DOKUZ EYLÜL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

LED TECHNOLOGIES IN ENERGY EFFICIENT APPLICATIONS

by

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July, 2009

İZMİR

LED TECHNOLOGIES IN ENERGY EFFICIENT APPLICATIONS

A Thesis Submitted to the
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M. Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"LED TECHNOLOGIES IN ENERGY EFFICIENT APPLICATIONS"** completed by **AYSUN TUTAK** under supervision of **PROF. DR. EYÜP AKPINAR** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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LED TECHNOLOGIES IN ENERGY EFFICIENT APPLICATIONS

ABSTRACT

In this thesis, a quarter part of 21" LCD backlight is done with rgb leds. The thesis consists of designing and analyzing the power board, the driver board and the led board. For the power board the buck converter topology has chosen for easy implementation and a microcontroller PIC 16F877 was used to generate pwm signal for the mosfet. Using microcontroller makes the system more stable according to analog circuits.

The most important thing is the heat, which the driver ICs (TLC5941 in this thesis) generates when there is excess voltage on them. The microcontroller is also used to prevent the IC from this voltage. The driver IC's requires control signals, to determine the current value and the brightness of leds. These control signals generated with another PIC 16F877.

Simulations are carried on Proteus ISIS 7. The application software is converted from Pic Basic Pro into hex files. The system pcb design was done with Proteus ARES 7.

At last the consuming energy was measured and compared with the same size of CCFL backlight TV.

Keywords: Light emitting diode technology, LCD, Buck Converter, PIC, 16F877, TLC5941, Pulse width modulation, Proteus, Pic Basic Pro

ENERJİ VERİMLİLİĞİ UYGULAMALARINDA LED TEKNOLOJİSİ

ÖZ

Bu tezde, 21" LCD arka aydınlatmasının dörtte biri rgb ledlerle yapılmıştır. Tez, güç kartının, sürücü kartın ve LED kartının tasarlanmasını ve analiz edilmesini kapsamaktadır. Güç kartının tasarımında kolay uygulaması nedeniyle alçaltıcı d.a.-d.a çevirici kullanılmıştır. Ayrıca mosfet'in sürülmesinde kullanılan darbe genişliği modülasyon sinyali 16F877 mikrodenetleyicisi ile oluşturulmuştur. Mikrodenetleyici kullanımı, sistemi analog devrelere göre daha kararlı yapmaktadır.

En önemli nokta ise ledleri süren entegreler (bu tezde TLC5941) üzerinde fazla voltaj oluştuğunda açığa çıkan ısıdır. Mikrodenetleyici aynı zamanda sürücü entegre üzerinde fazla voltaj oluşmasını engellemek amacıyla da kullanılmıştır. Sürücü entegre, akım değerinin ve ledlerdeki parlaklığın ayarlanması için kontrol sinyallerine ihtiyaç duyar. Kontrol sinyalleri diğer bir PIC 16F877 ile üretilir.

Simulasyon kısmı Proteus ISIS 7'de yapıldı. Uygulama yazılımı Pic Basic Pro'dan hex dosyalarına çevrilmiştir. Sistemin baskı devreleri de Proteus ARES 7 ile çizildi.

Son olarak, tüketilen enerji ölçüldü ve aynı boyutlardaki CCFL LCD Tv ile karşılaştırıldı.

Anahtar Sözcükler: Işık yayan diyod teknolojisi, LCD, Gerilim Azaltıcı Doğru Akım Çevirici, PIC, 16F877, TLC5941, Darbe genişliği modülasyonu, Proteus, Pic Basic Pro

CONTENTS

CHAPTER ONE
INTRODUCTION

1.1 The Problem: LED Technologies in Energy Efficient Applications

Considering the increase of energy demand and reduced energy sources, energy efficiency is the important point that everybody should dwell on.

Energy efficiency covers whole activities about energy production, transmission and the consumption. On the one hand, producing more energy with less cost and primary resources studies continues. On the other hand, producing more labour with same energy, or producing same amount labour with less energy studies continues.

In this thesis, the energy efficiency is taken up with one of the consumer electronics products, LCD Televisions. LCD televisions are widely used and many companies have cut the production of the CRT televisions.

The biggest advantage of LCD screens is the screen size and weight. LCD screens can be upwards 80% lighter than an equivalent dimension CRT screens. LCD does not contain electron beam that means the LCD screens produce less heat and use less energy.

LCD panels needs backlight illumination. Backlights are indispensable for the operation of LCD. Light sources or lamps are the core components of backlights. The two popular technologies are; Cold Cathode Fluorescent Lamps (CCFL) and the newest LED technology.

A CCFL lamp contains 2 – 10 mg mercury, and a mixture of gasses such as argon and neon. When high voltage is applied to the electrodes, ultraviolet energy is produced as the mercury and the internal gasses are ionized. The resulting ultraviolet energy from the mercury discharge stimulates the phosphor lining inside the lamp

producing visible light output in the 380 to 780 nm range (also known as the photonic region). (Yu, 2006)

The advantages of CCFL are; its high brightness, easiness to achieve display uniformity, thin profiles, long service life, power efficiency and infinitely dimmable feature.

The disadvantages of CCFL are; the need of high voltage and frequency, glass tubes can require special handling and packaging, tube thickness, flicker, cold starts and low temperature performance. CCFL backlight the image on LCD screen never exceeds colour gamut of 100% NTSC. (Anandan, 2006) And the mercury in CCFL is poisonous.

To overcome all these backwards, with the following advantages of LEDs, LED lamps have gradually substituted CCFL as backlight.

The advantages of LED are;

- very long service life (more than CCFL),
- good environmental performance (high UV, high temperature or humidity),
- solid state chip (nothing to break or burn out),
- no EMI or RFI,
- low power,
- many colour choices,
- the simplicity of driver circuit,
- full colour gamut at high brightness. (Yu, 2006)

Few disadvantages of LEDs are sensitive to ESD or voltage spikes, not true full spectrum White LED (unless tri-colour).

After discussing the advantages and disadvantages of the LEDs, let's look the history of the LED backlights.

The history starts in 1907 as British scientist Henry J. Round of Marconi Labs discovered that the junction of a semi-conductor produced light. The light was not bright enough to further investigations. LEDs were forgotten until the 1920s until Russian Oleg Vladimirovich Losev independently created the first LED. But no practical use was found.

In the 1950s, British experiments in electroluminescence, using a semiconductor called Gallium Arsenide (GaAs), LED to the development of the first infrared light-emitting diode. The Radio Corporation of America (RCA) LED the charge, with Rubin Braunstein. Braunstein discovered and reported the production of infrared light using various semiconductor alloys in 1955.

In 1961, experimenters Bob Biard and Gary Pittman working at Texas Instruments, found that GaAs emitted infrared radiation when electric current was applied and received the patent for the infrared LED. The first practical visible-spectrum (red) LED was developed in 1962 by Nick Holonyak Jr., while working at General Electric Company.

Holonyak was later at the University of Illinois at Urbana-Champaign and a graduate student of him, M. George Craford, invented the first yellow LED and eventually a much brighter red and red orange LED in 1972.

The production of blue, yellow and amber LEDs are made in 1990s. White LEDs were produced in the late 1990s.

In 2004 the World's first LED Backlight TV is announced by Sony. The Luxeon light source is integrated in Sony's 40" and 46" QUALIA series televisions.

NEC Display Solutions announced the launch of the World's first LED LCD monitor (Spectra View LCD2180 Wide Gamut LED, 21.3"), in 2005.

Samsung Electronics unveils an 82" LCD TV with LED backlight - the World's largest of its kind - at CES 2006.

1.2 Thesis Objective

As described in the previous section LEDs has the potential to improve the efficiency of the backlights in means of its long life, easy driver methods, and high illumination.

The first step is determining the specifications of the backlight that we want. According to these specifications, a simulation and application will be done.

Specifically, this thesis attempts to answer the following:

I. What are the characteristics of LEDs?
II. What type of LED Backlights available?
III. What are the specifications of driver circuit?
IV. How can we implement a driver circuit?
V. How much power do we need?
VI. What is the efficiency of the circuit?
VII. What are the results if we compare with CCFL?

1.3 Thesis Methodology

This section describes the approach used to answer the questions raised above. In this thesis, a quarter of 21" LCD backlight is done with RGB LEDs. In this thesis, the buck converter topology is chosen from different constant current, constant voltage topologies.

There are 3 sets of buck circuit to supply red, green and blue LEDs. The power system uses a microcontroller 16F877. Microcontroller is used for PWM closed loop control of mosfet to regulate the voltage. For dimming the individual parallel

branches of LEDs, 6 pieces of driver ICs are used. LEDs are driven at constant current. Principles of operation of this IC (TLC5941) will be explained. Another 16F877 microcontroller is used to generate control signals and make serial interface of driver ICs.

With this circuit structure, when temperature across junction of the LEDs increases, forward voltage of LEDs will drop. The result is increasing voltage and the power consumption on the driving IC. A vicious circle condition in LCD panels will occur and lead to fast increase of component temperature inside panels. Therefore, it will reduce luminance intensity of LCD panels and life cycle of components significantly.

To solve above problems the voltage on the driving IC should be constant. In this design, the reference and the measured voltages of the IC are compared. If the difference ΔV_m is positive, buck output V_{out} voltage is decreased till the difference is 0. If the difference ΔV_m is negative, V_{out} is decreased till the difference is 0.
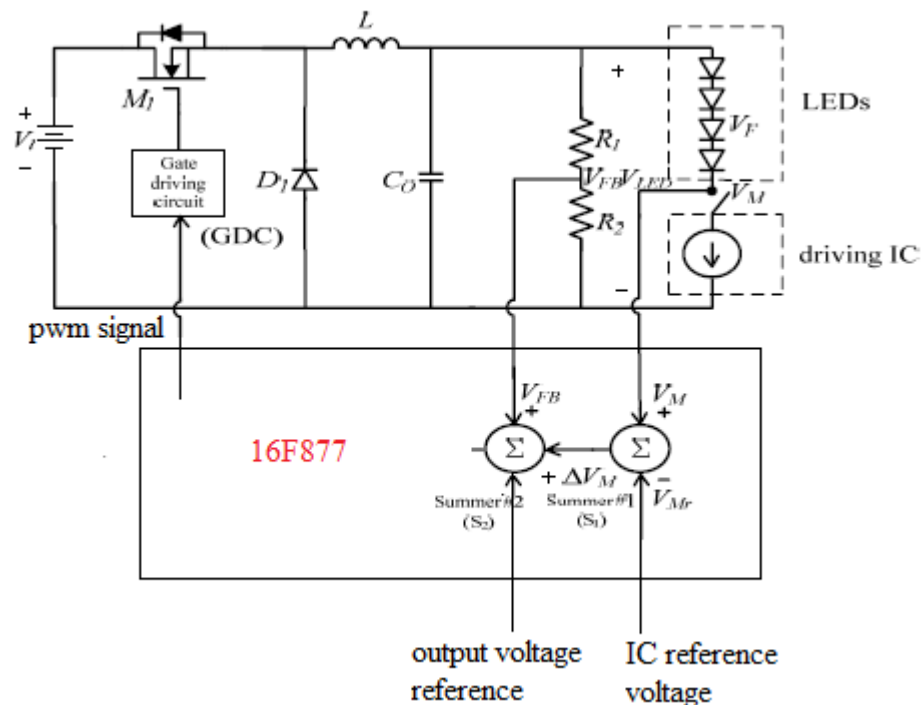
Figure 1.1 Block diagram of the proposed LED backlight power system

1.4 Thesis Outline

Chapter Two starts with the brief background of LEDs. The parameters affecting the LED performance are examined. Then, linear and switch mode regulator topologies are explained. At the end of this chapter, linear and switch mode topologies are compared.

Chapter Three covers the Buck Converter Topology. Firstly the general structure of the converter is explained. In this chapter CCM and DCM modes of this converter will be described widely.

Chapter Four contains whole design including component selection, using microcontroller, program writing and assembling.

The conclusion summarized in Chapter Five.

The hardware and software structure of the 16F877 microcontroller can be found in the appendices.

CHAPTER TWO
BRIEF SUMMARY OF LEDS AND CURRENT RIPPLE FREE
TOPOLOGIES

2.1 Summary of LEDs

LEDs produce light using a fundamentally different principle compared to incandescent or high-intensity discharge lamps.

Traditional light sources produces light an element to incandescence or establishing an electrical arc through a gas amalgam. LEDs are special diodes that emit light from a small semiconducting chip when a current is applied to it. The chip has two regions separated by a junction. The p region is dominated by positive electric charges, and the n region is dominated by negative electric charges. The junction acts as a barrier to the flow of electrons between the p and the n regions. Only when sufficient voltage is applied to the semi-conductor chip, can the current flow and the electrons cross the junction into the p region. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon. (Wikipedia, n.d.)
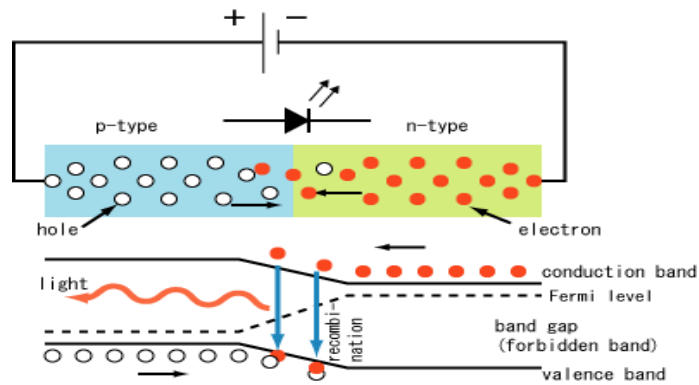
Figure 2.1 Internal operations of a LED

LEDs emit light into narrow wavelength band. The wavelength of the light emitted is the color of the LED. The wavelength depends on the band gap energy. So the color of the emitted light depends on the composition and the condition of the semiconducting material used. It can be infrared, visible or ultraviolet. Today LEDs are not able to emit white light . The white light is obtained with 2 different methods.

One is to use a phosphor material to convert monochromatic light from a blue or UV LED to broad spectrum white light, much in the same way a fluorescent light bulb works. The second method is multi-chip design. The individual light emission from each of the chips will blend to create a white-light emission from the package. This is more expensive method comparing with phosphor method. (Wikipedia, n.d.)

2.1.1 Performance of LEDs

The image quality of LCD Tv is dependent of the performance of LEDs. Typically LED performance is affected by the drive current, forward voltage and ambient temperature surrounding the LED.

2.1.1.1 Drive Current of LEDs

Light output of LED increases with increasing the driving current. But the driving current is inversely proportional with efficiency (lumen/watt). Driving LED light sources above the maximum recommended currents may result in lower lumen maintenance or, with excessive currents, catastrophic failure. (Cooper, 2007)
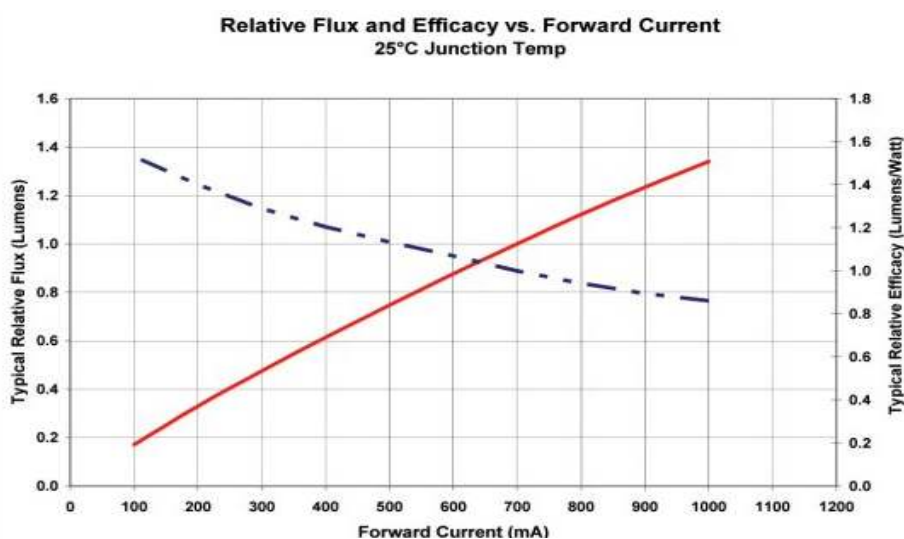

Figure 2.2 a) Forward current and relative flux relationship,
b) Forward current and relative efficacy relationship

Very important point that must be considered is; as LEDs heat up, the forward voltage drops and the current passing through the LED increases. The increased current generates additional heating of the junction. If nothing limits the current, the junction will fail due to the heat. This phenomenon is referred to as thermal runaway.

Therefore, constant current drivers are generally recommended for powering LED light sources.

2.1.1.2 Forward Voltage Drop of LEDs

Voltage changes from supply voltage variations will translate into changes light output. LEDs must be prevented damage of high voltage.

As the heats up, forward voltage of LEDs drops as following graph.

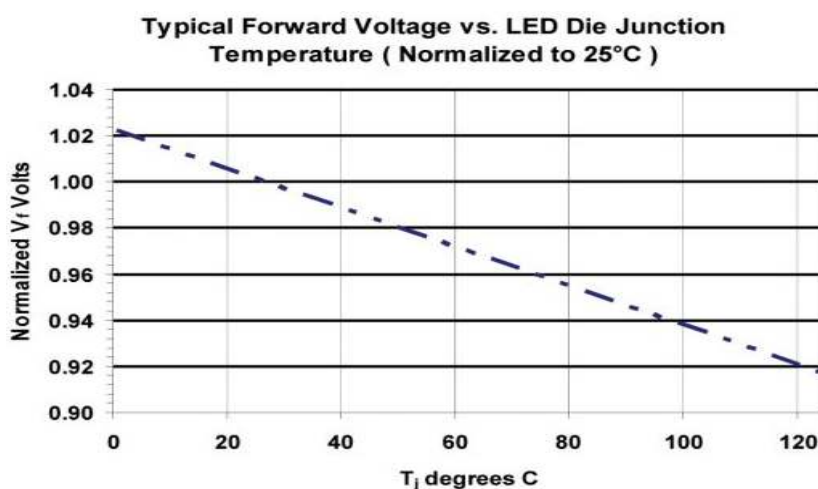Figure 2.3 Forward voltage and temperature relationship

When forward voltage of LEDs decreases under a constant voltage supply, voltage across LED driving IC will increase, resulting in a large power losses in driving IC. As a result, it will induce a fast temperature increase. Therefore it is critical to maintaining the voltage of LED driving ICs voltage constant, when ambient temperature of LEDs is variable.

2.1.1.3 Ambient Temperature Surrounding LED

Performance characteristics of LEDs are specified for a rated current and die junction temperature of 25ºC. Light output should be based on the anticipated operating temperatures. (Cooper, 2007)

The light output from an LED light source decreases with increasing LED die junction temperature. Higher LED die junction temperatures, resulting from increased power dissipation or changes in ambient temperature, can have a significant effect on light output.

Additional to light output decreases, temperature also effects the dominant and peak wavelength.
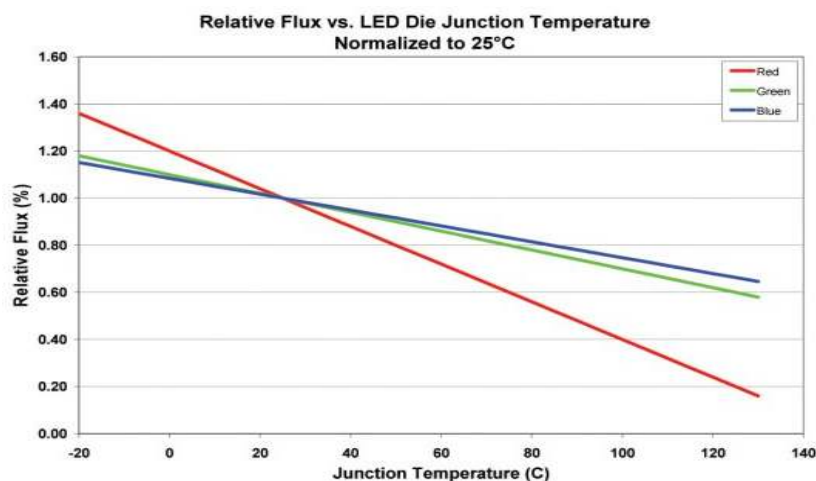
Figure 2.4 Relative flux and temperature relationship

LED die wavelength characteristics are commonly reported at 25°C junction temperatures. With increasing LED die junction temperatures resulting from higher drive currents or ambient conditions, wavelengths typically increase in from 0.03 to 0.13 nm/°C, depending on die type. (Cooper, 2007)

Temperature variation can also cause slight shifts in colour temperature for LED white light sources. Applications requiring specific wavelengths or colour

temperature should take this effect into account when designing drive conditions and heat sinking.

2.1.2 LED Backlight Overview

Basically there 2 types of LED backlights. First is Edge Lit Backlights and the second is Array LED Backlights.

Figure 2.5 Array type backlight

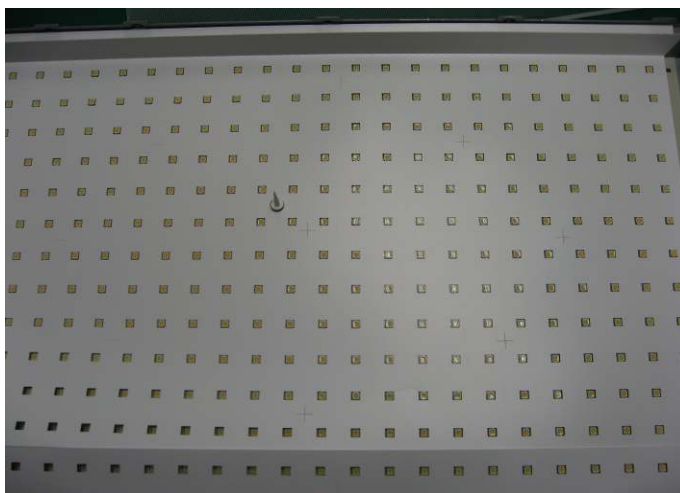For the array type backlight, the LEDs spreads on the board and covers the whole of the screen. The highest light obtained and the brightness uniform is about 80%. The other advantages are high reliability and low development costs. The disadvantages are the necessity of at least 4-5 mm thickness, higher current draw according to edge lit backlights.

Figure 2.6 Edge Lit type backlight

For the edge lit type backlight, the LEDs are arranged only one or few edge of the screen.

If the screen size is small for ex. mobile phones, small screen size monitors, it is better to use edge lit backlight. If the bigger screen sizes are considered for ex. lcd televisions it is a must to use array type backlights.

2.2 Current Ripple Free Topologies

Since LEDs are constant current driven devices and they are affected of voltage spikes, the design must consider the constant voltage and current.

2.2.1 Linear Voltage Regulators

Linear regulators are great for powering very low powered devices. They are easy to use and cheap. However, linear regulators are inefficient.

Linear regulators work by taking the difference between input and output voltages and the difference is burning up as waste heat. The larger the difference between input and output voltages, is producing more heat. The heat must be dissipated with bulky and expensive heat sinks. Typical efficiency is around 30 % - 40%.

2.2.1.1 Standard Regulator

Standard regulators use the Npn Darlington configuration. The minimum voltage that pass transistor is 2VBE + V_{CE}. The minimum voltage requirement is usually about 2.5V – 3V. In the standard regulator, the pass device is a network composed of one Pnp and two Npn transistors, which means the total current gain is extremely high (>300). (Simpson, n.d.)
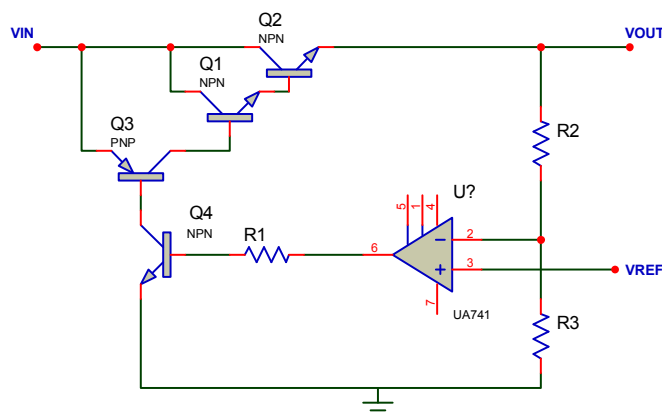
Figure 2. 7 Standard regulator

2.2.1.2 LDO (Low Dropout) Linear Regulators

Low dropout refers to the difference between the input and output voltages that allow circuit to regulate the output load voltage. The minimum voltage drop required across the regulator to maintain regulation is just the voltage across the pnp transistor. The maximum specified dropout voltage of an LDO regulator is usually about 0.7V to 0.8V at full current, with typical values around 0.6V. The maximum load current is about 1A. (Simpson, n.d.)

Figure 2.8 Low Dropout regulator

2.2.1.3 Quasi Low Dropout Regulators

Quasi low dropout regulator is a variation of the standard regulator. It uses an Npn and Pnp transistor as the pass device.

Figure 2.9 Quasi Low Dropout regulator

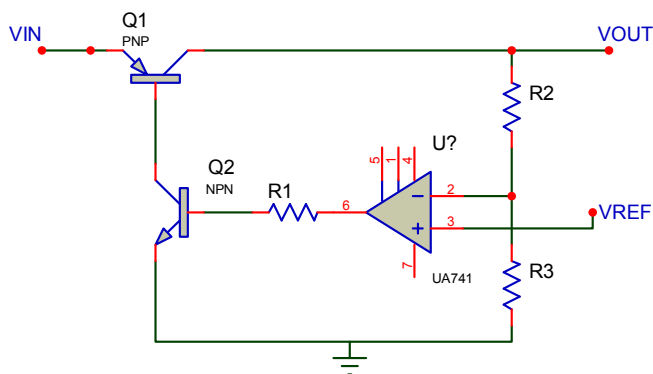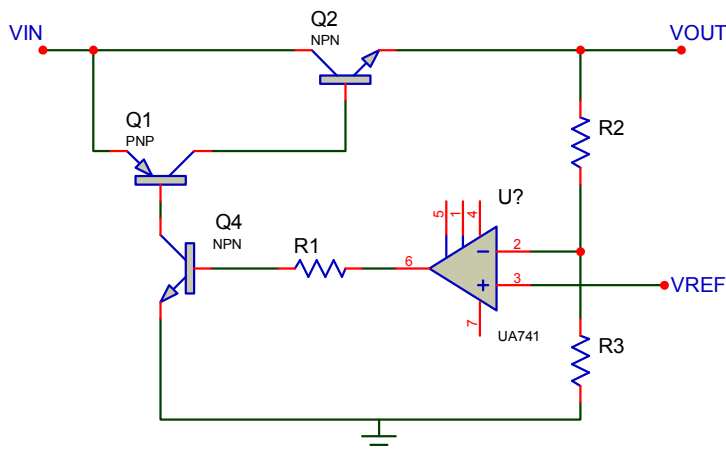The minimum voltage drop for Quasi low dropout regulator to maintain regulation is $V_{BE} + V_{CE}$. The rated current usually specified at about 1.5V. (Simpson, n.d.)

2.2.2 Switching Mode Regulators

2.2.2.1 Charge Pump Regulators

Charge pumps are inductorless dc-dc converters. They generate a voltage higher than the supply voltage from which they operate. Charge pumps use some form of switching devices to control the connection of voltages to the capacitor. For instance, to generate a higher voltage, the first stage involves the capacitor being connected across a voltage and charged up. In the second stage, the capacitor is disconnected from the original charging voltage and reconnected with its negative terminal to the original positive charging voltage. The pulsing nature of the higher voltage output is typically smoothed by the use of an output capacitor. (Rogers, n.d.)

Voltage multiplication greater than twice the supply can be achieved by cascading more than one capacitor series; in practice it is inefficient because of stray capacitance.
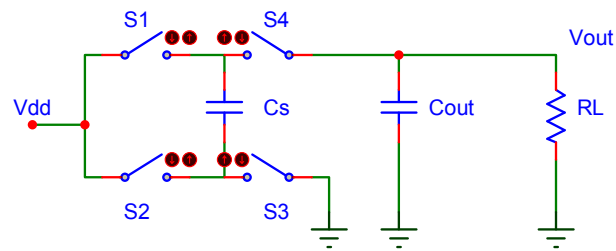
Figure 2.10 Charge pump regulator

If we consider about Dickson charge pump; it contains 2 pumping clocks Φ and $\overline{\Phi}$ which are anti-phase and have a voltage amplitude of V_Φ. C_s shows the stray capacitance.
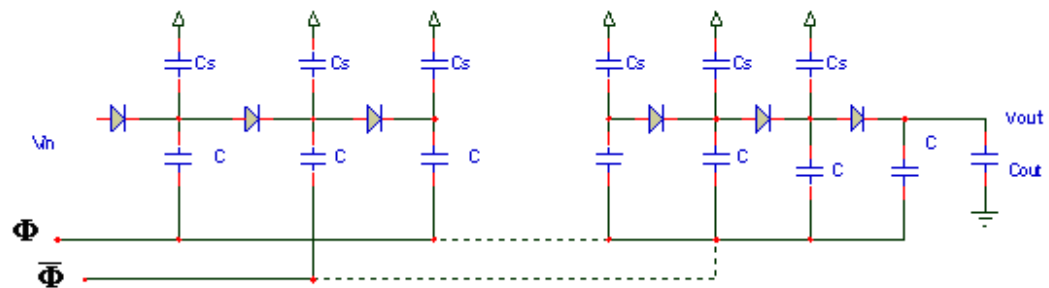
Figure 2.11 Dickson charge pump regulator

After some calculations the equivalent circuit is as below. And the ripple voltage is; $V_R = \dfrac{I_{out}}{f_{osc} \cdot C_{out}}$
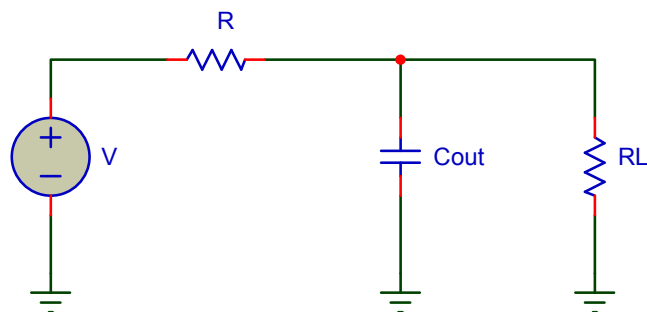
Figure 2.12 Charge pump equivalent circuit

To reduce ripple voltage the frequency of the clocks can be increased or larger output capacitance can be used. However, it would take the charge pump longer to reach its steady state. (Rogers, n.d.)

Figure 2. 13 If larger output capacitance is used, it takes the charge pump longer to reach its steady state.
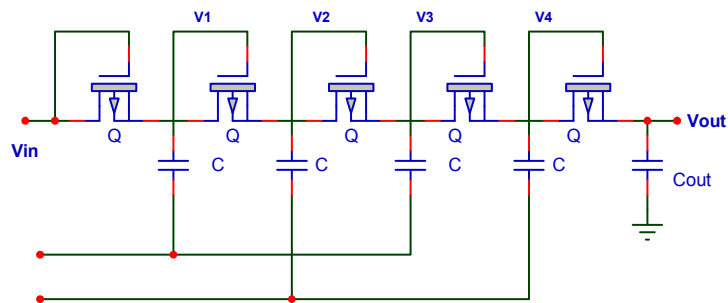
Figure 2.14 A practical implementation of Dickson Charge pump is the multiplier chain implemented using diode-connected Nmos transistors.

$$\Delta V = \frac{C}{C+C_s} \cdot V_\Phi - \frac{I_{out}}{C+C_s} \cdot f_{osc}$$

As the supply voltage decreases V_Φ decreases so does ΔV. It is obvious that Dickson charge pump is not suitable for low voltage operation.

2.2.2.2   Boost Converter

A boost converter, can only produce a higher output average voltage than the input voltage.
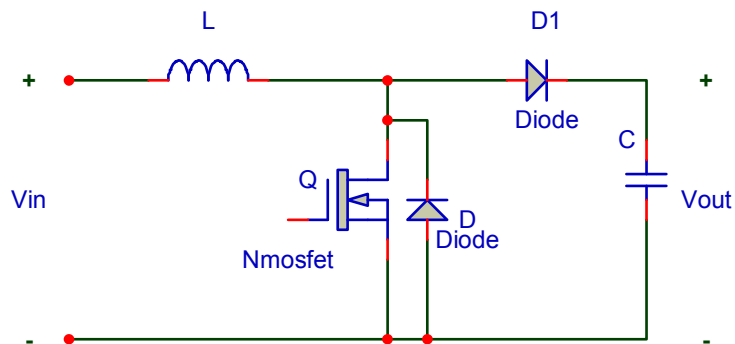
Figure 2.15 Boost converter

In a boost converter, an inductor L is placed in series with the input voltage source V_{in}. The input source feeds the output through the inductor and the diode D_1. In the steady state of operation, when the switch Q is on for a period of T_{on}, the input provides energy to the inductor. During the T_{on} period, inductor current I_L flows through the switch and the input voltage V_{in} is applied to the inductor in the forward direction. Therefore, the inductor current rises linearly from its present value I_{L1} to I_{L2}, During this T_{on} period, the output load current I_{out} is supplied from the output capacitor C_o. The output capacitor value should be large enough to supply the load current for the time period T_{on} with the minimum specified drop in the output voltage.
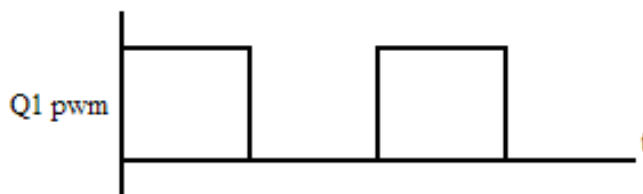
Figure 2.16 Boost converter mosfet gate signal
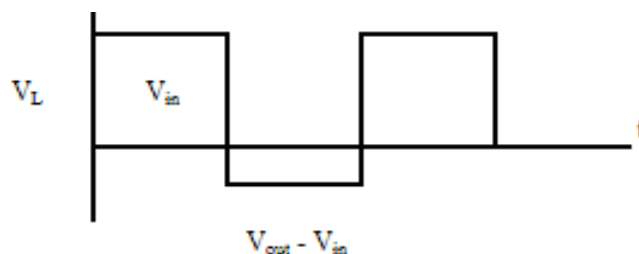
Figure 2.17 Boost converter inductor voltage
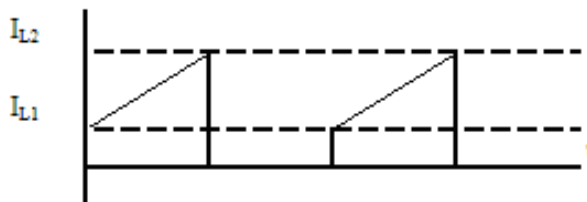
Figure 2.18 Boost converter inductor current
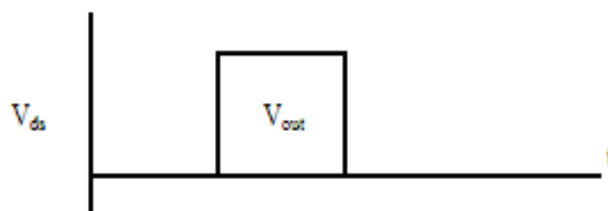
Figure 2.19 Boost converter output voltage

2.2.2.3 Buck – Boost Converter

Buck boost converter is a cascaded connection of buck and boost converters. The output voltage can be greater, less then the input voltage or equal to it.
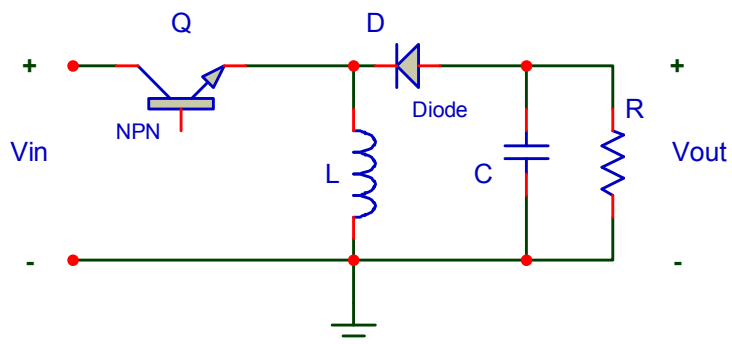
Figure 2.20 Buck - Boost converter circuit

The input electric power is sent to the output circuit by the switching operation of the regulator. The coil of the output circuit stores up the input electric power when switch is on. Then, it slips the electrical energy which was stored up when switch was off to the output and it supplies the load with the electric power. The capacitor of the output circuit does the supply of electric power to the load in the levelling like the coil. The negative potential occurs when slipping the electrical energy which was stored up at the coil to the load. (Kamil, 2007)
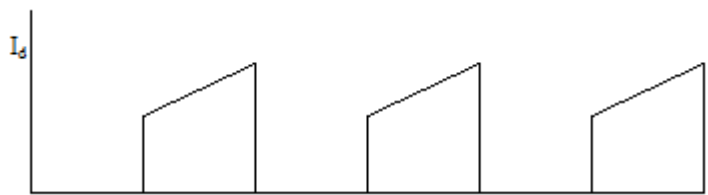
Figure 2.21 Buck - Boost converter diode current
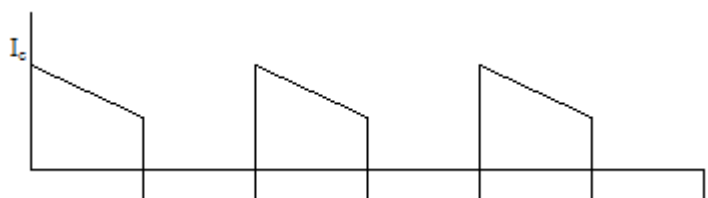
Figure 2.22 Buck – Boost converter capacitor current
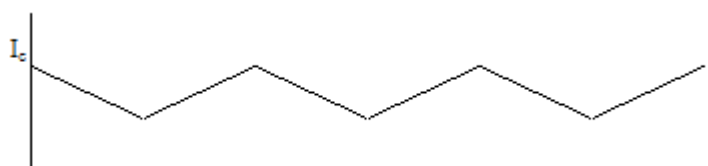
Figure 2.23 Buck – Boost converter inductor current

If D=0.5	$V_o=V_{in}$	(Unity gain)
If $0 \leq D < 0.5$	$V_o<V_{in}$	(Buck)
If $0.5 \leq D < 1$	$V_o>V_{in}$	(Boost)

One fundamental difference between buck-boost regulators of any topology and the buck regulator or the boost regulator is that the buck-boosts never connect the input power supply directly to the output. Both the buck and the boost regulator connect V_{in} to V_o (across the inductor and switch/diode) during a portion of their switching cycles, and this direct connection gives them better efficiency. (National Semiconductor, n.d.)

2.2.2.4 Sepic Converter

Sepic converter (single ended primary inductor converter) , is a dc-dc converter. The output voltage can be less than, greater than or equal to the input voltage. The

biggest advantage of sepic converter over buck-boost converter is the non-inverted output.
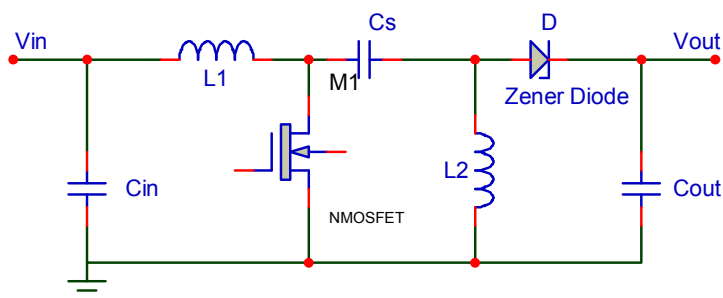
Figure 2.24 Sepic converter circuit

If I_{L1} never falls to 0, the converter is in continuous mode. In the steady state operation the average voltage on C_{in} is equal to V_{in}. C_{in} blocks dc current, so average I_{cin} is 0, and the only source for load current is average I_{L2}. Therefore, the average current through L_2 is the same as the average load current and is independent of the input voltage.
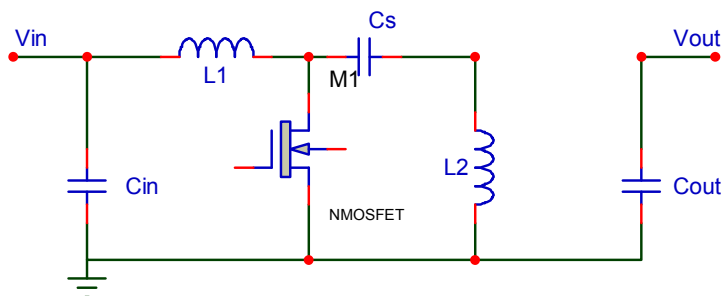
Figure 2.25 Sepic converter when the switch is on

When switch is on the input inductor is charged from the source, and the second inductor is charged from the first capacitor. No energy is supplied to the load capacitor during this time. (Ridley, 2006)
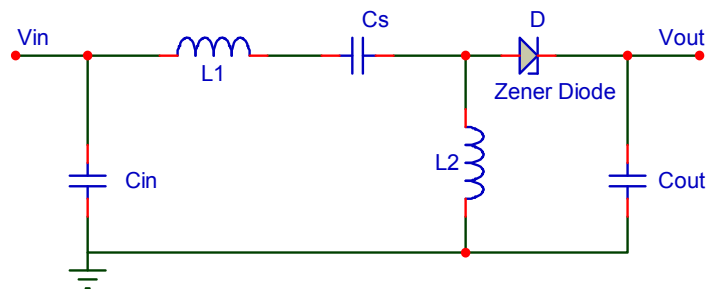
Figure 2.26 Sepic converter when the switch is off

With the switch off, both inductors provide current to the load capacitor.
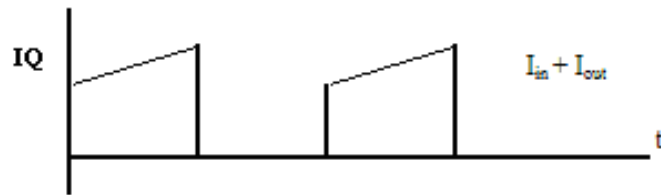
Figure 2.27 Sepic converter mosfet current
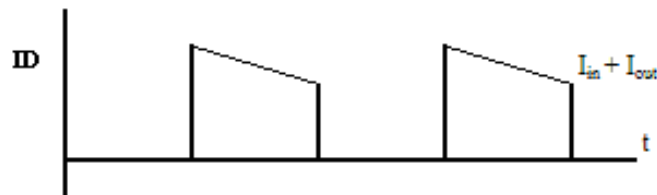
Figure 2.28 Sepic converter diode current
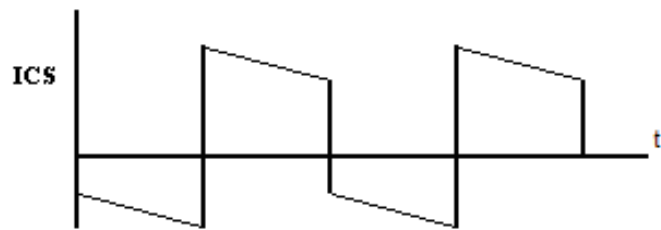
Figure 2.29 Sepic converter C_s current
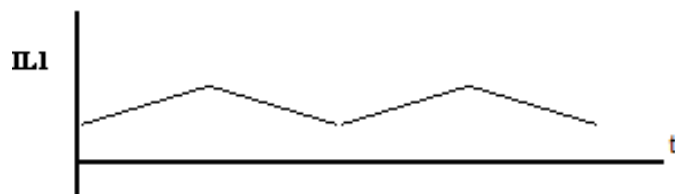
Figure 2.30 Sepic converter L_1 current
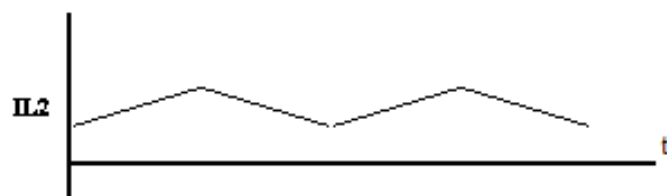
Figure 2.31 Sepic converter L_2 current

In continuous conduction mode;

$$D = \frac{V_{out} + V_D}{V_{in} + V_{out} + V_D}$$

$$L_1 = L_2 = L = \frac{V_{in(min)}}{\Delta I_L \cdot f_{sw}} \cdot D_{max}$$

2.2.2.5 Cuk Converter

The Cuk Converter has an output voltage magnitude that is either greater than or less than the input voltage magnitude, with an opposite polarity. The converter design based on the principle of using two buck–boost converters to provide an inverted dc output voltage. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. (Wikipedia, n.d.)
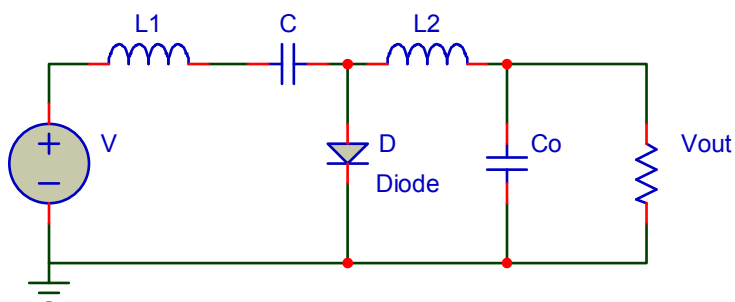
Figure 2.32 Cuk converter, when the switch is off
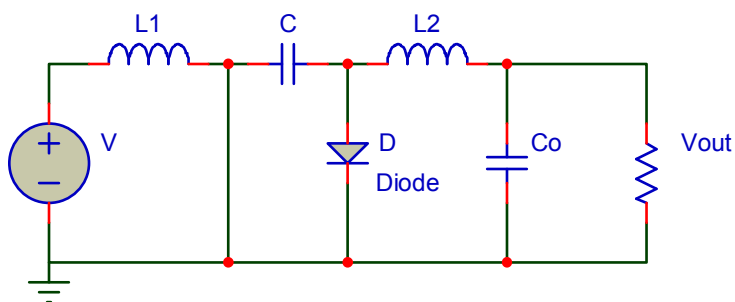
Figure 2.33 Cuk converter, when the switch is on

The operation of the basic Cuk converter in steady state consists of 2 states of transistor. In the first state when the transistor is off, the inductor currents flow through the diode and energy is stored in the transfer capacitor from the input and the inductor L_1. The energy stored in the inductor L_2 is transferred to the output. As a result, both of the inductor currents are linearly decreasing in the off-state. In the second state when the transistor is on, the inductor currents flow through the transistor and the transfer capacitor discharges while energy is stored in the inductor L_1. As the transfer capacitor discharges through the transistor, energy is stored in the inductor L_2. Consequently, both of the inductor currents are linearly increasing in the on-state. (Skvarenina, 2002)

$$I_{L1} \cdot t_{off} = I_{L2} \cdot t_{on} \qquad \frac{I_o}{I_i} = \frac{1-D}{D} \qquad \frac{V_o}{V_i} = \frac{D}{1-D}$$
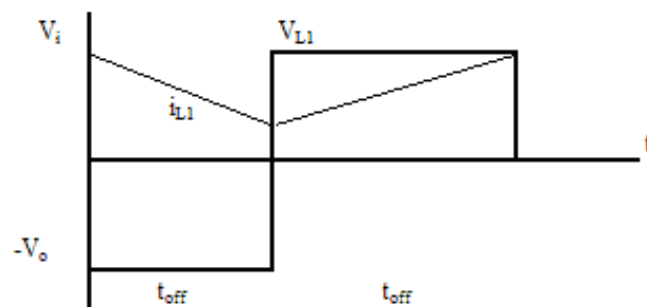
Figure 2.34 Cuk converter, L_1 voltage and current
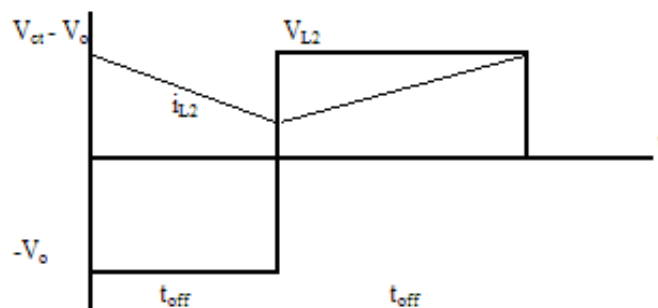
Figure 2.35 Cuk converter, L_2 voltage and current

2.2.2.6 Forward Converter

A forward converter is a transformer-isolated converter based on the basic buck converter topology.
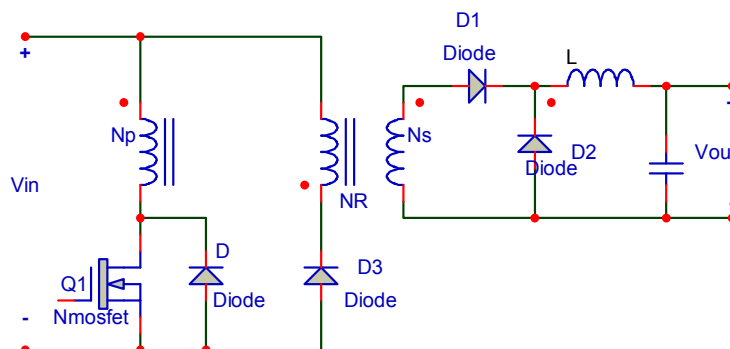
Figure 2.36 Forward converter circuit

In a forward converter, a switch is connected in series with transformer primary. Transformer is used to step down the primary voltage and provides isolation between V_{in} and V_{out}. (Kamil, 2007)

In steady state operation, when the switch is on state, the dot end of the windings are positive relative to the non-dot end. D_1 is forward biased, D_2 and D_3 are reverse biased. As the input voltage V_{in} is applied across the transformer primary, the magnetizing current I_M increases linearly from its initial zero value to a final value with a slope of V_{in}/L_M, where L_M is the magnetizing inductance of the primary winding. The total current that flows through the primary winding is this magnetizing current plus the inductor current (I_L) reflected on the primary side. This total current flows through the mosfet during the T_{on} period. The voltage across the diode D_2 is equal to the input voltage multiplied by the transformer turns ratio (N_S/N_P). In the case of a forward converter, the voltage applied across the inductor L in the forward direction during the T_{on} period, neglecting the transformer losses and the diode forward voltage drop. (Kamil, 2007)
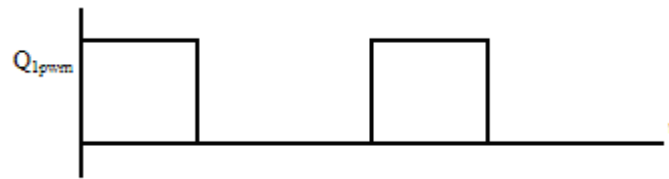
Figure 2.37 Forward converter mosfet gate voltage
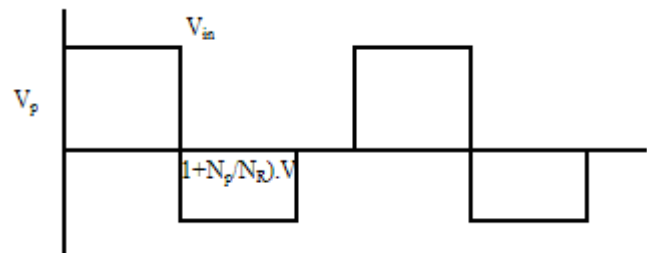
Figure 2.38 Forward converter primary side voltage
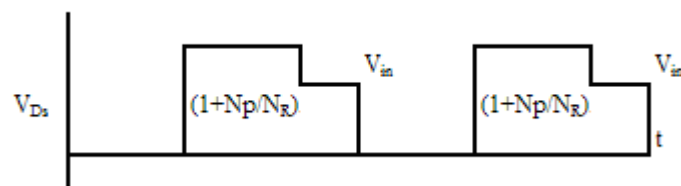
Figure 2.39 Forward converter mosfet voltage

Figure 2.40 Forward converter L current

$$(V_{in} \cdot \frac{N_s}{N_p} - V_{out}) \cdot T_{on} = V_{out} \cdot T_{off} \qquad \text{and} \qquad V_{out} = V_{in} \cdot \frac{N_s}{N_p} \cdot D$$

2.2.2.7 Flyback Converter

Flyback is a version of buck-boost converter. The flyback converter provide isolation between V_s and V_o. The output voltage is not inverted as in simpler buck boost version.

The transformer is used for dual purpose. It transfers energy from the source to the output and provides input to output voltage.

$$N_p \cdot \left(\frac{d_\Phi}{d_t} \right) = L_p \cdot \left(\frac{d_i}{d_t} \right) \qquad\qquad N_s \cdot \left(\frac{d_\Phi}{d_t} \right) = L_s \cdot \left(\frac{d_i}{d_t} \right)$$

Φ is the flux density.
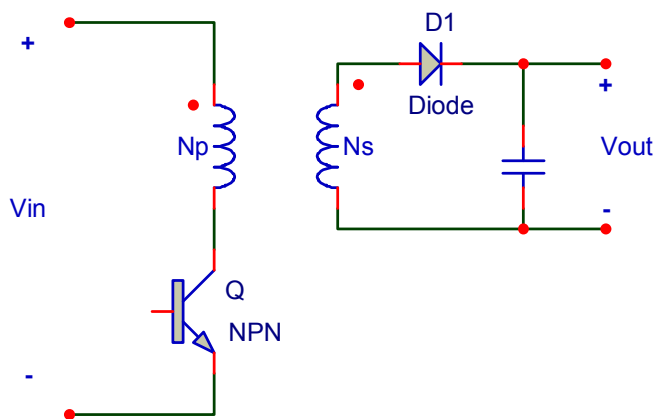
Figure 2.41 Flyback converter circuit
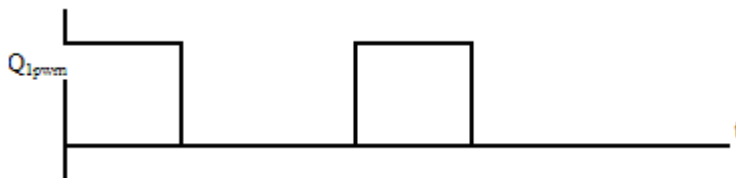
Figure 2.42 Forward converter mosfet gate signal
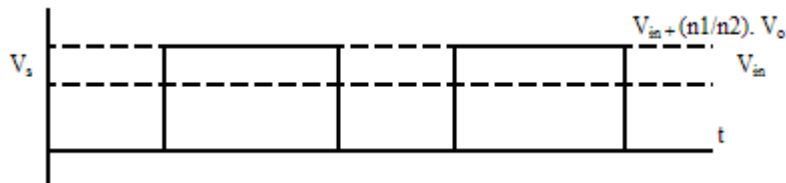
Figure 2.43 Forward converter secondary side voltage
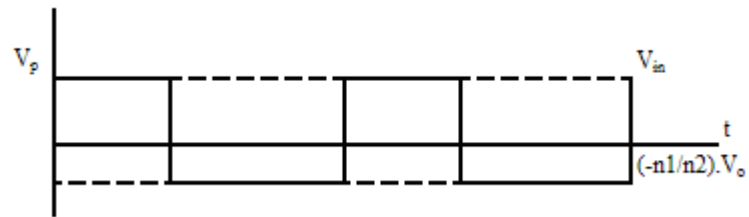
Figure 2.44 Flyback converter primary side voltage
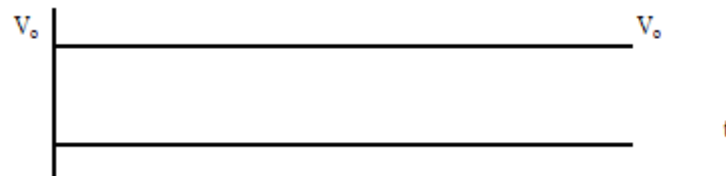
Figure 2.45 Flyback converter output voltage
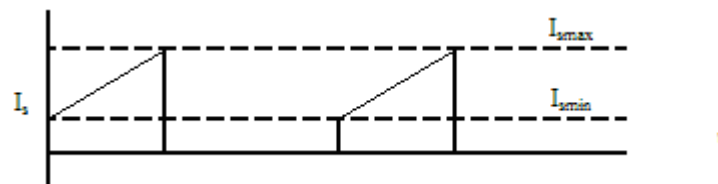
Figure 2. 46 Flyback converter secondary side current
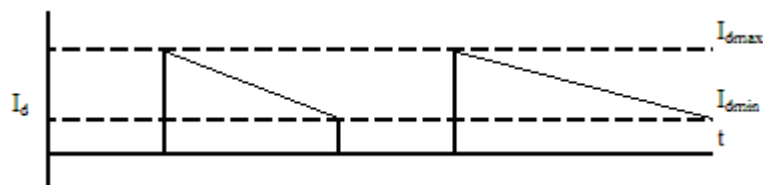
Figure 2.47 Flyback converter diode current

2.2.2.8 Push-Pull Converter

A push-pull converter is a transformer-isolated converter based on the basic forward topology.

The high-voltage DC is switched through the center-tapped primary of the transformer by two switches, Q_1 and Q_2, during alternate half cycles. These switches create pulsating voltage at the transformer primary winding. The transformer is used to step down the primary voltage and to provide isolation between the input voltage source V_{in} and the output voltage V_{out}. (Kamil, 2007)
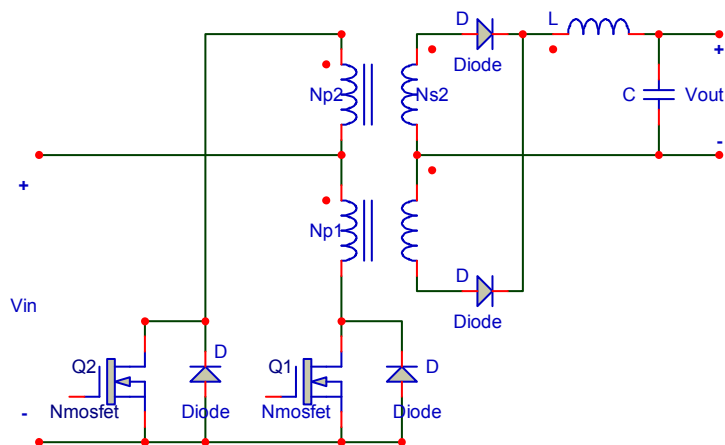
Figure 2.48 Push – Pull converter circuit
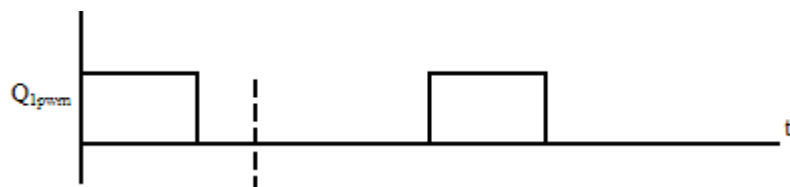
Figure 2.49 Push – Pull converter Q_1 mosfet gate signal
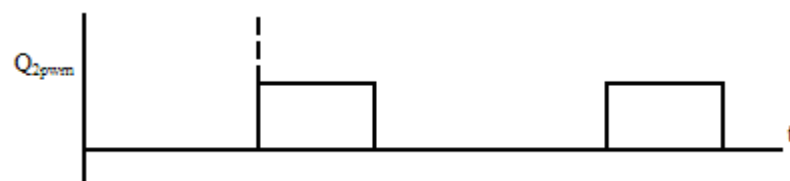
Figure 2.50 Push – Pull converter Q_2 mosfet gate signal
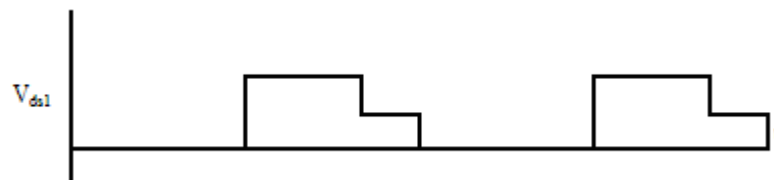
Figure 2.51 Push – Pull converter Q_1 mosfet voltage
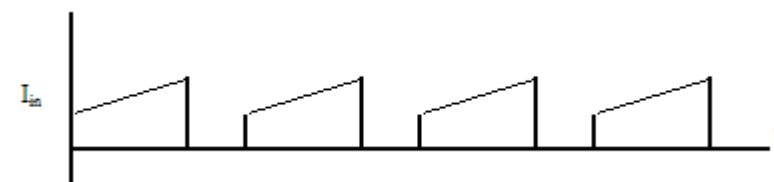
Figure 2.52 Push – Pull converter input current
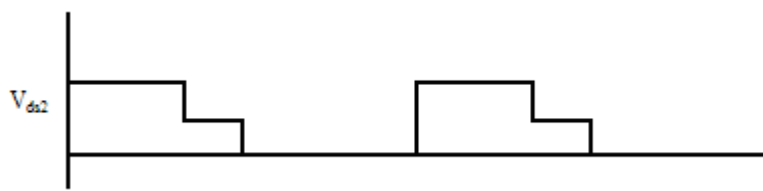
Figure 2.53 Push – Pull converter Q_1 mosfet voltage
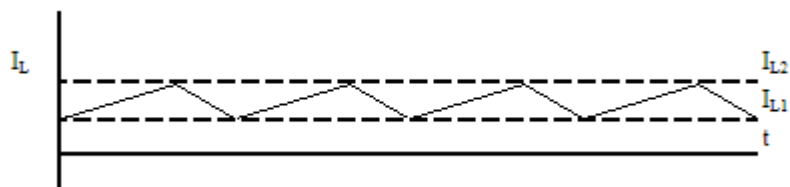
Figure 2.54 Push – Pull converter L current

2.2.2.9 Half Bridge Converter

Half Bridge converter operates in much the same fashion as the push – pull circuit.
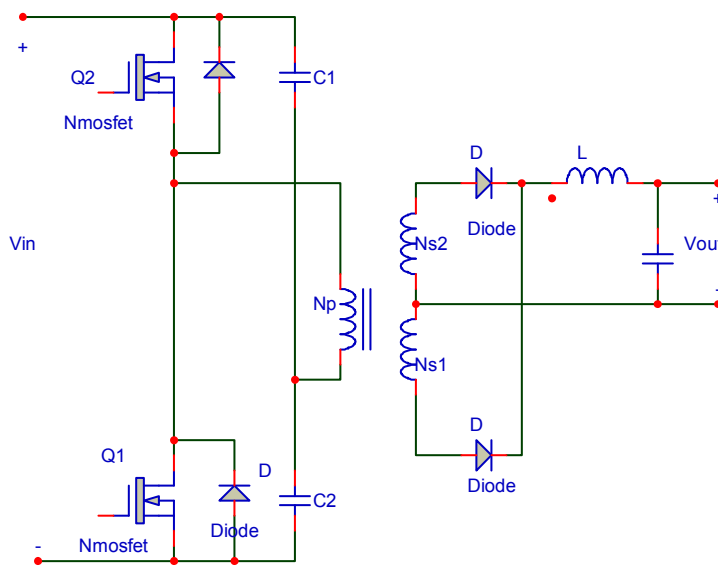
Figure 2.55 Half Bridge converter circuit

The input capacitors C_1 and C_2 split the input voltage equally so that when either transistor turns on, the transformer primary sees $V_{in}/2$. Consequently note no factor of "2" in the following transfer equation:

$$V_o = V_{in} \cdot \left(\frac{N_2}{N_1} \right) \cdot \left(\frac{t_{on}}{T} \right)$$

Since the two transistors are connected in series, they never see more than the input voltage V_{IN} plus the inevitable switching transient voltages. The necessity of a dead time is even more obvious here since the simultaneous conduction of both transistors results in a dead short across the input supply. Anti-parallel ultra-fast diodes return the magnetization energy as in the push-pull circuit but alternately to capacitors C_1 and C_2. This circuit has the slight inconvenience of requiring an isolated base drive to Q_1, but since most practical base drive circuits use a transformer for isolation, this shortcoming is hardly worth noting. (National Semiconductor, 2002)

2.2.2.10 Full Bridge Converter

A full-bridge converter is a transformer-isolated buck converter. The transformer primary is connected between the two legs formed by the switches Q_1, Q_4 and Q_3, Q_2. The switches Q_1, Q_2 and Q_3, Q_4 create a pulsating AC voltage at the transformer primary. The transformer is used to step down the pulsating primary voltage, as well as to provide isolation between the input voltage source and the output voltage V_{out}. As in half-bridge topology, the voltage stress on the switch is V_{in}. However, voltage applied on the primary when either of the switches is on is half of the input voltage, thereby doubling the switch current. In a push-pull topology, voltage applied on the transformer primary when either of the switches is on, is full input voltage; however, the voltage stress of the switch is twice the input voltage A full-bridge converter configuration retains the voltage properties of the half-bridge topology, and the current properties of push-pull topology. (Kamil, 2007)
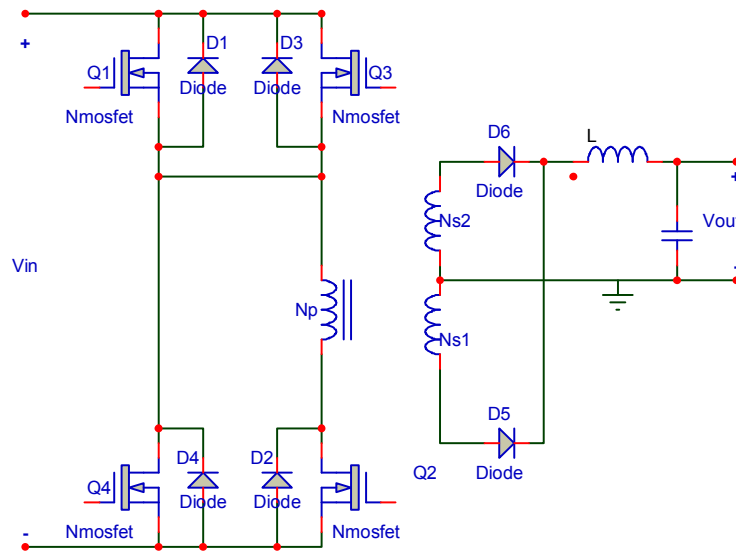
Figure 2.56 Full bridge converter circuit

The diagonal switch pairs, Q_1 Q_2 and Q_3 Q_4, are switched alternately at the selected switching period. In the steady state of operation when the diagonal switch pair, Q_1 Q_2, is on for a period of T_{on}, the dot end of the winding becomes positive with respect to the non-dot end. The diode D_4 become reverse-biased and diode D3 becomes forward-biased. The diode D_3 carries the full load current through the secondary winding N_{S1}.

At the end of the on period, when the switch pair Q_1 Q_2 is turned off, and when it remains off for the rest of the switching period T_S, the switch pair Q_3 Q_4 will be turned on after half of the switching period $T_S/2$,. Therefore, during the T_{OFF} period, all four switches are off. When the switch pair Q_1 Q_2 is turned off, the body diode of the switch pair Q_3 Q_4 provides the path for the leakage energy stored in the transformer primary. The output rectifier diode D_4 becomes forward-biased, and it carries half of the inductor current through the transformer secondary N_{S2}. Half of the inductor current is carried by the diode D_3 through the transformer secondary N_{S1}. Therefore, the net voltage applied across the secondary during T_{OFF} period is zero as previously discussed in half-bridge topology operation. This keeps the flux density in the transformer core constant to its final value of B_2. The output voltage V_{out} is applied to the inductor L in the reverse direction when both switches are off. (Kamil, 2007)
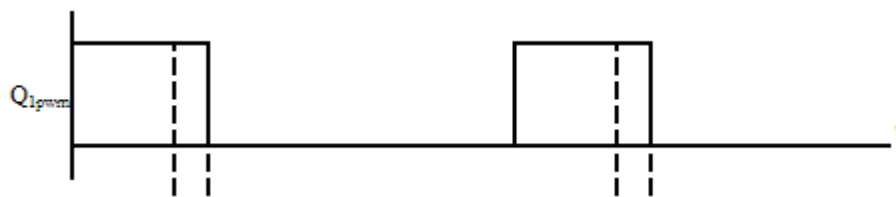
Figure 2.57 Full Bridge converter Q_1 mosfet gate signal
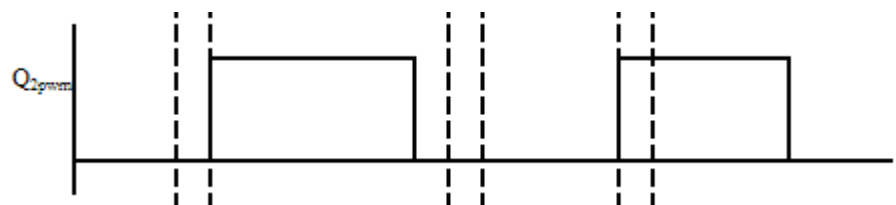
Figure 2.58 Full Bridge converter Q_2 mosfet gate signal
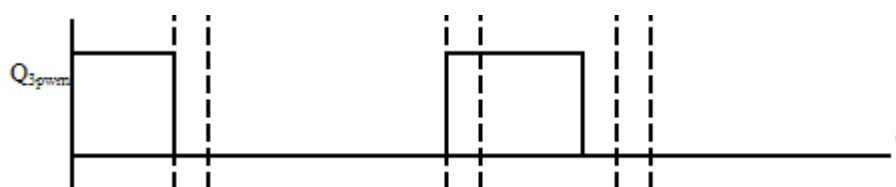
Figure 2.59 Full Bridge converter Q_3 mosfet gate signal
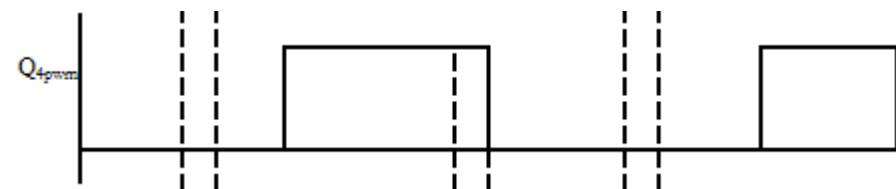
Figure 2.60 Full Bridge converter Q_4 mosfet gate signal
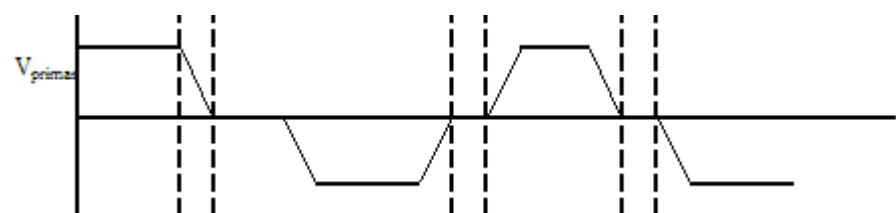
Figure 2.61 Full Bridge converter primary side voltage
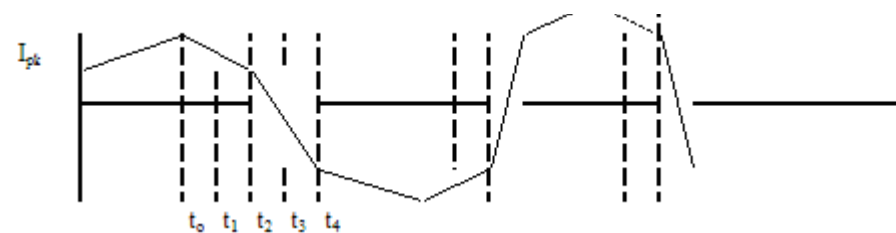
Figure 2.62 Full Bridge converter L current

2.3 Comparison of Linear and Switching Regulators

After examining the linear and switching regulators, the basic properties are compared at the following table.

Table 2.1 Linear and Switching regulators comparison (Rahman, 2007)

	Linear	*Switching*
Function	Only steps down; input voltage must be greater than output.	*Steps up, steps down or inverts.*
Efficiency	Low to medium, but actual battery life depends on load current and battery voltage over time; high if V_{in} - V_{out} is small.	*High, except at very low load currents (uA), where switch mode quiescent current is usually higher.*
Waste heat	High, if average load and/or input/output voltage difference is high.	*Low, as components usually run cool for power levels below 10W.*
Complexity	Low, which usually requires only the regulator and low-value bypass capacitors.	*Medium to high which usually requires inductor, diode, filter caps in addition to IC, for high power circuits external FETs are required.*
Size	Small to medium in portable designs, but may be larger if heat sinking is needed.	*Larger than the linear at low power, but smaller at power levels for which linear requires heat sink.*
Total cost	Low	*Medium to high, largely due to external components.*
Ripple / Noise	Low; no ripple, low noise, better noise rejection.	*Medium to high, due to ripple at switching rate.*

CHAPTER THREE

BUCK CONVERTER TOPOLOGY

3.1 Introduction

There are three basic switching power supply topologies in common use. These are the buck, boost, and buck-boost. These topologies are nonisolated, that is, the input and output voltages share a common ground. (Rogers, 1999)

The most common and probably the simplest converter topology is the buck converter, sometimes called a step-down converter. Power supply designers choose the buck power stage because the output voltage is always less than the input voltage in the same polarity and is not isolated from the input. (Rogers, 1999)
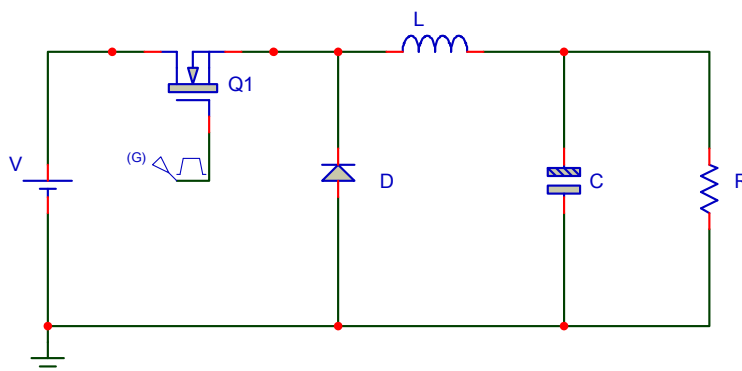
Figure 3.1 Buck converter circuit

During normal operation of buck converter, the Q_1 transistor is repeatedly switched on and off. The duration of on and off modes are governed by control circuit. The switching action causes a train of pulses at the junction of Q_1, C, and L which is filtered by the L/C output filter to produce a dc output voltage, V_O. (Rogers, 1999)

Buck converter can operate in continuous or discontinuous inductor current mode. Continuous inductor current mode is characterized by current flowing continuously in the inductor during the entire switching cycle in steady state operation.

Discontinuous inductor current mode is characterized by the inductor current being zero for a portion of the switching cycle. It starts at zero, reaches a peak value, and returns to zero during each switching cycle. (Rogers, 1999)

It is very desirable for a power stage to stay in only one mode over its expected operating conditions, because the power stage frequency response changes significantly between the two modes of operation. (Rogers, 1999)

For buck converter the Mosfet switch can be n-channel or p-channel. N-channel mosfet advantage is its lower $R_{DS(on)}$, but the driver circuit is more complicated because it needs a floating drive. For same die size P-channel mosfet has higher $R_{DS(on)}$ and does not require a floating drive circuit. (Rogers, 1999)

The two stages of buck converter are shown below.
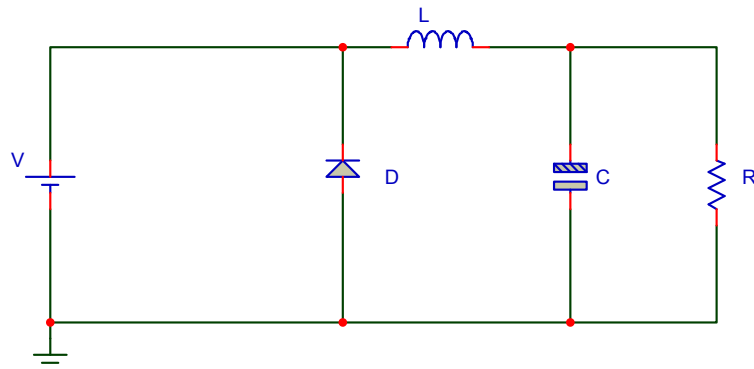
Figure 3.2 Buck converter, when the switch is on
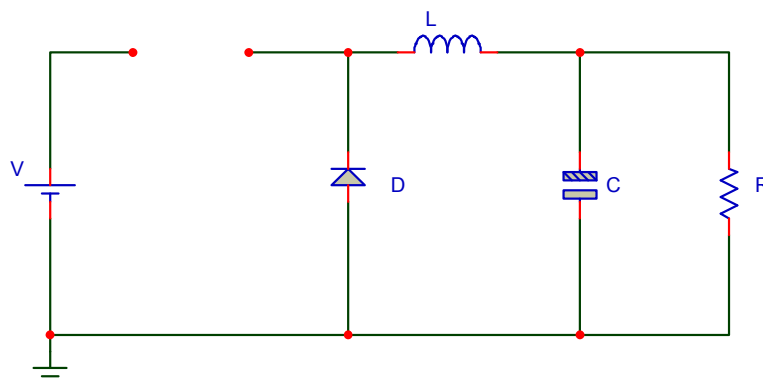
Figure 3.3 Buck converter, when the switch is off

3.1.1 Basic Switching Converter

In this circuit the semi conductor switch is made on and off. When the switch is in A position (on) the output is same as input voltage. If the switch is in B position (off) the output is zero. If the duration of switching period changes, the average output voltage changes. But the output is not pure dc.
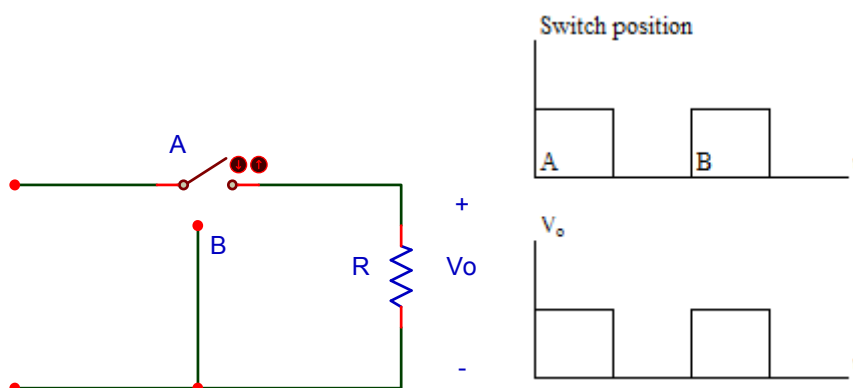
Figure 3.4 Basic switching converter circuit, switch position and output voltage

$$V_o = \int_0^T V_o(t) \cdot D \cdot T$$

3.1.1.1 Adding of Inductor

To reduce the ripple an inductor is connected in series with resistive load. The current on the load is same as inductor current. As it is known, the current passing through inductor can not change instantaneously.

When the switch is in A position, the energy stored in the inductor increases as well as the current. When the switch is in position B, the inductor acts as a source. The current on the inductor falls and the energy stored in inductor decreases. The linearity of the rising and falling currents depends on switching periods.
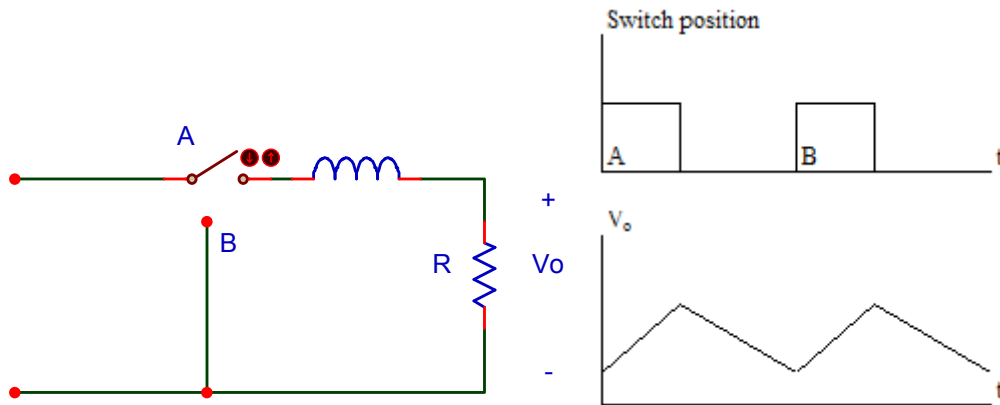
Figure 3.5 Basic switching converter circuit with inductor, switch position and output voltage

3.1.1.2 Adding of Capacitor

The inductor smoothes the current passing through the load. The capacitor reduces the ripple content in voltage across the load because the voltage on the capacitor can not change instantaneously. The combination of LC filter reduces the ripple in output efficiently to a very low level.
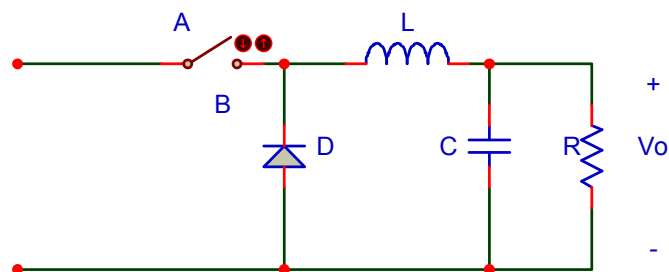
Figure 3.6 Basic switching converter with inductor and capacitor

3.1.1.3 Controlling The Switch

To stabilize the output controlling of switch is very important.

The switch is controlled with Pwm. Controller compares a portion of the rectified dc output with a voltage reference (V_{ref}) and varies the Pwm duty cycle to maintain a constant dc output voltage. If the output voltage wants to increase, the pwm lowers

its duty cycle to reduce the regulated output, keeping it at its proper voltage level. Conversely, if the output voltage tends to go down, the feedback causes the pwm duty cycle to increase and maintain the proper output.
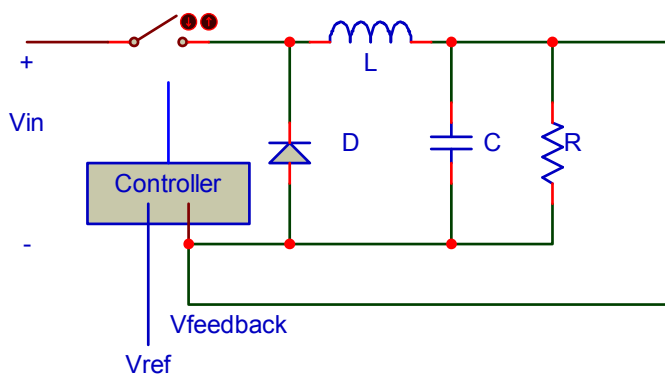
Figure 3.7 Switch is controlled with pwm signal

3.2 Continuous Conduction Mode

In continuous conduction mode (CCM) the inductor current never falls to zero. During the switch is on, switch conducts the source and inductor. Current pass through the switch and the diode is forward biased.
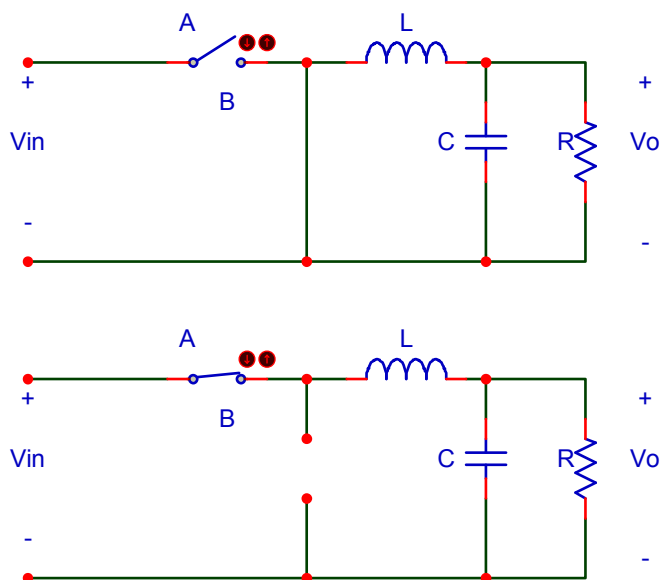
Figure 3.8 Buck converter in both on and off states

The positive V_L value makes the i_L increases linearly and continuously. When the switch is off, because of the energy stored on the inductor , I_L keeps on flowing at the same direction. Now, the current flows through the diode.

$$V_L = V_{in} - V_o \qquad \text{when} \qquad 0 < t < \text{ton}$$

The definition of continuous mode means that the inductance current or voltage is repeated with a time period T.
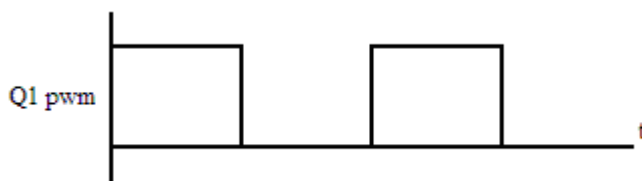
Figure 3.9 Buck converter mosfet gate signal
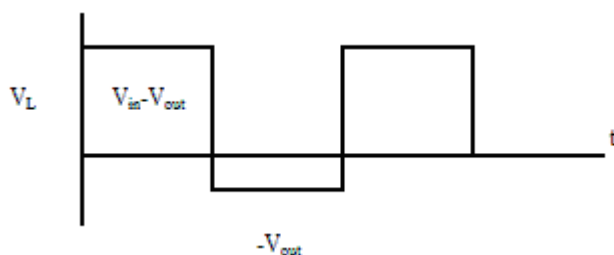
Figure 3.10 Buck converter inductor voltage
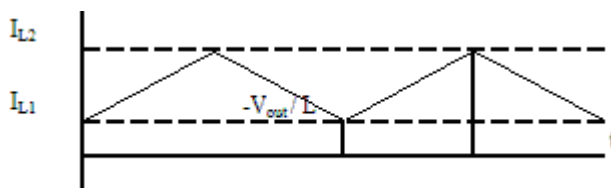
Figure 3.11 Buck converter inductor current
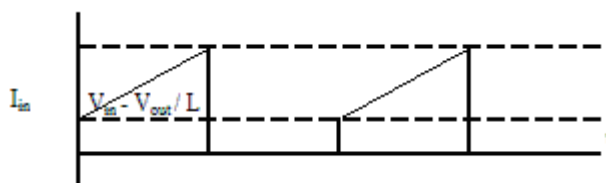
Figure 3.12 Buck converter input current

$$i_L(T_s) = i_L(0) + \left(\frac{1}{L}\right) \cdot \int_0^{T_s} V_L(t) \cdot dt \Rightarrow i_L(T_s) - i_L(0) = \left(\frac{1}{L}\right) \cdot \int_0^{T_s} V_L(t) \cdot dt \quad \text{when } t > t1$$

$$\int_0^{T_s} V_L(t) \cdot dt = \int_0^{t_{on}} V_L(t) \cdot dt + \int_{t_{on}}^{T_s} V_L(t) \cdot dt = 0$$

$$(V_d - V_0) \cdot t_{on} - V_o \cdot (T_s - t_{on}) = 0$$

$$\frac{V_o}{V_d} = \frac{t_{on}}{T_s} = D \quad \text{(duty cycle)}$$

It is assumed to output capacitor is too large. This assumption is true, because to have rippleness output voltage, capacitor is chosen large.

If the power loss on the circuit elements neglected;

Input power, Pd = Output Power, Po

$$V_d \cdot I_d = V_o \cdot I_o$$

3.3 Boundary Between Continuous Conduction Mode and Discontinuous Conduction Mode

During the boundary mode the voltage and current of inductor waveforms are as below.
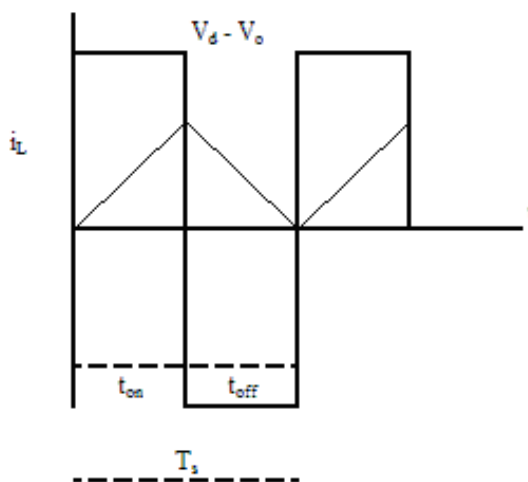
Figure 3.13 Buck converter at boundary condition

$$\left(\frac{1}{2}\right) \cdot \left[\left(i_{Lpeak} \cdot t_{on}\right) + \left(i_{Lpeak} \cdot t_{off}\right)\right] \cdot \left(\frac{1}{T_s}\right) = I_L$$

$$\left(\frac{1}{2}\right) \cdot i_{Lpeak} = I_{LB}$$

$$I_{LB} = \frac{t_{on} \cdot \left(V_d - V_o\right)}{2 \cdot L} = \frac{D \cdot T_s}{2 \cdot L} \cdot \left(V_d - V_o\right)$$

$$L_{boundary} = V_{out} \cdot \frac{1-D}{2 \cdot I_{LB} \cdot f}$$

$L_{boundary}$ is the value of L at the boundary of continuous conduction. The maximum $L_{boundary}$ is where $D \rightarrow 0$,

Thus $L > \dfrac{V_{out}}{2 \cdot I_{LB} \cdot f}$ will guarantee continuous conduction for all D. The continuous conduction can be achieved more easily when I_{LB} and f are large.

3.4 Discontinuous Conduction Mode

At low load periods, the converter may sleep into the discontinuous conduction mode. This occurs when the inductor current coasts to zero. At that moment the capacitor attempts to reverse i_L and 'backfeed' the inductor, but reversal is prevented by the freewheeling diode. The freewheeling diode opens, the circuit assumes the topology shown in following figure until the switch closes again. During the third state, the all load power is provided by the capacitor.
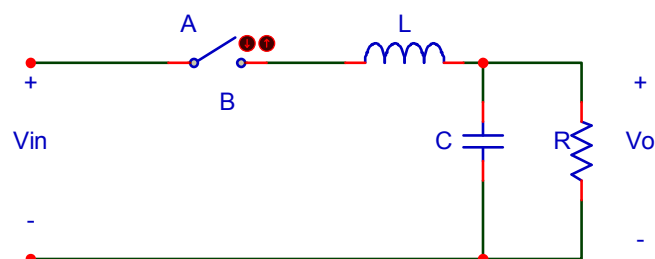
Figure 3.14 Buck converter in DCM 3rd state

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During discontinuity the voltage across the inductor is zero. The corresponding voltage waveform is as below.
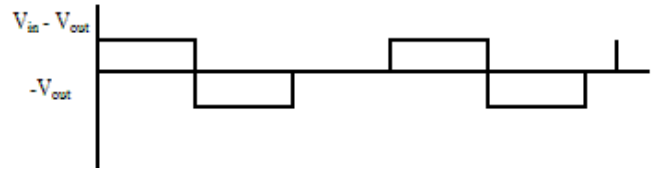
Figure 3.15 Discontinuity of Buck converter voltage

In DCM the properties of the converter changes;

- The converter conversion ratio D becomes load dependent
- Output impedance is increased
- Control of output voltage may be lost when load is removed

V_{in} is constant, current is discontinuous

When;

$$I_{LB} = V_{out} \cdot \frac{1-D}{2 \cdot L \cdot f} \quad \text{and} \quad V_{out} = \frac{V}{R} \quad \text{the minimum inductor value is} \quad L_{min} = \frac{(1-D) \cdot R}{2 \cdot f}$$

and the maximum inductor value is found as the following.

$$\frac{dI_{LB}}{dD} = \frac{T \cdot V_{in} \cdot (1 - 2 \cdot D)}{2 \cdot L} = 0 \rightarrow D = 0,5$$

$I_{LB(max)} = $ T. Vin / 8L is maximum boundary current.

When DCM existed, the relationship between input and output voltage is not D. If T, L,V in and D values are fixed at constant values and load resistance is increased then the current falls. When the current falls under the I_{LB} value, current becomes discontinuous.
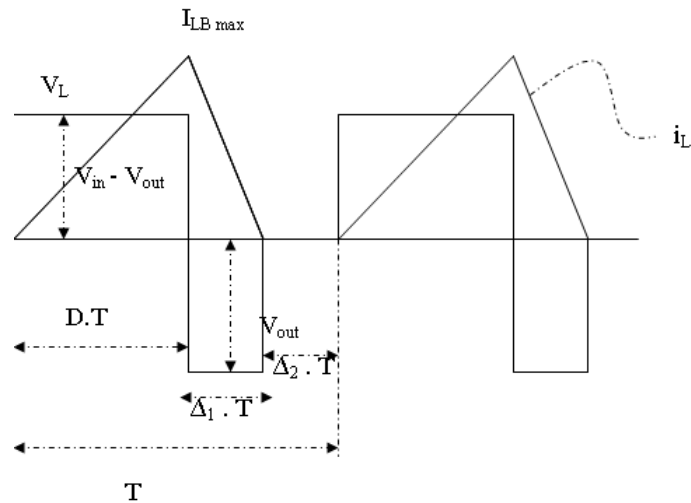
Figure 3.16 Buck Converter in DCM voltage and current waveforms

During the time the inductance current is zero $\Delta_2 \cdot T$, the power applied to load resistor is supplied by filter capacitor. At that time $V_L = 0$.

When the inductor voltage integral over one period is 0, the relationship between Vin and Vout is found. This is inductor volt-second balance equation.

$$\left(V_{in} - V_{out}\right) \cdot D \cdot T - V_{out} \cdot \Delta_1 \cdot T = 0 \rightarrow \frac{V_{out}}{V_{in}} = \frac{D}{D + \Delta_1}$$

From capacitor charge balance equation;
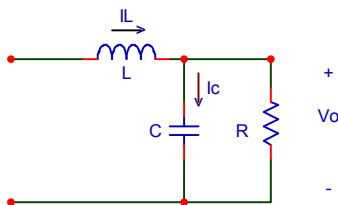
$$i_L(t) = i_C(t) + \frac{V}{R}$$ capacitor charge balance; $i_C = 0$ thus $i_L = 0$

$$i_L(D \cdot T) = I_{LB(max)} = \frac{\left(V_{in} - V_{out}\right) \cdot D \cdot T}{L}$$

average current;

$$i_L = \frac{1}{T} \cdot \int_0^T i_L(t) \cdot dt$$

triangle formula;

$$\int_0^T i_L(t) \cdot dt = \frac{1}{2} \cdot i_{LB(\max)} \cdot (D + \Delta_1) \cdot T$$

$$i_L = \frac{(V_{in} - V_{out}) \cdot D \cdot T \cdot (D + \Delta_1)}{2 \cdot L}$$

equate dc component to dc load current;

$$\frac{V_{out}}{R} = \frac{(V_{in} - V_{out}) \cdot D \cdot T \cdot (D + \Delta_1)}{2 \cdot L}$$

Two equations and two unknowns (V_{out} and Δ_1)

$$V_{out} = \frac{V_{in} \cdot D}{D + \Delta_1} \qquad \text{from inductor volt-second balance}$$

$$\frac{V_{out}}{R} = \frac{(V_{in} - V_{out}) \cdot D \cdot T \cdot (D + \Delta_1)}{2 \cdot L} \qquad \text{from capacitor charge balance}$$

Eliminate Δ_1 and solve for V_{out} ;

$$\frac{V_{out}}{V_{in}} = \frac{2}{1 + \sqrt{\left(1 + \frac{4 \cdot K}{D^2}\right)}}$$

Where $\dfrac{2 \cdot L}{R \cdot T}$ and valid for $K < K_{critic}$ $\qquad\qquad\qquad K_{critic}(D) = D'$
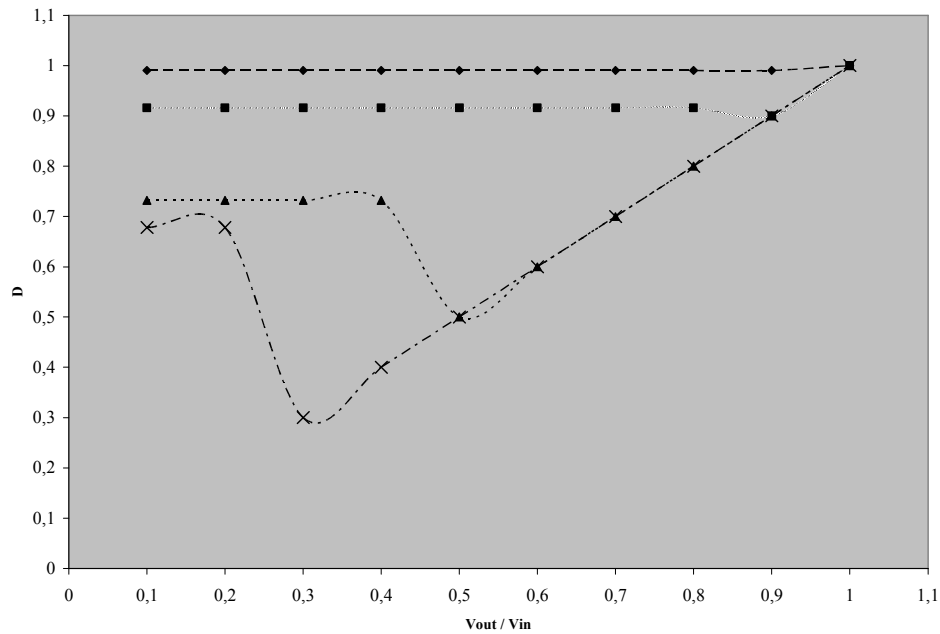
Figure 3.17 D and Vout / Vin relationship at different K values

3.5 Capacitor Ripple Voltage in Continuous Conduction

In ideal conditions, it is supposed that the capacitor value is too high enough to have V_{out} constant value. In practice the capacitor value is limited and the ripple on the capacitor is related with the current pass through the capacitor.

Capacitor current $i_C = i_L - I_{out}$

Capacitor C is charging when i_L is greater than I_{out}, and discharging when i_L is less than I_{out}.
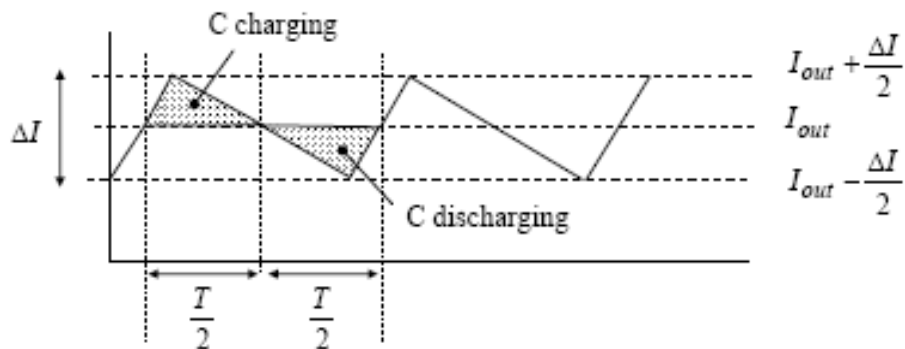
Figure 3.18 Buck converter capacitor charging and discharging periods
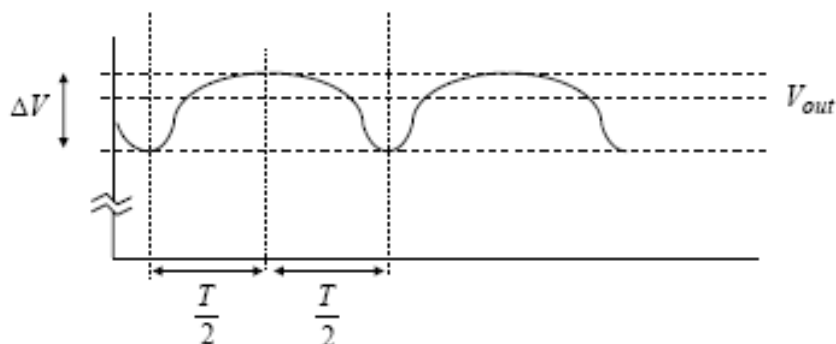
Figure 3.19 Buck Converter capacitor ripple voltage

Each charging and discharging area lasts T/2 seconds, and each area represents a charge increment ΔQ for the capacitor. The net charge flowing into the capacitor must be zero in steady state so that the capacitor voltage is periodic.

Using, $\Delta V = \dfrac{\Delta Q}{C}$ ΔV and the area of the triangular region in figure 4.19 , the peak to peak ripple voltage on C must be; $\Delta V = \dfrac{\Delta Q}{C} = \dfrac{1}{C} \cdot \dfrac{1}{2} \cdot \dfrac{T}{2} \cdot \dfrac{\Delta I}{2} = \dfrac{T \cdot \Delta I}{8 \cdot C}$

For the worst case; $\Delta I = 2.I_{out}$ then the worst case peak to peak voltage ripple on C is; $\Delta V = \dfrac{I_{out}}{4 \cdot C \cdot f}$

CHAPTER FOUR
DESIGN OF DRIVE CIRCUIT FOR LED

4.1 Introduction

The project is designed to provide a stable brightness led backlight. The aim is to protect backlight against high voltage, high current and heat variations.

The project is a combination of 4 subprojects.

- AC / DC rectification part
- DC / DC buck converter part (voltage control card)
- Led Driver part
- Led Panel design
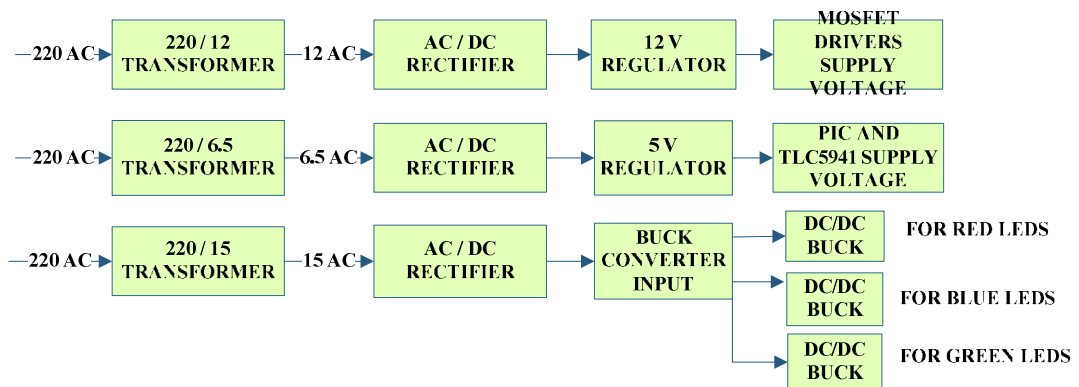
Figure 4.1 Power supply overview of the project

4.2 AC/DC Rectification

The voltage control of the leds is used with buck converter. Buck converter is a dc-dc converter. For the converter input, we need to have a 21V dc. Rectification is necessary not only for buck converter but also other integrated circuits supplies.

In this project it is required to have 21V dc for buck converter input; 5V dc for microcontroller and TLC5941 positive supply; 12V for TC4429 and IR2117 positive supply.
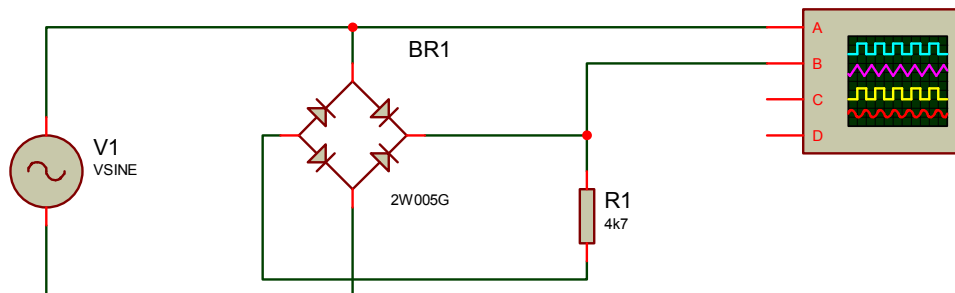
Figure 4.2 Rectifier circuit simulation
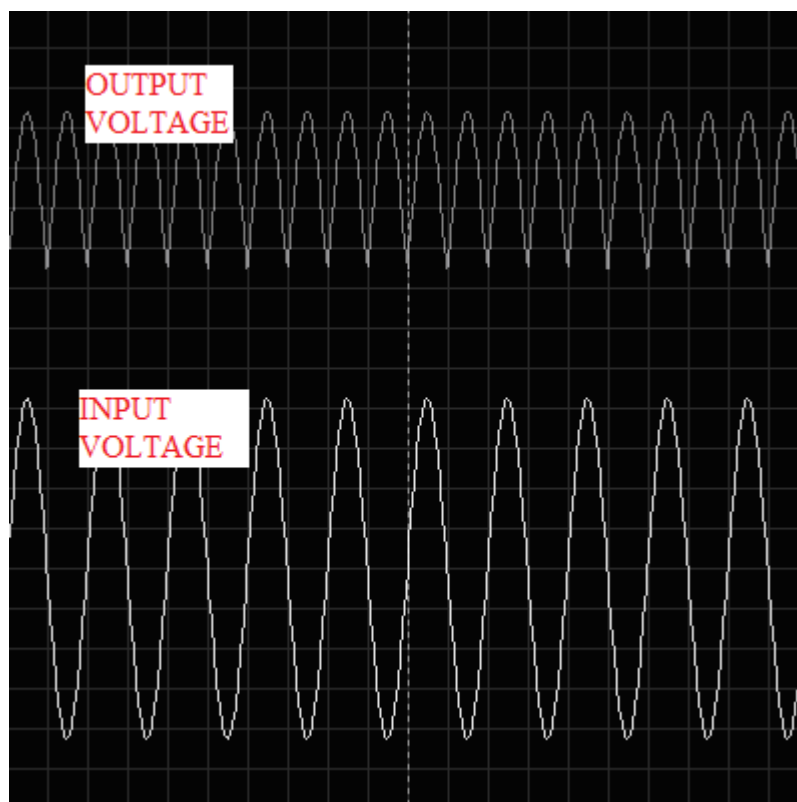
Figure 4.3 Simulation result of rectifier circuit, y=2V/div

The 4 diodes are arranged in "series pairs" with only two diodes conducting current during each half cycle.

The full-wave bridge rectifier gives mean DC value (0.637 Vmax) and the output waveform is twice that of the frequency of the input supply frequency. To increase average DC output level even higher a suitable smoothing capacitor should be connected across the output of the bridge circuit.
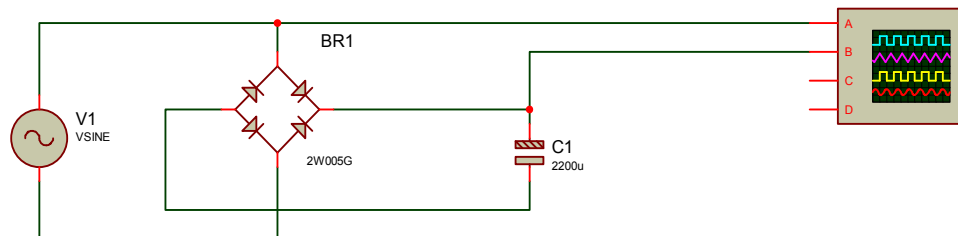
Figure 4.4 Rectifier with filter capacitor simulation
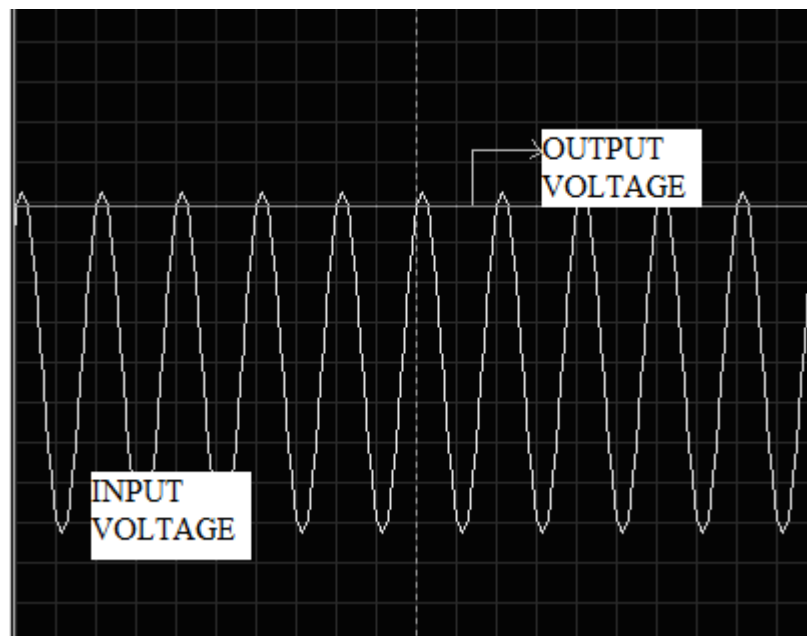
Figure 4.5 Simulation result of rectifier with filter capacitor, y=2V/div

The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth DC output voltage. The value is the $\sqrt{2}$ times of input.

For 220 V/ 6V transformer the rectified value is 8,48 V; to have a 5V dc LM7805 regulator is used.

For 220 V/ 12V transformer the rectified value is 16,97 V to have a 12V dc LM7812 regulator is used.

For 220 V/ 15V transformer the rectified value is 21,2 V. The output is the same as required. No regulator is used.

4.3 Voltage Control Card

After rectification; the next step is voltage controlling. Voltage controlling is very important step to prevent leds from high voltage effects.

As our leds specifications, the required voltages are as below.

$V_{RED, min} = 1.8$ V $\qquad V_{RED, max} = 2.4$ V $\qquad$ Average= 2,1V

$V_{BLUE, min} = 2.8$ V $\qquad V_{BLUE, max} = 3.5$ V $\qquad$ Average=3,15V

$V_{GREEN, min} = 2.9$ V $\qquad V_{GREEN, max} = 3.5$ V $\qquad$ Average= 3,2V

According to led panel board design, there are 4 leds per TLC5941 output channel. So, for our led panel board the required voltages are;

$V_{RED, total} = 8,4$ V

$V_{BLUE, total} = 12,6$ V

$V_{GREEN, total} = 12,8$ V

These voltages will obtained by 3 buck converters. As the required voltages are same for the blue and green leds, the two buck converters are designed with same hardware and software. Just the reference voltages are different.

4.3.1 Component Selection for Green and Blue Buck Converters

4.3.1.1 Inductor Selection

$V_{in} = 21.3$ V

$V_{ave, out} = 12.7$ V

$$D = \frac{12.7}{21.3} = 0.59$$

$f_{sw} = 50$ kHz

Inductor selection is done according to ripple current. As we have 32 parallel led branches and the current of one branch is 20 mA, we totally need 32 x 20 mA = 640 mA. The constant current is a must for led maintenance so the ripple current is accepted as 15 mA. This means 15 /640 = 0.023 nearly %2,3 ripple.

$$L = \frac{di}{dt} = \Delta V$$

$$\Delta V = 21.3 - 12.7 = 8.6\,V$$

$$di = 0.01\,A$$

$$dt = D \cdot \frac{1}{f_{sw}} = \frac{0.59}{50000} = 11.8\,u\sec$$

$$L \cdot \frac{0.015}{11.8 \cdot 10^{-6}} = 8.6$$

$$L = 6.7\,mH$$

As there are standard values for inductors, 6.8 mH inductor is chosen.

4.3.1.2 Capacitor Selection

Capacitor selection is done according to voltage ripple and the inductor value. As it is required 12.7 V, the maximum allowable voltage has chosen as 0.1 V.

From previous chapters, the formula was given as below.

$$C \cdot \frac{dV_c}{dt} = \Delta_i$$

$$V_c = \frac{1}{C} \cdot \int di \cdot dt$$

$$C = \frac{\Delta_i}{8 \cdot f \cdot \Delta V_c} = \frac{0.015}{8 \cdot 50000 \cdot 0.1} = 379 \ nF$$

This is the minimum value of capacitor. In this converter <u>68 uF</u> capacitor is used. Then, the output voltage ripple is;

$$\Delta V_c = \frac{\Delta_i}{8 \cdot f \cdot C} = \frac{0.015}{8 \cdot 50000 \cdot 68 \cdot 10^{-6}} = 55.1 \ \text{mV}$$

The output voltage is nearly constant.
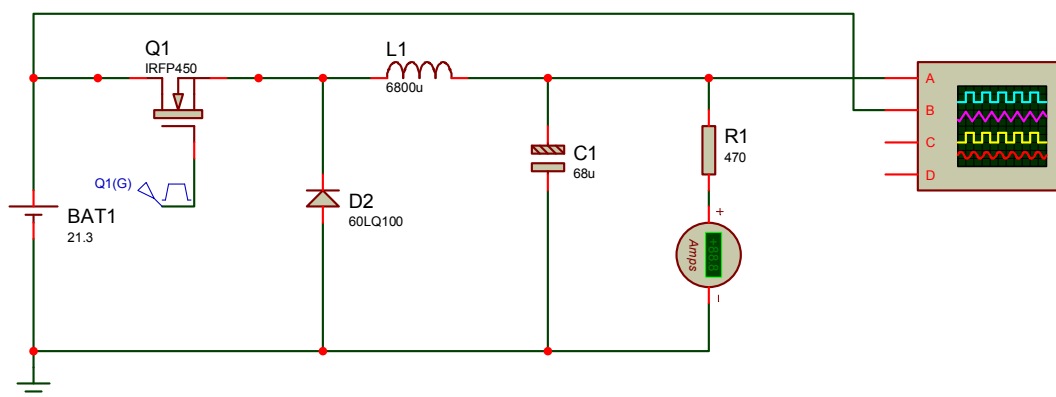
Figure 4.6 Buck converter simulation circuit for green and blue leds
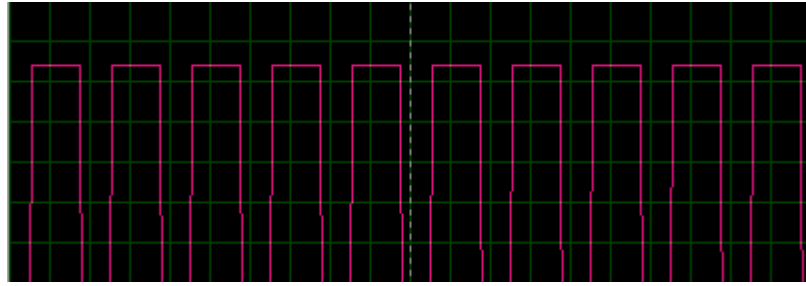
Figure 4.7 Buck converter pwm signal for D=0.59
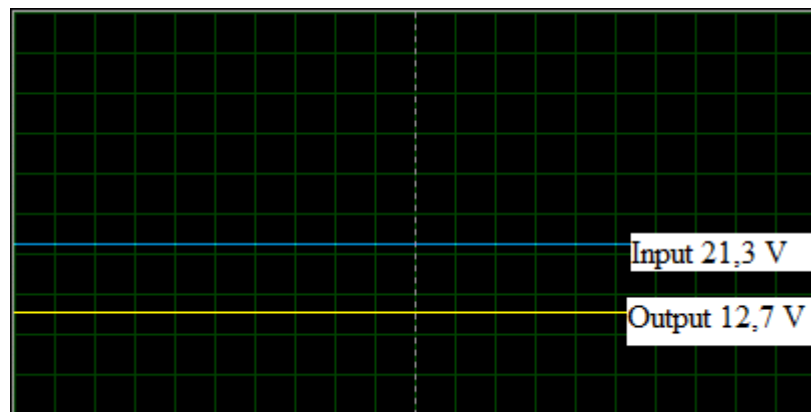
Figure 4.8 Simulation result of buck converter for blue and green leds, y=5V/div

4.3.2 Component Selection for Red Buck Converter

4.3.2.1 Inductor Selection

$$V_{in} = 21.3 \, V$$

$$V_{ave,out} = 8.4 \, V$$

$$D = \frac{8.4}{21.3} = 0.39$$

$$f_{sw} = 50 \, kHz$$

$$L \cdot \frac{d_i}{d_t} = \Delta V$$

$$\Delta V = 21.3 - 8.4 \, V$$

$$di = 0.015 \, A$$

$$dt = D \cdot \frac{1}{f_{sw}} = \frac{0.39}{50000} = 7.8 \, u \sec.$$

$$L \cdot \frac{0.015}{7.8 \cdot 10^{-6}} = 12.9$$

$$L = 6.7 \, mH$$

As there are standard values for inductors, 6.8 mH inductor is chosen. This value is same with the blue and green buck converters.

$$di = \frac{12.9 \cdot 7.8 \cdot 10^{-6}}{6.8 \cdot 10^{-3}} = 0.0149 = 14.9 \, mA$$

4.3.2.2 Capacitor Selection

$$C = \frac{\Delta i}{8 \cdot f \cdot \Delta V_c} = \frac{0.015}{8 \cdot 50000 \cdot 0.1} = 375 \, nF$$

This is the minimum value of capacitor. In this converter 68 uF capacitor is used. Then, the output voltage ripple is;

$$\Delta V_c = \frac{\Delta_i}{8 \cdot f \cdot C} = \frac{0.015}{8 \cdot 50000 \cdot 68 \cdot 10^{-6}} = 55.1 \, mV$$
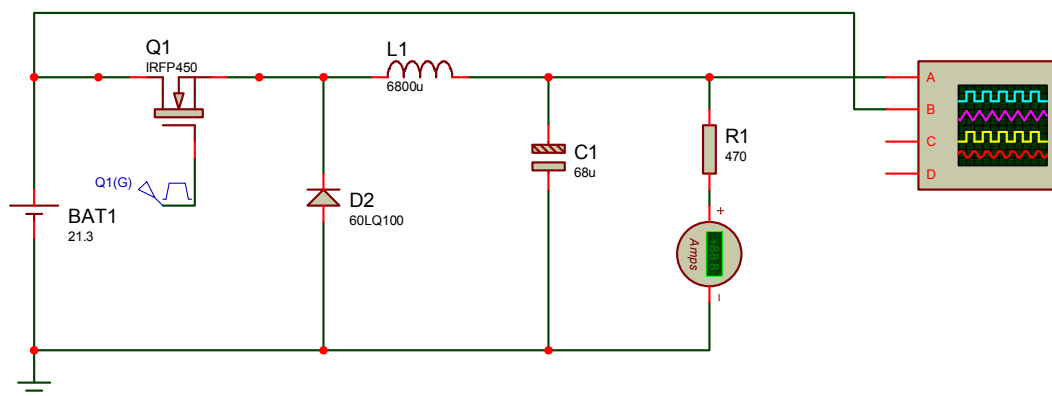
Figure 4.9 Buck converter simulation circuit for red leds
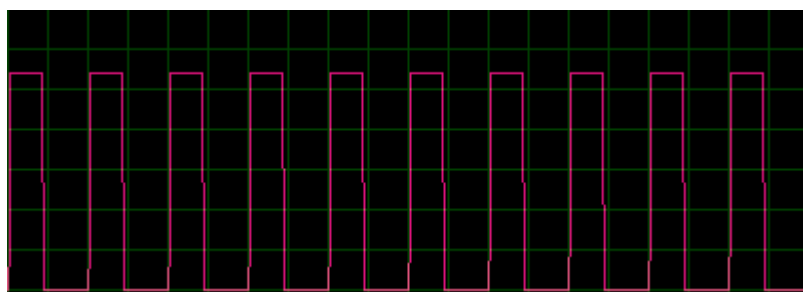
Figure 4.10 Buck converter pwm signal for D=0.39

Figure 4.11 Simulation result of buck converter for red leds, y=5V/div

After calculations, it is seen that the 3 buck converters have same hardware.

4.3.3 Switching Component Selection

The earliest power transistor was bipolar transistors until 1970s. There were some disadvantages of bipolar transistor as they require a high base current to turn on,

have relatively slow turn-off characteristics, and liable for thermal runaway due to a negative temperature co-efficient. In addition, the lowest attainable on-state voltage or conduction loss is governed by the collector-emitter saturation voltage $V_{CE(sat)}$.

In 1970s the mosfet came along. Mosfets are voltage controlled devices (not current controlled), have a positive temperature coefficient, stopping thermal runaway. The on-state-resistance has no theoretical limit, on-state losses can be far lower. The mosfet also has a body-drain diode, which is particularly useful in dealing with limited free wheeling currents.

In 1980s the Igbt came along. The Igbt has the output switching and conduction characteristics of a bipolar transistor but is voltage-controlled like a mosfet. In general, this means it has the advantages of high-current handling capability of a bipolar with the ease of control of a mosfet.

If mosfet and igbt is compared:

IGBTs have been the preferred device under these conditions:
- Low duty cycle
- Low frequency (<20kHz)
- Narrow or small line or load variations
- High-voltage applications (>1000V)
- Operation at high junction temperature is allowed (>100°C)
- >5kW output power

MOSFETs are preferred in:
- High frequency applications (>200kHz)
- Wide line or load variations
- Long duty cycles
- Low-voltage applications (<250V)
- < 500W output power

For the buck converter design; the MOSFET is chosen. Also there are 2 kinds of mosfets. i)N-Channel Mosfet , ii) P-Channel Mosfet

In NMOS transistors, the silicon channel between the source and drain is of p-type silicon. When a positive voltage is placed on the gate electrode, it repulses the holes in the p-type material forming a conducting (pseudo n-type) channel and turning the transistor on. A negative voltage turns the transistor off. With a PMOS transistor, the opposite occurs. A positive voltage on the gate turns the transistor off, and a negative voltage turns it on. NMOS transistors switch faster than PMOS.

For this project NMOS mosfet IRF540N is chosen for its ultra low on-resistance, fast switching, cheapness and easiness to find.
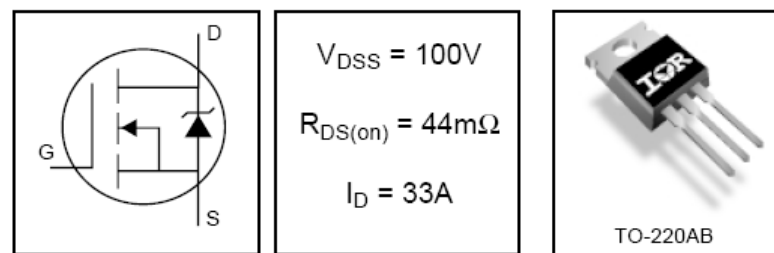
Figure 4.12 IRF540N is chosen as switching component of buck converters

4.3.3.1 Mosfet Driver Selection

As the voltage rail connected to the drain of the mosfet, a high side driver is required. The gate voltage must be controllable from the logic, which is normally referenced to ground. Thus, the control signals have to be level-shifted to the source of the high side power device. As a single high-side driver, IR2117 is chosen.

Figure 4.13 As a single high-side driver IR2217 is used

The output voltage is 10-20 V according to source of mosfet. This voltage is high enough to fully turn on mosfet. But there is a short come with this IC. It is its logic levels. The input high logic is minimum 9,5 V.

Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
V_{IH}	input voltage - logic "1" (IR2117) logic "0" (IR2118)	9.5	—	—	V	
V_{IL}	Input voltage - logic "0" (IR2117) logic "1" (IR2118)	—	—	6.0		

Figure 4.14 Logic levels of gate signal for IR2117

As the gate signal is produced with 16F877, and its logic high is just 5V, there should be another gate driver between Pic and IR2117. TC4429 is suitable for this operation.

Parameters	Sym	Min	Typ	Max	Units	Conditions
Input						
Logic '1', High Input Voltage	V_{IH}	2.4	—	—	V	
Logic '0', Low Input Voltage	V_{IL}	—	—	0.8	V	

Figure 4.15 Logic levels of gate signal for TC4429

This ICs input logic levels are compatible with pic pwm output and the TC4429 output is compatible with IR2117 input logic levels. So, these 2 IC's are cascade connected.

4.4 Pwm Generation

Pwm generation is done with 16F877 hardware pwm module. This module produces 10 bit resolution pwm output. The related registers are CCP1CON, CCP2CON , CCPR1L, PR2, T2CON. To configure PWM operation, following steps should be taken.

1. Set the PWM period by writing to the PR2 register.
2. Set the PWM duty cycle by writing to the CCPR1L register and CCP1CON<5:4> bits.
3. Make the CCP1 pin an output by clearing the TRISC<2> bit.
4. Set the TMR2 prescale value and enable Timer2 by writing to T2CON.

5. Configure the CCP1 module for PWM operation.

PWM period is calculated with following equation.

$$PR2 = (Period/(4 * T_{osc} * TMR2\ Prescale)) - 1$$

Duty cycle is;

$$CCPR1L:CCP1Con<5:4> = Pwm\ Duty\ Cycle\ /\ (Tosc * TMR2\ Prescale)$$

For the project the initial values are $F_{sw} = 50$ kHz and duty cycle is 0.62 for blue and green leds.

Period = 1 / 50000 = 0.00002

T_{osc} = 1 / 20000000 = 0.00000005

Pwm Duty Cycle = D. Period = 0.62 * 0.00002

TMR2 Prescale = 1

PR2= ((0.00002 / (4*0.00000005*1)) -1 then PR2= 99

For CCPR1L:CCP1Con<5:4>

CCPR1L:CCP1Con<5:4> = 0.62 * 0.00002 / (0.00000005*1) = 248
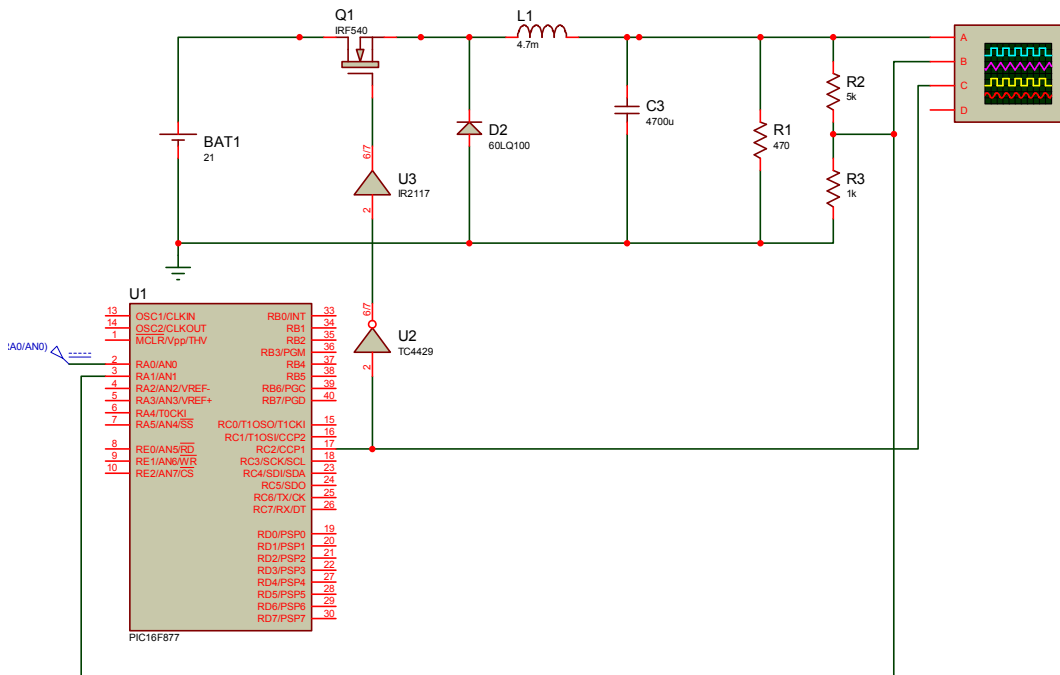
Figure 4.16 Simulation circuit of voltage control card
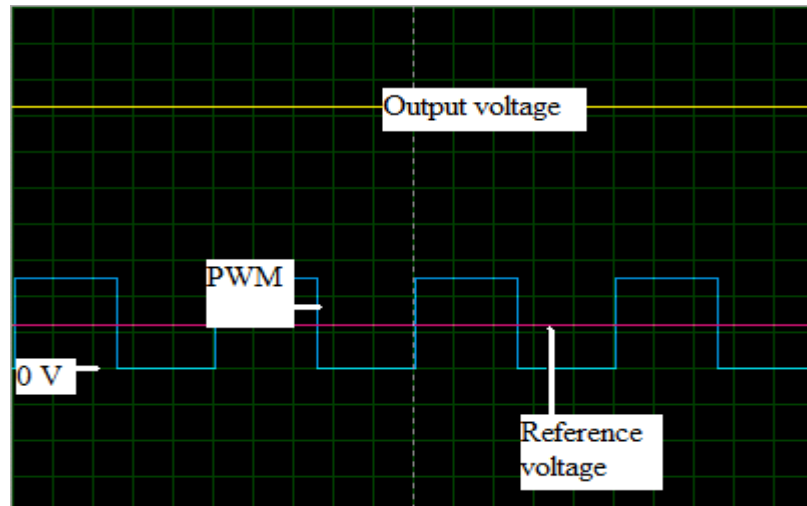
Figure 4.17 Simulation result of voltage control card
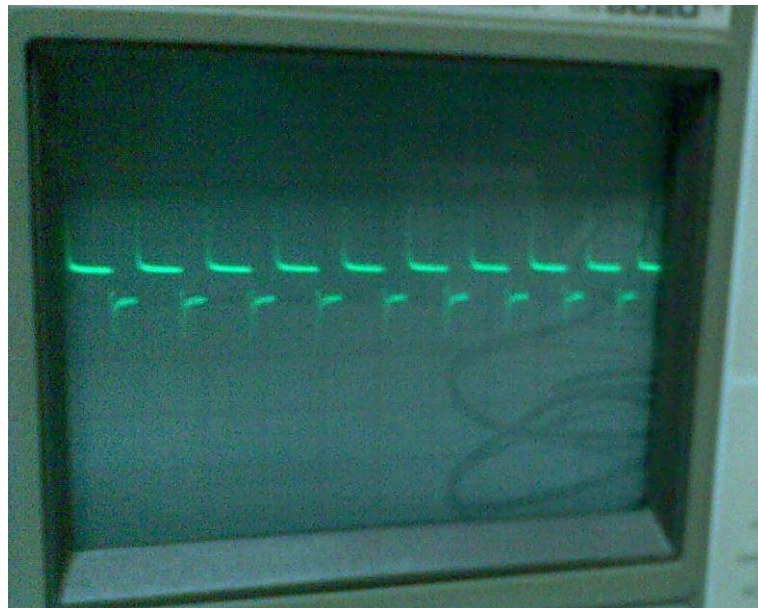
Figure 4.18 The pwm output of pic 16F877 when x =20us/div, y=5V/div
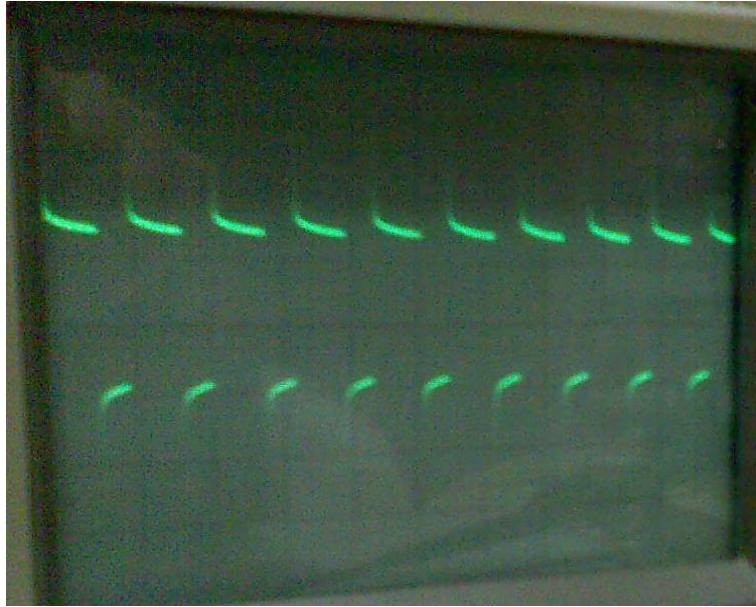
Figure 4.19 The pwm output of TC4429 when x =20us/div, y=5V/div
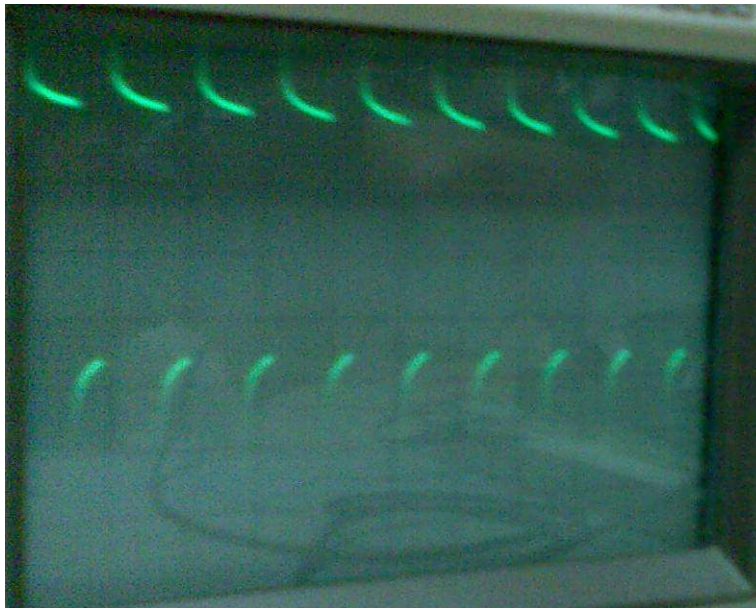
Figure 4.20 The source voltage of IRF540N when x=20us/div, y=5V/div
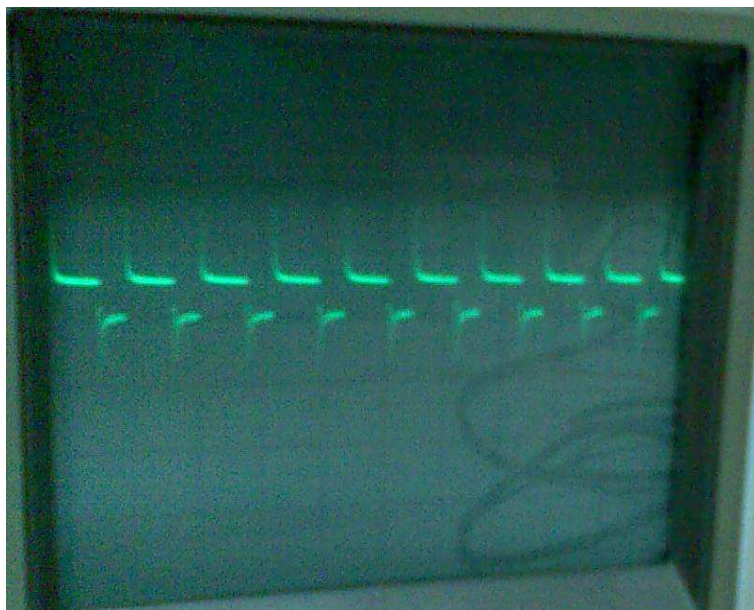
Figure 4.21 The gate voltage of IRF540N when x=20us/div, y=5V/div X10

4.5 Voltage control on driver IC

Voltage control on driver IC is done by the microcontroller. The reference value of the driver IC and present voltage value of the IC is measured with pic. Normally, the difference should be 0. If there is difference between these 2 values, the pwm duty cycle is changing, the output voltage changes according to pwm changes also. The voltage on the leds are constant, so the changing value is the voltage change of driver IC.
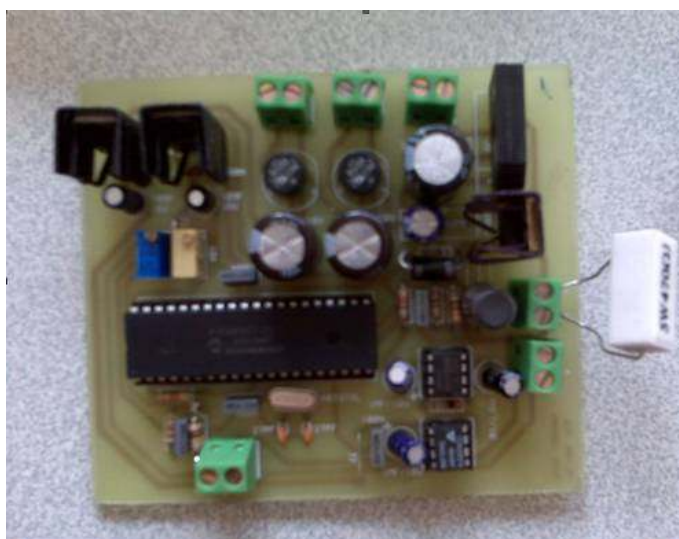
Figure 4.22 One of the buck converters

4.6 Software of the Voltage Control Card

4.6.1 Algorithm of the software
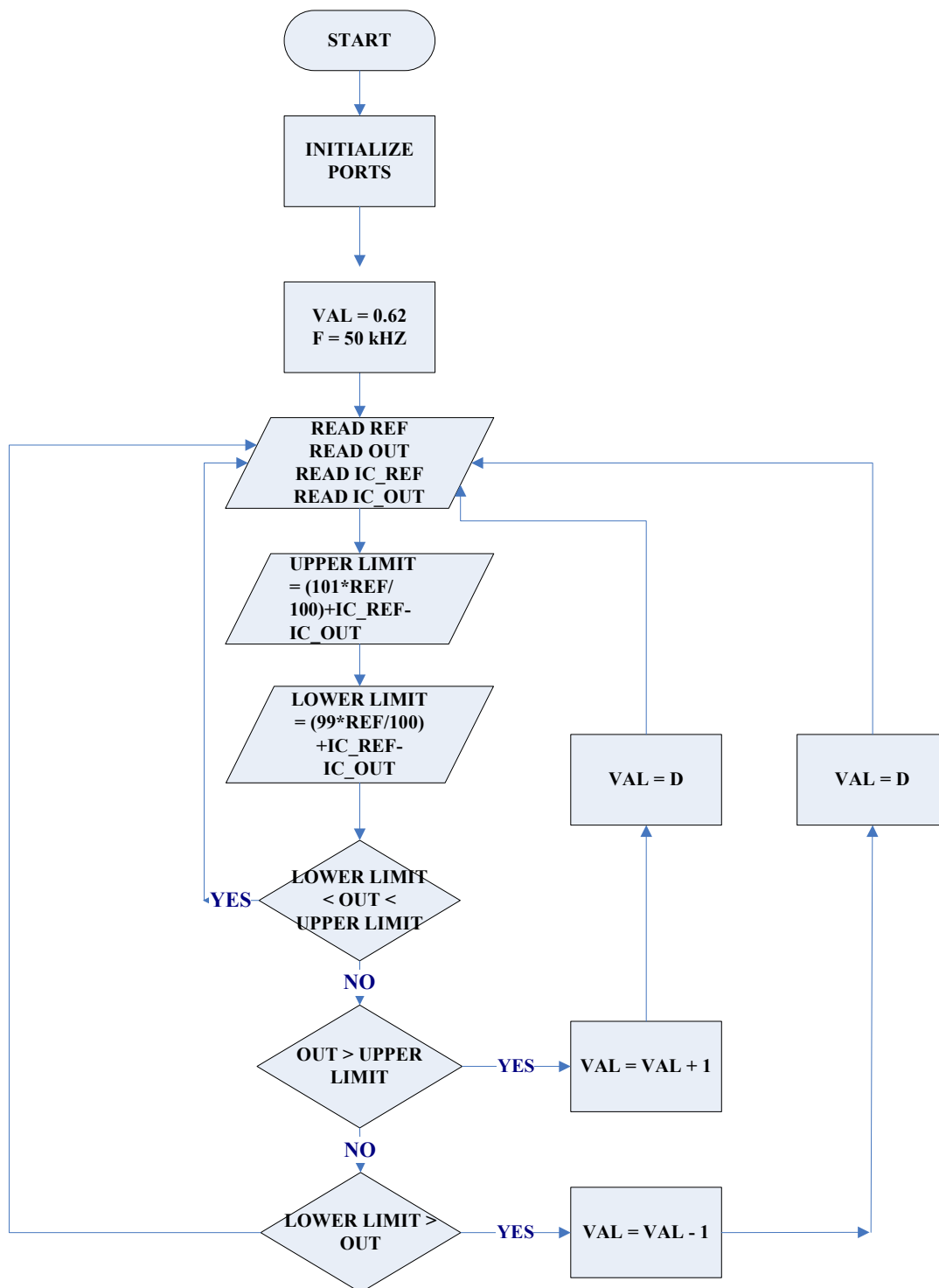
Figure 4.23 Software algoritm of voltage control card

4.6.2 Code of the software

```
'************************************************************

'*  AYSUN TUTAK                                            *

'*  2006900211                                             *

'*  This is the software of the voltage control card for  blue leds    *

'************************************************************

ADCON1=%10000000              'all portA is analog, right justified
TRISA=$FF                     'all portA is input
TRISB=00                      'all portB is output
TRISC=00                      'all portA is output
TRISD=00                      'all portA is output
TRISE=00                      'all portA is output
PR2=99                        'switching frequency is 50kHz
CCP1CON=%00001100             'CCP1 pin is in pwm mode
T2CON=%00000100               '1:1 prescale, timer2 on, 1:1 postscale


REF VAR WORD                  'REF is 16 bits
OUT VAR WORD                  'OUT is 16 bits
VAL  VAR WORD                 'VAL is 16 bits
IC_REF  VAR WORD              'IC_REF  is 16 bits
IC_OUT VAR WORD               'IC_OUT is 16 bits
HIGH_LEVEL  VAR WORD          'HIGH_LEVEL  is 16 bits
LOW_LEVEL VAR WORD            'LOW_LEVEL is 16 bits


DEFINE ADC_BITS  10           'ADC is 10 bits
DEFINE ADC_CLOCK 2            'ADC clock is for 20MHz crystal
DEFINE ADC_SAMPLES 5          'ADC is done 5 samples for a
                              millisecond
DEFINE OSC 20                 'Pic clock is 20MHz


VAL=248                       'Initial D=0,62
```

PUT_VAL: 'Duty cycle is written in related registers

CCPR1L.7=VAL.9

CCPR1L.6=VAL.8

CCPR1L.5=VAL.7

CCPR1L.4=VAL.6

CCPR1L.3=VAL.5

CCPR1L.2=VAL.4

CCPR1L.1=VAL.3

CCPR1L.0=VAL.2

CCP1CON.5=VAL.1

CCP1CON.4=VAL.0

GOTO CONTINUE

CONTINUE:

PAUSE 8   'Wait 8 milliseconds

ADCIN 0, REF   'AN0 input value is saved as REF

ADCIN 1, OUT   'AN1 input value is saved as OUT

ADCIN 2, IC_REF   'AN2 input value is saved as IC_REF

ADCIN 3, IC_OUT   'AN3 input value is saved as IC_OUT

PAUSEUS 3   'Wait 3 microseconds

HIGH_LEVEL = (101*REF/100)+IC_REF-IC_OUT   'Upper limit of output

LOW_LEVEL = (99*REF/100) +IC_REF-IC_OUT   'Lower limit of output

IF (LOW_LEVEL <= OUT)&& (OUT <= HIGH_LEVEL) THEN CONTINUE

IF OUT > HIGH_LEVEL THEN AZALT

IF OUT < LOW_LEVEL THEN ARTTIR

GOTO CONTINUE

AZALT:

VAL=VAL+1

GOTO PUT_VAL

ARTTIR:

VAL=VAL-1

GOTO PUT_VAL

4.7 Led Panel Board

The board is made up of 128 rgb leds and 384 diodes (for high reverse voltage protection) for a quarter of 21'' lcd panel. There are 3 power inputs for red, blue and green leds. The board layout is as below.
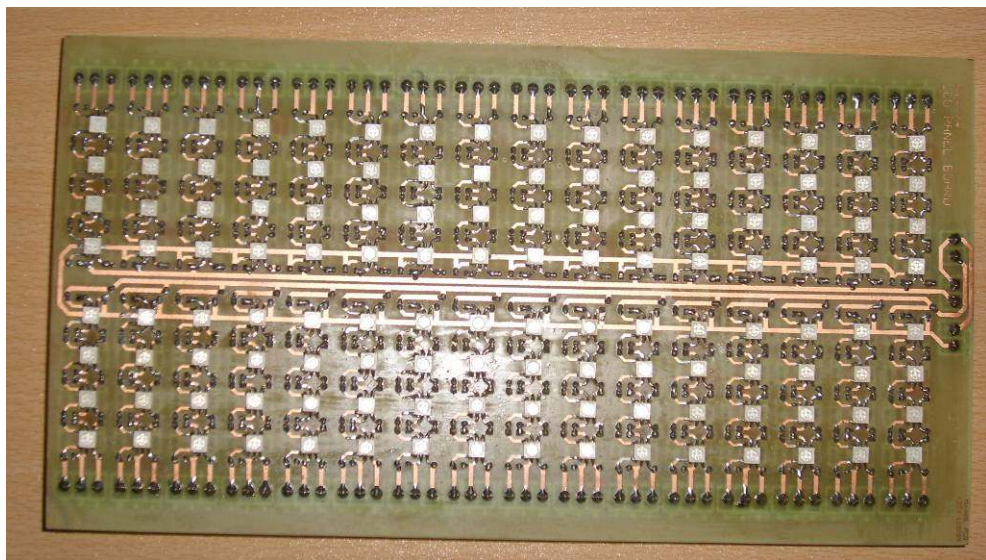
Figure 4.24 Top view of the led panel board
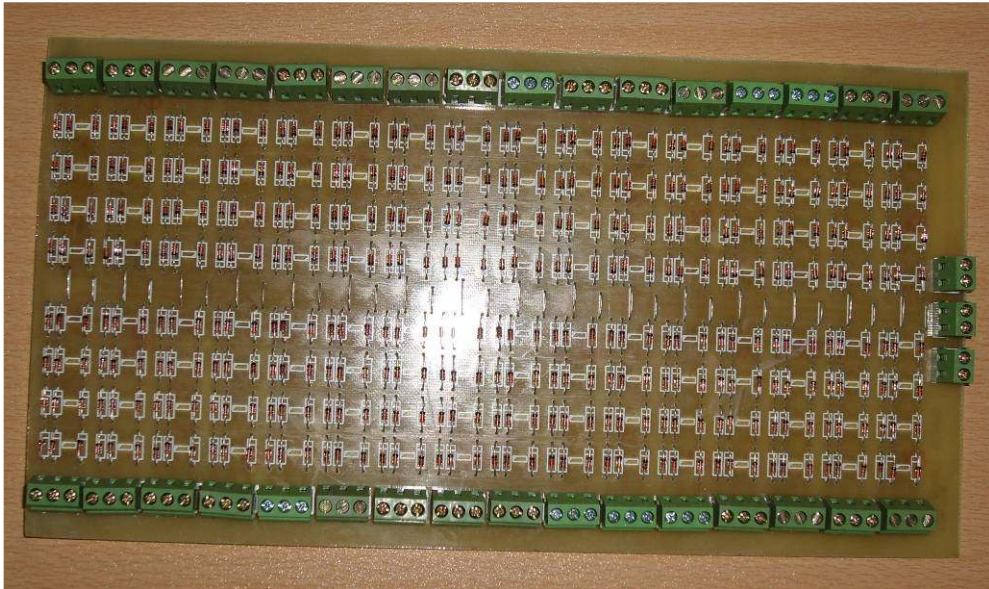
Figure 4.25 Bottom view of the led panel board

4.8 Led Driver Board

For 128 rgb leds, 6 TLC5941 IC's are used. Each IC is used to drive 16 channel x 4 series leds.

The TLC5941 is a 16-channel constant current sink led driver. Each channel has an individually adjustable 4096-step grayscale pwm brightness control and 64-step constant current sink (dot correction).

TLC5941 has a serial interface to be connected to microprocessors or digital signal processors.

There are 3 pins to input the data. There are;   SIN, SCLK and XLAT.
- SIN is the pin that serial data enters.
- SCLK is the clock signal for serial data. The rising edge of SCLK signal shifts the data from the SIN pin to the internal register.
- XLAT signal high level pulse is used to latch the serial data to input registers of the IC. Because, the internal registers are level triggered.

All data are clocked in with the MSB first. The length of serial data is 96 bit or 192 bit, depending on the programming mode. Dot correction is done with 6 bits for a channel (totally 6 bits x 16 channels) , grayscale is done with 12 bits for a channel (totally 12 bits x 16 channels)

More than two TLC5941s can be connected in series by connecting an SOUT pin from one device to the SIN pin of the next device.
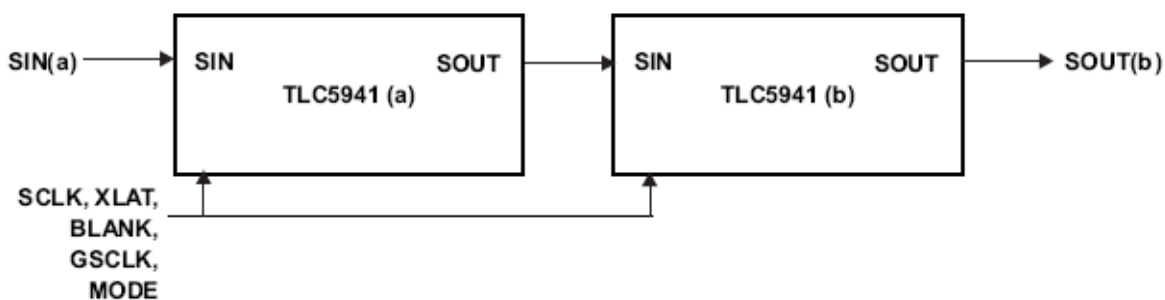
Figure 4.26 Connection of 2 TLC5941 ICs

- MODE signal assigns the operation mode of the IC. If it is Low, the mode is Grayscale PWM; if it is High the mode is Dot Correction.
- GSCLK signal is the clock signal for grayscale dimming.
- BLANK signal is used for enable / disable outputs. If it is Low, the output channels work under normal conditions; if it is High, all output channels are disabled and the grayscale counter is reset.
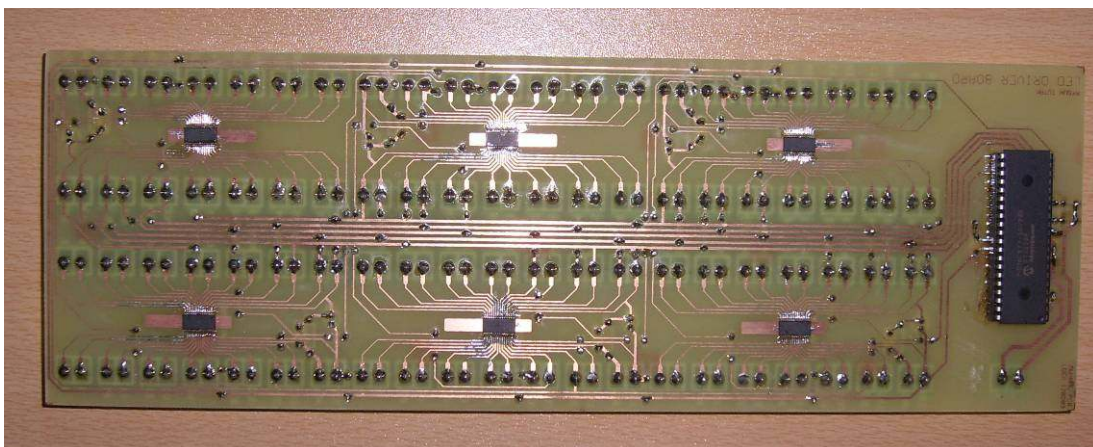
Figure 4.27 Top view of the led driver board
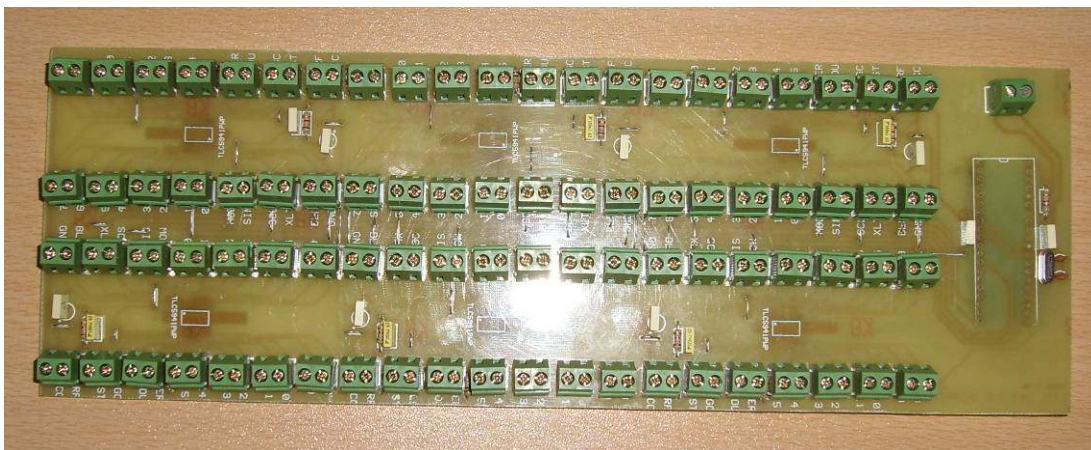
Figure 4.28 Bottom view of the led driver board

4.8.1 Setting Maximum Channel Current

The maximum channel current is adjusted with a single resistor. $R_{(IREF)}$ is placed between IREF pin and GND pin. The maximum output current is;

$I_{max} = (V_{(IREF)} / R_{(IREF)}) \times 31.5$ where;

$V_{(IREF)} = 1.24$ V and

$R_{(IREF)}$ is user selected external resistor.

4.8.2 Setting Grayscale

The TLC5941 can adjust the brightness of each channel OUTn using a PWM control scheme. The use of 12 bits per channel results in 4096 different brightness steps, from 0% to 100% brightness. The brightness level is;

Brightness in % = (GSn / 4095) x 100 where;

GSn is the programmed grayscale value for output n (GSn = 0 to 4095) and

n = 0 to 15

grayscale data for all OUTn

4.8.3 Setting Dot Correction

The TLC5941 has the capability to fine-adjust the output current of each channel (OUT0 to OUT15) independently. This is also called dot correction. This feature is used to adjust the brightness deviations of LEDs connected to the output channels OUT0 to OUT15. The dot correction level is;

$I_{OUTn} = I_{max}$ X (DC_n / 63) where;

I_{max} is the maximum programmable output current for each output

DC_n is the programmed dot correction value for output n (DC_n = 0 to 63)

n = 0 to 15

4.8.4 Serial Data Transfer Rate

The maximum number of cascading TLC5941 devices depends on the application system and is in the range of 40 devices. The minimum clock frequencies are;

$f_{(GSCLK)} = 4096$ X $f_{(update)}$

$f_{(SCLK)} = 193$ X $f_{(update)}$ X n where;

$f_{(GSCLK)}$ is the minimum frequency needed for GSCLK

$f_{(SCLK)}$ is the minimum frequency needed for SCLK and SIN

$f_{(update)}$ is the update rate whole cascading system

n is the number cascaded of TLC5941 device

4.9 Software of the Led Driver Card

4.9.1 Algorithm of the software

```
            ┌──────────────┐
            (    START      )
            └──────┬───────┘
                   │
            ┌──────▼───────┐
            │  INITIALIZE  │
            │    PORTS     │
            └──────┬───────┘
                   │
            ┌──────▼───────┐
            │  F = 2.5 MHz │
            │ (Clock of the│
            │   TLC5941)   │
            └──────┬───────┘
                   │
            ┌──────▼───────┐
            │  Send  Dot   │
            │Correction data│
            │ of Red, Green │
            │  and Blue    │
            └──────┬───────┘
                   │
            ┌──────▼───────┐
            │Send Grayscale│
            │ data of Red, │
            │Green and Blue│
            └──────┬───────┘
                   │
            ┌──────▼───────┐
            │  FOR 4096    │
            │ CLOCK CYCLE  │
            │  BLANK = 1   │
            └──────┬───────┘
                   │
            ┌──────▼───────┐
            │  FOR 3 usec  │
            │  BLANK = 0   │
            └──────────────┘
```
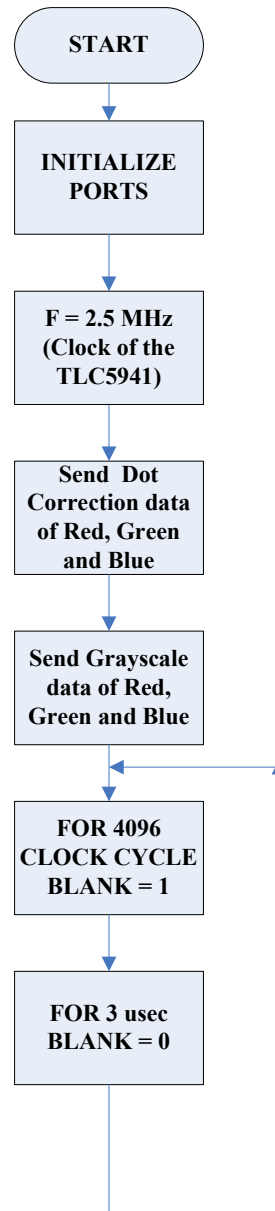
Figure 4.29 Algorithm of
led driver card software

4.9.2 Code of the software

```
'***************************************************************
'* AYSUN TUTAK                                                 *
'* 2006900211                                                  *
'* This is the software of the led driver card                *
'***************************************************************
Include "modedefs.bas"
 TRISA=00                        'Port A output
 TRISB=00                        'Port B output
 TRISC=00                        'Port C output
 TRISD=00                        'Port D output
 TRISE=00                        'Port E output


INITIALIZE:


PR2=1                           'Set pwm frequency 2,5MHz
CCP1CON=%00001100               'CCP1 is pwm output
T2CON=%00000100                 'Timer 2 on, prescale 1
CCPR1L= %00000001               'Set pwm duty cycle=0.5


DEFINE OSC 20                   'Xtal is 20 MHz

S_IN VAR PORTC.4
SCLK VAR PORTC.3
XLAT VAR PORTD.2
GSCLK VAR PORTC.2
BLANK VAR PORTD.4
MODE VAR PORTD.5


B VAR BYTE
R VAR BYTE
```

```
G VAR BYTE
Re VAR BYTE
B1 VAR BYTE
G1 VAR BYTE
GS_R VAR WORD
GS_B VAR WORD
GS_G VAR WORD
DC_R VAR BYTE
DC_B VAR BYTE
DC_G VAR BYTE


B=1
R=1
G=1
B1=1
Re=1
G1=1


GS_B = %1110101111110000        'Grayscale data of blue
GS_R = %1110101111110000        'Grayscale data of red
GS_G = %1110101111110000        'Grayscale data of green
DC_R = %11011100                'Dot scale data of red
DC_B = %11011100                'Dot scale data of blue
DC_G = %11011100                'Dot scale data of green


HIGH BLANK                      'Leds are off
LOW XLAT
GOSUB DC_OUT                    'Goto dc_out subroutine
GOSUB GS_OUT                    'Goto gs_out subroutine
GOSUB FOREVER                   'Goto forever subroutine


DC_OUT:
```

```
HIGH MODE                          'Dot correction mode


FOR  B=1 TO 32                     'Send dot correction value for Blue leds
SHIFTOUT S_IN, SCLK, 1 , [DC_B \ 6]
NEXT B


FOR R=1 TO 32                      'Send dot correction value for Red leds
SHIFTOUT S_IN, SCLK, 1 , [DC_R \ 6]
NEXT R


FOR  G=1 TO 32                     'Send dot correction value for Green leds
SHIFTOUT S_IN, SCLK, 1 , [DC_G \ 6]
NEXT G


HIGH XLAT
PAUSEUS 5
LOW XLAT
LOW MODE                           'Gray scale mode
RETURN


GS_OUT:


FOR  B1=1 TO 32                    'Send grayscale value for Blue leds
SHIFTOUT S_IN, SCLK, 1 , [GS_B \ 12]
NEXT B1


FOR Re=1 TO 32                     'Send grayscale value for Red leds
SHIFTOUT S_IN, SCLK, 1 , [GS_R \ 12]
NEXT Re


FOR  G1=1 TO 32                    'Send grayscale value for Green leds
SHIFTOUT S_IN, SCLK, 1 , [GS_G \ 12]
```

NEXT G1

HIGH XLAT
PAUSEUS 5
LOW XLAT
RETURN

FOREVER:
LOW BLANK
PAUSEUS 1600
HIGH BLANK
PAUSEUS 3
LOW BLANK
GOTO FOREVER
END
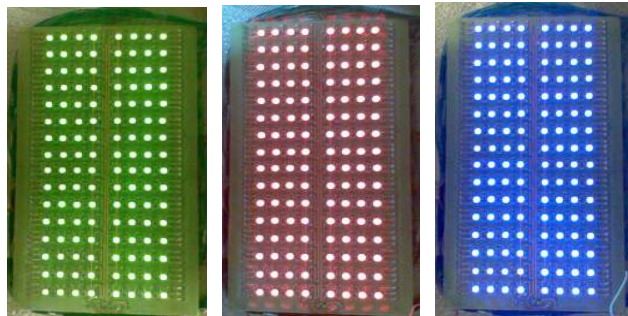
Figure 4.30 a) only green leds are lighting, b) only red leds
are lighting, c) only blue leds are lighting

Figure 4.31 Full circuit when all leds are lighting

CHAPTER FIVE
CONCLUSIONS

This thesis introduced a new LCD backlight technology. In the thesis, the current ripple free regulator topologies were examined and the buck converter topology was chosen for led backlight driver voltage supply. TLC5941 led driver IC's were used to maintain constant current on the leds. The control of buck converters and the led driver ICs were made by microcontrollers. The power consumption of leds are as below.

Table 5.1 Power calculation of leds

I_{LED} = 20 mA	Minimum (Watt)	Maximum (Watt)
Red Leds	4,608	6,144
Blue Leds	7,168	8,96
Green Leds	7,424	8,96
Total (for a quarter)	19, 2	24, 064
Total (for all 21" tv)	76,8	96,256

The required luminance is about 450-500 cd/m^2 for lcd televisions. If we want to have 500 cd/m^2 lcd television we use the following equation.

$$\frac{(\text{Luminance per led}) \times (\text{Total number of leds}) \times (\text{LUE of the panel})}{(\text{Area of lcd panel})} = 500 cd/m^2$$

For the project design our parameters are;

- Luminance per led = 1450 mcd / led
- Total number of leds = 128
- Area of lcd panel = 0.03 m^2 (a quarter of 21" lcd tv)
- LUE = ?

Then;

$$\frac{(1450 \text{ mcd / led}) \times (128 \text{ leds}) \times \text{LUE of panel}}{0.03 \text{ m}^2} = 500 \text{ cd}/m^2$$

The lcd panel LUE (light utilization efficiency) is the parameter determines the ratio of light after the following components (Figure 5.1) of lcd tv consumes the light power. For this design the LUE of the lcd panel must be higher than % 8.08.
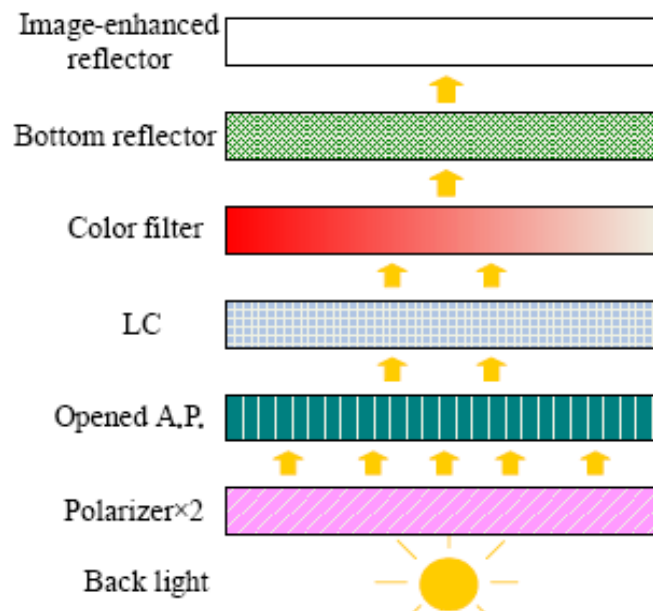
Figure 5.1 The LCD panel components

If we look the formula the total luminance is;

- Directly proportional with the number of leds.
- Directly proportional with the luminance / led.
- Directly proportional with the LUE of the panel.
- Inversely proportional with the area of the panel.

Our aim is to decrease power. So we should decrease the number of leds used in the design. As the total luminance and the area of the panel have to be constant, the 2 parameters are important. High LUE panels and high luminous efficiency leds. Luminous efficiency is the lumen (amount of light) value per watt.

Physicians and optical engineers study on these 2 parameters. They try different semiconductor materials for leds, different optical reflectors, filters to improve the efficiency of the backlight.

In the Table 5.2, the comparison of some CCFL and LED panel models is given. The power consumption is related with lots of things and some are given here.

Table 5.2 Comparison some CCFL and LED monitors and televisions

Display model	Size (Inch)	Technology	Luminance (cd/m2)	Viewing angle (maximum)	Max. Power consumption (Watt)
Sun Microsystems 19-Inch LCD Flat Panel Monitor	19	CCFL	300	70° vertical 80° horizontal	37
Scanport H21 21 inch LCD Monitor	21	CCFL	450	170° both	100
Sony LMD240MD	21	CCFL	300	85° both	100
Planar DOME C5i (Gray) 21 inch LCD Monitor	21	CCFL	700	170° both	90
LCD 2180WG-LED	21.3	LED	200	176° both	100
ViewSonic VLED221wm	22	LED	250	-	36
Lenovo LCD L2440X 24"TFT LED	24	LED	300	178° both	45

From the table, it is hard to have definite results of the led and CCFL power consumption without neglecting other parameters. The led technology is very new and if we think the advantages of leds such as full color gamut, longer service life, no EMI and RFI; the studies of decreasing power consumption is very important to benefit from leds. So the physicians, optical engineers and electronical engineers should study together and the investigations must be growed.

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APPENDICES

APPENDIX A. 16F877 HARDWARE SUMMARY

Introduction

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to "Programmable Interface Controller", but shortly thereafter was renamed "Programmable Intelligent Computer".

16F877 Features and Pin Functions

16F877 is a 40 pin microcontroller. The basic core features of 16f877 are;

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input, DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
- Up to 368 x 8 bytes of Data Memory (RAM)
- Up to 256 x 8 bytes of EEPROM data memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and
- Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode

- Selectable oscillator options

- Low-power, high-speed CMOS FLASH/EEPROM technology

- Fully static design

- In-Circuit Serial Programming (ICSP) via two pins

- Single 5V In-Circuit Serial Programming capability

- In-Circuit Debugging via two pins

- Processor read/write access to program memory

- Wide operating voltage range: 2.0V to 5.5V

- High Sink/Source Current: 25 mA

- Commercial and Industrial temperature ranges

- Low-power consumption:

    - < 2 mA typical @ 5V, 4 MHz

    - 20 mA typical @ 3V, 32 kHz

    - < 1 mA typical standby current

- Timer0: 8-bit timer/counter with 8-bit prescaler

- Timer1: 16-bit timer/counter with prescaler, can be incremented during sleep via external crystal/clock

- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler

- Two Capture, Compare, PWM modules

    - Capture is 16-bit, max. resolution is 12.5 ns

    - Compare is 16-bit, max. resolution is 200 ns

    - PWM max. resolution is 10-bit

- 10-bit multi-channel Analog-to-Digital converter

- Synchronous Serial Port (SSP) with SPI (Master Mode) and I2C (Master/Slave)

- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address

- detection

- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)

Brown-out detection circuitry for Brown-out Reset (BOR)

Pin Functions

MCLR/VPP/THV   Master clear (reset) input Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.

PORT A is a bi-directional I/O port.

RA0 / AN0   RA0 can also be analog input0

RA1 / AN1   RA1 can also be analog input1

RA2 / AN2 / VREF- RA2 can also be analog input2 or negative analog reference voltage

RA3 / AN3 / VREF+ RA3 can also be analog input3 or positive analog reference voltage

RA4 / TOCK1   RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.

RA5 / SS / AN4   RA5 can also be analog input4 or the slave select for the synchronous serial port.

PORT B is a bi-directional I/O port. PORT B can be software programmed for internal weak pull-up from all inputs.

RB0 / INT   RB0 can also be the external interrupt pin.

RB1

RB2

RB3 / PGM   RB3 can also be the low voltage programming input

RB4   Interrupt on change pin

RB5   Interrupt on change pin.

RB6 / PGC   Interrupt on change pin or In-Circuit Debugger pin. Serial programming clock.

RB7 / PGD   Interrupt on change pin or In-Circuit Debugger pin. Serial programming data.

PORTC is a bi-directional I/O port.

RC0/T1OSO/T1CKI RC0 can also be the Timer1 oscillator or a Timer1 clock input.

RC1/T1OSI/CCP2   RC1 can also be the Timer1 oscillator input or Capture2 input / Compare2 output / PWM2 output.

RC2/CCP1   RC2 can also be the Capture1 input / Compare1 output / PWM1 output.

RC3/SCK/SCL   RC3 can also be the synchronous serial clock input / output for both SPI and I^2C modes.

RC4/SDI/SDA   RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).

RC5/SDO   RC5 can also be the SPI Data Out (SPI mode).

RC6/TX/CK   RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.

RC7/RX/DT   RC7 can also be the USART Asynchronous Receive or Synchronous Data.

<u>PORTD</u> is a bi-directional I/O port or parallel slave port when interfacing to a microprocessor bus.

RD0/PSP0

RD1/PSP1

RD2/PSP2

RD3/PSP3

RD4/PSP4

RD5/PSP5

RD6/PSP6

RD7/PSP7

<u>PORTE</u> is a bi-directional I/O port.

RE0/RD/AN5   RE0 can also be read control for the parallel slave port, or analog input5.

RE1/WR/AN6   RE1 can also be write control for the parallel slave port, or analog input6.

RE2/CS/AN7   RE2 can also be select control for the parallel slave port, or analog input7.

VSS   Ground reference for logic and I/O pins.

VDD   Positive supply for logic and I/O pins.

NC   These pins are not internally connected. These pins should be left unconnected.

Memory Organization

16F877 has 3 memory blocks. These are Program memory, Data memory and the Eeprom data memory.

16F877 has 13-bit program counter capable of 8K x 14 program memory and 8K x 14 words of flash. Data memory is partitioned into 4 banks. Each bank extends up to 128 bytes. The lower locations of each bank are reserved for Special function registers implemented as static RAM. These registers are classified into 2 groups; Core (cpu) and peripheral.

The **status** register contains the arithmetic status of the ALU, the RESET status and the bank select bits for data memory. Register bank select, clrwdt, sleep, carry, borrow bits are in these register.

The **option-reg** register contains various control bits to configure TMR0 prescaler/WDT postscaler.

The **int-con** register contains various enable and flag bits for the TMR0 register overflow, RB Port change and External RB0/INT pin interrupts.

The **PIE1** register the individual enable bits for the peripheral interrupts.

The **PIR1** register contains the individual flag bits for the peripheral interrupts.

The **PIE2** register contains the individual enable bits for the CCP2 peripheral interrupt, the SSP bus collision interrupt, and the EEPROM write operation interrupt.

The **PIR2** register contains the flag bits for the CCP2 interrupt, the SSP bus collision interrupt and the EEPROM write operation interrupt.

The Power Control (PCON) Register contains flag bits to allow differentiation between a Power-on Reset (POR), a Brown-out Reset (BOR), a Watchdog Reset (WDT), and an external MCLR Reset.

Input Output Ports

There are Port A, Port B, Port C, Port D, PortE, Parallel Slave Port on 16F877.

Port A is a 6 bit wide bi-directional port. The corresponding data direction register is TRISA. Setting a TRISA bit (= 1) will make the corresponding PORTA pin an input , Clearing a TRISA bit (= 0) will make the corresponding PORTA pin an output . Pin RA4 is multiplexed with the Timer0 module clock input to become the RA4/T0CKI pin. Other PORTA pins are multiplexed with analog inputs and analog VREF input. The operation of each pin is selected by clearing/setting the control bits in the ADCON1 register (A/D Control Register1).

Port B is an 8 bit wide bi-directional port. The corresponding data direction register is TRISB. Setting a TRISB bit (= 1) will make the corresponding PORTB pin an input. Clearing a TRISB bit (= 0) will make the corresponding PORTB pin an output. Three pins of PORTB are multiplexed with the Low Voltage Programming function: RB3/PGM, RB6/PGC and RB7/PGD.

Port C is an 8 bit wide bi-directional port. The corresponding data direction register is TRISC. Setting a TRISC bit (= 1) will make the corresponding PORTC pin an input. Clearing a TRISC bit (= 0) will make the corresponding PORTC pin an output. PORTC pins have Schmitt Trigger input buffers. When the I2C module is enabled, the PORTC<4:3> pins can be configured with normal I2C levels, or with SMBus levels by using the CKE bit (SSPSTAT<6>).

Port D is an 8-bit port with Schmitt Trigger input buffers. Each pin is individually configurable as an input or output. PORTD can be configured as an 8-bit wide microprocessor port (parallel slave port) by setting control bit PSPMODE (TRISE<4>). In this mode, the input buffers are TTL.

Port E has three pins (RE0/RD/AN5, RE1/WR/AN6, and RE2/CS/AN7) which are individually configurable as inputs or outputs. These pins have Schmitt Trigger input buffers.

Parallel Slave Port is Port D when control bit PSPMODE (TRISE<4>) is set. In Slave mode, it is asynchronously readable and writable by the external world through RD control input pin RE0/RD and WR control input pin RE1/WR.

Data Program and Flash Program Memory

The Data Eeprom and Flash Program Memory are readable and writable during normal operation over the entire VDD range. These operations take place on a single byte for Data EEPROM memory and a single word for Program memory. A write operation causes an erase-then-write operation to take place on the specified byte or word. A byte or word write automatically erases the location and writes the new value (erase before write). Writing to EEPROM data memory does not impact the operation of the device. Writing to program memory will cease the execution of instructions until the write is complete. The program memory cannot be accessed during the write.

Read and write access to both memories take place indirectly through a set of Special Function Registers (SFR). The six SFRs used are; EEDATA, EEDATH, EEADR, EEADRH, EECON1, EECON2.

Timers of 16F877

There are 3 timers on 16F877. These are Timer 0, Timer 1 and Timer 2.

Timer 0 is;

- 8-bit timer/counter
- Readable and writable
- 8-bit software programmable prescaler
- Internal or external clock select
- Interrupt on overflow from FFh to 00h
- Edge select for external clock

Related registers with Timer 0 are; TMR0, INTCON and OPTION_REG.

Timer 1 is;

- 16-bit timer/counter (TMR1H and TMR1L registers)
- Readable and writable
- Internal or external clock select
- Interrupt on overflow
- Can be used for Compare mode (CCP1 and CCP2)

If the CCP1 or CCP2 module is configured in Compare mode to generate a special event trigger" (CCP1M3:CCP1M0 = 1011), this signal will reset Timer1.

Related registers with Timer 1 are; T1CON, TMR1H, TMR1L, PIE1, PIR1, INTCON.

Timer 2 is;

- 8-bit timer with a prescaler and a postscaler
- Readable and writable
- Can be used for PWM mode

Related registers with Timer 2 are; T2CON, PR2, TMR2, PIE1, PIR1, INTCON.

Capture / Compare / Pwm Modules:

Each Capture/Compare/PWM (CCP) module contains a 16-bit register which can operate as a 16-bit Capture register, 16-bit Compare register or PWM Master/Slave Duty Cycle register.

Capture/Compare/PWM Register1 (CCPR1) is comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte). The CCP1CON register controls the operation of CCP1. The special event trigger is generated by a compare match and will reset Timer1.

Capture/Compare/PWM Register2 (CCPR2) is comprised of two 8-bit registers: CCPR2L (low byte) and CCPR2H (high byte). The CCP2CON register controls the operation of CCP2. The special event trigger is generated by a compare match and will reset Timer1 and start an A/D conversion (if the A/D module is enabled).

In **Capture mode**, CCPR1H:CCPR1L captures the 16-bit value of the TMR1 register when an event occurs on pin RC2/CCP1. The event can be; every falling edge, every rising edge, every 4th rising edge, every 16th rising edge.

In **Compare mode**, the 16-bit CCPR1 register value is constantly compared against the TMR1 register pair value. When a match occurs, the RC2/CCP1 pin can be driven high, driven low or remains unchanged.

In Pulse Width Modulation mode, the CCPx pin produces up to a 10-bit resolution PWM output.

Master Synchronous Serial Port (MSSP) Module

The Master Synchronous Serial Port (MSSP) module is a serial interface, useful for communicating with other peripheral or microcontroller devices. These peripheral devices may be serial EEPROMs, shift registers, display drivers, A/D converters. The MSSP module can operate in one of the Serial Peripheral Interface (SPI) mode or Inter Integrated Circuit (I^2C) mode.

Related registers are; SSPSTAT, SSPCON, SSPCON2.

In SPI mode; it is allowed that 8 bits of data to be synchronously transmitted and received simultaneously. Typically Serial Data Out (SDO), Serial Data Clock (SCK), Serial Data In (SDI), Slave Select (SS) pins are used.

In I^2C mode; fully implements all master and slave functions (including general call support) and provides interrupts on START and STOP bits in hardware, to determine a free bus (multi-master function). The MSSP module implements the standard mode specifications, as well as 7-bit and 10-bit addressing.

The Universal Synchronous Asynchronous Receiver Transmitter (USART) module is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI.) The USART can be configured as a full duplex asynchronous system that can communicate with peripheral devices such as CRT terminals and personal computers, or it can be configured as a half duplex synchronous system that can communicate with peripheral devices such as A/D or D/A integrated circuits, serial EEPROMs.

Analog Digital Converter Module

The Analog-to-Digital (A/D) Converter module has eight inputs for 16F877.

The A/D conversion of the analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low voltage reference input that is software selectable to some combination of VDD, VSS, RA2, or RA3.

A/D Converter Module has 4 registers; A/D Result High Register (ADRESH), A/D Result Low Register (ADRESL), A/D Control Register0 (ADCON0) and A/D Control Register1 (ADCON1).

Special Features of CPU

Oscillator Types

The PIC16F877 can be operated in four different oscillator modes. The user can program two configuration bits (FOSC1 and FOSC0) to select one of these four modes:

• LP Low Power Crystal
• XT Crystal/Resonator
• HS High Speed Crystal/Resonator
• RC Resistor/Capacitor

RC Oscillator (FOSC1:FOSC0 11)

This is the least expensive solution for device oscillation. Only a resistor and a capacitor is required. Most variation in time-base.

HS Mode (High Gain) (FOSC1:FOSC0 10)

This is high frequency application. Oscillator circuit's mode consumes the most current of the three crystal modes.

XT (Medium Gain) (FOSC1:FOSC0 01)

Standard crystal/resonator frequency. Oscillator circuit's mode consumes the middle current of the three crystal modes.

LP (Low Gain) (FOSC1:FOSC0 00)

Low power/frequency applications. Oscillator circuit's mode consumes the least current of the three crystal modes.

XT, LP or HS modes need a crystal or ceramic resonator is connected to the OSC1 and OSC2 pins to establish oscillation.

Capacitor selection range are given with following table.

	32 kHz	33 pF
LP Mode	200 kHz	15 pF
	200 kHz	47-68 pF
XT Mode	1 MHz	15 pF
	4 MHz	15 pF
	4 MHz	15 pF
HS Mode	8 MHz	15-33 pF
	20 MHz	15-33 pF

Power on Reset

A Power-on Reset pulse is generated on-chip when VDD rise is detected. To take advantage of the POR, MCLR pin directly (or through a resistor) connected to VDD. This will eliminate external RC components usually needed to create a Power-on Reset. A minimum rise time for VDD is required.
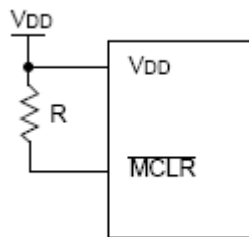
Power Up Timer

The Power-up Timer provides a fixed 72 ms nominal time-out on power-up only from the POR. The Powerup Timer operates on an internal RC oscillator. The chip is kept in reset as long as the PWRT is active. The PWRT's time delay allows VDD to rise to an acceptable level. A configuration bit is provided to enable/disable the PWRT.

Oscillator Start Up Timer

The Oscillator Start-up Timer (OST) provides 1024 oscillator cycle (from OSC1 input) delay after the PWRT delay is over. This ensures that the crystal oscillator or resonator has started and stabilized. The OST time-out is invoked only for XT, LP and HS modes and only on Power-on Reset or wake-up from SLEEP.

Brown Out Reset

The configuration bit, BODEN, can enable or disable the Brown-out Reset circuit. If VDD falls below VBOR (about 4V) for longer than TBOR (about 100mS), the

brown-out situation will reset the device. If VDD falls below VBOR for less than TBOR, a reset may not occur. Once the brown-out occurs, the device will remain in brown-out reset until VDD rises above VBOR. The power-up timer then keeps the device in reset for TPWRT (about 72mS). If VDD should fall below VBOR during TPWRT, the brown-out reset process will restart when VDD rises above VBOR with the power-up timer reset. The power-up timer is always enabled when the brown-out reset circuit is enabled regardless of the state of the PWRT configuration bit.

APPENDIX B. 16F877 SOFTWARE SUMMARY

Introduction

There are 35 instructions for 16F877 assembly programming. Instructions are classified into 3 groups.

- Byte oriented instructions
- Bit oriented instructions
- Literal and control operations

For byte-oriented instructions, 'f' represents a file register designator and 'd' represents a destination designator. The file register designator specifies which file register is to be used by the instruction. The destination designator specifies where the result of the operation is to be placed. If 'd' is zero, the result is placed in the W register. If 'd' is one, the result is placed in the file register specified in the instruction.

ADDLW	Add Literal and W
ANDWF	AND W with f
CLRF	Clear f
CLRW	Clear W
COMF	Complement f
DECF	Decrement f
DECFSZ	Decrement f, Skip if 0
INCF	Increment f
INCFSZ	Increment f, Skip if 0
IORWF	Inclusive OR W with f
MOVF	Move f
MOVWF	Move W to f
NOP	No Operation

RLF	Rotate Left f through Carry
RRF	Rotate Right f through Carry
SUBWF	Subtract W from f
SWAPF	Swap Nibbles in f
XORWF	Exclusive OR W with f

For bit-oriented instructions, 'b' represents a bit field designator which selects the number of the bit affected by the operation, while 'f' represents the number of the file in which the bit is located.

BCF	Bit Clear f
BSF	Bit Set f
BTFSS	Bit Test f, Skip if Set
BTFSC	Bit Test, Skip if Clear

For literal and control operations, 'k' represents an eight or eleven bit constant or literal value.

ADDWF	Add W and f
ANDLW	AND Literal with W
CALL	Call Subroutine
CLRWDT	Clear Watchdog Timer
GOTO	Unconditional Branch
IORLW	Inclusive OR Literal with W
MOVLW	Move Literal to W
RETFIE	Return from Interrupt
RETLW	Return with Literal in W
RETURN	Return from Subroutine
SLEEP	Go into standby mode
SUBLW	Subtract W from Literal
XORLW	Exclusive OR Literal with W

All instructions are executed within one single instruction cycle, unless a conditional test is true or the program counter is changed as a result of an instruction. In this case, the execution takes two instruction cycles with the second cycle executed as a NOP. One instruction cycle consists of four oscillator periods.

Assembly Language vs. High Level Lnguages

Assembly language is much harder to program. It is more detailed and intimate knowledge of the processor is required. High quality assembly language programs run much faster, use less memory.

High level programming languages are much easier. High level languages allow faster development times than work in assembly language, even with highly skilled programmers. Programs written in high level languages (especially object oriented programming languages) are much easier and less expensive to maintain than similar programs written in assembly language.

In this thesis the Pic Basic Pro language will be used.

Introduction to Pic Basic Pro

Pic Basic Pro is a programming language that makes easier and quicker to program PIC Microcontrollers.

The PicBasic Pro Compiler produces code that may be programmed into a wide variety of PICmicro microcontrollers having from 8 to 84 pins and various on-chip features including A/D converters, hardware timers and serial ports.

For operation of Pic Basic Pro Compiler it needs;

- a text editor or word processor for creation of program source file
- PICmicro MCU programmer

- PicBasic Pro Compiler
- a PC

Pic Basic is a language that is combination of assemby command macros that are used for LCD, EEPROM, analog digital converter, serial interface, shift register, various types signal outputs and lots of frequently used applications. This program language reduces these operations into one command.

Data receiving and transmitting with 24CXX series eeproms I2CREAD, I2CWRITE commands; for writing on LCD screen LCDOUT command; for condition control IF…THEN…ELSE…ENDIF, WHILE…WEND commands; for synchronous and asynchronuous communication SHIFTIN, SHIFTOUT, SERIN, SEROUT commands can be given as examples.

Pic Basic Pro Math Operations

The Pic Basic Compiler performs all math operations in full hierarchal order. Multiplies and divides are performed before adds and subtracts. All math operations are unsigned and performed with 16-bit precision.

Math Operators	Description
+	Addition
-	Subtraction
*	Multiplication
**	Top 16 Bits of Multiplication
*/	Middle 16 Bits of Multiplication
/	Division
//	Remainder (Modulus)
DIV32 32	bit division
<<	Shift Left
>>	Shift Right
ABS	Absolute Value
COS	Cosine

DCD	2n Decode
DIG	Digit
MAX	Maximum*
MIN	Minimum*
NCD	Encode
REV	Reverse Bits
SIN	Sine
SQR	Square Root
&	Bitwise AND
|	Bitwise OR
^	Bitwise Exclusive OR
~	Bitwise NOT
&/	Bitwise NOT AND
|/	Bitwise NOT OR
^/	Bitwise NOT Exclusive OR

Pic Basic Pro Comparison Operations

Comparison Operator	Description
= or ==	Equal
<> or !=	Not Equal
<	Less Than
>	Greater Than
<=	Less Than or Equal
>=	Greater Than or Equal

Pic Basic Pro Logical Operations

Logical Operator	Description
AND or &&	Logical AND
OR or ||	Logical OR

XOR or ^^	Logical Exclusive OR
NOT AND	Logical NAND
NOT OR	Logical NOR
NOT XOR	Logical NXOR

Pic Basic Pro Statements

@ Statement	@ provides a shortcut for inserting one assembly language statement into PBP program.
ADCIN Channel,Var	Read the on-chip analog to digital converter channel and store the result in the variable Var.
ASM {assembler code} ENDASM	These two instructions are used to mix assembly language code with PicBasic statements.
BRANCH Index,[Label{,Label...}]	BRANCH causes the program to jump to a different location based on a variable index.
CALL Label	Execute the assembly language subroutine named Label.
CLEAR	Set all RAM registers to zero.
CLEARWDT	Clear (tickle) the Watchdog Timer.
COUNT Pin,Period,Var	Count the number of pulses that occur on Pin during the Period and stores the result in Var.
DATA {@Location,}Constant{,Constant...}	Store constants in on-chip non-volatile EEPROM when the device is first programmed.
DEBUG Item {,Item...}	Send one or more items to a predefined pin at a predefined baud rate in standard asynchronous format using 8 data bits, no parity and 1 stop bit (8N1).

DISABLE	DISABLE both debug and interrupt processing following this instruction.
DIV32 Number	PBPs multiply (*) function operates as a 16-bit x 16-bit multiply yielding a 32-bit result.
DTMFOUT Pin,{Onms,Offms,}[Tone{,Tone...}]	Produce DTMF touch tone sequence on Pin.
EEPROM {Location,}[Constant{,Constant...}]	Store constants in on-chip EEPROM.
ENABLE	ENABLE debug and interrupt processing that was previously DISABLEd following this instruction.
END	Stop program execution and enter low power mode
ERASECODE Block	Some flash PICmicro MCUs, like the PIC18Fxxx series, require a portion of the code space to be erased before it can be rewritten with WRITECODE.
FOR Count = Start TO End {STEP {-} Inc} {Body} NEXT {Count}	The FOR..NEXT loop allows programs to execute a number of statements a given number of times using a variable as a counter.
FREQOUT Pin,Onms,Frequency1{,Frequency2}	Produce the Frequency(s) on Pin for Onms milliseconds.
GOSUB Label	Jump to the subroutine at Label saving its return address on the stack.
GOTO Label	Program execution continues with the statements at Label.
HIGH Pin	Make the specified Pin high.
HPWM Channel,Dutycycle,Frequency	Generate hardware pwm.

HSERIN {ParityLabel,}{Timeout,Label,}[Item{,...}]	Receive one or more items from the hardware serial port on devices that support asynchronous serial communications in hardware.
HSEROUT [Item {,Item...}]	Send one or more Items to the hardware serial port on devices that support asynchronous serial communications in hardware.
HSERIN2 {ParityLabel,}{Timeout,Label,}[Item{,...}]	Receive one or more items from the second hardware serial port on devices that support asynchronous serial communications in hardware.
HSEROUT2 [Item {,Item...}]	Send one or more Items to the second hardware serial port on devices that support asynchronous serial communications in hardware.
I2CREAD DataPin,ClockPin,Control,{Address,}[Var{,Var...}]{,Label}	Send Control and optional Address bytes out the ClockPin and DataPin and store the byte(s) received into Var.
I2CWRITE DataPin,ClockPin,Control,{Address,}[Value{,Value...}]{,Label}	I2CWRITE sends Control and optional Address out the I2C ClockPin and DataPin followed by Value.
I2CIN Control, Address, Variable {,Variable}	
I2COUT Control, Address, Value {,Value}	

 PRO and STD versions

IF Comp {AND/OR Comp...} THEN Label	Performs one or more comparisons. Each Comp term can relate a variable to a constant or other variable and includes one of the comparison operators.

' PRO version only

IF Comp {AND/OR Comp...} THEN

Statements...
ELSE
  Statements...
ENDIF

INPUT Pin	Makes the specified Pin an input.
{LET} Var = Value	Assign a Value to a Variable.
LCDOUT Item {,Item...}	Display Items on (LCD). PICBasic supports LCD modules with a Hitachi 44780 controller or equivalent.
LOOKDOWN Search,[Constant{,Constant...}],Var	The LOOKDOWN statement searches a list of 8-bit Constant values for the presence of the Search value.
LOOKDOWN2 Search,{Test}[Value{,Value...}],Var	The LOOKDOWN2 statement searches a list of Values for the presence of the Search value.
LOOKUP Index,[Constant{,Constant...}],Var	The LOOKUP statement can be used to retrieve values from a table of 8-bit constants.
LOOKUP2 Index,[Value{,Value...}],Var	The LOOKUP2 statement can be used to retrieve entries from a table of Values.
LOW Pin	Make the specified Pin low.
NAP Period	Places the microcontroller into low power mode for short periods of time.
ON INTERRUPT GOTO Label	ON INTERRUPT allows the handling of microcontroller interrupts by a PICBasic subroutine.
OUTPUT Pin	Make the specified Pin an output.
OWIN Pin, Mode,[Item {,Item}]	Optionally send a reset pulse to a one-wire device and then read one or more bits or bytes of data from it, optionally ending with another reset pulse.

OWOUT Pin, Mode, [Item{, Item...}]	Optionally send a reset pulse to a one-wire device and then writes one or more bits or bytes of data from it, optionally ending with another reset pulse.
PAUSE Period	Pause the program for Period msec.
PAUSEUS Period	Pause the program for Period usec.
PEEK Address,Var	Read the microcontroller register at the specified Address and stores the result in Var.
POKE Address,Value	Write Value to the microcontroller register at the specified Address.
POT Pin,Scale,Var	Reads a potentiometer (or some other resistive device) on Pin.
PULSIN Pin,State,Var	Measures pulse width on Pin.