or color temperature of light [7]. They use the ARM7 based 32-bit microcontroller i.e. LPC2148, designed by the NXP as the controller of the White LED down panel. White LED down panel is connected to the GPIO pins of the LPC2148 microcontroller with different intermediate modules to supply proper current to drive the LED down panel. This paper examines the implementation of Pulse Width Modulation (PWM) to study and compare the different effects of PWM using the internal module of LPC2148 microcontroller and GPIO pins (without referring the inbuilt module of the microcontroller) and analyze these outcomes on the lighting system of the White LED down panel.

2. COMPARISON WITH THE EXISTING TECHNOLOGY

There are many existing technology of lighting like fluorescent tube lights, and CFL (Compact Fluorescent Lamps) bulbs in the world. Although, they are easily available at low cost in the market but they consume more power than LED (Light Emitting Diode). The lifespan of these existing bulbs is much lower (up to 1 year) than the LED bulbs or panels.

The only thing that restricts the LED bulbs or panels from installing widely in homes is the initial cost of installation of LED panels. The cost of LED bulbs or panels is much higher than the existing tube lights or fluorescent lamps. But, this does not restrict the wide use LED bulbs worldwide as the lifespan and power saving is more than the bulbs made from existing technology [15].

Table1: Comparison between Incandescent bulbs, Fluorescent tube lights, CFL and LED [19]

	Incandescent	Tube lights	CFL	LED
Light intensity	Cannot be controlled	Cannot be controlled	Cannot be controlled	Can be controlled
Lifespan	Approx 1200 hours	8000 hours	10000 hours	50000 hours or more
Power in Watts	40 W	16 W	10 W	6 W
Contains Mercury	No	Yes	Yes	No
Produce heat	Yes (higher than others)	Yes	Yes	Very much lower than others
Eco-friendly	No (affects more on environment)	No	No	Yes
RoHS Complaint	Yes	No	No	No
Optical Efficiency	Lowest among all	Moderate	Moderate	High
Power Consumption in a year [20]	2190 KWh approx	531 KWh approx	531 KWh approx	228 KWh approx
Cost of Bulbs	$2	$1.4	$2-$3	$25-$30
Annual Operating & Maintenance Costs	Money spent is much higher than others	Less than incandescent bulbs	Less than incandescent and slightly higher than tube lights.	Much lower than the existing lighting technology.

On analyzing the above table 1, they get LEDs are better than any other existing lighting technology. LEDs do not emit any UV rays and not contain lead or mercury, which are harmful to environment as well as humans.

LEDs are providing better energy consumption that is helpful for power shortage countries and consume less resource in comparison to others due to the highest operational lifespan among all. So, the rate of manufacturing is much lower than the other lighting bulbs. It only requires higher initial installing cost than others which can be recovered from annual power saving and maintenance costs.

3. CONCEPT OF PULSE WIDTH MODULATION (PWM)

Pulse Width Modulation, abbreviated as PWM, is a method of transmitting information in the form of modulating pulses i.e. variable width of the pulses. It is the modulation technique for generating variable width pulses to represent the amplitude of an input signal. PWM is generally based on the principle that is the average power delivered is directly proportional to the modulation duty cycle. PWM is a technique for getting analog results with digital means [13] [18]. Duty cycle is defined as the percentage of the ratio of the ON time to the total time i.e. ON + OFF time, in a fixed period of time.

$$\text{Duty cycle} = \frac{\text{ON time}}{\text{Total time}} * 100$$

Take an example, an LED is connected with a 9V battery and a switch forming a closed circuit. They implement the PWM on this circuit and calculate the output power across the LED.

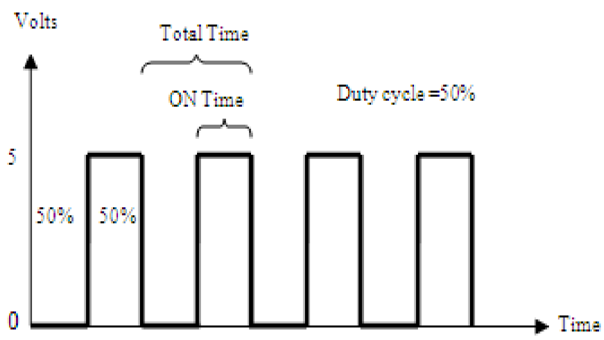

Fig 1: waveform of 50% duty cycle.

The figure 1 shows the 50% duty cycle as the output which is roughly gives out 50% of the average power means 50% of the 5V i.e. 2.5V as the output power. The LED in the circuit will glow with 50% duty cycle means half of the power supply will be used in the output i.e. 2.5V compared to the average power i.e. 5V due to the implementation of the Pulse Width Modulation (PWM) [17].

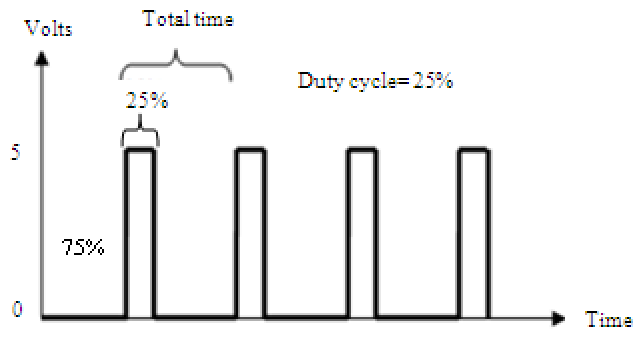

Fig 2: Waveform of 25% duty cycle.

When they apply this 25% duty cycle of PWM across the LED circuit, the LED will glow with 25% of the total power i.e. 1.25V. The brightness of the LED will be very dim due to the 25% of the total power used i.e. 1.25V across the LED due to decrease in duty cycle of the waveform as shown in figure 2.

4. WHITE LED DOWN PANEL

Even with the leaps and bounds that have taken place in power LEDs in recent years, a single device is rarely enough to provide all the light needed for general illumination. More than one LED will be needed if goal is to light a space formerly occupied by at the light bulb. Various white LEDs are arranged in a definite order to form a white LED down panel. Placing the LEDs in series guarantees that the same current flows through each device. In series combination, if any of the LEDs fail and create an open circuit, the entire white LED down panel goes dark. In addition, this configuration leads to highest output voltage, which translates into larger, more expensive circuit components and more requirements for safety. Thus, LEDs must be arranged in a series-parallel array. This arrangement has the advantage of using a lower output voltage and reducing the hazard of electric shock. If one LED fails open circuit, the other two branches continue to operate. The dimmable white LED lighting only needs the information of brightness, or dimming [11] [17].

Fig 3: Square white LED panel of 12V.

White LED down panel, shown in above figure, has a 4*6 series-parallel array i.e. it consists of 6 parallel branches with each branch having 4 LEDs in series. Voltage across each LED in series combination is 3V resulting in grand total of 12V across each parallel branch of the white LED down panel. LED driver, being a current source, will force current I/6 current, I is the current drawn through the LED driver, through each parallel branch.

Fig 4: Back-side of the white LED panel showing series configuration.

The figure 2 shows the series connection of four White LEDs on a single strip and showing black covering on each series connected LED. The black covering on each back side of the LED is the heat sink to avoid LED from large current flow or burning of the connection due to the high voltage.

5. INTERNAL PWM MODULE IN CASE OF LPC2148 MICROCONTROLLER

They uses the ARM7 based 32-bit microcontroller designed by the NXP, having 64 pins (16 pins on each side of the microcontroller) in which 45 pins are 5 volts tolerant Input/output pins i.e. LPC2148 as the centre controller of the White LED down panel. This microcontroller has inbuilt PWM peripheral that will be implemented to control the illumination of the White LED down panel. System peripherals including timer and PWM module can achieve the functions required by the system and implement the function of the controller [10]. They implement the inbuilt Pulse Width Modulation (PWM) peripheral of LPC2148 microcontroller and using GPIO pins to implement PWM (without using the inbuilt PWM peripheral of microcontroller) to illuminate the White LED down panel. The comparison between both types of implementation of PWM and their influences are analyzed and compared. The different types of intermediate modules like without any LED driver, BJT transistors, relays and current driver IC (ULN2003) are used between the LPC2148 microcontroller and the white LED down panel, to study changes and effects of the lighting on the White LED down panel. So, the LED intensity is fundamentally decided by the ratio-duty of PWM [12] [15]. LPC2148 microcontroller has seven match registers allow up to six single edges controlled or three double edges controlled PWM outputs. In LPC2148 microcontroller, there are six different controlled PWM (Pulse Width Modulation) outputs at GPIO Port P0 [3] [2] [1] as depicted in the table 2.

Table 2: Symbols and Pin configuration of PWM outputs

Symbol	Pin configuration	Type	Description
P0.0	19	Output	PWM1- pulse width modulator output 1
P0.1	21	Output	PWM3- pulse width modulator output 3
P0.7	31	Output	PWM2- pulse width modulator output 2
P0.8	33	Output	PWM4- pulse width modulator output 4

P0.9	34	Output	PWM6- pulse width modulator output 6
P0.21	1	Output	PWM5- pulse width modulator output 5

This microcontroller has inbuilt register which are initialized during the implementation of the PWM. The registers description of the LPC 2148 is referred from [1]:-

Table 3: PWM registers description

NAME	DESCRIPTION
PWMTCR	PWM Timer Counter Register controls the Timer Control functions.
PWMPR	PWM Prescale Register is incremented at every PWMPR+1 cycle.
PWMTC	PWM Timer Counter is incremented at every PWMPR+1 cycle and controlled through the PWMTCR.
PWMPC	PWM Prescale Counter is incremented to the value stored in PR.
PWMMCR	PWM Match Control Register is used to control interrupt and PWMTC when a match occurs.
PWMPCR	PWM Control Register enables PWM outputs and select PWM channel types.
PWMLER	PWM Latch Enable Register enables the new value of PWM match.

6. STRATEGIES TO IMPLEMENT PWM IN CASE OF LPC2148 (ARM7) MICROCONTROLLER

6.1 Implementation of inbuilt PWM module of LPC2148 microcontroller

```
void PWM(void)
{
PINSEL1=0x00000400;
PWMTCR=0x00000002;
PWMPR=0x00000000;
PWMMCR=0x00000002;
PWMPCR=0x00002000;
PWMMR0=0x000000ff;
PWMTCR=0x00000009;
PWMLER=0x00000021;
while(1)
 {
  PWMMR5=0;
  PWMLER=0x00000021;
  delay(9);
  PWMMR5=255;
  PWMLER=0x00000021;
  delay(1);
 }
}
int main()
{
 PWM();
 delay(1);
 while(1);
}
```

The above code shows the implementation of the PWM on the LPC2148 microcontroller, by NXP using Keil µvision4 software. In the PWM coding implementation, we have to initialize inbuilt PWM registers [1] of the LPC2148 microcontroller. They define a function *void PWM();*in which all the inbuilt registers[1] of the PWM module are initialized to perform a specific task. In *void PWM();*function, PWM output 5 (PWMMR5) is taken to observe the Pulse Width Modulation of the LPC2148 microcontroller as the other PWM output channels share their pins as UART0 and UART1 (PWM1, PWM3, PWM4, PWM6) and PWM2 shares with IRQ EINT2 and can also be configured as the GPIO pins. So, PWM5 output channel is left which shares P0.21 with only general purpose input output (GPIO) pin. The while(1) loop defines the infinite loop which executes continuously the PWM program in order to display the continuous Pulse Width as the output on pin P0.21. In while(1) loop, PWMLER (Pulse Width Modulation Latch Enable Register) is declared after the initialization of PWMMR5 as it enables the new PWM match values [1].

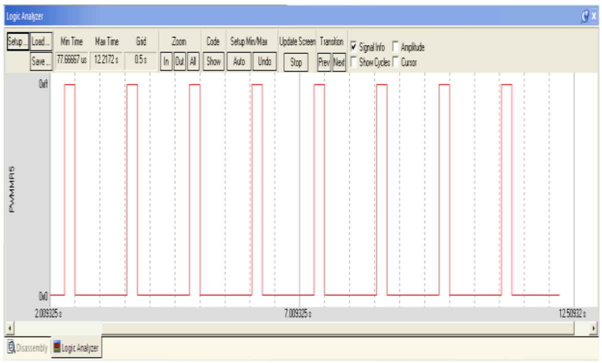

Fig 5: PWM5 waveform on the logic analyzer of 10% duty cycle implemented using inbuilt module of LPC2148.

The above figure 5 depicts the continuous PWM waveform of 10% ON period and 90% OFF period. The above waveform in the figure 5 is analyzed in the logic analyzer of the Keil µvision4 software and observed the output at pin P0.21. The above figure showing the10% duty cycle of the PWM according to the delay is declared after every initialization of PWMMR5. The range of Pulse Width Modulation waveform is considered from 0x00 to 0xff. To observe or display the waveform in logic analyzer, they have to mask the value in the setup option of logic analyzer. The mask is configured according to the highest value of PWMMR5 considered i.e.

0xff. So, they set the Max value to 0xff and Min value to 0x00 in setup option of the logic analyzer.

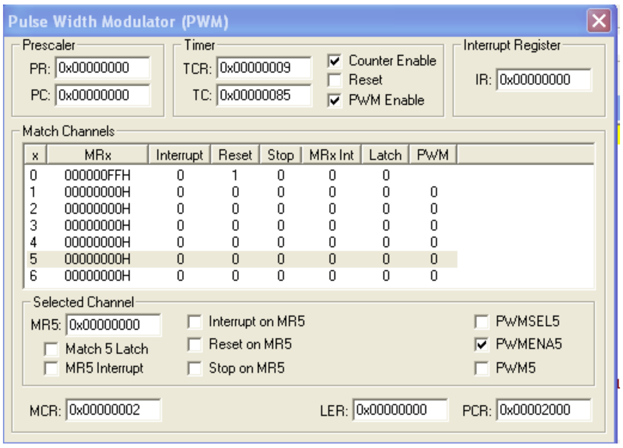

Fig 6 (a): output of PWM5 on PWM peripheral as falling edge.

The figures 6(a) and 6(b) are considered in the Pulse Width Modulation peripherals provided in the Keil µvision4. The figure 6(a) shows the output of the PWM5 on the PWM peripheral and is showing the falling edge i.e. 0 on the PWMMR5. To observe the falling edge waveform as the output on pin P0.21, they kept the PWM5 option unchecked (option can been seen on the right bottom side of the figure 6(a)) and PWMMR0 is enabled through PWMMCR (PWM Match Counter Register).

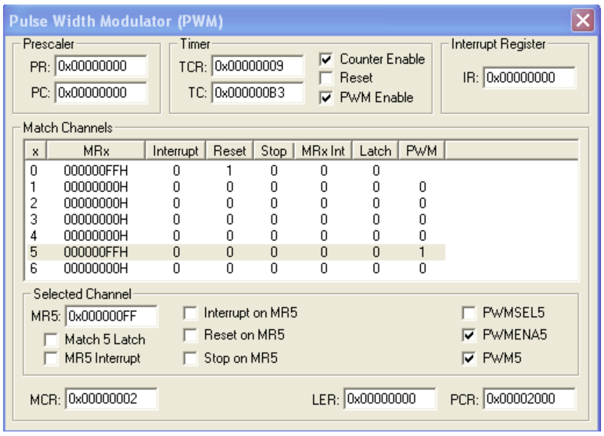

Fig 6 (b): output of PWM5 on PWM peripheral as rising edge.

The above figure 6(b) is observed as the rising edge waveform of PWM output. To analyze the rising edge waveform as the PWM output on pin P0.21, they check the provided option of PWM5 (on the right bottom of the figure 6(b)) and make PWMMR0 enabled through PWMMCR (PWM March Counter Register).

When they checked the provided option of PWM5 in Pulse Width Modulation peripherals, they observed that PWM (in its 6th row) started with value 1 which confirms that the waveform producing is of rising edge. Similarly, when they kept the option of PWM5 unchecked, they observed the same PWM output started with the value 0 which confirms the waveform of falling edge.

6.2 Implementation of Pulse Width Modulation (PWM) using GPIO pins (without initializing internal registers)

```
int main()
{
 IODIR0=0x000000ff;
 IOCLR0=0xffffffff;
while(1)
 {
  IOSET1=0x00000000;
  b=IOSET1;
  delay(9);
  IOCLR1=b;
  IOSET1=0x00000001;
  b=IOSET1;
  delay(1);
  IOCLR1=b;
  }
 }
```

In this, they have implemented the PWM using GPIO (General Purpose Input Output) pins of LPC2148 to observe the output waveform in the logic analyzer of Kiel micro-vision4 software. GPIO has two ports i.e. P0 and P1 and defines the 4 basic registers [2] that are:-

Table 4: Description of GPIO registers [2].

NAME	DESCRIPTION
IOPIN	GPIO Port Pin value register reads the current state of GPIO configured port pins.
IODIR	GPIO Port Direction Control Register controls the direction of each port pin individually.
IOSET	GPIO Output Set Register controls the state of output pins.
IOCLR	GPIO Output Clear Register clears the state of the output pins in IOSET.

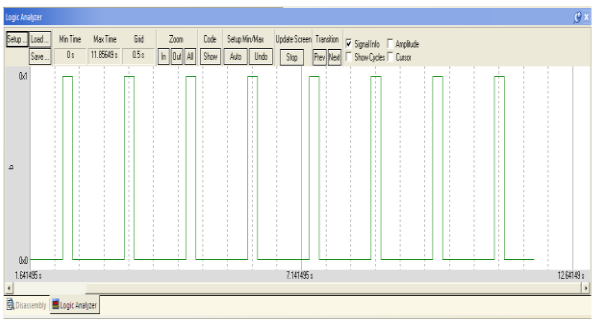

Fig 7: PWM waveform of 10% duty cycle implemented by using GPIO pins of LPC2148.

The figure 7 shows the implementation of Pulse Width Modulation waveform of 10% duty cycle. The waveform is in hexadecimal form ranging from 0x00 to 0xff. And the mask is set according to the highest value of the waveform.

7. DRIVER CIRCUITS FOR WHITE LED PANEL

7.1 Without any intermediate module or any driver

The each GPIO pin of the LPC2148 microcontroller can safely supply or sink a maximum of 4mA current and the White LED down panel consists of combination of high current LEDs. So, it would be difficult for GPIO pins of LPC2148 microcontroller to drive such a high current consuming White LED down panel. Hence, it is not recommended to directly supply current to a LED of 20mA or a white LED. And thus, the matrix form of LEDs mounted on the square panel cannot be directly linked to the GPIO pins of the LPC2148 microcontroller. So, it is not recommended to connect the white LED down panel directly to the GPIO pins of the LPC2148 microcontroller. But, a single LED of 2mA or 5mA can be connected directly to the GPIO pins of the LPC2148microcontroller.

7.2 Implementing Transistors as a driver

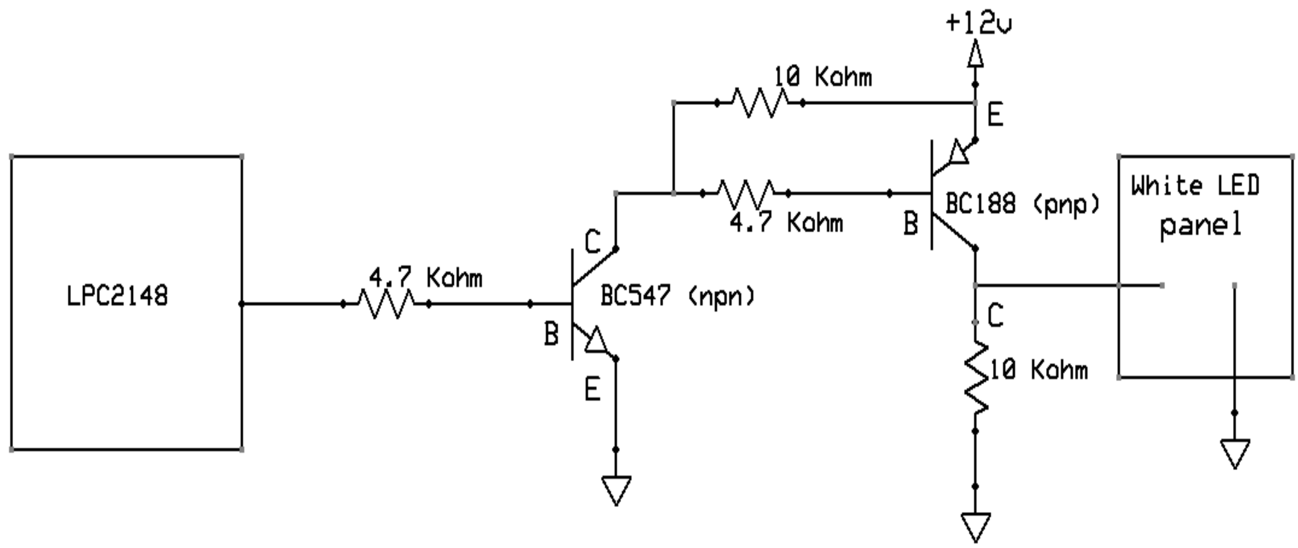

Fig 8: Schematic diagram of the transistors circuit as the intermediate module.

The above figure shows the basic schematic diagram of the intermediate circuit connection between the LPC2148 microcontroller and the white LED down panel. This schematic diagram has been drawn on the ExpressSCH software.

The figure shows the use of LPC2148 as the controller whose GPIO pin is connected to the base (B) of the npn (BC547) transistors and the output of this transistor is at collector (C), connected to the input base (B) of the pnp (BC188) transistor. The output of the intermediate circuit is taken at the collector (C) terminal of the pnp transistor, connected to the positive terminal of the white LED down panel. The three terminals i.e. emitter (E) of the npn transistor, collector (C) of the pnp transistor and the negative terminal of the white LED down panel in the above figure, are connected to ground.

According to the schematic diagram, when LPC2148 microcontroller pin is at high, the connection between the emitter and collector terminal of the pnp transistor goes open circuit. So, the output at collector terminal of the pnp transistor goes low i.e. 0V due to the open circuit of pnp transistor. Similarly, when the same pin of the microcontroller is at low, the connection between the emitter and the collector terminal of the pnp transistor goes closed circuit and the output at the collector terminal is observed high i.e. +12 V.

7.3 Implementing Relay as a driver

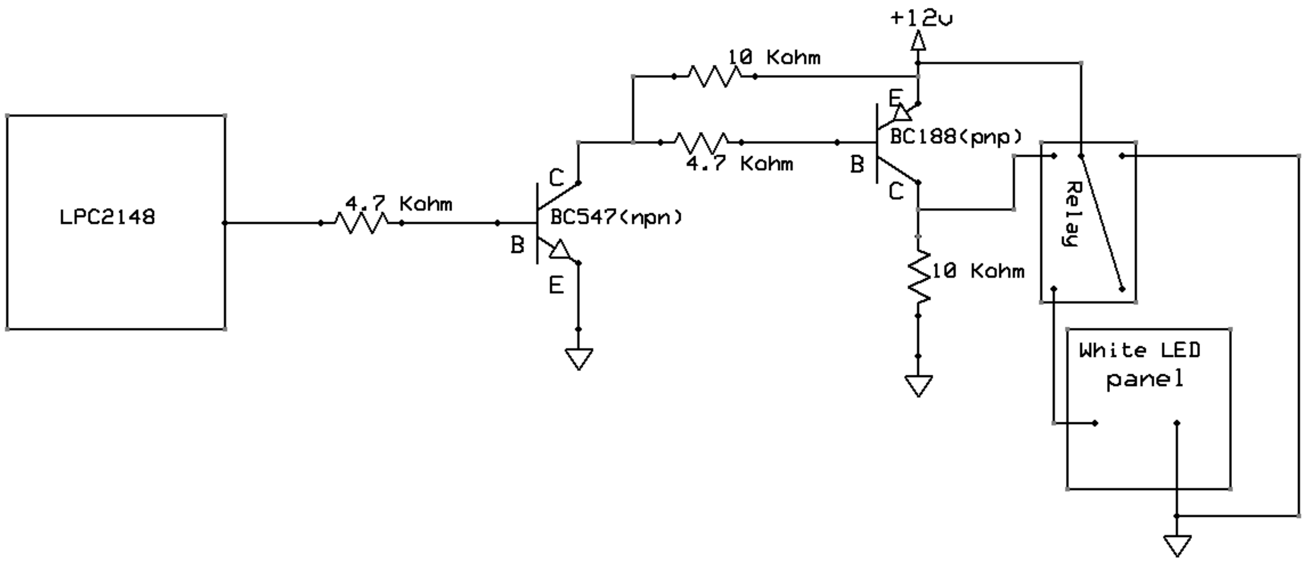

Fig 9: schematic diagram of the intermediate circuit using a relay of 12V.

This intermediate circuit diagram is similar to the intermediate circuit in figure 9. The only difference is the use of relay between the output collector terminal of the pnp transistor and the white LED panel.

But, using relay as the intermediate circuit is not useful and not recommended due to slow switching speed of the relays compared to the PWM execution on the circuit. So, most relays won't operate on and off fast enough to reproduce the PWM switching frequency. Possibly a small reed relay might work but most PWM signals are usually wired to the transistors (as discuss earlier) or logic chips sources that can handle the speed of the PWM switching frequency[1][2].

There is the availability of solid state relay which offering fast switching speeds. It features a fast typical switching speed of 800 µs (i.e.1.25KHZ) that provides higher throughput in test equipment. But, it is not enough for the compatibility with the LPC214X as it operate upon 50MHZ. So, PWM does not vary fast as 50MHZ at that switching speed. So, using a relay as the intermediate circuit is not recommended.

7.4 Using ULN2003 current driver IC

Now, they have implemented the current driver IC i.e. ULN2003 as the intermediate circuit. ULN2003 consists of seven NPN Darlington pairs that features high voltages output and relay driver application. The current rating of each Darlington pair is 500mA which more than the single GPIO pin of the LPC2148, as discuss earlier. Above a certain frequency (generally 200 hertz) the human eye cannot distinguish the individual pulses, and by adjusting the pulse width while keeping the 'ON' state LED current at a certain level the average level of light perceived varies accordingly. LED driver ICs accept logic-level PWM signals and are able to act as a high fidelity bi-level amplifiers-applying pulses to the LEDs at a controlled current that match the logic signal [2][5].

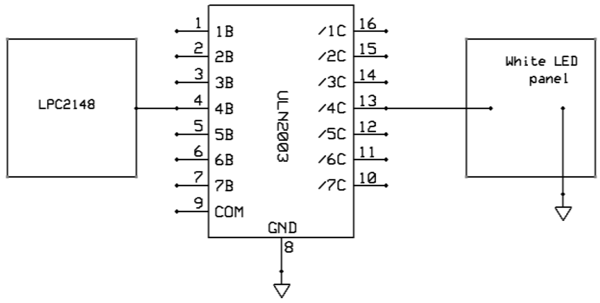

Fig 10: Schematic diagram of ULN2003IC as the intermediate circuit.

In the above schematic diagram, one of the GPIO pin of the microcontroller is connected to a input pin (4B) of the ULN2003 IC and the high voltage output is take n at the corresponding pin (i.e. 4C or 13). This high voltage output pin connected to the positive terminal of the white LED down panel and negative terminal of the panel connected to ground. This ULN2003 alone works successfully as the intermediate circuit to drive the square white LED down panel.

8. CONCLUSION

In this paper, they have implemented PWM in different ways using LPC2148 to achieve dimming of white LED down panels. By providing dimming control to white LED panel, they are be able to save electricity since dimming control enable light intensity variation using different PWM strategies.

The existing technology of bulbs consumes more power than LEDs producing. LEDs consume less power and do not produce any heat or radiation that affects human eyes. They are eco friendly power saving diode, which can help in abating the pollution crisis facing the world. LEDs usually have lifespan of approx 7 years or more that helps in controlling the resources usage drastically and avoid of producing fluorescent tube lights or incandescent bulbs.

The PWM strategy, discussed above, has the ability to control the intensity of lightning emitted by the LED panels and can save power to a great extend. It can help the developing countries facing shortage of power supply and the power cuts being faced by people. This strategy can be implemented in offices or homes to lower power consumption, ultimately reducing the power bills to a great extend and can help the lighting system to break out due to sudden power break down. And by implementing PWM (Pulse Width Modulation) strategies to control the intensity White LED panels on the basis of environment requirement, more energy and maintenance costs can be saved.

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10. AUTHOR’S PROFILE

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