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Resonant Inverting Step down DC-DC Converter

A Project Report

Submitted by

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DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY
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BONAFIDE CERTIFICATE

Certified that this project report entitled **"Resonant Inverting Step down DC-DC Converter"** is the bonafide work of

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Who carried out the project work under my Supervision

Signature of the Head of the Department

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KUMARAGURU COLLEGE OF TECHNOLOGY, COIMBATORE 641 049

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ABSTRACT

This paper presents a resonant soft-switching step down converter with inverted output voltage polarity. Buck converters are step-down DC-DC converters that are widely being used in different electronic devices like operational amplifiers, localized microprocessor to obtain different level of voltage. These converters which employing high frequency switching devices operating on PWM principle. The switching devices are made to turn on and turn off the entire load current at high di/dt and also withstand high voltage stress across them. Due to these two effects there occurs increased power losses in these converters and reduces the efficiency significantly. The reduction in efficiency is highly unacceptable as it leads to shorter life and derated device conditions. Switching losses can be minimized if each switch is made to turn-on and turn-off when the voltage across it and/or current through it is zero at the instant of switching. The resonant tank is the medium of energy transfer and provides soft-switching instants for all active elements. In this particularly, zero-current switching is employed. In this project Resonant inverting DC-DC step down converter operation are explained with mathematical expressions and it is to be simulated in matlab. Analysis is to be made on this circuit by changing the parameters of the circuit and it is to be verified by practical circuit. The prototype model is also designed, fabricated and tested.

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ABBREVIATIONS

DC	Direct Current
AC	Alternating Current
PWM	Pulse Width Modulation
EMI	Electromagnetic Interference
ZCS	Zero current switching
ZVS	Zero Voltage switching
RF	Radio Frequency
C	Capacitor
L	Inductor
ESR	Effective Series Resistance
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
IGBT	Insulated Gate Bipolar Transistor
SCC	Switched Capacitor Converters
SRC	Series-Resonant Converter

LIST OF SYMBOLS

Q_1, Q_2	Power MOSFETs
D_1, D_2, D_3	Diodes
L_r	Resonant inductor
C_r	Resonant capacitor
C_0	Output capacitor
R	Resistor
V_s	Supply voltage
I_r	Inductor current
V_r	Resonant voltage
I_1	Input current
I_2	Switch current
I_o	output current
I_{d3}	Diode current
f_r	Resonant frequency

CHAPTER 1

CHAPTER 1

1. INTRODUCTION

1.1 INTRODUCTION OF RESONANT DC-DC CONVERTERS

Switching converters have been widely employed for DC–DC power conversion because the converter operating frequency is considerably increased and consequently the converter size and weight are reduced. Soft-switching techniques are developed to reduce switching losses and electromagnetic interference (EMI).At soft-switching condition, switching frequency can be further increased to enhance the converter power density. This condition is commonly attained by zero-voltage switching (ZVS) and/or zero-current switching (ZCS). . The main advantage of Switched capacitor DC-DC converter is that no magnetic component is required for storing energy, making it possible to fabricate a smaller size and lighter weight converter in an integrated circuit.

To provide a regulated negative voltage, the PWM buck-boost converter, and switched capacitor converters (SCCs) are employed classically. Quasi-resonant buck-boost converter is a soft switching counterpart of PWM buck-boost converter in which a high-frequency resonant tank is utilised to reduce switching losses. The main advantage of this technique is its less additional elements. However, two inductors are required where the main inductor of parent converter is still a relatively bulky component. Moreover, the voltage stress of switch is higher than that of the PWM counterpart.

A major drawback is the current spikes produced by charging/discharging of the circuit capacitors via only parasitic resistors of the switches. Very low power handling and high EMI are consequences of this kind of operation. To provide a fractional voltage gain, many diodes and capacitors ought to be used, which result in an increase of the converter cost, volume and conduction losses. Resonant converters are a family of soft-switching converters, in which energy is transferred through a high frequency resonant tank and switching is performed at zero-crossing instants of current and/or voltage. The main advantage of resonant converters is that the size of passive components is reduced greatly. In series-resonant converter (SRC), the converter passive components include only a high-frequency resonant tank and a filtering capacitor at the output.

A very small inductor is added to create a resonant turn-on and turn-off when the transistors are switched on or off, respectively. Zero-current switching condition in both switching on and off is obtained so that both switched loss and electromagnetic interference are low.

All semiconductor devices operate under soft-switching condition at turn-on and turn-off switching instants, independent of the load current and operating voltages. The voltage regulation of such converter is also difficult because the magnitude of the output voltage must be a fraction or a multiple of the source voltage. In order to regulate the converter, the switching capacitor's charge and discharge characteristics must also be taken into account and, thus, the switching device's duty ratio is used to control the amount of power through the switching capacitor.

1.2 OBJECTIVES OF THE PROJECT

The objective of this project is to

- To design and simulate the Resonant inverting step down DC-DC converter to reduce the switching losses and Electromagnetic Interferences.
- Hardware implementation of Resonant inverting step down DC-DC converter.

1.3 ORGANIZATION OF THESIS

This gives an overall outline of the project report.

CHAPTER 1

It describes the general introduction, objective of Resonant DC-DC Converters.

CHAPTER 2

It describes the Evolution and Components of Buck converter.

CHAPTER 3

It describes about the operation and effect of resonant tank with its applications.

CHAPTER 4

In this chapter it describes the introduction of Switching Techniques.

CHAPTER 5

It includes the modes of operation of Resonant inverting step down DC-DC converter

CHAPTER 6

It includes the introduction MATLAB (simulink), simulation details.

CHAPTER 7

It includes the description of all components used in the hardware. It shows the schematic diagram of the hardware and output waveforms and test results.

CHAPTER 8

Gives the conclusion and recommendations for the future work.

CHAPTER 2

CHAPTER 2

DC-DC CONVERTER

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc.

2.1 EVOLUTION OF BUCK CONVERTER

The buck converter here onwards is introduced using the evolutionary approach. Let us consider the circuit in Figure 2.1 containing a single pole double-throw switch.

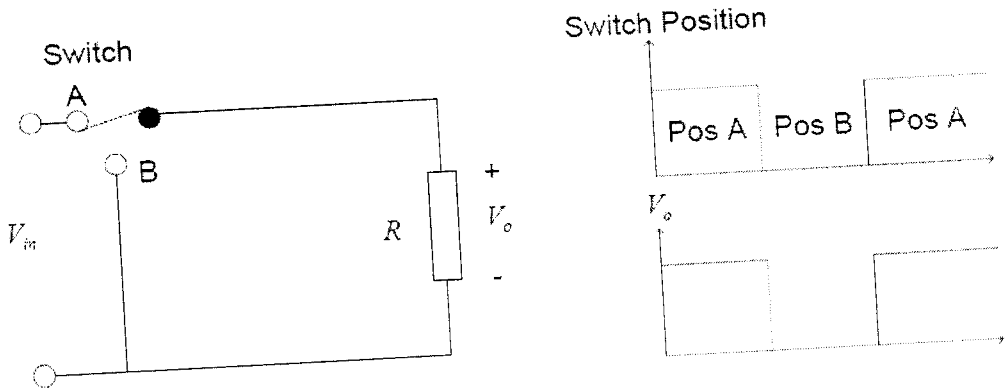

Fig 2.1 A resistor with single-pole double throw switch

For the above circuit, the output voltage equals the input voltage when the switch is in position A and it is zero when the switch is in position B. By varying the duration for which the switch is in position A and B, it can be seen that the average output voltage can be varied, but the output voltage is not pure dc. The circuit in Figure 2.1 can be modified as shown in Figure 2.2 by adding an inductor in series with the load resistor. An inductor reduces ripples in current passing through it and the output voltage would contain less ripple since the current through the load resistor is the same as that of the inductor. When the switch is in position A, the current through the inductor increases and the energy stored in the inductor increases. When the switch is in position B, the inductor acts as a source and maintains the current through the load resistor. During this period the energy stored in the inductor decreases and its current falls. It is important to note that there is continuous conduction through the load for this circuit. If the time constant due to the inductor and load resistor is relatively large compared with the period for which the switch is in position A or B, then the rise and fall of current through inductor is more or less linear as shown in Figure 2.2.

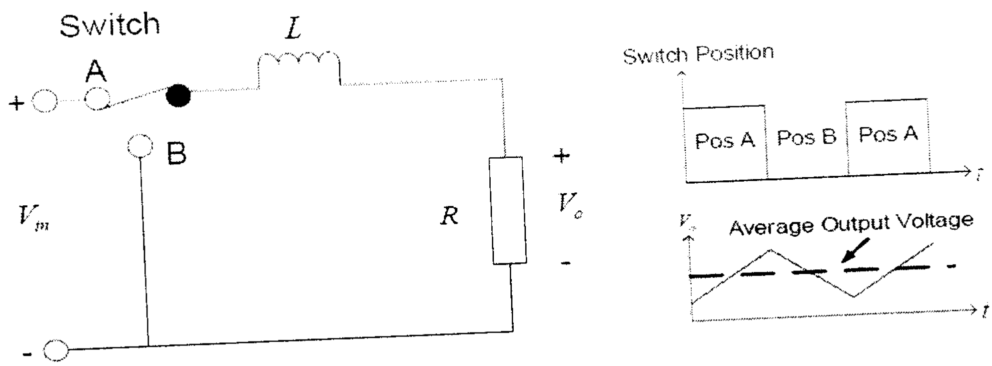

Fig 2.2 Effect of an inductor

The next step in the evolutionary development of the buck converter is to add a capacitor across the load resistor and this circuit is shown in Figure 2.3. A capacitor reduces the ripple content in voltage across it, whereas an inductor smoothes the current passing through it. The combined action of LC filter reduces the ripple in output to a very low level.

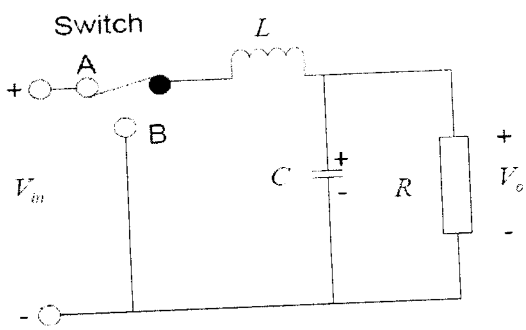

Fig 2.3 Circuit with an LC filter

With the circuit in Figure 2.3 is possible to have a power semiconductor switch to correspond to the switch in position A and a diode in position B.The circuit that results is shown in Figure 2.4. When the switch is in position B, the current will pass through the diode. The important thing now is the controlling of the power semiconductor switch.

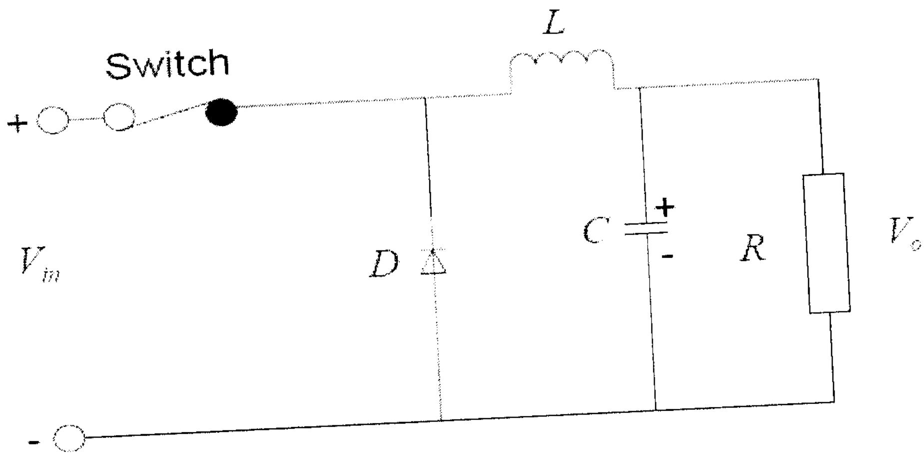

Fig 2.4 Buck converter with load resistor

The circuit in Figure 2.4 can be regarded as the most elementary buck converter without a feedback. The Buck Converter transfers small packets of energy with the help of a power switch a diode and an inductor and is accompanied by an output filter capacitor and input filter. All the other topologies such as the Boost, Buck-Boost Converter etc vary by the different arrangement of these basic components. This circuit can be further modified by adding the feedback part which is integral for a SMPS because based on the feedback it stabilizes the output.

2.2 PURPOSE OF DIFFERENT COMPONENTS IN BUCK CONVERTER

SWITCH

In its crudest form a switch can be a toggle switch which switches between supply voltage and ground. But for all practical applications which we shall consider we will deal with transistors. Transistors chosen for use in switching power supplies must have fast switching times and should be able to withstand the voltage spikes produced by the inductor. The input on the gate of the transistor is normally a Pulse Width Modulated (PWM) signal which will determine the ON and OFF time. Sizing of the power switch is determined by the load current and off-state voltage capability. The power switch (transistor) can either be a MOSFET, IGBT, JFET or a BJT. Power MOSFETs are the key elements of high frequency power systems such as high-density power supplies. Therefore MOSFETs have now replaced BTJ's in new designs operating at much higher frequencies but at lower voltages. At high voltages MOSFETs still have their limitations. The intrinsic characteristics of the MOSFET produce a large on-resistance which increases excessively when the devices breakdown voltage is raised. Therefore the power MOSFET is only useful upto voltage ratings of 500V and so is restricted to low voltage applications or in two-transistor forward converters and bridge circuits operating off-line. At high breakdown voltages (>200V) the on-state voltage drop of the power MOSFET becomes higher than that of a similar size bipolar device with similar voltage rating. This makes it more attractive to use the bipolar power transistor at the expense of worse high frequency performance. As improvements in fabrication techniques, new materials, device characteristics take place than MOSFETs are likely to replace BJTs.

INDUCTOR

The function of the inductor is to limit the current slew rate (limit the current in rush) through the power switch when the circuit is ON. The current through the inductor cannot change suddenly. When the current through an inductor tends to fall, the inductor tends to maintain the current by acting as a source. This limits the otherwise high- peak current that would be limited by the switch resistance alone. The key advantage is when the inductor is used to drop voltage, it stores energy. Also the inductor controls the percent of the ripple and determines whether or not the circuit is operating in the continuous mode. Peak current through the inductor determines the inductor's required saturation current rating, which in turn dictates the approximate size of the inductor. Saturating the inductor core decreases the converter efficiency, while increasing the temperature of the inductor, the MOSFET and the diode. The size of the inductor and capacitor can be reduced by the implementation of high switching frequency, multiphase interleaved topology, and a fast hysteric controller. A smaller inductor value enables a faster transient response, it also results in larger current ripple which causes higher conduction losses in the switches, inductor and parasitic resistances. The smaller inductor also requires a larger filter capacitor to decrease the output voltage ripple. Inductors used in switched supplies are sometimes wound on toroidal cores, often made of ferrite or powdered iron core with distributed air-gap to store energy.

A DC-DC converter transfers energy at a controlled rate from an input source to an output load, and as the switching frequency increases, the time available for this energy transfer decreases. For example, consider a buck converter operating at 500 kHz with a 10 μH inductor. For most DC-DC converters, changing the frequency to 1 MHz allows use of exactly one half the inductance, or 5μH.

CAPACITOR

Capacitor provides the filtering action by providing a path for the harmonic currents away from the load. Output capacitance (across the load) is required to minimize the voltage overshoot and ripple present at the output of a step-down converter. The capacitor is large enough so that its voltage does not have any noticeable change during the time the switch is off. Large overshoots are caused by insufficient output capacitance, and large voltage ripple is caused by insufficient capacitance as well as a high equivalent-series resistance (ESR) in the output capacitor. The maximum allowed output-voltage overshoot and ripple are usually specified at the time of design. Thus, to meet the ripple specification for a step-down converter circuit, we must include an output capacitor with ample capacitance and low ESR.

The problem of overshoot, in which the output-voltage overshoots its regulated value when a full load is suddenly removed from the output, requires that the output capacitor be large enough to prevent stored inductor energy from launching the output above the specified maximum output voltage. Since switched power regulators are usually used in high current, high performance power supplies, the capacitor should be chosen for minimum loss. Loss in a capacitor occurs because of its internal series resistance and inductance. Capacitors for switched regulators are partly chosen on the basis of Effective Series Resistance (ESR). Solid tantalum capacitors are the best in this respect. For very high performance power supplies, sometimes it is necessary to use parallel capacitors to get a low enough effective series resistance.

REEWHEELING DIODE

Since the current in the inductor cannot change suddenly, a path must exist for the nductor current when the switch is off (open). This path is provided by the freewheeling iode (or catch diode).The purpose of this diode is not to rectify, but to direct current flow in he circuit and to ensure that there is always a path for the current to flow into the inductor. It is lso necessary that this diode should be able to turn off relatively fast. Thus the diode enables the converter to convert stored energy in the inductor to the load. This is a reason why we have higher efficiency in a DC-DC Converter as compared to a linear regulator. When the switch closes, the current rises linearly (exponentially if resistance is also present). When the switch opens, the freewheeling diode causes a linear decrease in current. At steady state we have a saw tooth response with an average value of the current.

FEEDBACK

Feedback and control circuitry can be carefully nested around these circuits to regulate the energy transfer and maintain a constant output within normal operating conditions. Control by pulse-width modulation is necessary for regulating the output. The transistor switch is the heart of the switched supply and it controls the power supplied to the load.

CHAPTER 3

CHAPTER 3

RESONANT TANK

A **resonant circuit** or **tuned circuit** that consists of an inductor and a capacitor. When connected together, they can act as an electrical resonator, storing electrical energy oscillating at the circuit's resonant frequency.

3.1 OPERATION

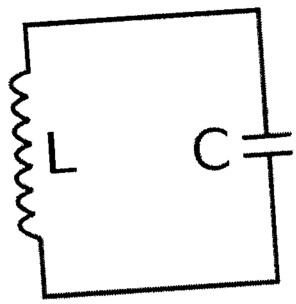

Fig.3.1 LC Circuit

An LC circuit can store electrical energy vibrating at its resonant frequency. A capacitor stores energy in the electric field between its plates, depending on the voltage across it, and an inductor stores energy in its magnetic field depending on the current through it.

If a charged capacitor is connected across an inductor, charge will start to flow through the inductor, building up a magnetic field around it, and reducing the voltage on the capacitor. Eventually all the charge on the capacitor will be gone and the voltage across it will reach zero. However, the current will continue, because inductors resist changes in current, and energy to keep it flowing is extracted from the magnetic field, which will begin to decline. The current will begin to charge the capacitor with a voltage of opposite polarity to its original charge. When the magnetic field is completely dissipated the current will stop and the charge will again be stored in the capacitor, with the opposite polarity as before. Then the cycle will begin again, with the current flowing in the opposite direction through the inductor.

The charge flows back and forth between the plates of the capacitor, through the inductor. The energy oscillates back and forth between the capacitor and the inductor until (if not replenished by power from an external circuit) internal resistance makes the oscillations die out. Its action, known mathematically as a harmonic_oscillator, is similar to a pendulum swinging back and forth, or water sloshing back and forth in a tank. For this reason the circuit is also called a **tank circuit**. The oscillation frequency is determined by the capacitance and inductance values used. In typical tuned circuits in electronic equipment the oscillations are very fast, thousands to millions of times per second.

3.2 RESONANT EFFECT

The resonance effect occurs when inductive and capacitive reactances are equal in absolute value. The frequency at which this equality holds for the particular circuit is called the resonant frequency. The resonant frequency of the LC circuit is

$$\omega = \sqrt{\frac{1}{LC}}$$

where L is the inductance in henries, and C is the capacitance in farads. The angular frequency ω has units of radians per second.

The equivalent frequency in units of hertz is

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi\sqrt{LC}}.$$

LC circuits are often used as filters; the L/C ratio is one of the factors that determines their "Q" and so selectivity. For a series resonant circuit with a given resistance, the higher the inductance and the lower the capacitance, the narrower the filter bandwidth. For a parallel resonant circuit the opposite applies. Positive feedback around the tuned circuit ("regeneration") can also increase selectivity.

.3 SERIES LC CIRCUIT

.3.1 RESONANCE

Here L and C are connected in series to an AC power supply. Inductive reactance magnitude (X_L) increases as frequency increases while capacitive reactance magnitude (X_C) decreases with the increase in frequency. At a particular frequency these two reactances are equal in magnitude but opposite in sign. The frequency at which this happens is the resonant frequency (f_r) for the given circuit.

Hence, at f_r :

$$X_L = -X_C$$

$$\omega L = \frac{1}{\omega C}$$

Converting angular frequency into hertz we get

$$2\pi f L = \frac{1}{2\pi f C}$$

Here f is the resonant frequency. Then rearranging,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

In a series AC circuit, X_C leads by 90 degrees while X_L lags by 90. Therefore, they cancel each other out. The only opposition to a current is coil resistance. Hence in series resonance the current is maximum at resonant frequency.

- At f_r, current is maximum. Circuit impedance is minimum. In this state a circuit is called an *acceptor circuit*.
- Below f_r, $X_L \ll (-X_C)$. Hence circuit is capacitive.

- Above f_r, $X_L \gg (-X_C)$. Hence circuit is inductive.

3.3.2 IMPEDANCE

First consider the impedance of the series LC circuit. The total impedance is given by the sum of the inductive and capacitive impedances:

$$Z = Z_L + Z_C$$

By writing the inductive impedance as $Z_L = j\omega L$ and capacitive impedance as $Z_C = (j\omega C)^{-1}$ and substituting we have

$$Z = j\omega L + \frac{1}{j\omega C}.$$

Writing this expression under a common denominator gives

$$Z = \frac{(\omega^2 LC - 1)j}{\omega C}.$$

The numerator implies that if $\omega^2 LC = 1$ the total impedance Z will be zero and otherwise non-zero. Therefore the series LC circuit, when connected in series with a load, will act as a band-pass filter having zero impedance at the resonant frequency of the LC circuit.

3.4 PARALLEL LC CIRCUIT

3.4.1 RESONANCE

Here a coil (L) and capacitor (C) are connected in parallel with an AC power supply. Let R be the internal resistance of the coil. When X_L equals X_C, the reactive branch currents are equal and opposite. Hence they cancel out each other to give minimum current in the main line. Since total current is minimum, in this state the total impedance is maximum.

Resonant frequency given by:

$$f = \frac{1}{2\pi\sqrt{LC}}.$$

Note that any reactive branch current is not minimum at resonance, but each is given separately by dividing source voltage (V) by reactance (Z). Hence I=V/Z, as per Ohm's law.

- At f_r, line current is minimum. Total impedance is maximum. In this state a circuit is called a *rejector circuit.*
- Below f_r, circuit is inductive.
- Above f_r,circuit is capacitive.

3.4.2 IMPEDANCE

The same analysis may be applied to the parallel LC circuit. The total impedance is then given by:

$$Z = \frac{Z_L Z_C}{Z_L + Z_C}$$

and after substitution of Z_L and Z_C and simplification, gives

$$Z = \frac{-j\omega L}{\omega^2 LC - 1}.$$

Note that

$$\lim_{\omega^2 LC \to 1} Z = \infty$$

but for all other values of $\omega^2 LC$ the impedance is finite (and therefore less than infinity). Hence the parallel LC circuit connected in series with a load will act as band-stop filter having infinite impedance at the resonant frequency of the LC circuit.

.5 APPLICATIONS OF RESONANCE EFFECT

1. Most common application is tuning. For example, when we tune a radio to a particular station, the LC circuits are set at resonance for that particular carrier frequency.
2. A series resonant circuit provides voltage magnification.
3. A parallel resonant circuit provides current magnification.
4. A parallel resonant circuit can be used as load impedance in output circuits of RF amplifiers. Due to high impedance, the gain of amplifier is maximum at resonant frequency.
5. Both parallel and series resonant circuits are used in induction heating.

CHAPTER 4

CHAPTER 4

SWITCHING TECHNIQUES

he two techniques of switching are

- Hard switching
- Soft switching

.1 HARD SWITCHING

The conventional PWM power converters were operated in a switched mode operation. Power switches have to cut off the load current within the turn-on and turn-off times under the hard switching conditions. Hard switching refers to the stressful switching behavior of the power electronic devices. The switching trajectory of a hard-switched power device is shown in Fig. During the turn-on and turn-off processes, the power device has to withstand high voltage and current simultaneously, resulting in high switching losses and stress. Dissipative passive snubbers are usually added to the power circuits so that the dv/dt and di/dt of the power devices could be reduced, and the switching loss and stress are diverted to the passive snubber circuits. However, the switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converters. Typical converter switching frequency was limited to a few tens of kilo-Hertz (typically 20kHz to 50kHz) in early 1980's. The stray inductive and capacitive components in the power circuits and power devices still cause considerable transient effects, which in turn give rise to electromagnetic interference (EMI) problems. The transient ringing effects are major causes of EMI.

In the 1980's, lots of research efforts were diverted towards the use of resonant converters. The concept was to incorporate resonant tanks in the converters to create oscillatory (usually sinusoidal) voltage or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. The reduction of switching loss and the continual improvement of power switches allow the switching frequency of the resonant converters to reach hundreds of kilo-Hertz (typically 100kHz to 500kHz). Consequently, magnetic sizes can be reduced and the power density of the converters increased. Various forms of resonant converters have been proposed and developed. However, most of the resonant converters suffer several problems. When compared with the conventional PWM converters, the resonant current and voltage of resonant converters have high peak values, leading to higher conduction loss and higher V and I ratings requirements for the power devices.

4.2 SOFT SWITCHING

In late 1980's and throughout 1990's, further improvements have been made in converter technology. New generations of soft-switched converters that combine the advantages of conventional PWM converters and resonant converters have been developed. These soft-switched converters have switching waveforms similar to those of conventional PWM converters except that the rising and falling edges of the waveforms are 'smoothed' with no transient spikes. Unlike the resonant converters, new soft-switched converters usually utilize the resonance in a controlled manner. Resonance is allowed to occur just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. Other than that, they behave just like conventional PWM converters. With simple modifications, many customized control integrated control (IC) circuits designed for conventional converters can be employed for soft-switched converters. Because the switching loss and stress have been reduced, soft-switched converter can be operated at the very high frequency (typically 500kHz to a few Mega-Hertz). Soft-switching converters also provide an effective solution to suppress EMI and have been applied to DC-DC, AC-DC and DC-AC converters. This chapter covers the basic technology of resonant and soft-switching converters. Various forms of soft-switching techniques such as ZVS, ZCS, voltage clamping, zero transition methods etc.

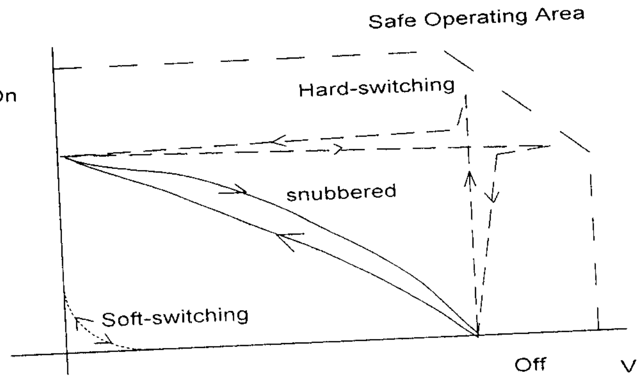

Fig.4.1 Typical switching trajectories of power switches.

Prior to the availability of fully controllable power switches, thyristors were the major power evices used in power electronic circuits. Each thyristor requires a commutation circuit, which sually consists of a LC resonant circuit, for forcing the current to zero in the turn-off process. his mechanism is in fact a type of zero-current turn-off process. With the recent advancement n semiconductor technology, the voltage and current handling capability, and the switching speed of fully controllable switches have significantly been improved. However, the use of resonant circuit for achieving zero-current-switching (ZCS) and/or zero-voltage-switching (ZVS) has also emerged as a new technology for power converters. The concept of resonant switch that replaces conventional power switch. A resonant switch is a sub-circuit comprising a semiconductor switch S and resonant elements, L_r and C_r. The switch S can be implemented by a unidirectional or bidirectional switch, which determines the operation mode of the resonant switch. Two types of resonant switches, including zero-current (ZC) resonant switch and zero-voltage (ZV) resonant switches, are shown in Fig.3 and Fig.4, respectively.

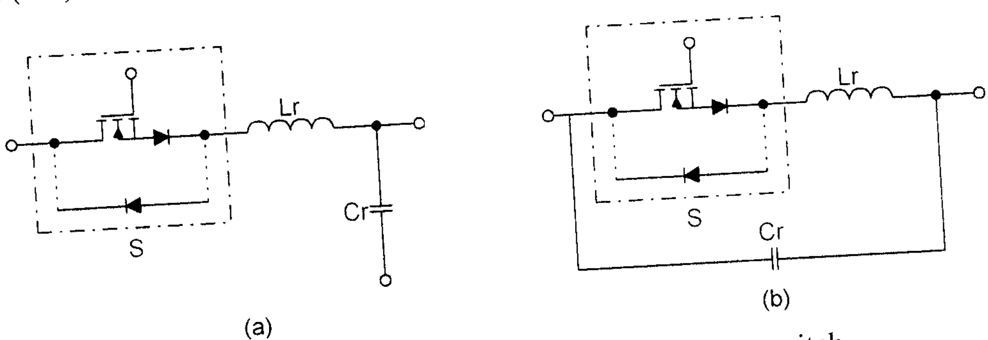

Fig.4.2 Zero-current (ZC) resonant switch.

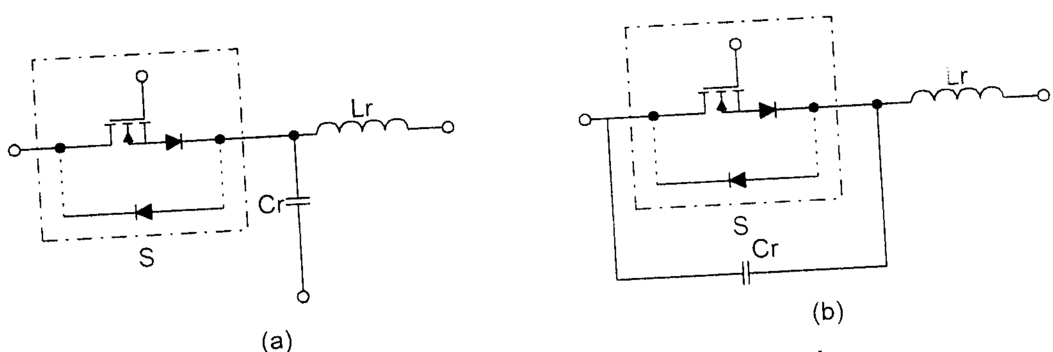

Fig.4.3 Zero-voltage (ZV) resonant switch.

4.3 ZC RESONANT SWITCH

In a ZC resonant switch, an inductor L_r is connected in series with a power switch S in order to achieve zero-current-switching (ZCS). If the switch S is a unidirectional switch, the switch current is allowed to resonate in the positive half cycle only. The resonant switch is said to operate in *half-wave* mode. If a diode is connected in anti-parallel with the unidirectional switch, the switch current can flow in both directions. In this case, the resonant switch can operate in *full-wave* mode. At turn-on, the switch current will rise slowly from zero. It will then oscillate, because of the resonance between L_r and C_r. Finally, the switch can be commutated at the next zero current duration. The objective of this type of switch is to shape the switch current waveform during conduction time in order to create a zero-current condition for the switch to turn off.

4.4 ZV RESONANT SWITCH

In a ZV resonant switch, a capacitor C_r is connected in parallel with the switch S for achieving zero-voltage-switching (ZVS). If the switch S is a unidirectional switch, the voltage across the capacitor C_r can oscillate freely in both positive and negative half-cycle. Thus, the resonant switch can operate in *full-wave* mode. If a diode is connected in anti-parallel with the unidirectional switch, the resonant capacitor voltage is clamped by the diode to zero during the negative half-cycle. The resonant switch will then operate in *half-wave* mode. The objective of a ZV switch is to use the resonant circuit to shape the switch voltage waveform during the off time in order to create a zero-voltage condition for the switch to turn on.

CHAPTER 5

CHAPTER 5

MODES OF OPERATION

.1 CIRCUIT DIAGRAM

To simplify the analysis in Fig.1, it is assumed that all the circuit elements are ideal and ie output capacitor C is large enough such that the output voltage is constant during one witching cycle. Assume that the converter is in steady state, the resonant voltage v_r and resonant urrent i_r are both zero before Mode I, and Q_1 and Q_2 are off.

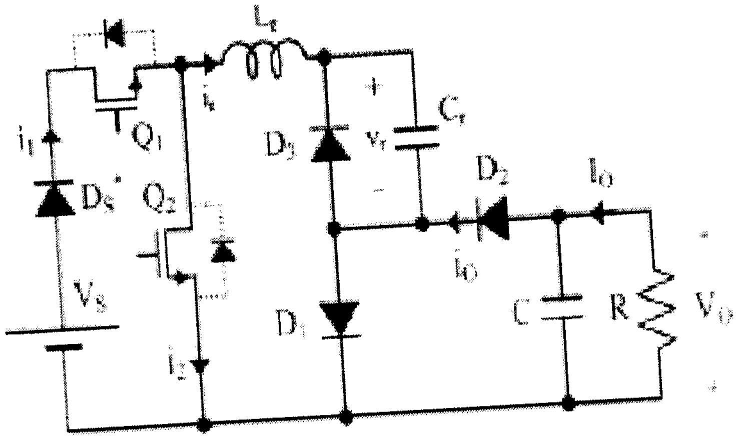

Fig.5.1 Resonant inverting step-down DC-DC converter

5.2 EQUIVALENT MODES

MODE-1(t_1-t_2):

At t= t_1,

- Q_1 is turned ON and thereby D_1 become forward biased.
- Because of L_r, Q_1 is turned ON (under ZCS).
- In this mode, the resonant capacitor C_r charges through a resonance with L_r until it reaches zero at t_2.

At the end of interval,

- V_r has reached $2V_s$

- Q_1, D_s and D_1 are turned off (under ZCS).

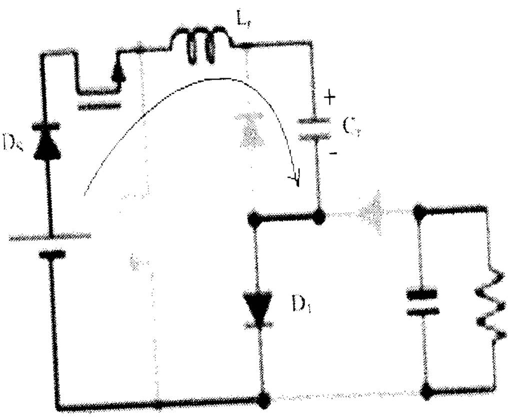

Fig.5.2 Mode-1

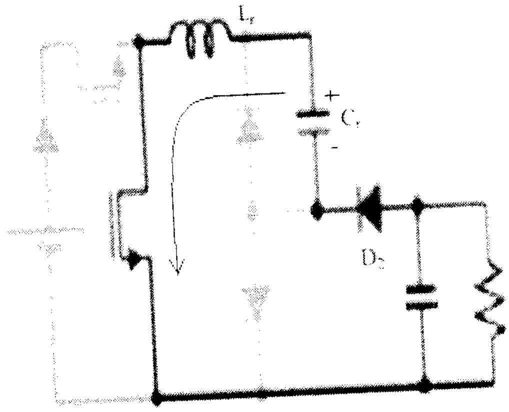

Fig.5.3 Mode-2

MODE-2(t_2-t_3):

At $t=t_2$,

- Q_2 is turned ON (under ZCS) and D_2 become forward biased.
- Thus, stored energy in C_r is absorbed by load and L_r.

At the end of the interval,

- V_r reaches Zero.

MODE-3(t_3-t_4):

At $t=t_3$,

- C_r is completely discharged and D_3 become forward biased.
- In this mode, the energy absorbed by L_r is transferred to the load.
- Thus, the magnitude of I_r decreases linearly until it reaches Zero at t4.

At the end of this mode,

- Q_2, D_2 and D_3 are turned off (under ZCS).
- The entire energy absorbed by C_r in Mode 1 is now pumped to the load.

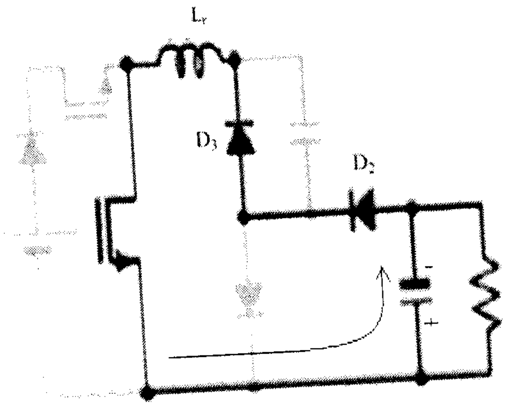

Fig.5.4 Mode-3

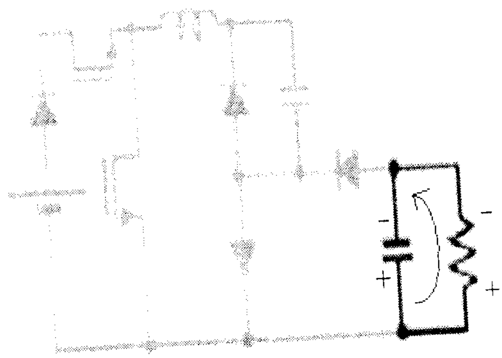

Fig.5.5 Mode-4

MODE-4(t_4-t_5):

- In this mode, all semiconductor devices are off and the load is supplied by the output capacitor.

3 SIMULATION OF RESONANT INVERTING STEP DOWN DC-DC CONVERTER

3.1 MATLAB

The name MATLAB stands for matrix laboratory. MATLAB is a high-performance anguage for technical computing. It Integrates computation, visualization, and programming in n easy-to-use environment where problems and solutions are expressed in familiar nathematical notation. In this project the modeling and simulation of the proposed system is lone using MATLAB (using simulink and power system block set tool boxes).

SIMULINK

Simulink is a software package for modeling, simulating, and analyzing non linear dynamical systems. It is a graphical mouse-driven program that allows somebody to model a system by drawing a block diagram on the screen and manipulating it dynamically. Simulink is a platform for multi domain simulation and Model-Based Design for dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries, and can be extended for specialized applications.

5.3.2 SIMULATION CIRCUIT

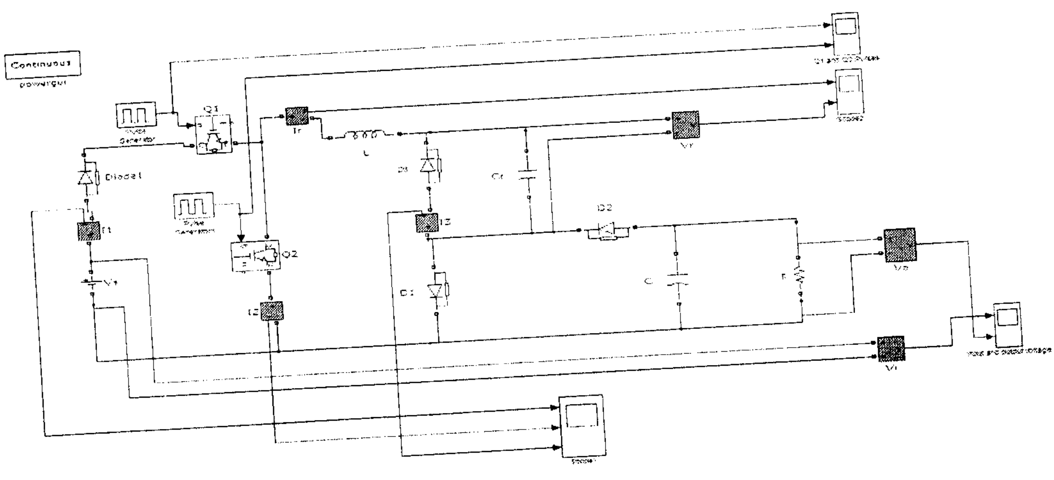

Fig. 5.6 Simulation circuit for resonant inverting step-down DC-DC converter.

TABLE.1 Specifications of the Simulation Circuit

S.No	Source/Elements	Parameter specification
1	DC Source	36 V
2	IGBT(Q_1 and Q_2)	Resistance Ron(Ohm) = 0.001 Ohm Inductance Lon (H) = 0 H Forward voltage V_f = 1 V Current 10% fall time T_f = 1e-6 s Current tail time T_t = 2e-6 s Initial Current Ic = 0 A Snubber resistance Rs (Ohms) = 1e5 Ohm Snubber capacitance Cs (F) = inf
3	Diode (D_1, D_2 ,D_3 & D_s)	Resistance Ron(Ohm) = 0.001 Ohm Inductance Lon (H) = 0 H Forward voltage V_f = 0.8 V Initial Current I_c = 0 A Snubber resistance Rs (Ohms) = 500 Ohm Snubber capacitance Cs (F) = 250e-9 F
4	Inductance (L_r)	Inductance (H) = 0.5e-m H
5	Capacitance (C_r)	Capacitance (F) = 11e-6 F
6	Capacitance (c)	Capacitance(F) = 200e-6F
7	Pulse (P1)	Pulse type = Time based Time (t) = use simulation time Amplitude = 1 Period (Secs) = 0.001 sec Pulse Width (% of period) = 25 Phase delay (Secs) = 0 sec
	Pulse (P2)	Pulse type = Time based Time (t) = use simulation time Amplitude = 1 Period (Secs) = 0.001 sec Pulse Width (% of period) = 50 Phase delay (Secs) = 0.00025 sec
8	Resistance (R)	Resistance (Ohms) = 80 (Ohms)

3.3 SIMULATION RESULTS AND DISCUSSIONS

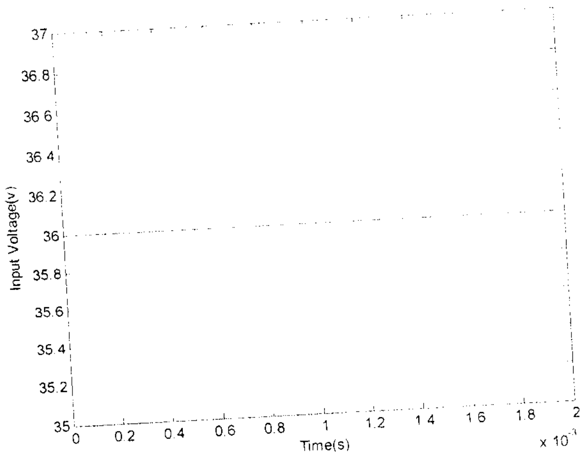

Fig.5.7 Input voltage

Fig.5.7, refers the input voltage of 36V, when Q_1 and Q_2 is turned OFF.

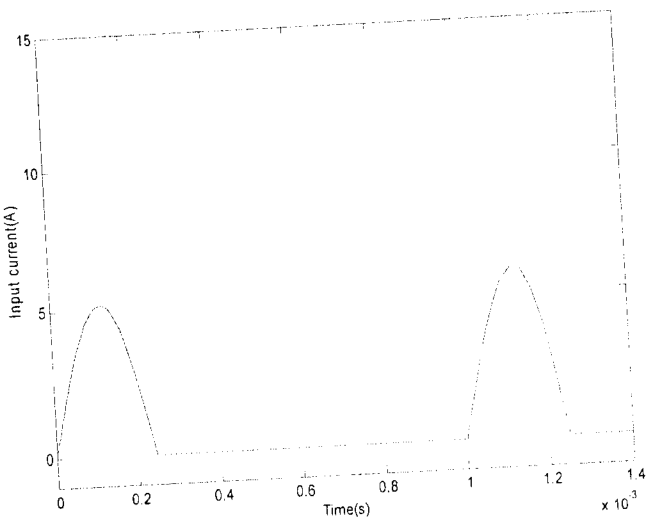

Fig.5 8 Input current

Fig.5.8, refers the input current when the switch Q1 is turned ON the supply voltage Vs is connected to resonant inductor and capacitor. In this mode I, the capacitor charges to 2Vs.

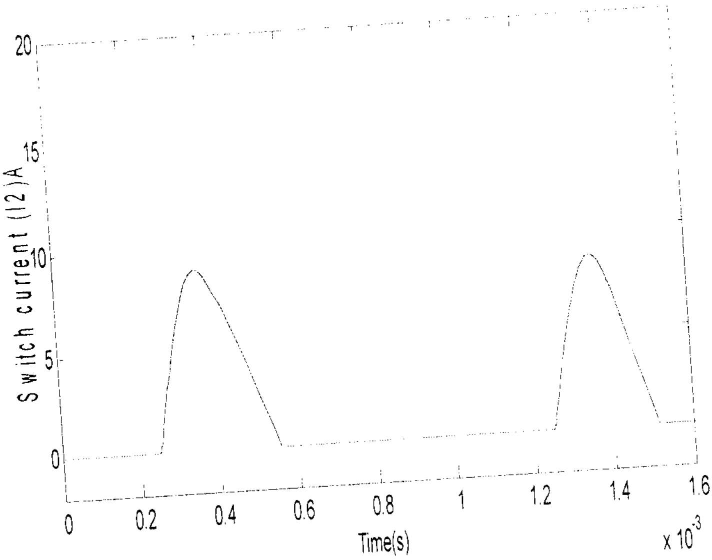

Fig. 5.9 Switch current

Fig.5.9 refers, the switch Q2 is turned ON. This is mode II, here the resonant capacitor discharges through the switch.

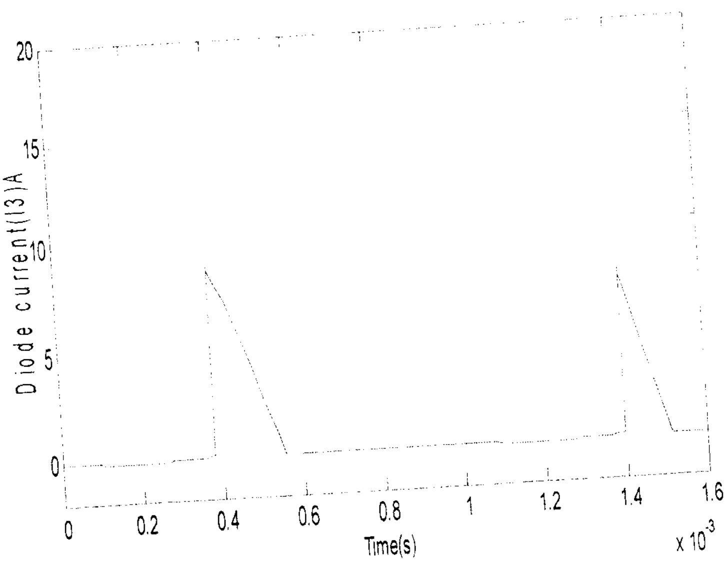

Fig.5.10 Diode current

Fig.5.10 refers the diode current. In mode III, when the capacitor discharges completely, the diode D3 is forward biased and the energy stored in the inductor is decreased linearly to the load.

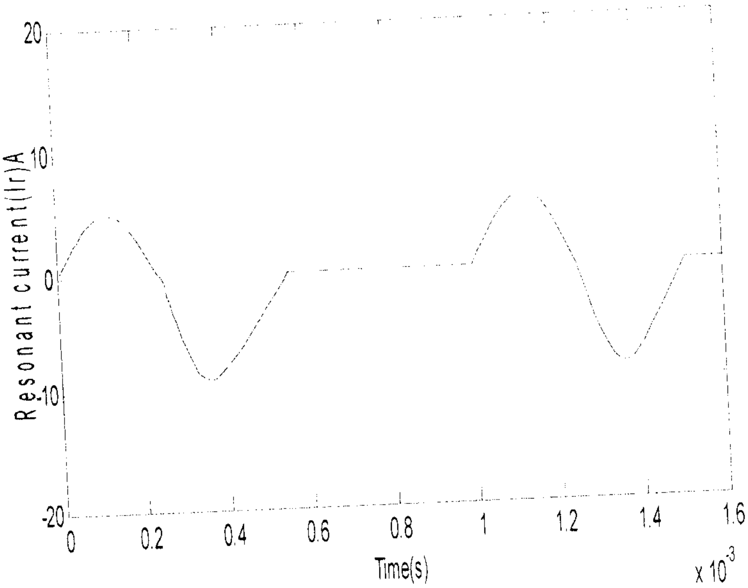

Fig.5.11 Resonant current

Fig.5.11 refers the resonant current, it increases positive as the capacitor is charged and it decreases negative as the capacitor discharges and reaches zero.

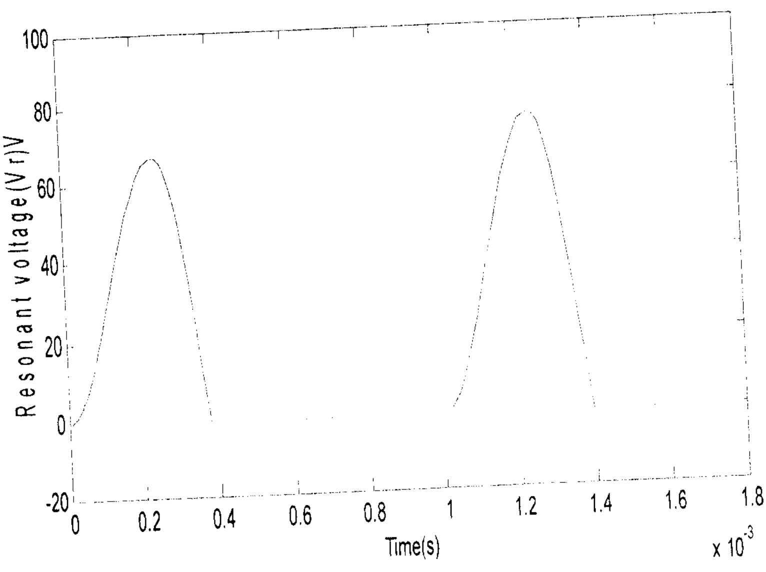

Fig.5.12 Resonant voltage

Fig.5.12 refers the resonant voltage, when the switch Q1 is turned ON, the capacitor charges to 2Vs.

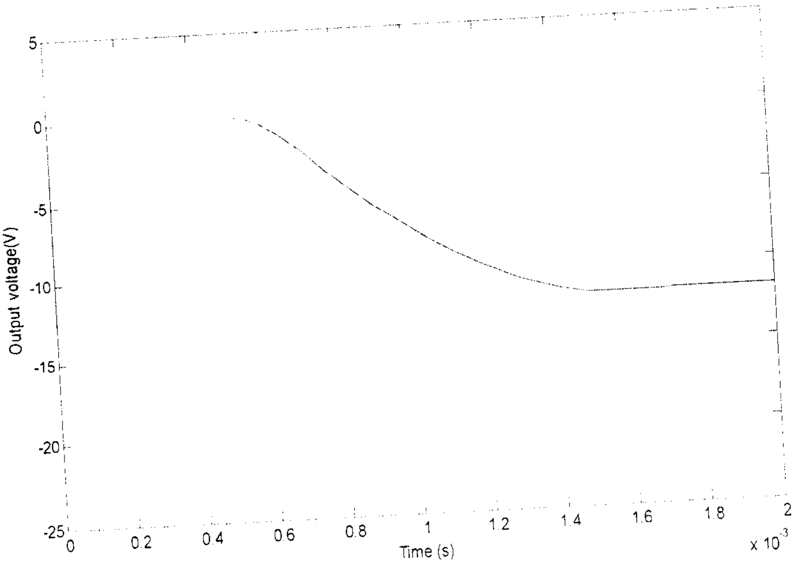

Fig.5.13 Output voltage

Fig 5.13 refers the output voltage of 12V with the negative polarity.

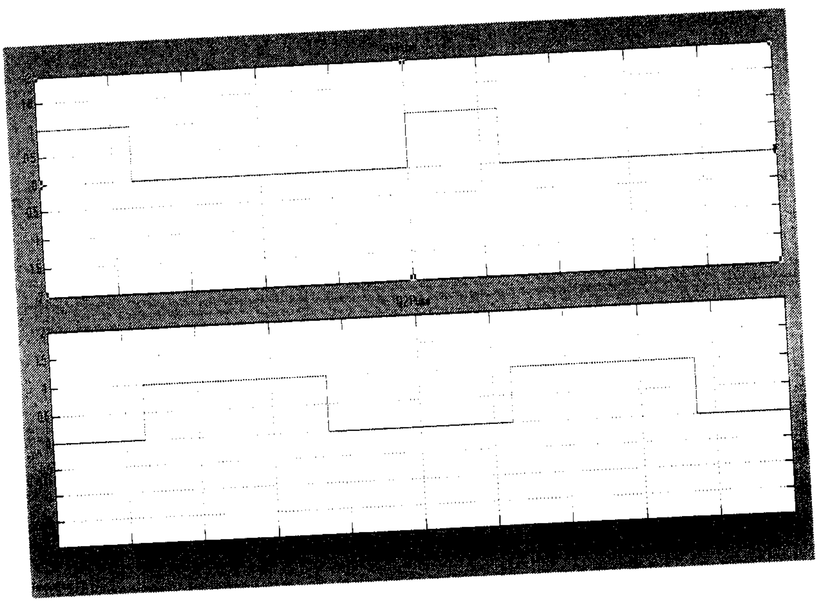

Fig.5.14 Switching pulses

Fig.5.14 refers the switching pulses of the switches Q_1 and Q_2.

CHAPTER 6

CHAPTER 6

HARDWARE IMPLEMENTATION OF RESONANT INVERTING STEP DOWN DC-DC CONVERTER

The prototype model of Resonant inverting step down DC-DC converter is shown in Fig.6.1. It is designed to produce the output voltage with the negative polarity is used for the applications like Operational amplifiers (OP-AMP), dynamic read-only memories (RAM), localised micro processors, data acquisition systems and telecommunication modules.

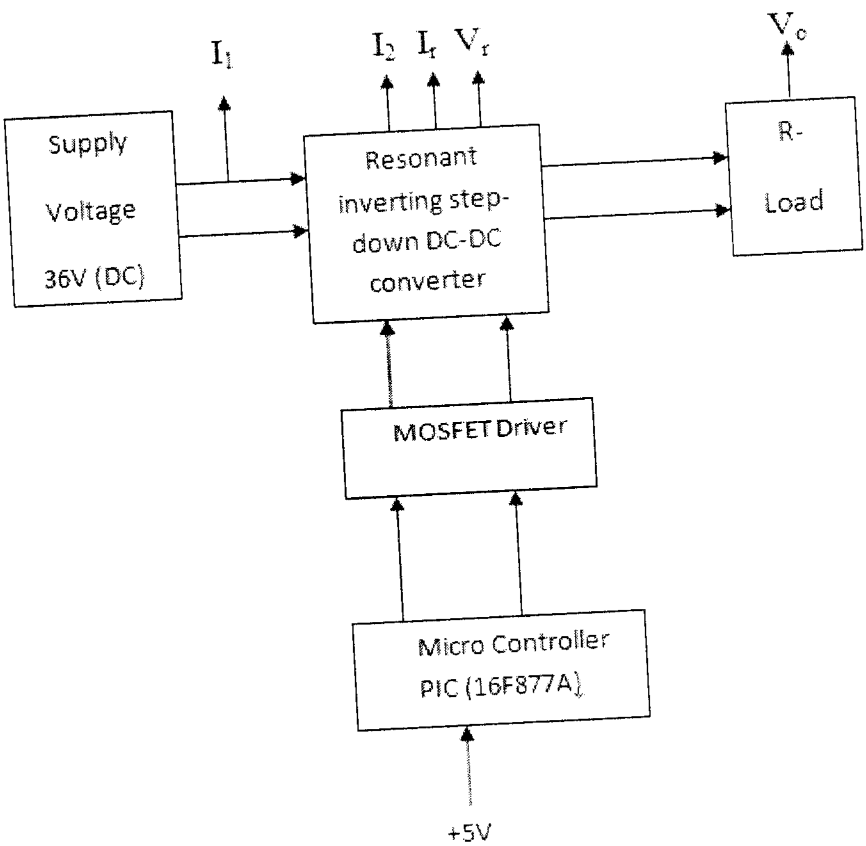

Fig.6.1 Hardware Block Diagram

6.1 BLOCK DIAGRAM DESCRIPTION

The entire system is divided into the following subsystems

- Power supply circuit

- Resonant inverting step down DC-DC converter.
- PIC 16F877A

.1.1 POWER SUPPLY UNIT

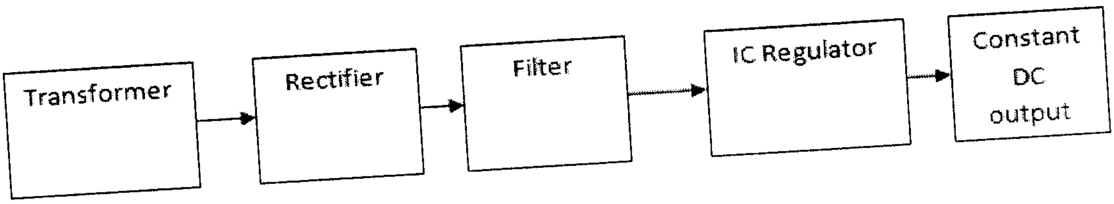

Figure 6.2 Block diagram of power supply

The Ac voltage, typically 220V rms, is connected to a transformer, which steps that ac voltage down to the level of the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation.

A regulator circuit removes the ripples and also remains the same dc value even if the input dc voltage varies, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of the popular voltage regulator IC units. The power circuit diagram is shown in figure 6.3

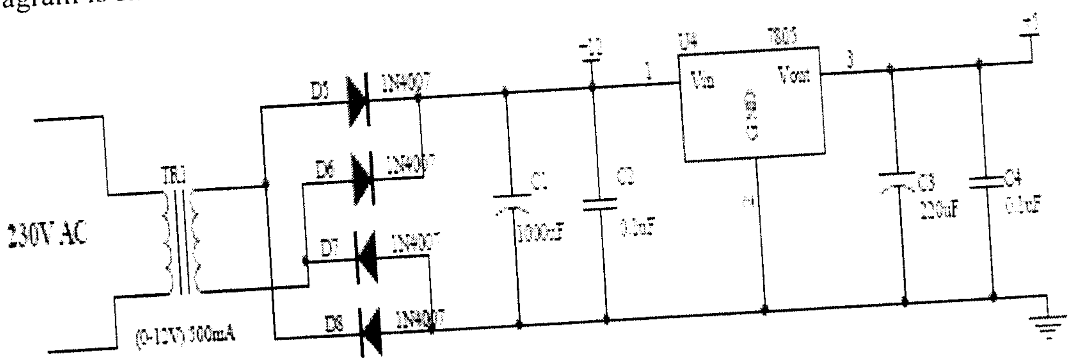

Fig.6.3 Power supply circuit diagram

.1.2 RESONANT INVERTING STEP DOWN DC-DC CONVERTER

The Resonant inverting step down DC-DC converter module consist of two power switches (MOSFET), one inductor and two capacitor. The supply voltage of 36V is given as the input to operate the circuit. The capacitor and the inductor acts as energy storage device. The triggering pulse for the two MOSFET in this module is generated by the micro controller PIC16F877A and driven by the driver circuit. The schematic diagram is shown in Fig.6.4.

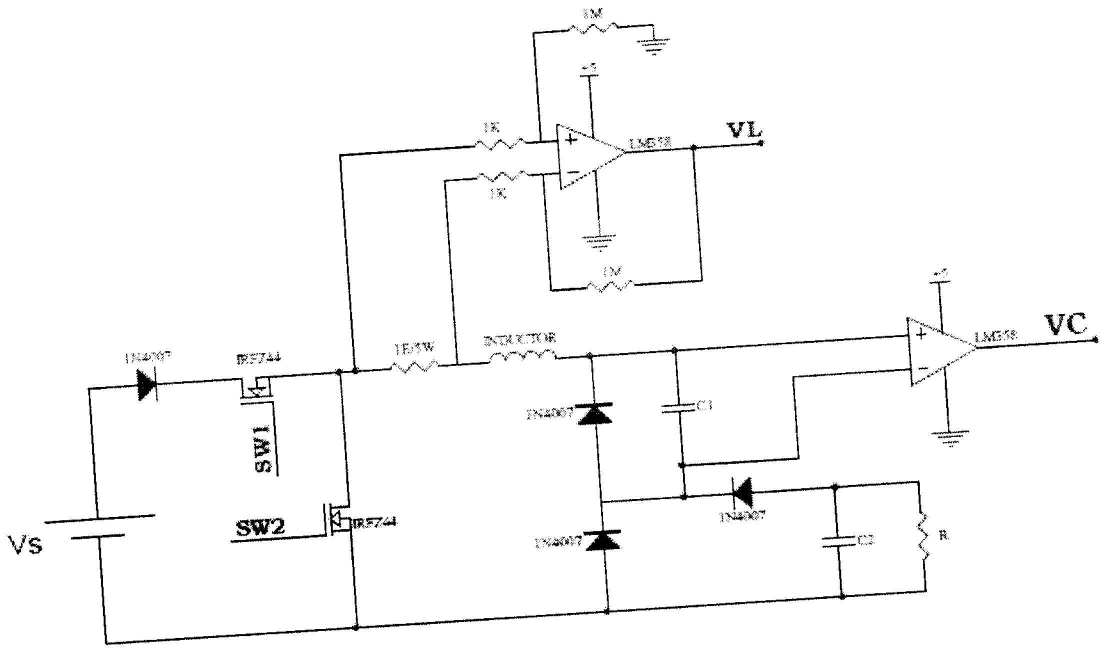

Fig.6.4 Schematic diagram of Resonant inverting step down DC-DC converter

ADVANTAGES OF MOSFET

- MOSFET provides much better system reliability.
- Driver circuitry is simpler and cheaper.
- MOSFET's fast switching speed permit much higher switching frequencies and thereby the efficiency are increased.
- Overload and peak current handling capacity is high
- MOSFETs have better temperature stability
- MOSFET's leakage current is low

- Drain-source conduction threshold voltage is absent which eliminates electrical noise.

6.1.3 MICROCONTROLLER FOR RESONANT DC-DC CONVERTER

The gate pulse for the switches is generated by PIC16F877A controller. This micro controller circuit works in 5V power supply. So separate step down rectifier unit is made for the controller. The details about PIC16F877A are given in APPENDIX II. This controller is isolated from the main circuits by means of Driver circuit. The schematic of micro controller circuit is shown in Fig.6.5.

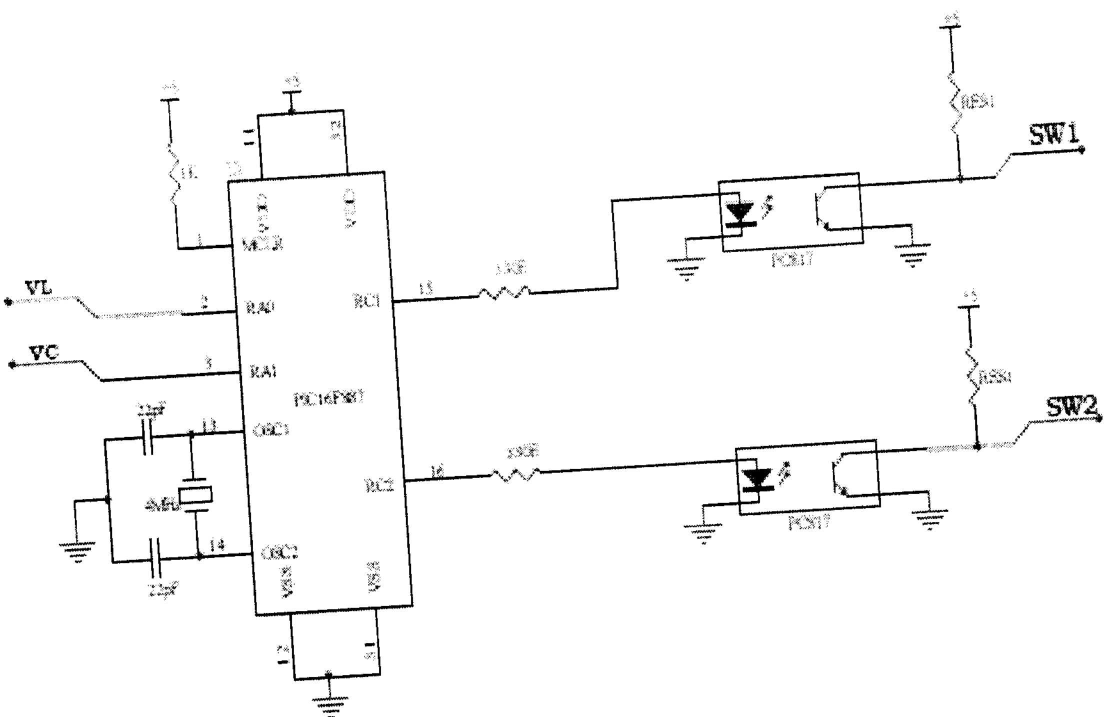

Fig 6.5 Schematic of micro controller circuit

2 HARDWARE PROTOTYPE AND RESULTS

The designed hardware model is as shown in fig.6.6. The output waveforms of the sonant inverting step down DC-DC converter are shown in the figures. The output voltage with e negative polarity of 9.23V is obtained at the ends of operation.

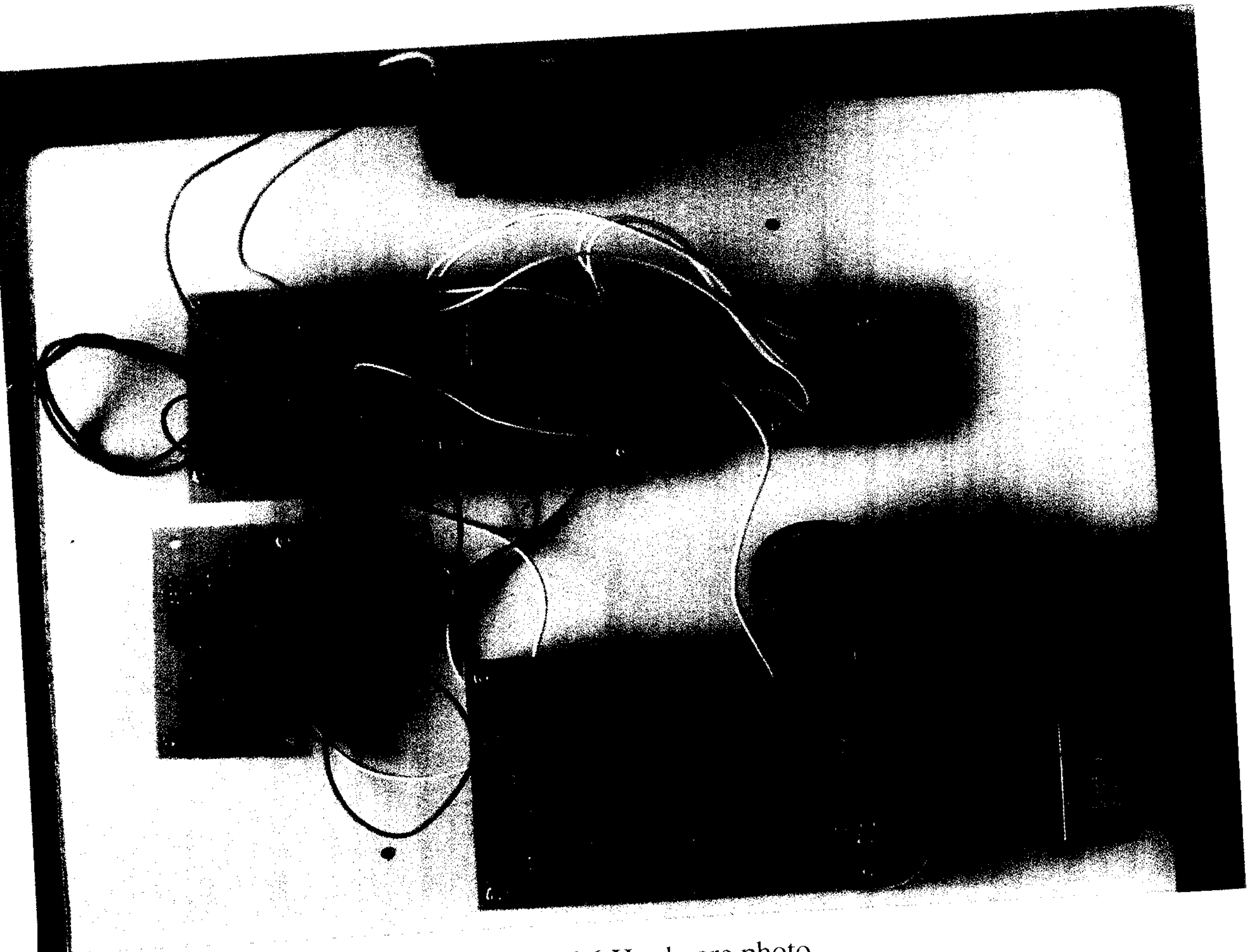

Fig 6.6 Hardware photo

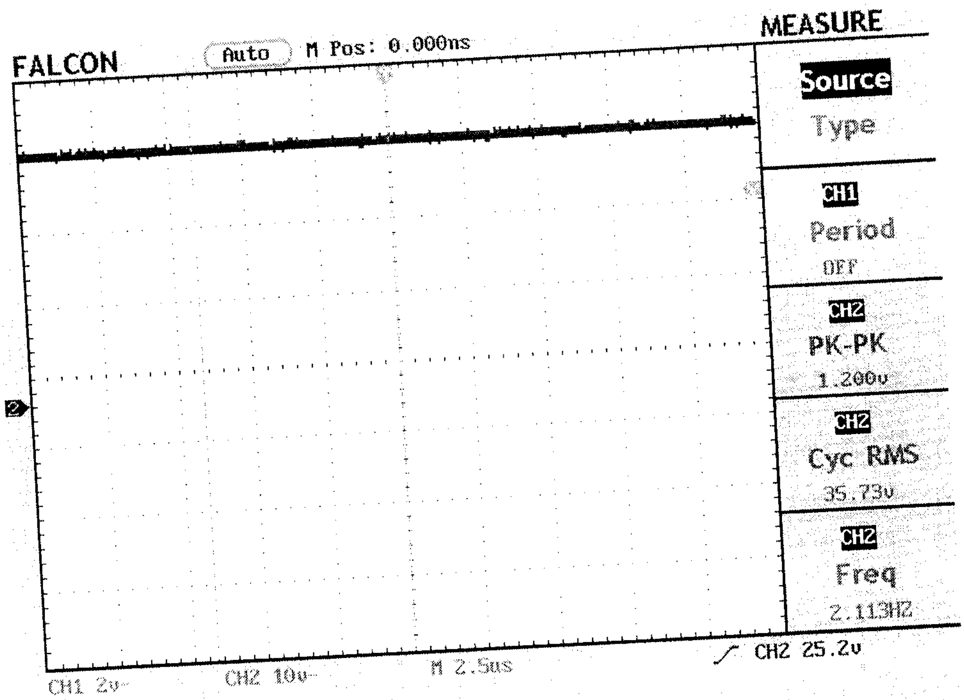

Fig. 6.7 Input Voltage

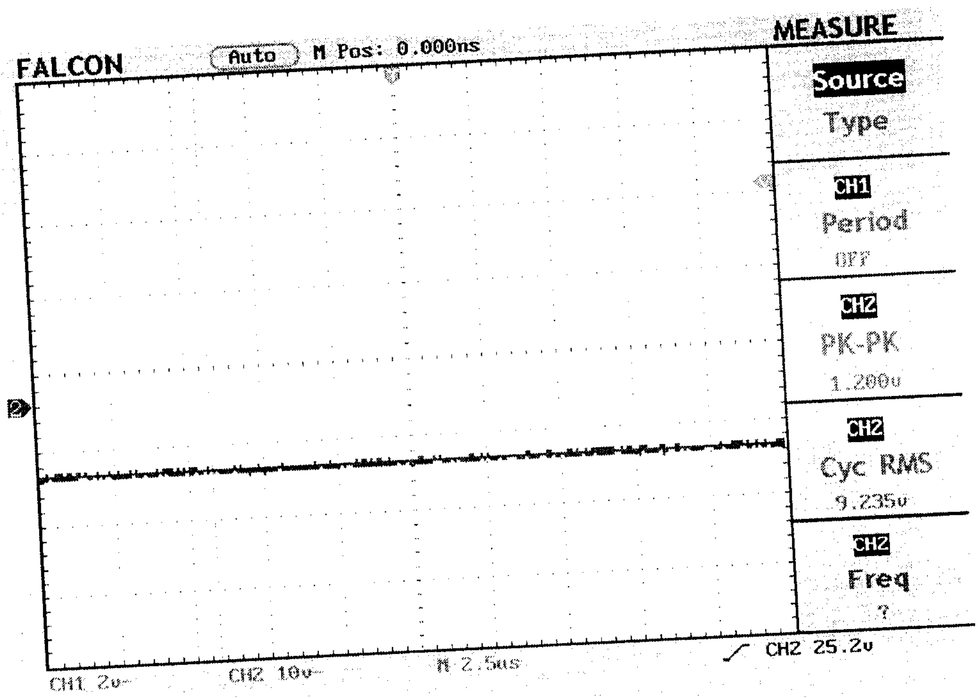

Fig. 6.8 Output Voltage

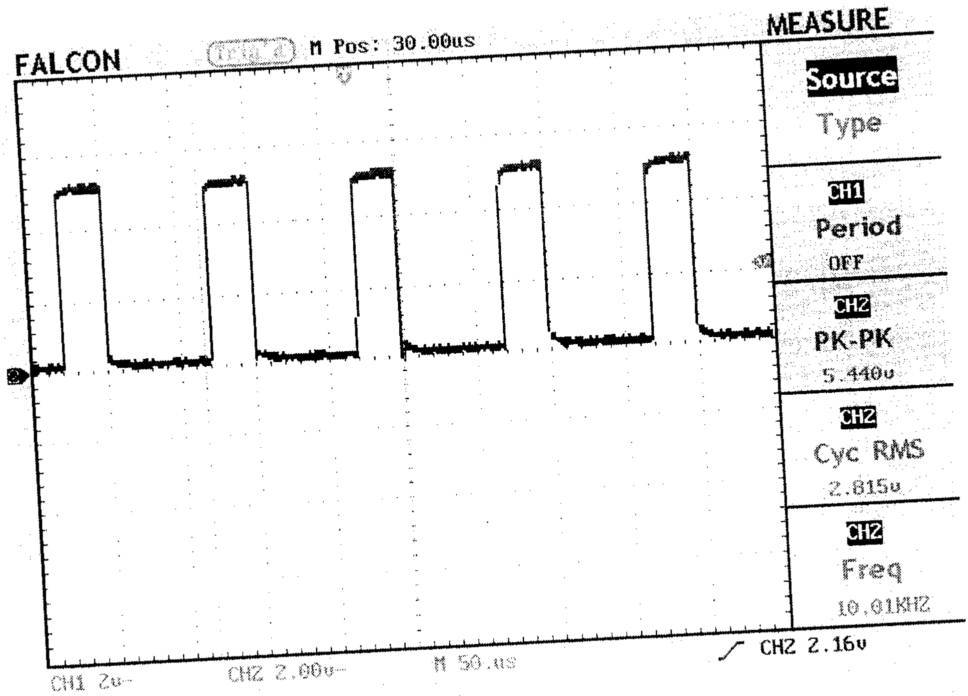

Fig. 6.9 Q_1 Pulse

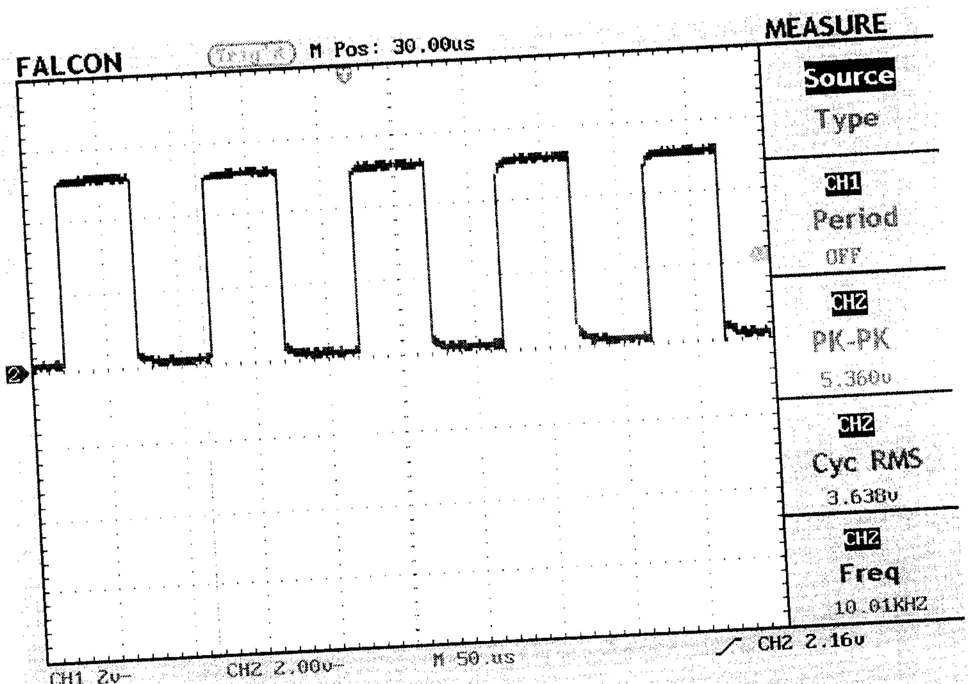

Fig. 6.10 Q_2 Pulse

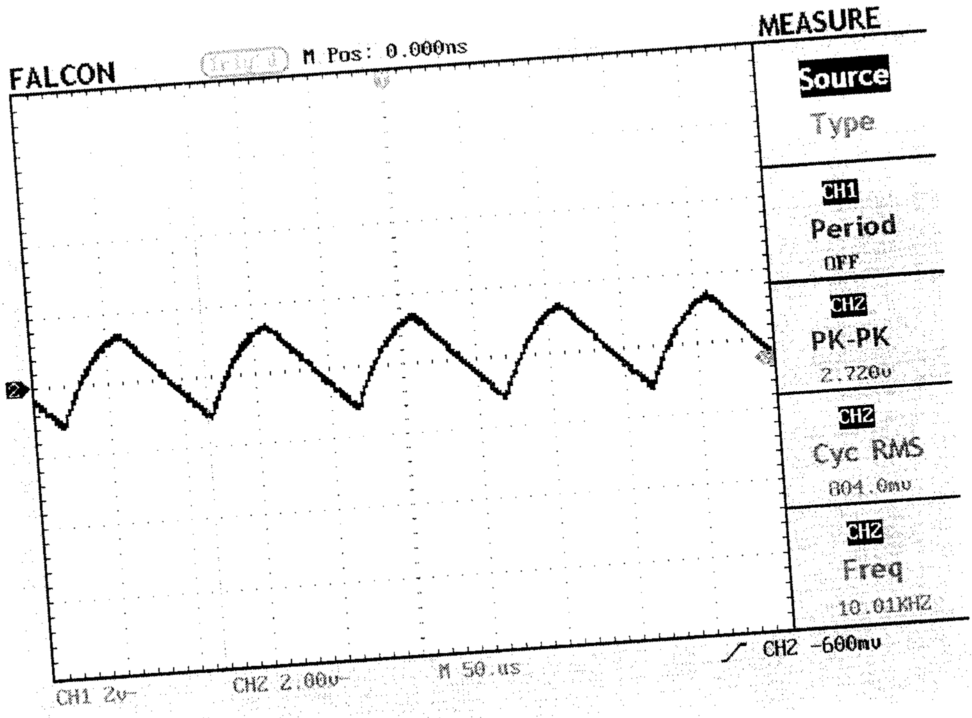

Fig.6.11 Resonant Current

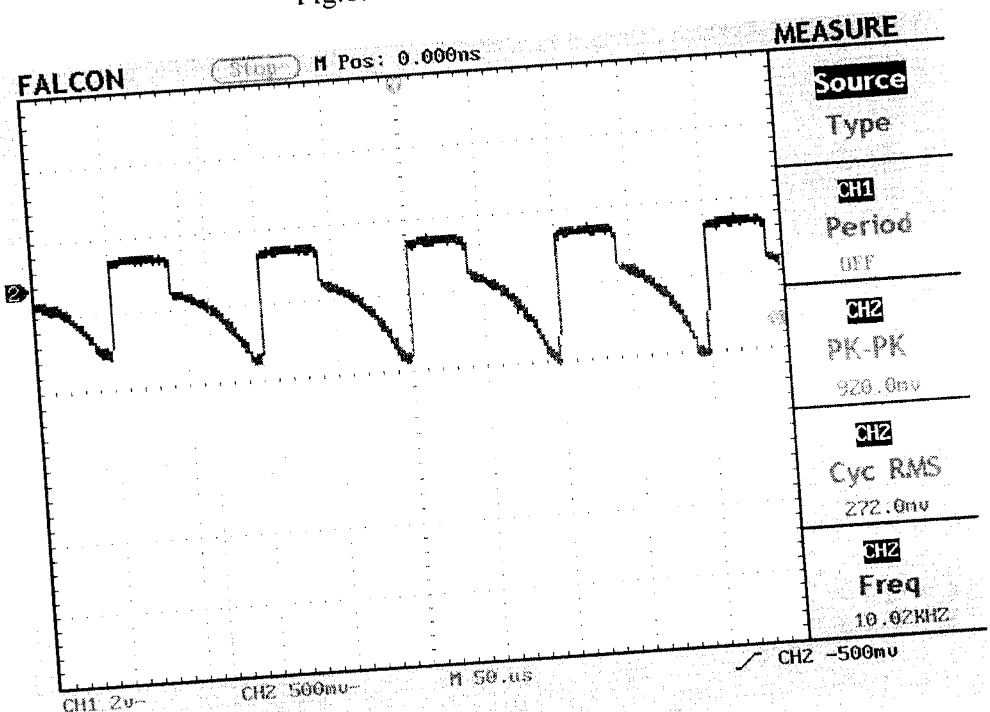

Fig.6.12 Resonant Voltage

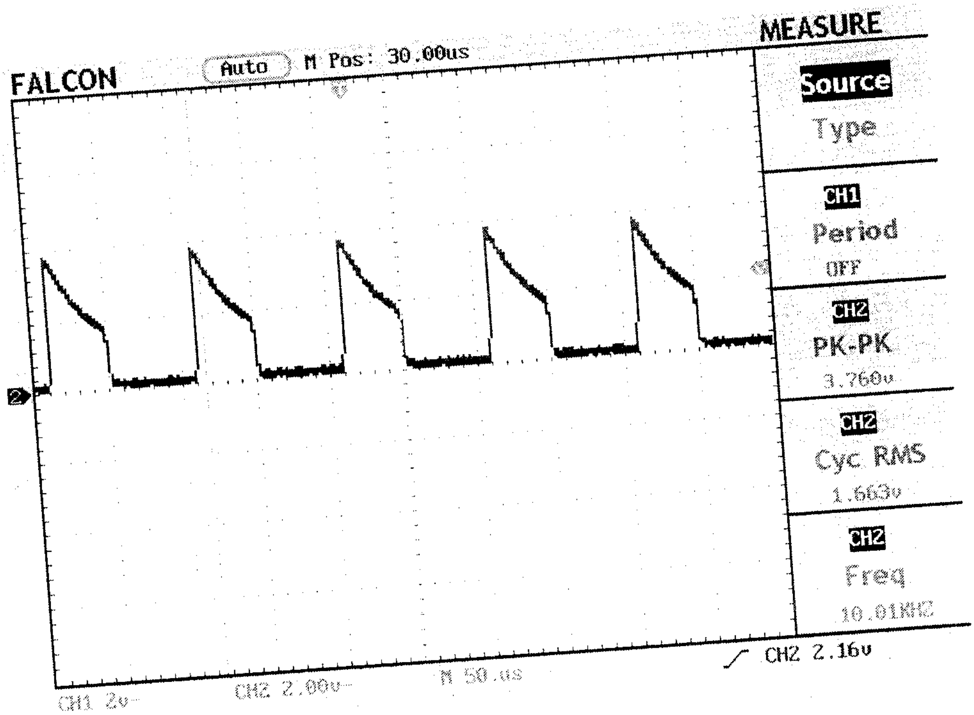

Fig.6.13 Diode Current(I_3)

CHAPTER 7

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

1 CONCLUSION

This project reveals a Resonant inverting step down DC-DC converter with resistive load. ero current switching was proposed as a control technique, therefore, switching losses and lectromagnetic interference are reduced. The main advantage of this project is less additional elements. The principle and the modes of operation are explained. The output voltage is used for he applications wherein the regulated negative output voltage is required like operational amplifiers, localized microprocessors. The control technique and operating principle has been verified by simulation in MATLAB. The results are verified with the hardware circuit were it is designed by PIC16F877A controller.

7.2 FUTURE SCOPE

In the future scope of the work, the Resonant inverting step down DC-DC converter can be designed with the closed loop to enhance the performance and efficiency of the system. The electromagnetic interference can be analysed by using Line Impedance Stabilization Network (LISN).

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APPENDIX I

FAIRCHILD
SEMICONDUCTOR®

www.fairchildsemi.com

LM2904,LM358/LM358A,LM258/ LM258A

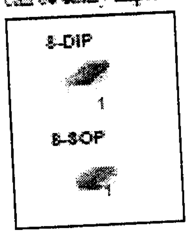
Dual Operational Amplifier

Features

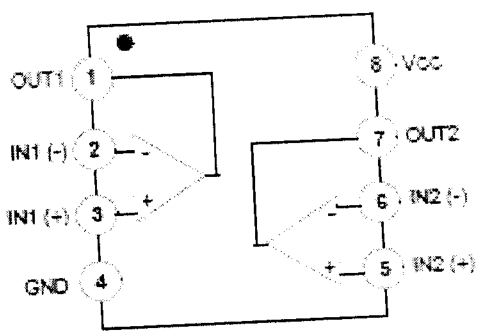
- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain: 100dB
- Wide Power Supply Range:
  LM258/LM258A, LM358/LM358A: 3V~32V (or ±1.5V ~ 16V)
  LM2904 : 3V~26V (or ±1.5V ~ 13V)
- Input Common Mode Voltage Range Includes Ground
- Large Output Voltage Swing: 0V DC to Vcc -1.5V DC
- Power Drain Suitable for Battery Operation

Description

The LM2904,LM358/LM358A, LM258/LM258A consist of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltage. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. Application areas include transducer amplifier, DC gain blocks and all the conventional OP-AMP circuits which now can be easily implemented in single power supply systems.

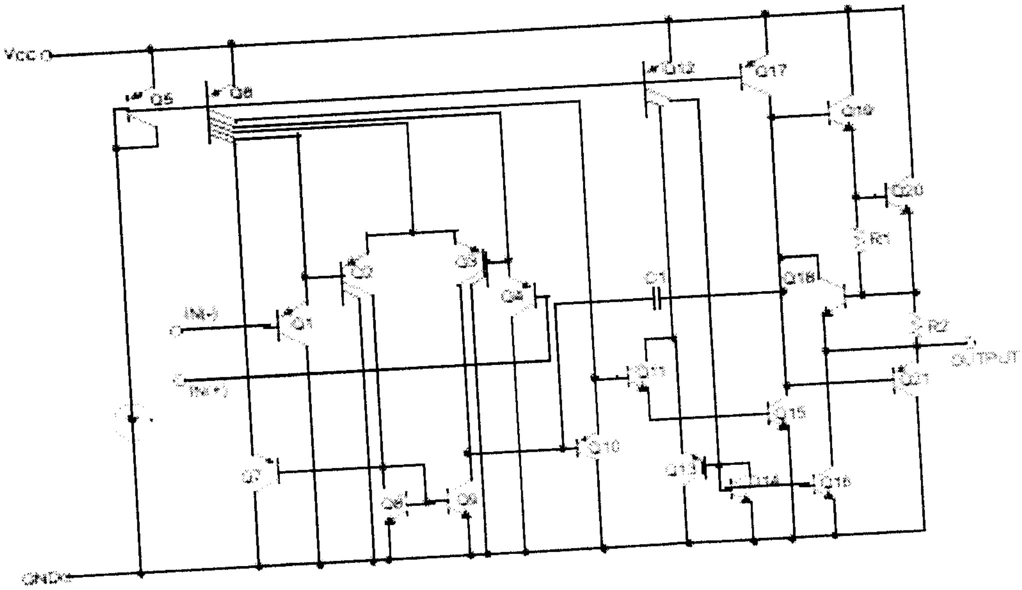


Internal Block Diagram



Schematic Diagram

(One section only)



Absolute Maximum Ratings

Parameter	Symbol	LM258/LM258A	LM358/LM358A	LM2904	Unit
Supply Voltage	V_{CC}	±16 or 32	±16 or 32	±13 or 26	V
Differential Input Voltage	$V_{I(DIFF)}$	32	32	26	V
Input Voltage	V_I	-0.3 to +32	-0.3 to +32	-0.3 to +26	V
Output Short Circuit to GND $V_{CC} \leq 15V$, $T_A = 25°C$(One Amp)	-	Continuous	Continuous	Continuous	-
Operating Temperature Range	T_{OPR}	-25 ~ +85	0 ~ +70	-40 ~ +85	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	-65 ~ +150	-65 ~ +150	°C

Electrical Characteristics

(V_{CC} = 5.0V, V_{EE} = GND, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions		LM258 Min.	LM258 Typ.	LM258 Max.	LM358 Min.	LM358 Typ.	LM358 Max.	LM2904 Min.	LM2904 Typ.	LM2904 Max.	Unit
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V, $V_{O(P)}$ = 1.4V, R_S = 0Ω		-	2.9	5.0	-	2.9	7.0	-	2.9	7.0	mV
Input Offset Current	I_{IO}	-		-	3	30	-	5	50	-	5	50	nA
Input Bias Current	I_{BIAS}	-		-	45	150	-	45	250	-	45	250	nA
Input Voltage Range	$V_{I(R)}$	V_{CC} = 30V (LM2904, V_{CC}=26V)		0	-	V_{CC} -1.5	0	-	V_{CC} -1.5	0	-	V_{CC} -1.5	V
Supply Current	I_{CC}	R_L = ∞, V_{CC} = 30V (LM2904, V_{CC}=26V)		-	0.8	2.0	-	0.8	2.0	-	0.8	2.0	mA
		R_L = ∞, V_{CC} = 5V		-	0.5	1.2	-	0.5	1.2	-	0.5	1.2	mA
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L= 2kΩ, $V_{O(P)}$ = 1V to 11V		50	100	-	25	100	-	25	100	-	V/mV
Output Voltage Swing	$V_{O(H)}$	V_{CC}=30V (V_{CC} =26V for LM2904)	R_L = 2kΩ	26	-	-	26	-	-	22	-	-	V
			R_L= 10kΩ	27	28	-	27	28	-	23	24	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L= 10kΩ		-	5	20	-	5	20	-	5	20	mV
Common-Mode Rejection Ratio	CMRR	-		70	85	-	65	80	-	50	80	-	dB
Power Supply Rejection Ratio	PSRR	-		65	100	-	65	100	-	50	100	-	dB
Channel Separation	CS	f = 1kHz to 20kHz (Note1)		-	120	-	-	120	-	-	120	-	dB
Short Circuit to GND	I_{SC}	-		-	40	60	-	40	60	-	40	60	mA
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V, V_{CC} = 15V, $V_{O(P)}$ = 2V		20	30	-	20	30	-	20	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V, V_{CC} = 15V, $V_{O(P)}$ = 2V		10	15	-	10	15	-	10	15	-	mA
		$V_{I(+)}$ = 0V, $V_{I(-)}$ =1V, V_{CC} = 15V, $V_{O(P)}$ = 200mV		12	100	-	12	100	-	-	-	-	µA
Differential Input Voltage	$V_{I(DIFF)}$	-		-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	V

Note:

1. This parameter, although guaranteed, is not 100% tested in production.

MC78XX/LM78XX/MC78XXA

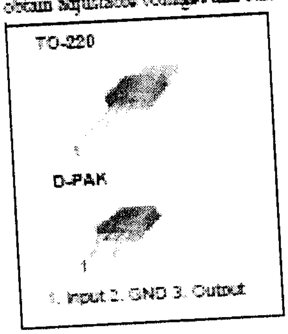
3-Terminal 1A Positive Voltage Regulator

Features

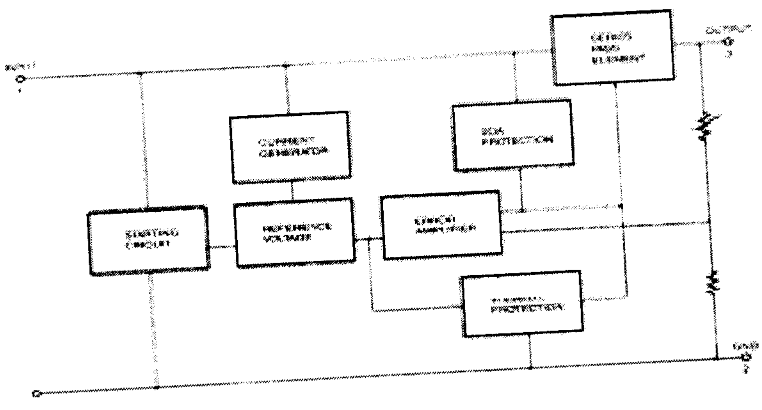
- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The MC78XX/LM78XX/MC78XXA series of three terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.



Internal Block Digram



Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V)	V_I	35	V
(for V_O = 24V)	V_I	40	V
Thermal Resistance Junction-Cases (TO-220)	$R_{θJC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{θJA}$	65	°C/W
Operating Temperature Range	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics (MC7805/LM7805)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I = 10V, C_I= 0.33μF, C_O= 0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7805/LM7805 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA ≤ Io ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	$ΔI_Q$	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	ΔVo/ΔT	Io= 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	μV/Vo
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

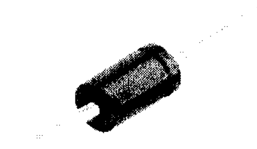
Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.



DO-41
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers (Glass Passivated)

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A = 75°C	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{stg}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W

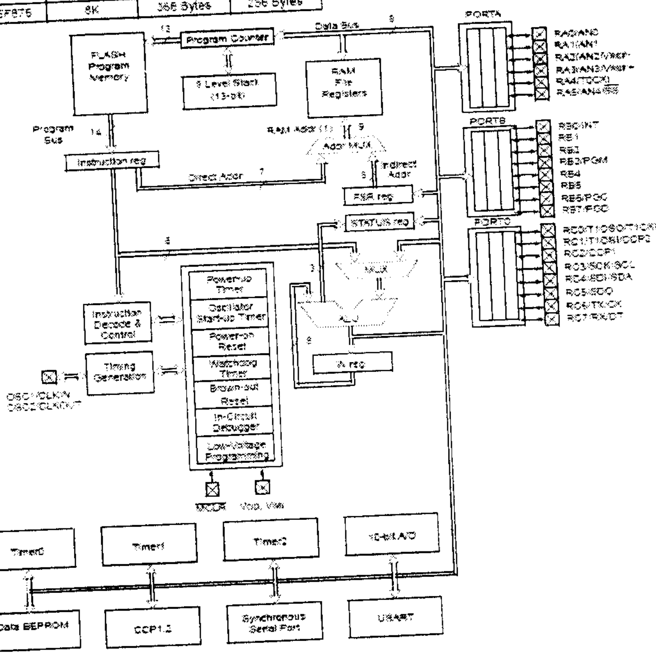
Electrical Characteristics T_A = 25°C unless otherwise noted

Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle T_A = 75°C	30							µA
I_R	Reverse Current @ rated V_R T_A = 25°C	5.0							µA
	T_A = 100°C	500							µA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz	15							pF

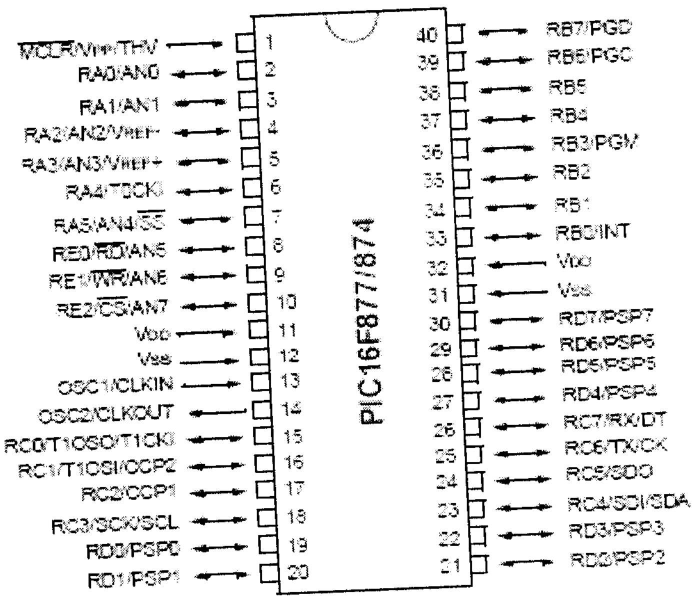
APPENDIX II

RCHITECTURE OF PIC 16F877A

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes



Pin Configuration of PIC16F877A



IMER 0 CONTROL REGISTER:

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
$\overline{RBPU}$	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0
bit 7							bit 0

it 7: **RBPU**

it 6: **INTEDG**

it 5: **T0CS**: TMR0 Clock Source Select bit

1 = Transition on T0CKI pin

0 = Internal instruction cycle clock (CLKOUT)

bit 4: **T0SE**: TMR0 Source Edge Select bit

1 = Increment on high-to-low transition on T0CKI pin

0 = Increment on low-to-high transition on T0CKI pin

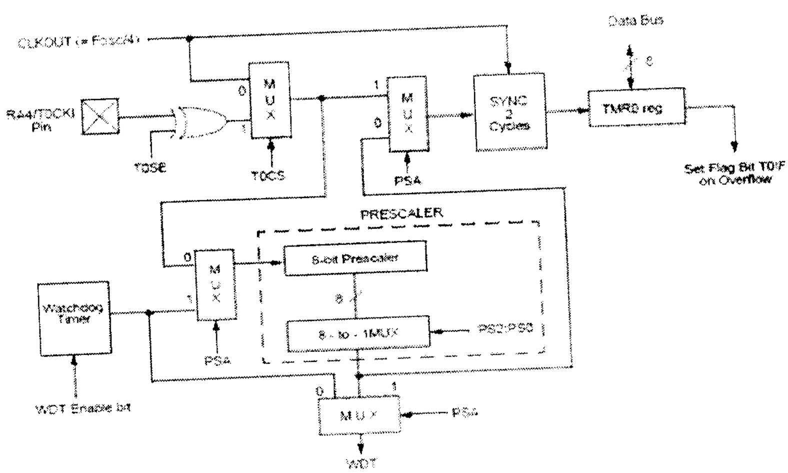
bit 3: **PSA**: Prescaler Assignment bit

1 = Prescaler is assigned to the WDT

0 = Prescaler is assigned to the Timer0 module

bit 2-0: **PS2 PS1 PS0**: Prescaler Rate Select bits

TIMER 0 BLOCK DIAGRAM:



TIMER 1 CONTROL REGISTER:

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	T1CKPS1	T1CKPS0	T1OSCEN	T1SYNC	TMR1CS	TMR1ON
bit7							bit0

bit 7-6: **Unimplemented:** Read as '0'

bit 5-4: **T1CKPS1:T1CKPS0**: Timer1 Input Clock Prescale Select bits

11 = 1:8 Prescale value

10 = 1:4 Prescale value

01 = 1:2 Prescale value

00 = 1:1 Prescale value

bit 3: **T1OSCEN**: Timer1 Oscillator Enable Control bit

1 = Oscillator is enabled

0 = Oscillator is shut off (The oscillator inverter is turned off to eliminate power drain)

bit 2: **T1SYNC**: Timer1 External Clock Input Synchronization Control bit

TMR1CS = 1

1 = Do not synchronize external clock input

0 = Synchronize external clock input

TMR1CS = 0

This bit is ignored. Timer1 uses the internal clock when TMR1CS = 0.

bit 1: **TMR1CS**: Timer1 Clock Source Select bit

1 = External clock from pin RC0/T1OSO/T1CKI (on the rising edge)

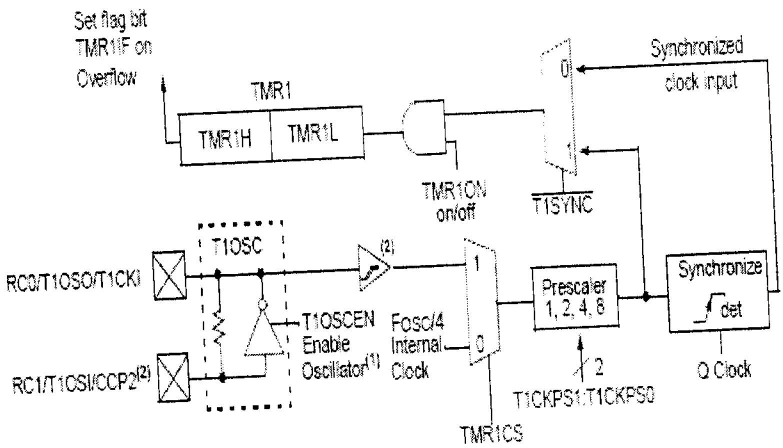
0 = Internal clock (FOSC/4)

bit 0: **TMR1ON**: Timer1 On bit

1 = Enables Timer1

0 = Stops Timer1

TIMER 1 BLOCK DIAGRAM:



TIMER 2 CONTROL REGISTER:

U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	TOUTPS3	TOUTPS2	TOUTPS1	TOUTPS0	TMR2ON	T2CKPS1	T2CKPS0
bit7							bit0

bit 7: **Unimplemented:** Read as '0'

bit 6-3: **TOUTPS3:TOUTPS0**: Timer2 Output Postscale Select bits

0000 = 1:1 Postscale

0001 = 1:2 Postscale

0010 = 1:3 Postscale

1111 = 1:16 Postscale

bit 2: **TMR2ON**: Timer2 On bit

1 = Timer2 is on

0 = Timer2 is off

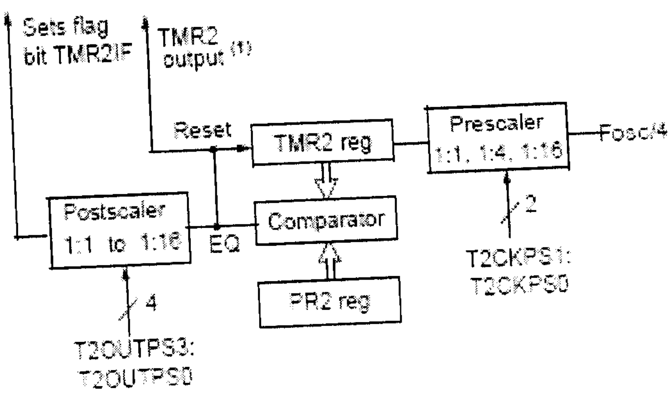
bit 1-0: **T2CKPS1:T2CKPS0**: Timer2 Clock Prescale Select bits

00 = Prescaler is 1

01 = Prescaler is 4

1x = Prescaler is 16

TIMER2 BLOCK DIAGRAM:



CCP1CON REGISTER/CCP2CON REGISTER:

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	CCPxX	CCPxY	CCPxM3	CCPxM2	CCPxM1	CCPxM0
bit7							bit0

bit 7-6: **Unimplemented:** Read as '0'

bit 5-4: **CCPxX :CCPxY**: PWM Least Significant bits

Capture Mode: Unused

Compare Mode: Unused

PWM Mode: These bits are the two LSB s of the PWM duty cycle. The eight MSB s are found in CCPRxL.

bit 3-0: **CCPxM3:CCPxM0**: CCPx Mode Select bits

0000 = Capture/Compare/PWM off (resets CCPx module)

0100 = Capture mode, every falling edge

0101 = Capture mode, every rising edge

0110 = Capture mode, every 4th rising edge

0111 = Capture mode, every 16th rising edge

1000 = Compare mode, set output on match (CCPxIF bit is set)

1001 = Compare mode, clear output on match (CCPxIF bit is set)

1010 = Compare mode, generate software interrupt on match (CCPxIF bit is set, CCPx pin is unaffected)

1011 = Compare mode, trigger special event (CCPxIF bit is set, CCPx pin is unaffected); CCP1 resets TMR1; CCP2 resets TMR1 and starts an A/D conversion (if A/D module is enabled)

11xx = PWM mode

N-channel enhancement mode TrenchMOS™ transistor

GENERAL DESCRIPTION

N-channel enhancement mode standard level field-effect power transistor in a plastic envelope using 'trench' technology. The device features very low on-state resistance and has integral zener diodes giving ESD protection up to 2kV. It is intended for use in switched mode power supplies and general purpose switching applications.

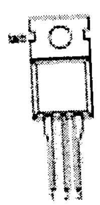
QUICK REFERENCE DATA

SYMBOL	PARAMETER	MAX.	UNIT
V_{DS}	Drain-source voltage	55	V
I_D	Drain current (DC)	49	A
P_{tot}	Total power dissipation	110	W
T_j	Junction temperature	175	°C
$R_{DS(ON)}$	Drain-source on-state resistance V_{GS} = 10 V	22	mΩ

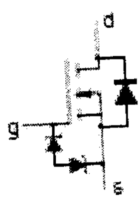
PINNING - TO220AB

PIN	DESCRIPTION
1	gate
2	drain
3	source
tab	drain

PIN CONFIGURATION



SYMBOL



LIMITING VALUES

Limiting values in accordance with the Absolute Maximum System (IEC 134)

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{DS}	Drain-source voltage	-	-	55	V
V_{DGR}	Drain-gate voltage	R_{GS} = 20 kΩ	-	55	V
$\pm V_{GS}$	Gate-source voltage	-	-	20	V
I_D	Drain current (DC)	T_{mb} = 25 °C	-	49	A
I_D	Drain current (DC)	T_{mb} = 100 °C	-	35	A
I_{DM}	Drain current (pulse peak value)	T_{mb} = 25 °C	-	160	A
P_{tot}	Total power dissipation	T_{mb} = 25 °C	-	110	W
T_{stg}, T_j	Storage & operating temperature	-	- 55	175	°C

ESD LIMITING VALUE

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_C	Electrostatic discharge capacitor voltage, all pins	Human body model (100 pF, 1.5 kΩ)	-	2	kV

THERMAL RESISTANCES

SYMBOL	PARAMETER	CONDITIONS	TYP.	MAX.	UNIT
$R_{th\,j-mb}$	Thermal resistance junction to mounting base	-	-	1.4	K/W
$R_{th\,j-a}$	Thermal resistance junction to ambient	in free air	60	-	K/W

STATIC CHARACTERISTICS

T_j = 25°C unless otherwise specified

SYMBOL	PARAMETER	CONDITIONS		MIN.	TYP.	MAX.	UNIT
$V_{(BR)DSS}$	Drain-source breakdown voltage	V_{GS} = 0 V; I_D = 0.25 mA;		55	-	-	V
			T_j = -55°C	50	-	-	V
$V_{GS(TO)}$	Gate threshold voltage	V_{DS} = V_{GS}; I_D = 1 mA		2.0	3.0	4.0	V
			T_j = 175°C	1.0	-	-	V
			T_j = -55°C	-	-	4.4	
I_{DSS}	Zero gate voltage drain current	V_{DS} = 55 V; V_{GS} = 0 V;		-	0.05	10	µA
			T_j = 175°C	-	-	500	µA
I_{GSS}	Gate source leakage current	V_{GS} = ±10 V; V_{DS} = 0 V		-	0.04	1	µA
			T_j = 175°C	-	-	20	µA
$\pm V_{(BR)GSS}$	Gate source breakdown voltage	I_G = ±1 mA;		16	-	-	V
$R_{DS(ON)}$	Drain-source on-state resistance	V_{GS} = 10 V; I_D = 25 A		-	15	22	mΩ
			T_j = 175°C	-	-	42	mΩ

DYNAMIC CHARACTERISTICS

T_{mb} = 25°C unless otherwise specified

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
g_{fs}	Forward transconductance	V_{DS} = 25 V; I_D = 25 A	6	-	-	S
C_{iss}	Input capacitance	V_{GS} = 0 V; V_{DS} = 25 V; f = 1 MHz	-	1350	1800	pF
C_{oss}	Output capacitance		-	330	400	pF
C_{rss}	Feedback capacitance		-	155	215	pF
Q_g	Total gate charge	V_{DD} = 44 V; I_D = 50 A; V_{GS} = 10 V	-	-	62	nC
Q_{gs}	Gate-source charge		-	-	15	nC
Q_{gd}	Gate-drain (miller) charge		-	-	26	nC
$t_{d\,on}$	Turn-on delay time	V_{DD} = 30 V; I_D = 25 A;	-	18	26	ns
t_r	Turn-on rise time	V_{GS} = 10 V; R_G = 10 Ω	-	50	75	ns
$t_{d\,off}$	Turn-off delay time	Resistive load	-	40	50	ns
t_f	Turn-off fall time		-	30	40	ns
L_d	Internal drain inductance	Measured from contact screw on tab to centre of die	-	3.5	-	nH
L_d	Internal drain inductance	Measured from drain lead 6 mm from package to centre of die	-	4.5	-	nH
L_s	Internal source inductance	Measured from source lead 6 mm from package to source bond pad	-	7.5	-	nH

REVERSE DIODE LIMITING VALUES AND CHARACTERISTICS

T_j = 25°C unless otherwise specified

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
I_{DR}	Continuous reverse drain current		-	-	49	A
I_{DRM}	Pulsed reverse drain current		-	-	160	A
V_{SD}	Diode forward voltage	I_F = 25 A; V_{GS} = 0 V	-	0.95	1.2	V
		I_F = 40 A; V_{GS} = 0 V	-	1.0	-	
t_{rr}	Reverse recovery time	I_F = 40 A; $-dI_F/dt$ = 100 A/µs;	-	47	-	ns
Q_{rr}	Reverse recovery charge	V_{GS} = -10 V; V_R = 30 V	-	0.15	-	µC

APPENDIX III

PIC PROGRAMMING

```
#include<pic.h>

__CONFIG(0X20A4);
__CONFIG(0X3FFF);

void main()
{
        TRISC=0;
        PORTC=0;

        TRISA=0X01;
        PORTA=0;

        ANSEL=0;
        ANSELH=0;

        PR2=99;
        T2CON=0x04;

        CCP1CON=0X0C;
        CCP2CON=0X0C;

        CCPR1L=30;
        CCPR2L=50;

        while(1);
        {
                if(RA0==1)
                {
                        CCPR1L=0;
                        CCPR2L=100;
                }
                else
                {
                        CCPR1L=30;
```

```
            CCPR2L=50;
        }
    }
```