DESIGN OF A BIDIRECTIONAL DC-DC CONVERTER FOR A HYBRID ELECTRIC VEHICLE

A PROJECT REPORT

Submitted by

R.RAM PRAKASH - 71205105036

T.K.SANTHOSH - 71205105037

T.THARANKUMAR - 71205105051

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COIMBATORE – 641 006

ANNA UNIVERSITY: CHENNAI 600 025

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ANNA UNIVERSITY: CHENNAI 600 025

BONAFIDE CERTIFICATE

Certified that this project report entitled **"Design of Bidirectional DC-DC Converter for a Hybrid Electric Vehicle"** is the bonafide work of

R.RamPrakash	-	Register No. 71205105036
T.K.Santhosh	-	Register No. 71205105037
T.Thrankumar	-	Register No. 71205105051

who carried out the project work under our supervision.

Signature of the Head of the Department

Prof.K.Regupathy Subramanian

Signature of the Guide

Prof.K.Regupathy Subramanian

Ms. G. Poorani

71205105036

71205105037

Certified that the candidate with university Register No. 71205105051 was examined in project viva voce Examination held on 27-04-2009

Internal Examiner

External Examiner

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY COIMBATORE 641 006.

ABSTRACT

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This project presents the design and fabrication of a zero voltage switching (ZVS) isolated bidirectional dc-dc converter based on a dual full-bridge topology. The fabrication of the converter is done using PIC microcontroller.

Compared to the traditional dc-dc converter for similar applications, the new topology has such advantages as: simple circuit topology with soft switching implementation, high efficiency and simple control circuitry.

This converter costs low and provides buck-boost function in both directions of power conversion. This concept is useful to system applications where batteries and fuel cells are used, such as hybrid electric vehicles in which power transfers have to be managed in both directions.

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1. INTRODUCTION

1.1 Objective

The objective of the project is to design a bidirectional dc-dc converter which will supply a high power better than the existing devices. The requirements are: 12 volts to 24 volts conversion in the forward direction for high power applications and in the reverse direction 24 volts to 12 volts conversion for the storage battery.

1.2 DC-DC Converter

In many industrial applications, it is required to convert a fixed voltage dc source into a variable voltage dc source. A DC-DC converter converts directly from dc to dc and is simply known as a dc converter. A dc converter can be considered as dc equivalent to an ac transformer with a continuously variable turn ratio. Like a transformer, it can be used to step down or step up a dc voltage.

DC converters are widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklift trucks and mine haulers. They provide smooth acceleration control, high efficiency and fast dynamic response.

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the required supply voltage, and possibly even negative voltage).

Also, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

A DC-DC converter is also known as a chopper. It converts a given constant DC voltage into a variable average DC voltage across the load by placing a static switch between the DC source and the load. The switch chops off the dc supply into ON and OFF periods.

1.3 Boost converter

A **boost converter (step-up converter)** is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce the output voltage ripple.

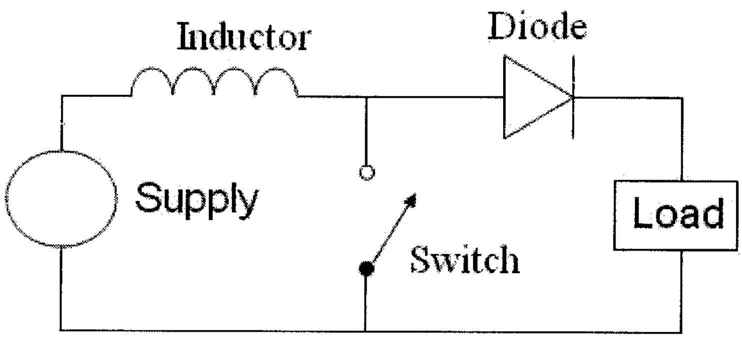


Fig 1.1 The basic schematic of a boost converter

1.4 Buck converter

A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode) and an inductor and a capacitor.

The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess power as heat; also, output voltage isn't regulated (varies with input voltage). A buck converter, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating, making it useful for tasks such as converting the 12-24V typical battery voltage in a laptop down to the few volts needed by the processor

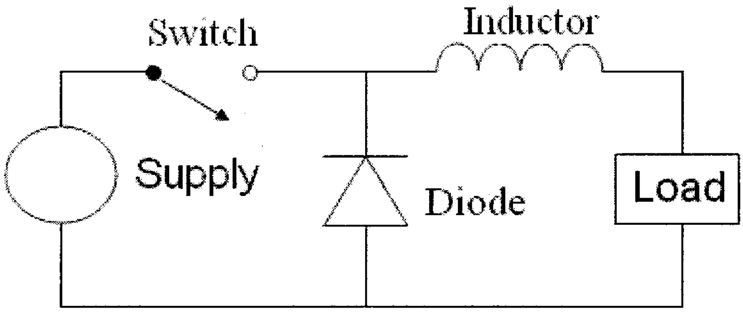


Fig 1.2 Buck Converter

1.5 Limitations of Traditional Converter

- Output power of the converter is small because of the limitation of the single transistor in carrying high current.
- At high currents, the size of components to be used will increase with increase in losses resulting in the decrease in efficiency.
- There is no isolation between input and output, which is required in many applications.

1.6 ZVS Converters

The switches of a ZVS converters turn-on and turn-off at zero voltage. The circuit is shown in Fig1.3. The capacitor C_r is connected in parallel with the switch to achieve ZVS. The internal switch capacitance C_j is added with the capacitor C, and it affects the frequency only, thereby contributing no power dissipation in the switch.

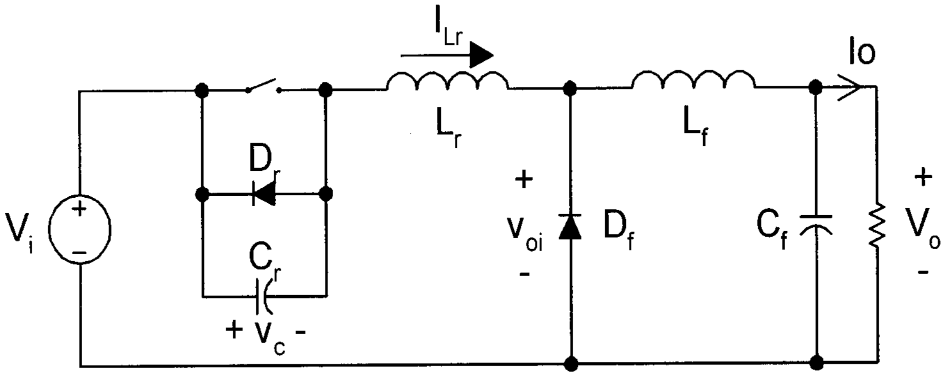


Fig1.3 Converter with ZVS technology

If the capacitor is implemented with a transistor and an anti-parallel diode, the voltage across C_f is clamped by diode and the switch is operated in a half-wave configuration. If the diode is connected in series with transistor, the voltage across C_f can oscillate freely, and the switch is operated in a full-wave configuration. A ZVS shapes the switch voltage waveform during the off-time to create a zero-voltage condition for the switch to turn ON.

1.7 ZCS CONVERTERS

The switches of a zero current switching converter turn ON and turn OFF at zero current. The circuit consists of switch S, inductor L_f and capacitor C_f as shown in Fig1.4. Inductor L_r is connected in series with a power switch S to achieve ZCS. It is classified into two types L type and M type. In both types, the inductor L_r limits the di/dt of the switch current, and L_r and C_r constitute a series circuit.

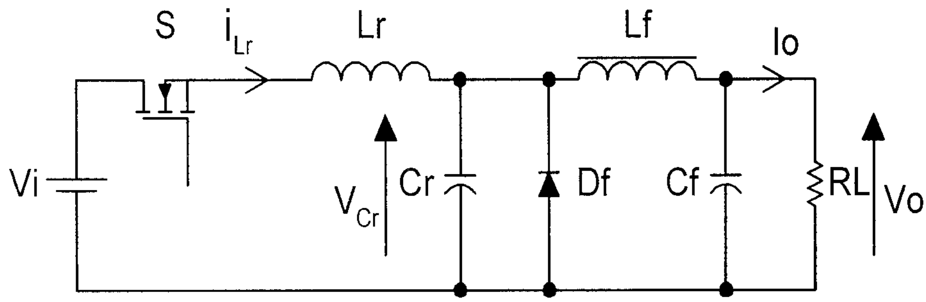


Fig1.4 Converter with ZCS technology

When the switch current is zero, there is a current I=Cj (dv/dt) flowing through internal capacitance C_j due to a finite slope of switch voltage at turn-off. The current flow causes power dissipation in the switch and limits the high switching frequency. The switch can be implemented either in half-wave configuration or in full-wave configuration for unidirectional and bidirectional current flows respectively.

The practical devices do not turn-off at zero current due to their recovery times. As a result, an amount of energy can be trapped in the inductor L of the M type configuration, and voltage transients appear across the switch. This favours L type configuration over the M type one.

1.8 COMPARISON BETWEEN ZCS AND ZVS

ZCS can eliminate the switching losses at turn-off and reduce the switching losses at turn-on. As a relatively large capacitor is connected across the output diode during resonance, the converter operation becomes insensitive to the diode's junction capacitance. The major limitations associated with ZCS when power MOSFETS are used are the capacitive turn-on losses. Thus, the switching loss is proportional to the switching frequency.

During turn-on, considerable rate of change of voltage can be coupled to the gate drive circuit through the Miller capacitor, thus increasing switching loss and noise. Another limitation is that the switches are under high current stress, resulting in high conduction loss. It should be noted that ZCS is particularly effective in reducing switching loss for power devices (such as IGBT) with large tail current in the turn-off process.

ZVS eliminates the capacitive turn-on loss. It is suitable for high-frequency operation. For single-ended configuration, the switches could suffer from excessive voltage stress, which is proportional to the load.

For both ZCS and ZVS, output regulation of the resonant converters can be achieved by variable frequency control. ZCS operates with constant on-time control, while ZVS operates with constant off-time control. With a wide input and load range, both techniques have to operate with a wide switching frequency range, increasing the complexity of resonant converters design optimally.

HYBRID ELECTRIC VEHICLE

2. HYBRID ELECTRIC VEHICLE

2.1 Introduction

Hybrid Electric Vehicle (HEV) combines the internal combustion engine of a normal vehicle with the battery and electric motor of an electric vehicle. This results in twice the fuel economy of conventional vehicles. Also it offers the extended range and rapid refueling that consumers expect from a normal vehicle, with all the energy and environmental benefits of an electric vehicle which can be used in a wide range of applications, from personal transportation to commercial hauling.

Hybrid power systems are designed as a means to compensate for the shortfall in battery technology. Because batteries could supply only enough energy for short trips, an on-board generator, powered by an internal combustion engine, could be installed and used for longer trips. This is the concept of the HEV. Electric vehicles are only being used in selected market applications where fewer kilometers are travelled. Conventional motor vehicles powered by Internal Combustion Engines (ICE) pose substantial economic, environmental and energy security issues for the planet.

The development of a compact, high efficiency dc-dc converter can introduce several modifications to the overall automobile design. The overall performance of the bi-directional dc-dc converter will be improved if the dual bus system will be a successful and cost effective solution for future automobiles. Especially in automotive applications where high ambient temperature (~200°C) is present, conventional dc-dc converters with magnetic elements can be very inefficient, and dc-dc converters with bulky inductors can suffer limited space issue.

The other criterion that needs to be fulfilled from this bi-directional converter is high efficiency even in partial loads. Classical dc-dc converters suffer from limited efficiency at partial loads, and the maximum efficiency is achieved at full load. Thereby, a new dc-dc converter having an operating principle other than the inductive energy transfer method could be advantageous.

Several capacitor clamped converters may be considered as a solution to meet this criterion to achieve high efficiency operation and bi-directional power handling capability.

Bidirectional power management is an important attribute of a dc-dc converter used in several applications. In a hybrid automobile, there are many electric loads grouped into two main categories depending on the voltages they use. The main traction motor is powered from the high voltage bus (around 500 V). There are also low voltage loads that need to be powered from a low voltage source in the range of 40-50 V.

The low voltage source could be a battery or a stepped down voltage from the high voltage battery pack or any source. When the high voltage source is a fuel cell, the low voltage source is normally a battery pack. During the start up time of the vehicle, the low voltage battery pack delivers power to the fuel cell system and to the main motor, and the low voltage loads in the vehicle; the dc-dc works in the up conversion mode.

Once the fuel cell is ready, it provides power to the main motor and low voltage loads. The low voltage battery is also charged from the fuel cell if required. During this time, the dc-dc converter works in the down conversion mode. Thus, a dc-dc converter used in the system must have the capability to deliver power in both directions depending on the state of the fuel cell or the battery voltage.

2.1 Why HEV?

More efficient cars can make a big difference to society in terms of environmental benefits, and the pollution in the urban air has motivated buyers to purchase cleaner cars. Use of HEVs will reduce smog-forming pollutants below the current national average. Hybrids will never be true zero-emission vehicles, however, because of their internal combustion engine. But the first hybrid on the market will cut emissions of global warming pollutants by a third to a half, and later models may cut emissions by even more.

One of the most important differences between a HEV and a normal vehicle is the HEV's ability to reclaim a portion of the energy lost to braking. In a HEV, when the driver brakes, the motor becomes a generator, using the kinetic energy of the vehicle to generate electricity that can be stored in the battery for later use. Traditional brakes are necessary, as well as a consistent strategy for smoothly blending the two braking systems. Regenerative and friction brakes need to be controlled electronically so that stopping ability is maximized to make the dual brake operation not noticeable to the driver. Regenerative braking capability helps minimize energy loss and recover the energy used to slow down or stop a vehicle.

Engines can be sized to accommodate average load, not peak load, which reduces the engine's weight. Fuel efficiency is greatly increased (hybrid consumes significantly less fuel than vehicles powered by gasoline alone). Emissions are greatly decreased. HEVs can reduce dependency on fossil fuels because they can run on alternative fuels. Special lightweight materials are used to reduce the overall vehicle weight of the HEVs.

2.2 HEV Components

A HEV is an optimized mix of many components. The vehicle drive train consists of:

- Electric traction motors/controllers
- Electric energy storage systems, such as batteries, ultra capacitors, and flywheels
- Hybrid power units such as spark ignition engines, compression ignitions direct injection (diesel) engines, gas turbines, and fuel cells
- Fuel system for hybrid power units
- Transmission system

The model of a hybrid electric vehicle is shown in Figure 2.1. HEVs are now at the forefront of transportation technology development. They are reducing critical resource consumption, dependence on foreign oil, air pollution, and traffic congestion. Their widespread penetration into the automotive market depends mainly on the economics of producing a complex hybrid power system, rather than the inherent capabilities of the technology itself.

Hence the project is initiated to design and develop a bidirectional dc-dc converter which is a component of power supply to the HEV.

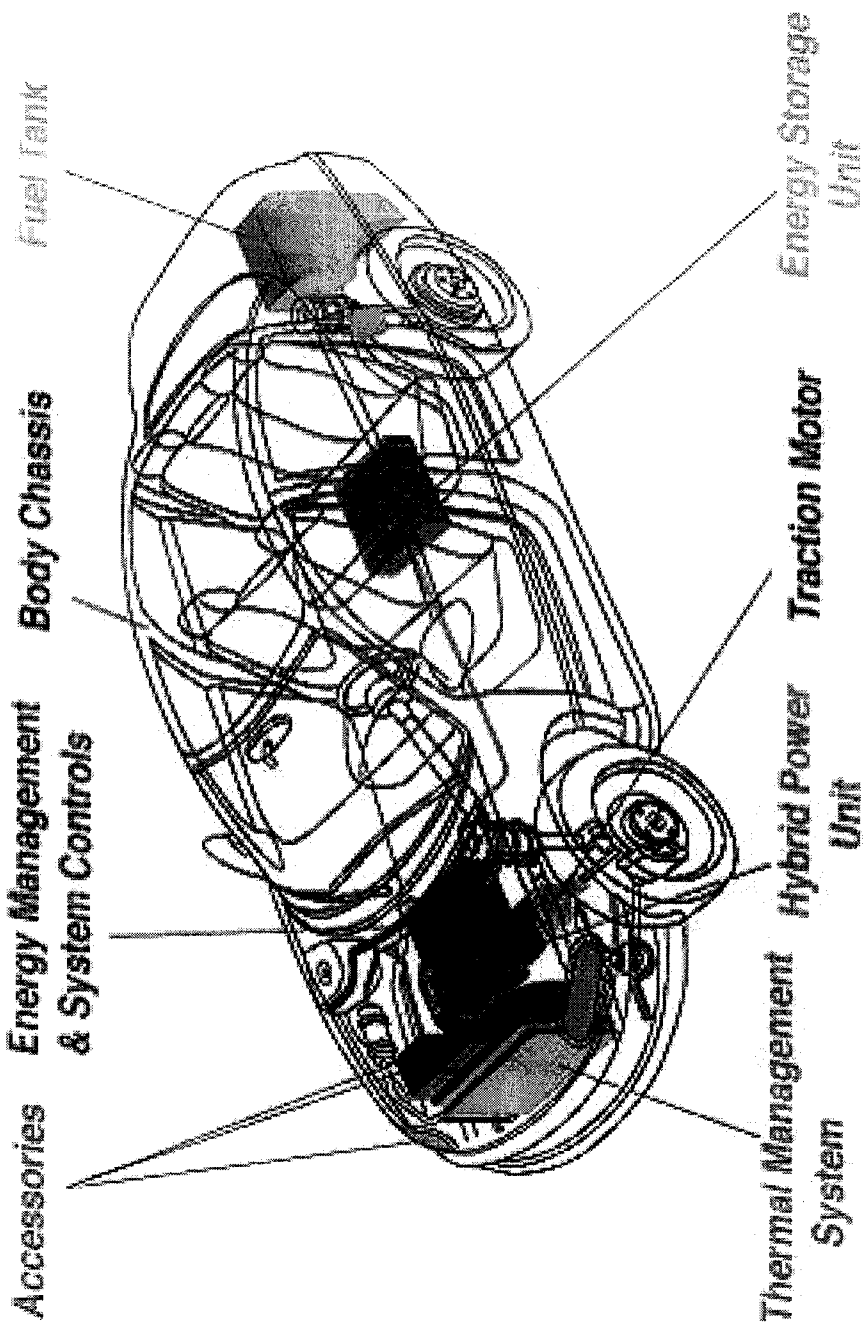


Fig 2.1 Hybrid Electric Vehicle Model

ZVS FULL BRIDGE BI-DIRECTIONAL DC-DC CONVERTER

3. ZVS FULLBRIDGE BIDIRECTIONAL DC-DC CONVERTER

3.1 Introduction

In recent years, growing concerns about environmental issues have demanded more energy efficient non polluting vehicles. The rapid advances in fuel cell technology and power electronics have enabled the significant developments in fuel cell powered electric vehicles. The fuel cells have numerous advantages such as high current output ability, clean electric generation, and high efficiency operation. However, the fuel cell characteristics are different from that of the traditional chemical-powered battery. The fuel cell output voltage drops quickly when first connected to the load and gradually decreases as the output current raises.

The fuel cell also lacks energy storage capability. Therefore, in electric vehicle applications, an auxiliary energy storage device (i.e., lead-acid battery) is always needed for a cold start and to absorb the regenerated energy fed back by the electric machine.

In addition, a dc-dc converter is also needed to draw power from the auxiliary battery to boost the high-voltage bus during vehicle starting.

Until the fuel cell voltage raises to a level high enough to hold the high-voltage bus, the excess load from the battery will be released. The regenerated braking energy can also be fed back and stored in the battery using the dc-dc converter.

A full-bridge bidirectional dc-dc converter, shown in Fig3.3, is considered one of the best choices for these applications. However, this system has a complicated configuration, high cost, and large size. Several half-bridge based topologies have been published in the literature to reduce the device count and increase efficiency. A voltage imbalance exists between the two split capacitors, thus an additional control circuit to eliminate the voltage imbalance is required. In this project, the design of a new bidirectional dc-dc converter is undertaken.

3.2 Operation

To overcome the limitations of the traditional converter, this project considers a ZVS Bi-Directional Full Bridge DC-DC Converter and its controller method for implementing dc-dc power management. It consists of a battery, low voltage side converter, isolation transformer, high voltage side converter and DC motor. The two modes of operations in the converter are:

1. Forward mode
2. Reverse mode

3.2.1 Forward mode of operation

In the forward mode of operation, DC voltage from battery is inverted by the low voltage side converter. The inverted AC voltage from the low voltage side converter is fed to the isolation transformer. From the isolation transformer, the inverted AC voltage is stepped up and also high voltage side converter is isolated from low voltage side converter. The figure shows the block diagram for forward mode of operation of the converter.

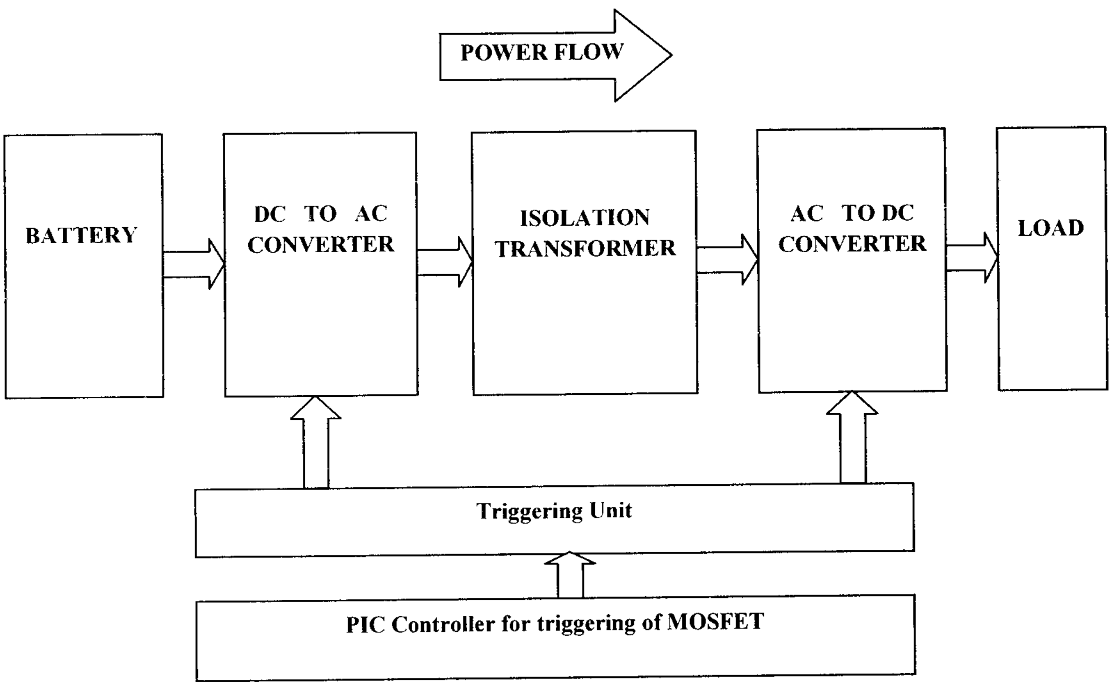


Fig 3.1 Block diagram for forward mode operation

3.2.2 Reverse mode of operation

In the reverse mode of operation, the input given to the high voltage side converter is inverted and is fed to the isolation transformer where it is stepped down. Then it is rectified by the low voltage side converter to recharge the battery. Hence the DC power has been managed in both forward and reverse directions.

The block diagram for reverse mode of operation of converter is shown in Figure3.2.

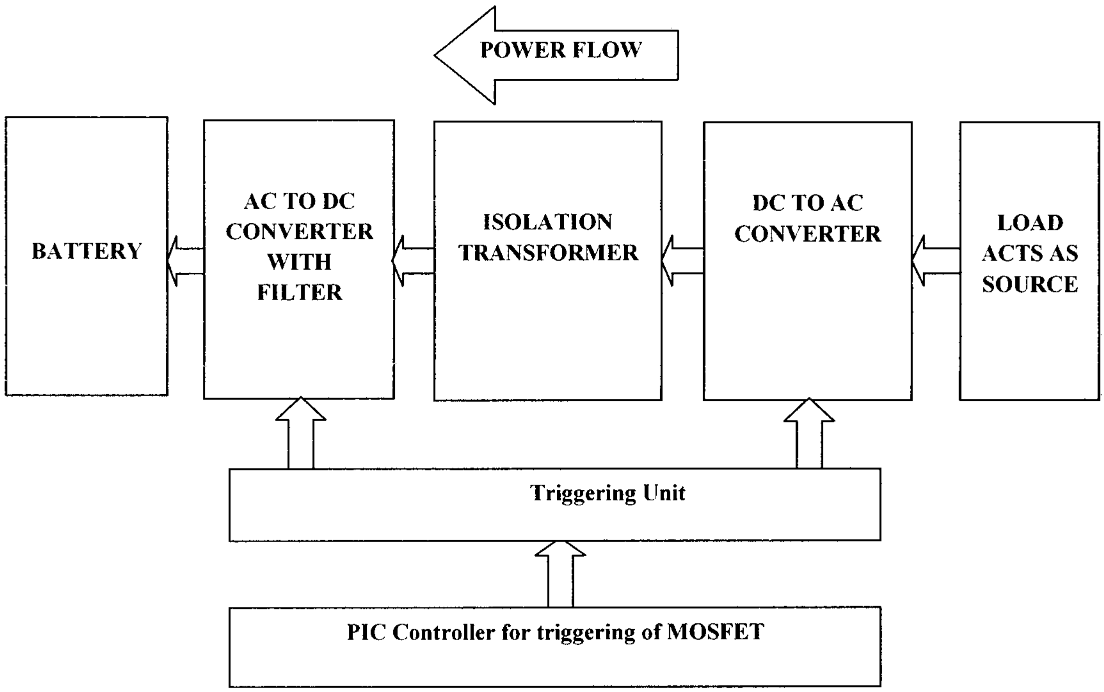


Fig 3.2 Block diagram for reverse mode operation

3.3 Circuit Diagram

The circuit diagram for ZVS Full Bridge Bi-Directional DC-DC converter is shown in Figure3.3. Input signals from the micro controller are given to drive circuits of MOSFETs where the triggering pulses are generated. The triggering pulses are applied across gate-source terminals of each MOSFET. MOSFETs which are to be conducted are given with drain-source voltage in addition to the triggering pulses provided. The drain-source voltage magnitude depends on the power transfer in both forward and reverse directions.

During forward mode of operation the MOSFET 1 and MOSFET 3 are given with similar triggering sequence while MOSFET 2 and MOSFET 4 are given with exactly opposite pulses when compared to the pulses provided for MOSFET 1 and MOSFET 3.

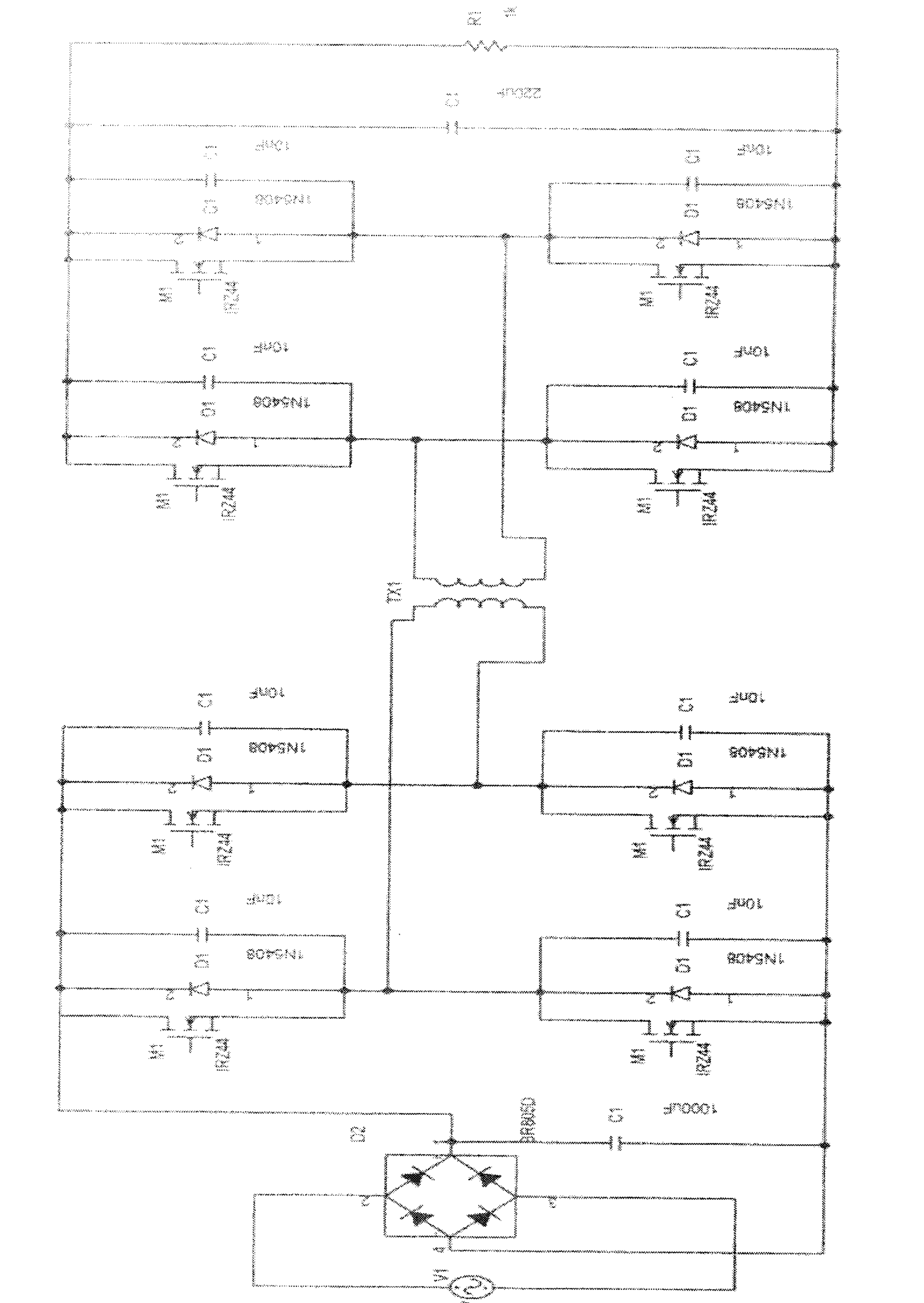


Fig 3.3 Circuit Diagram for ZVS Full Bridge Bi-Directional DC-DC converter

DRIVER CIRCUIT

4. DRIVER CIRCUIT

The driver circuit is designed using totem pole arrangement and it uses optocoupler to provide bias for the transistors in the totem pole arrangement. The driver circuit is shown in Figure4.1. Here MCT2E is the optocoupler that comprises a photo transistor and an LED. The input pulse to this driver circuit is given from the Programmable Interrupt Controller (PIC).

Set of codings has been embedded on PIC using embedded C in order to generate triggering pulses to excite the driver circuits for the purpose of triggering MOSFETs.

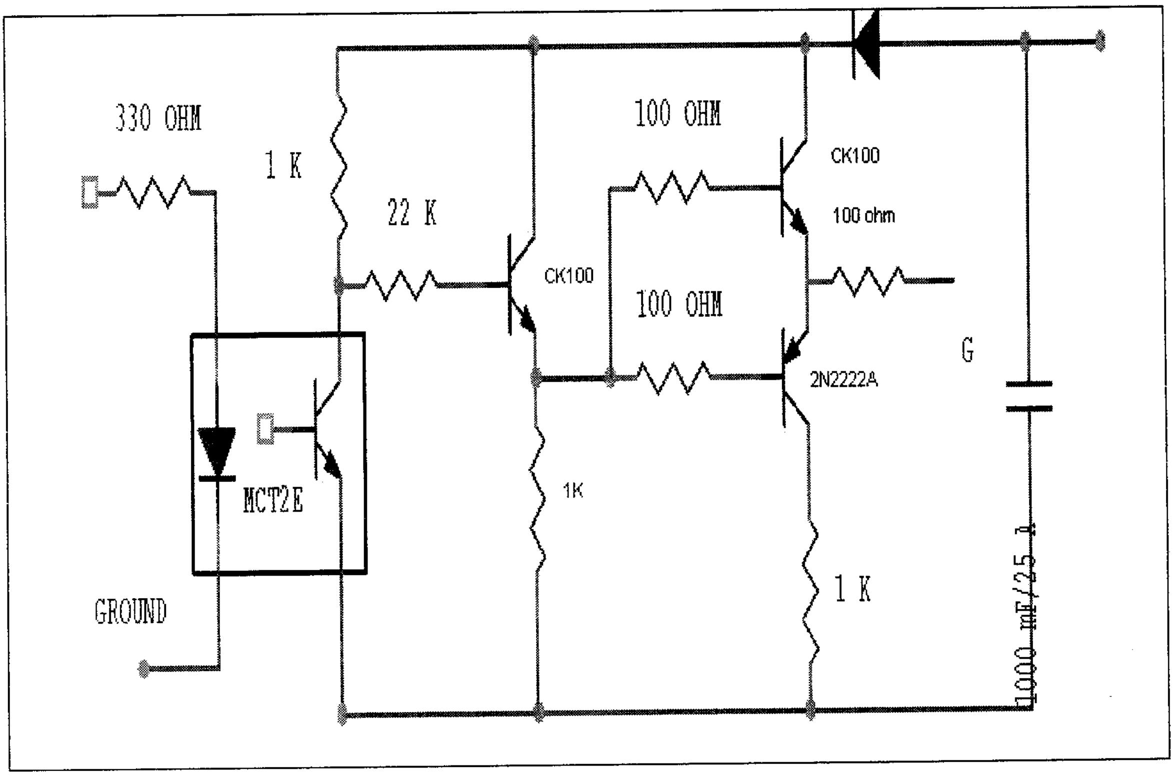


Fig 4.1 Driver Circuit

When a LOW level signal is received from the PIC, LED is forward biased and the phototransistor will conduct thereby giving biasing signal to the transistors Q1 and Q2. Hence a positive triggering pulse for gate of the MOSFET is obtained.

When the input from the PIC is HIGH, then the LED is reverse biased. At this time the photo transistor would not conduct and therefore transistors Q1 and Q2 in the circuit will be turned OFF.

Hence a negative triggering pulse for the gate of MOSFET is obtained in this case. The transistor Q3 is provided to maintain a zero level after a pulse has been produced in order to maintain a sequence of HIGH and LOW level pulses.

SWITCHING PULSE SEQUENCE

5. SWITHCHING SEQUENCE

Soft switching can mitigate some of the mechanisms of switching loss and possibly reduce the generation of EMI (Electro Magnetic Interference). Semiconductor devices are switched on or off at the zero crossing of their voltage or current waveforms.

Transistor turn-on transition occurs at zero voltage.

- Diodes may also operate with zero-voltage switching.
- Zero – voltage switching eliminates the switching loss induced by diode
- Stored charge and device output capacitances.
- Zero – voltage switching is usually preferred in modern converters.

5.1 Switching pulse for Forward Direction

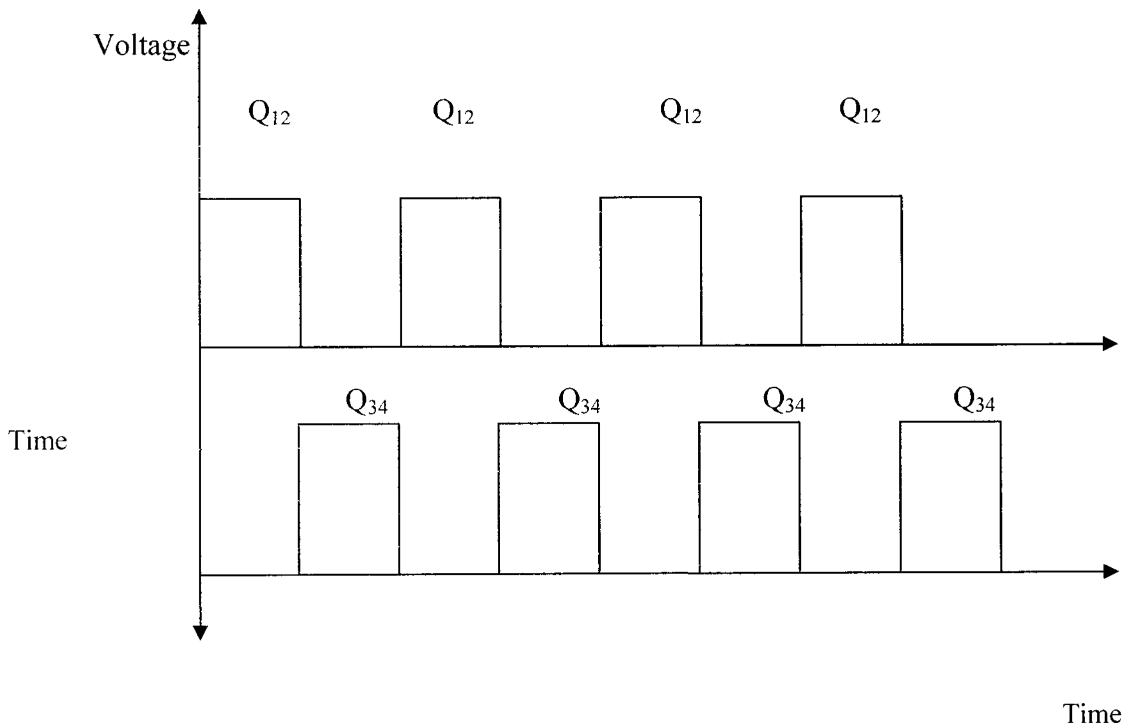


Fig 5.1 Triggering Pulse Sequence for Forward Mode

5.2 Switching pulse for Reverse Direction

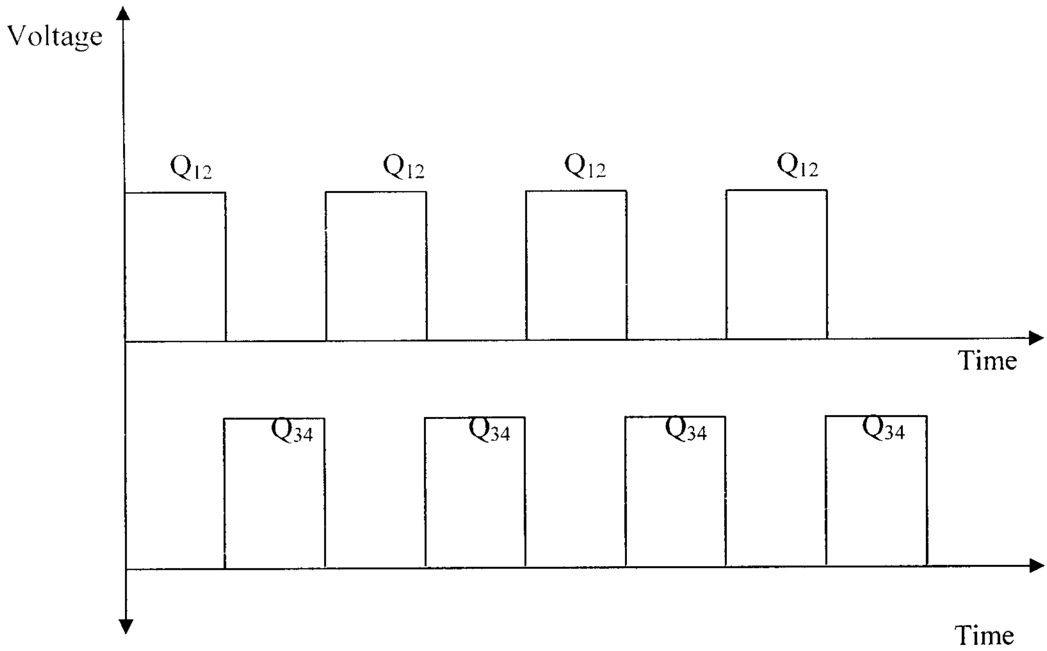


Fig 5.2 Triggering Pulse Sequence for Reverse Mode

PROGRAMMABLE INTERRUPT CONTROLLER

6. PROGRAMMABLE INTERRUPT CONTROLLER

6.1 Introduction

The microcontroller that has been used for this project is from PIC series. 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 "**Peripheral Interface Controller**".

PICs are popular with developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability.

PIC microcontroller is the first RISC based microcontroller fabricated in CMOS (Complementary Metal Oxide Semiconductor) that uses separate bus for instruction and data allowing simultaneous access of program and data memory.

The main advantage of CMOS and RISC combination is low power consumption resulting in a very small chip size with a small pin count. The main advantage of CMOS is that it has immunity to noise than other fabrication techniques.

Various microcontrollers offer different kinds of memories. EEPROM, EPROM, FLASH etc. are some of the memories of which FLASH is the most recently developed.

Technology that is used in PIC16F877 is flash technology, so that data is retained even when the power is switched off. Easy programming and erasing are other features of PIC16F877.

Figure6.1 shows the pin diagram of PIC16f877. Here the output is taken from PORT C. the controller is given with a clock signal of 2 MHz. A crystal oscillator of maximum frequency of 4 MHz is used to give clock signal to the programmable interrupt controller.

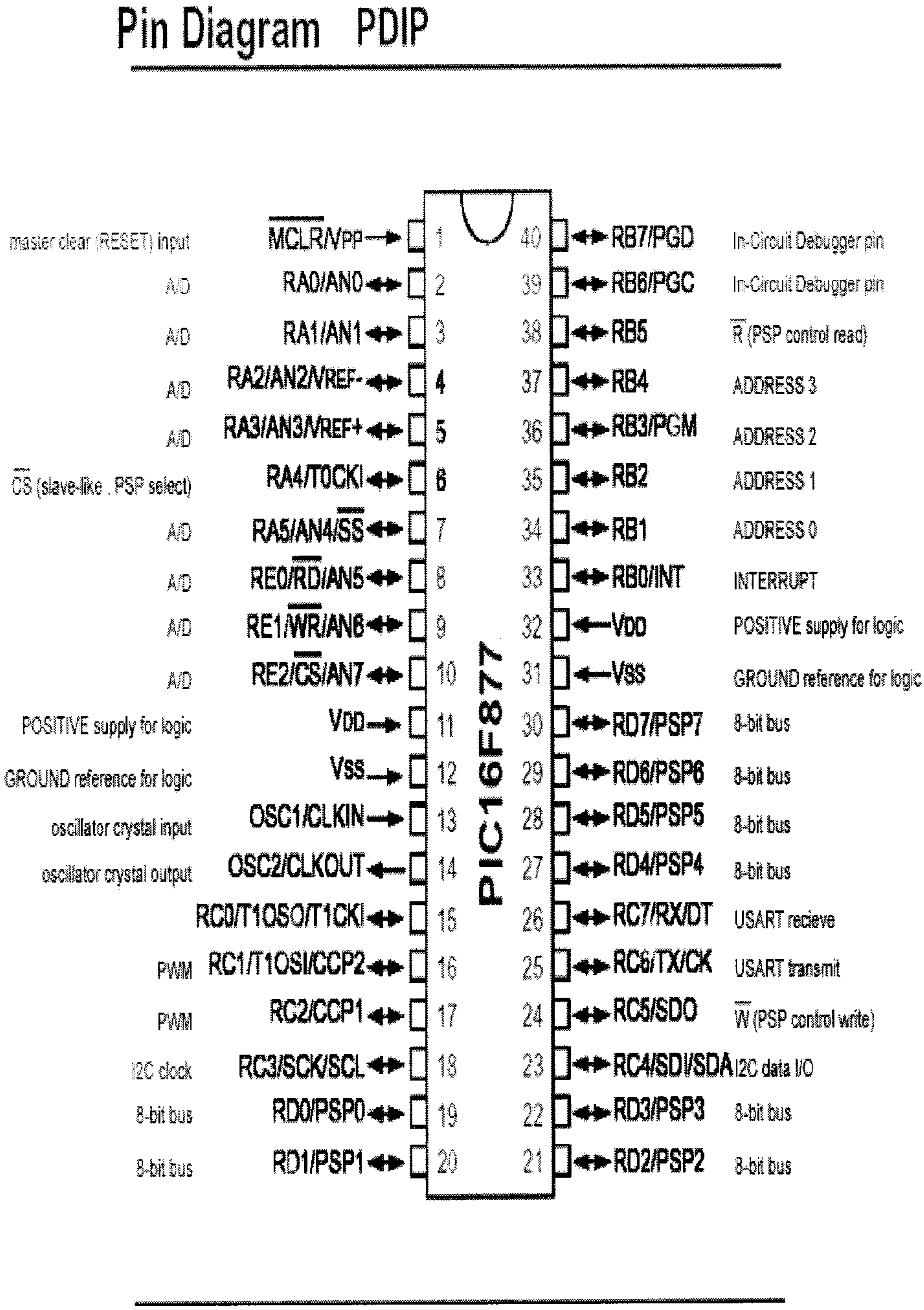


Fig 6.1 Pin Diagram of Programmable Interrupt Controller

Figure6.2 shows the internal architecture of programmable interrupt controller 16F877. Some pins of these I/O ports are multiplexed with an alternate function for the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin. Additional information on I/O ports may be found in the IC micro™ Mid-Range Reference Manual.

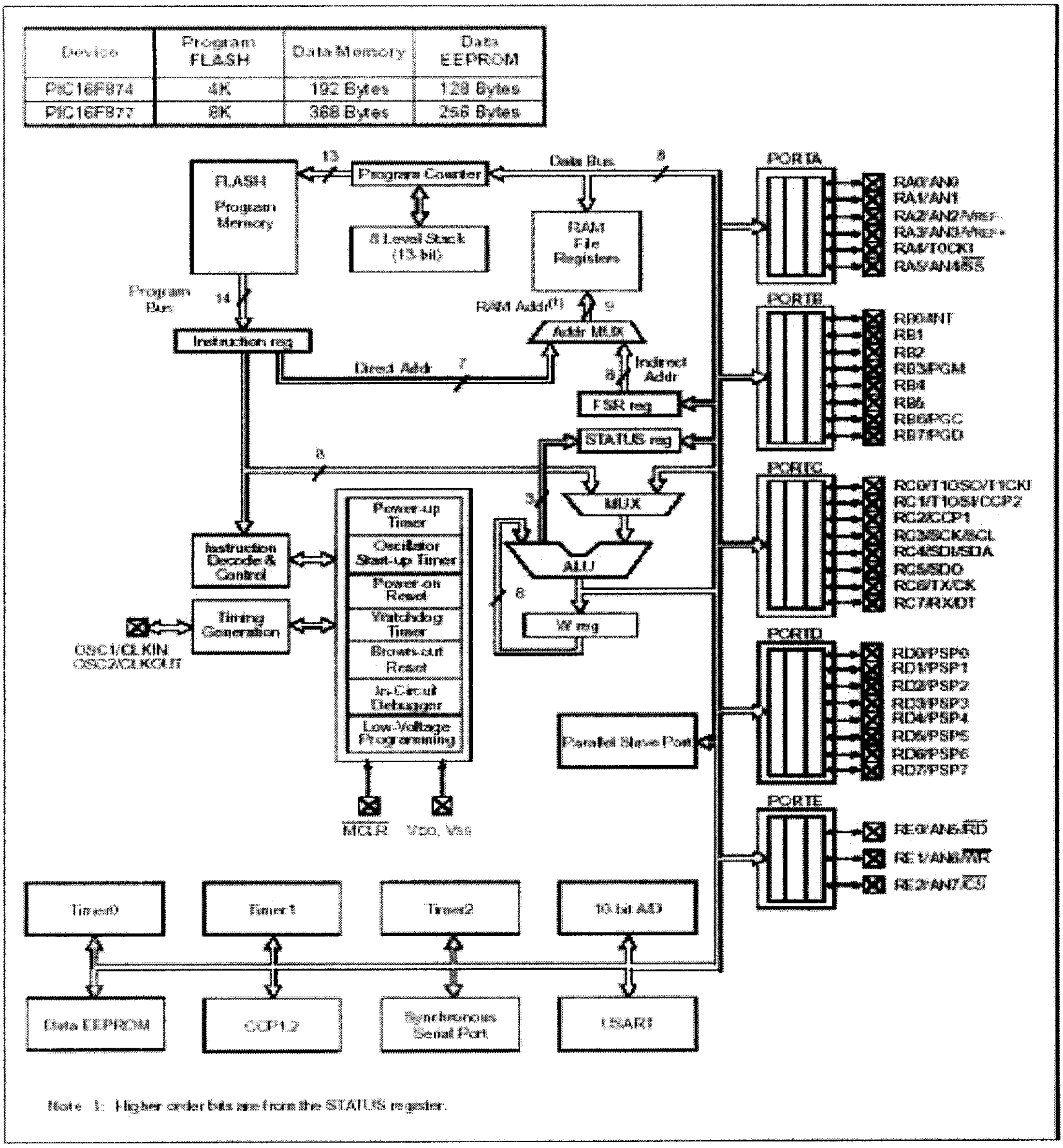


Fig 6.2 Architecture of Programmable Interrupt Controller

6.2 Program:

The PIC controller is programmed with 'C' language.

```
void main()
{
  setup_adc_ports(NO_ANALOGS);
  setup_adc(ADC_OFF);
  setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1);
  setup_comparator(NC_NC_NC_NC);
  setup_vref(FALSE);
  SET_TRIS_B( 0x00 );
  SET_TRIS_a( 0xfF );
  output_low(pin_b1);
  output_low(pin_b2);
  output_low(pin_b3);
  output_low(pin_b0);
  while(1)
  {
    if(input(pin_a0))
    {
      output_high(pin_b0);
      delay_ms(15);
      output_low(pin_b0);
       delay_ms(2);
      output_high(pin_b1);
      delay_ms(15);
      output_low(pin_b1);
```

```
        delay_ms(2);
    }
    else
    {
       output_high(pin_B2);
       delay_ms(15);
       output_low(pin_b2);
        delay_ms(2);
       output_high(pin_b3);
       delay_ms(15);
       output_low(pin_b3);
        delay_ms(2);
     }
  // TODO: USER CODE!!
  }
  // TODO: USER CODE!!
}
```

6.3 SOFTWARES USED:

PIC 'C' COMPILER:

- Suitable for programming any kind of microcontroller
- It has huge in-built functions from which we can select for a specific function.
- On compiling, the software itself generates a code suitable for microcontroller.
- The programming for the microcontroller 16F877 is done by using PIC 'C' Compiler. In this, the programming is done in 'C' language and then converted to hexa file.

WINPIC800:

This software is used to embed the program into the microcontroller. Initially program is loaded into the software and transferred to microcontroller by using a specialized interfacing circuit.

It has multipurpose functions such as:

- To read the program from the microcontroller
- To erase the program in the microcontroller if necessary
- To program any type of microcontroller
- To check whether the program is embedded properly

PROTEUS 7 PROFESSIONAL:

It is used to draw a complete circuit for a micro-controller based system and then test it interactively, all from within the same piece of software. Simulation done using this software is used to develop the design.

This is an all purpose simulation software which can used for simulating any kind of circuit, PCB design etc.

We have used ISIS professional which is a part of Proteus to simulate the microcontroller circuit which is shown in Figure6.3.

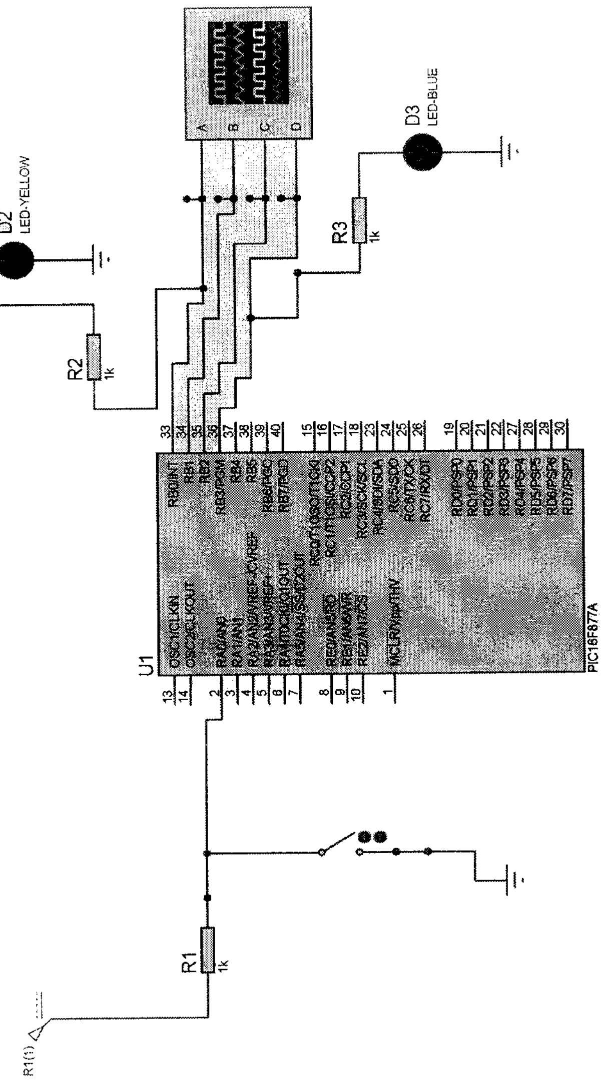


Fig 6.3 PIC Programming Simulation

SIMULATION RESULTS

7. SIMULATION RESULTS

Simulation test for ZVS Full Bridge Bi-Directional DC-DC Converter done using MATLAB SIMULINK. The components involved are chosen from SIMPOWER SYSTEMS. In the test triggering pulses for the MOSFETS are generated from pulse generator and the drain source voltage is supplied from separate DC source.

7.1 Forward Mode

A soft switching ZVS Bi-Directional Full Bridge DC-DC Converter has been built in simulation and tested to validate the soft switching analysis. Here the simulation is done in MATLAB simulink and compared with the experimental results.

In the forward mode of operation, 12V DC voltage from battery is inverted by the low voltage side converter. The inverted AC voltage from the low voltage side converter is fed to the isolation transformer.

From the isolation transformer, the inverted AC voltage is stepped up and also high voltage side converter is isolated from low voltage side converter. Thus 24V DC voltage can be obtained in output of the high voltage side converter.

Attractive feature of this converter is reduction of magnetic saturation due to asymmetricity of circuits or transient phenomenon. The maximum efficiency can be obtained which more applicable to high power traction systems.

The circuit for forward mode operation is shown in the Figure7.1. The Figure7.2 shows the input and output waveforms of forward mode of operation.

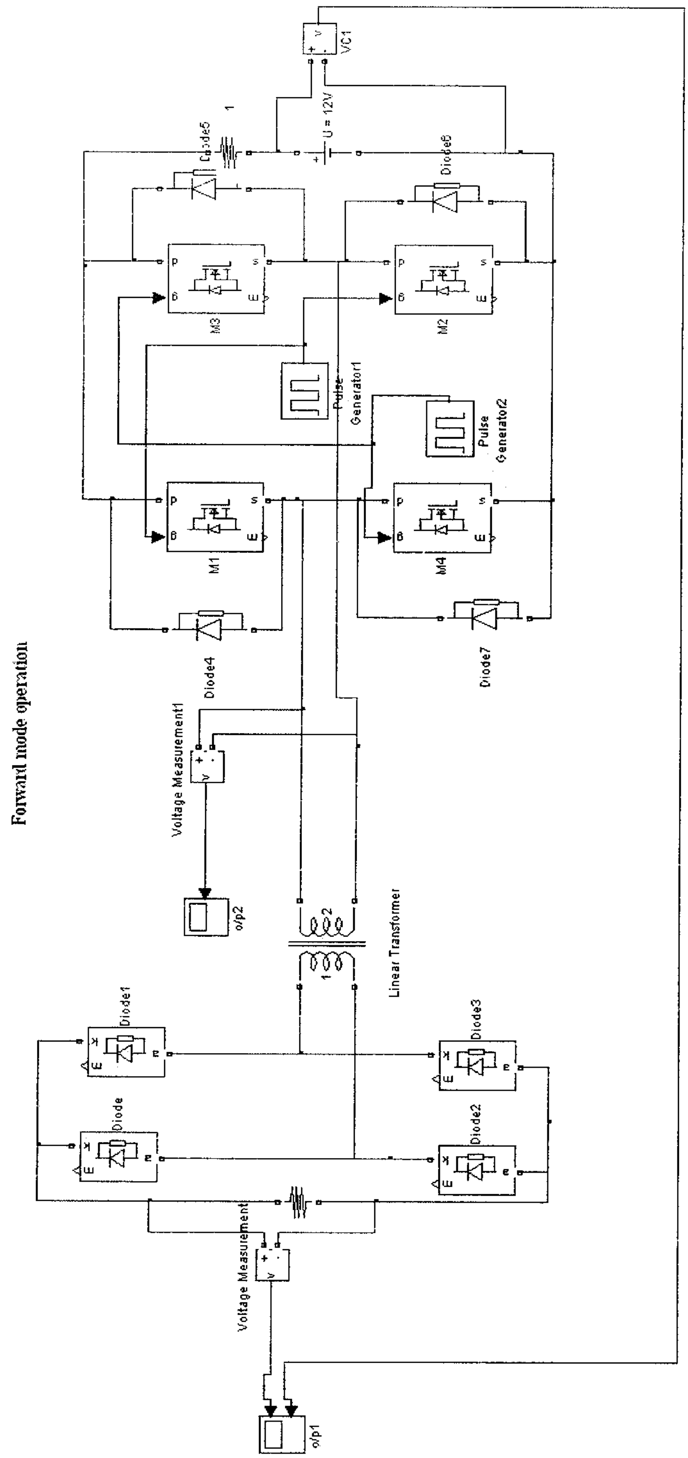


Fig 7.1 Simulation Circuit for Forward Mode Operation

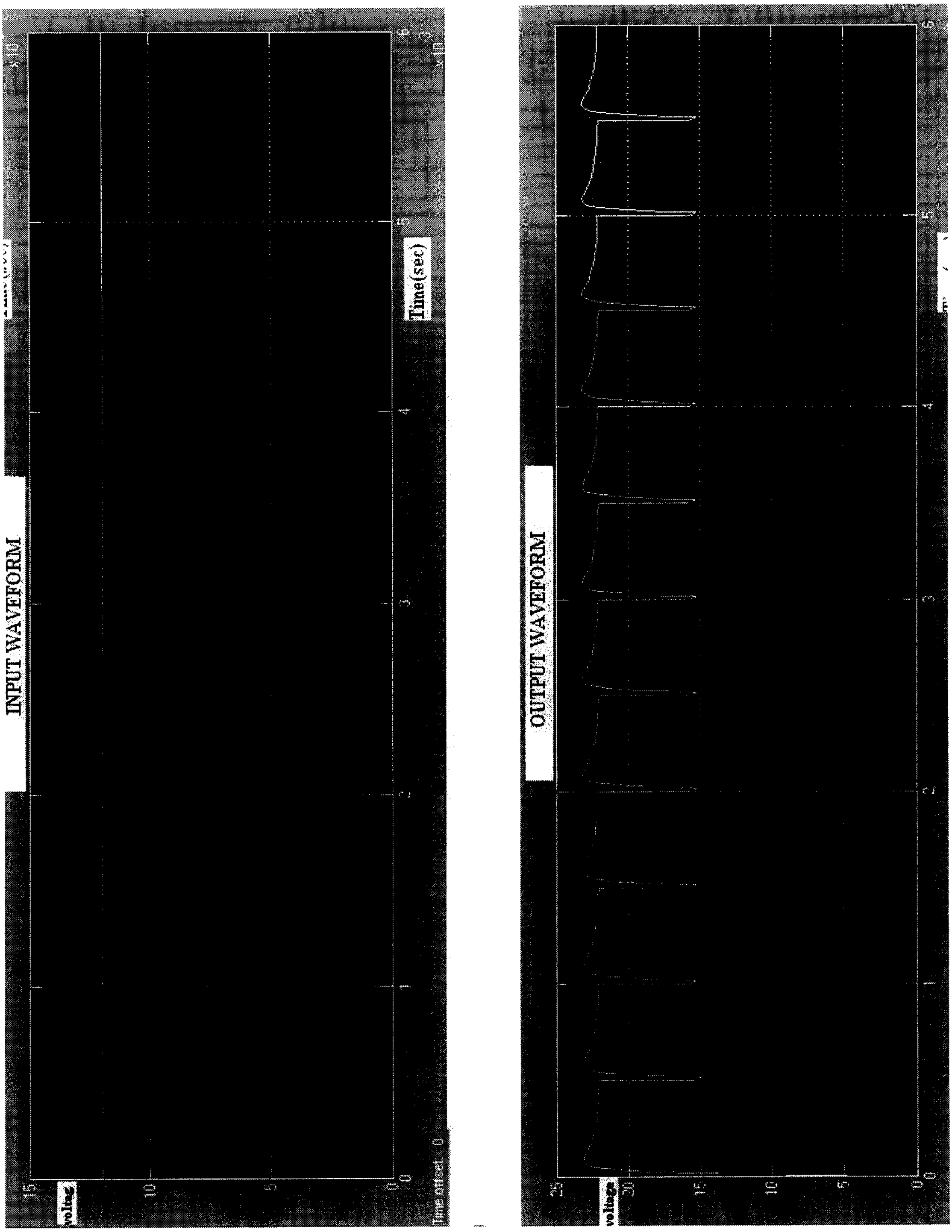


Fig 7.2 Input and Output Waveforms for Forward Mode Operation

7.2 Reverse Mode

In the reverse mode of operation, 24V DC input is given to the high voltage side converter and is inverted. The inverted AC voltage is then fed to the isolation transformer where the voltage is stepped down. In this reverse mode of operation, the isolation transformer acts as a step down transformer.

Then it is given to the low voltage side converter where it is rectified to DC voltage which has a measurable quantity of 6V that can be used to recharge the battery.

Due to its simplicity and robustness, the ZVS Bi-Directional Full Bridge DC-DC converter is suitable for low power to high power and high power to low power applications. The simulation circuit for reverse mode operation is shown in the Figure 7.3. The input and output voltage waveforms using MATLAB are shown in the figure 7.4.

REVERSE MODE OPERATION

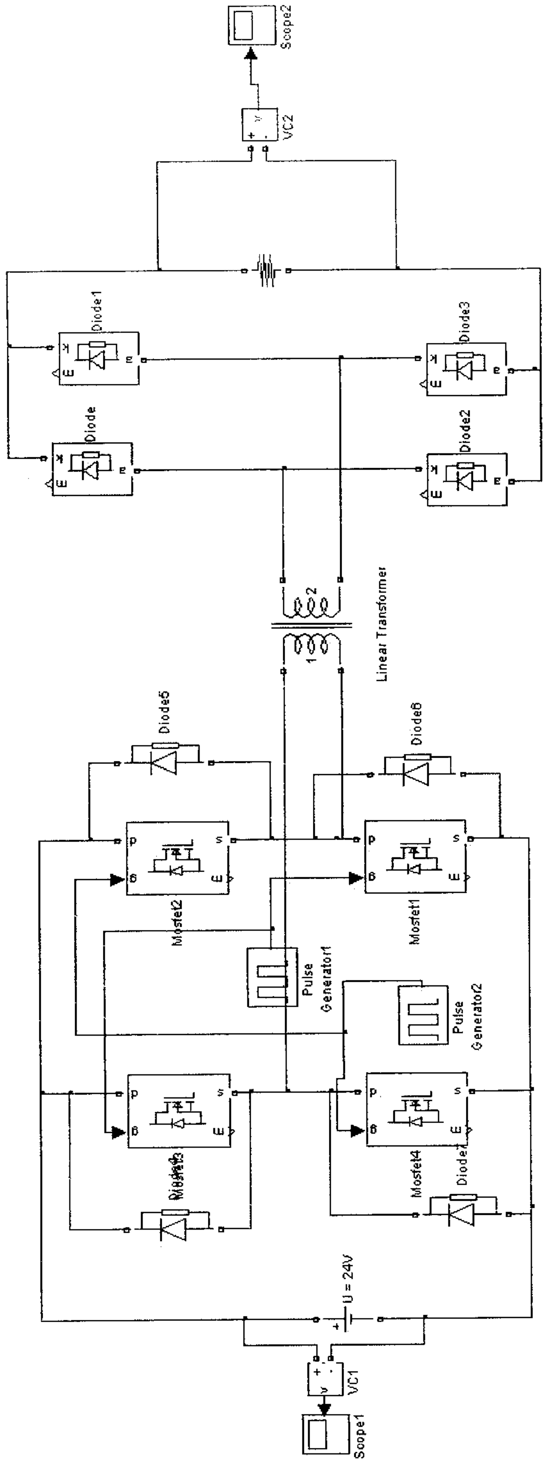


Fig 7.3 Simulation Circuit for Reverse Mode Operation

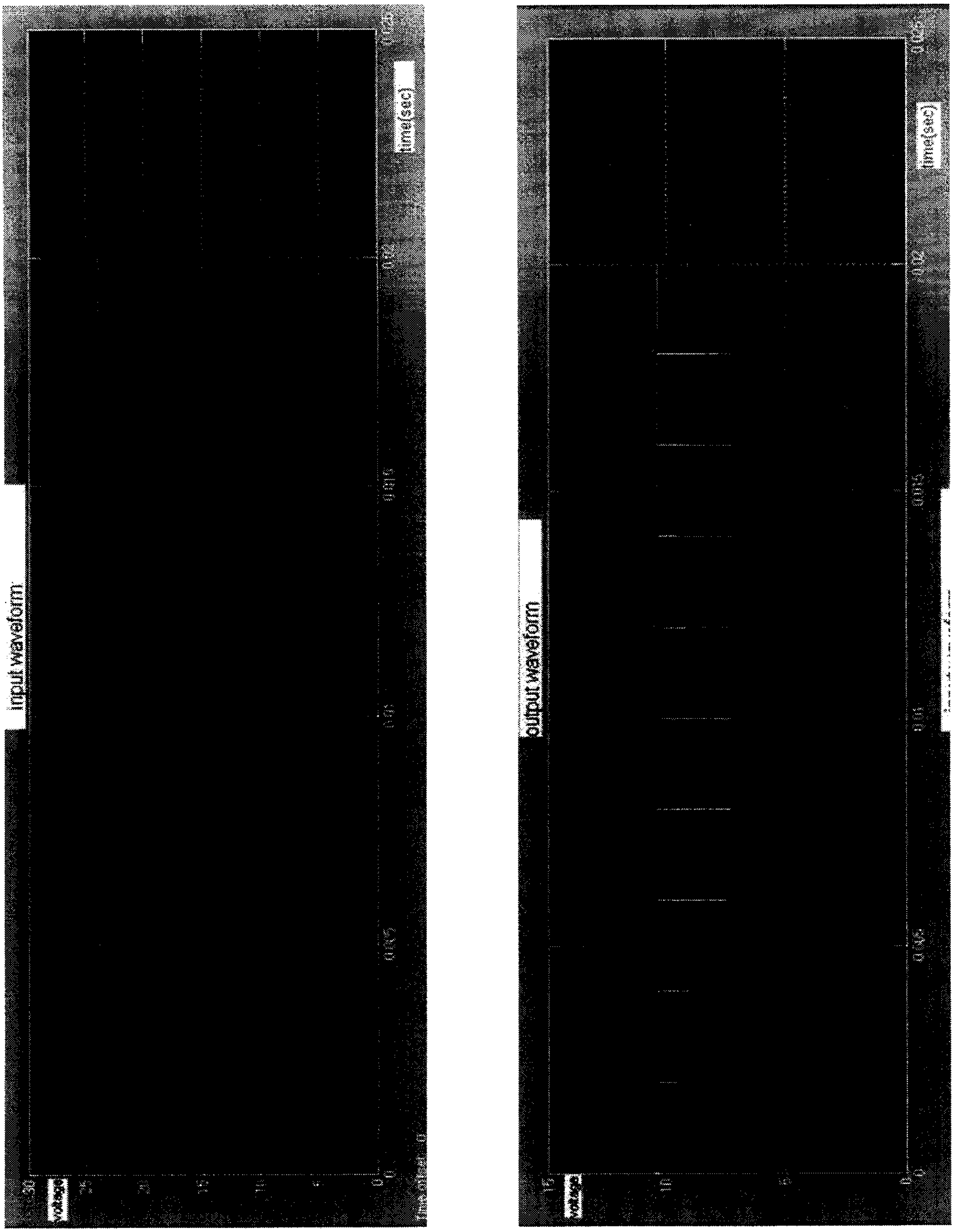


Fig 7.4 Input and Output Waveforms for Forward Mode Operation

EXPERIMENTAL RESULTS

8. EXPERIMENTAL RESULTS

A DC/DC converter can be operated alternately as a step-up converter in a forward direction of energy flow and as a step-down converter in a reverse direction of energy flow. Potential isolation between the low-voltage side and the high-voltage side of the converter is achieved by a magnetic compound unit, which has not only a transformer function but also an energy store function.

In its simplest form, a DC-DC converter simply uses resistors as needed to break up the flow of incoming energy. This is called linear conversion. However, linear conversion is a wasteful process which unnecessarily dissipates energy and can lead to overheating.

A more complex, but more efficient manner of DC-DC conversion is switched mode conversion, which operates by storing power, switching off the flow of current, and restoring it as needed to provide a steadily modulated flow of electricity corresponding to the circuit requirements. This is far less wasteful than linear conversion, saving up to 95% of otherwise wasted energy.

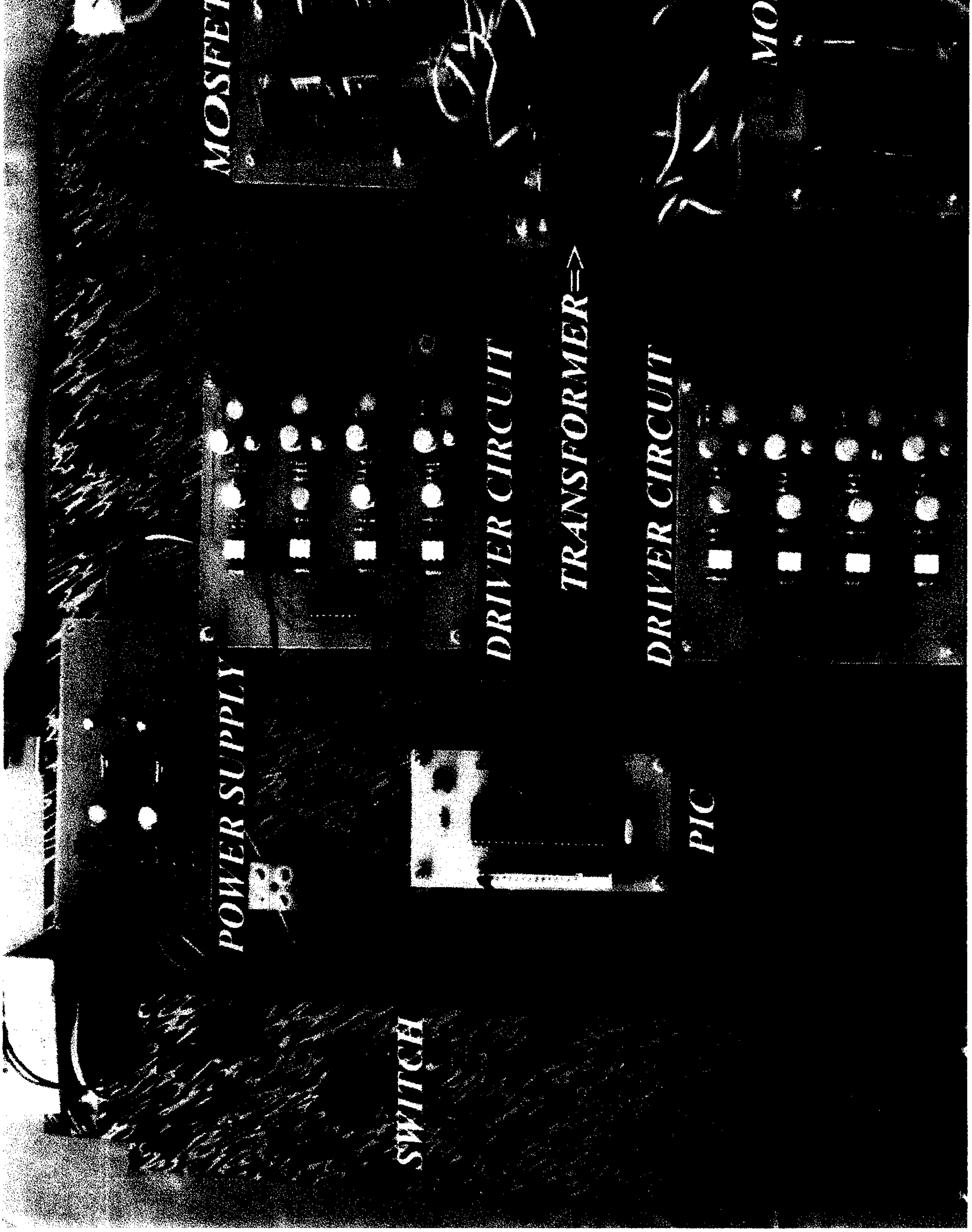
In Forward mode the input given is 6V and the output obtained is 12V. In the Reverse mode of operation the input is 12V and the output is 6V. Actually the system is designed for closed loop configuration but for experimental purpose, to reduce the circuit complexity an external switch is used for mode reversal. The output obtained in both the cases is verified using a CRO (Cathode Ray Oscilloscope). In this project the same circuit is used for both Forward and Reverse mode of operations. Thus the circuit complexity and losses are minimized.

Advantages of ZVS full bridge bidirectional dc-dc converter:

- Promising for medium and high power applications.
- Auxiliary power supply in fuel cell vehicles and power generation.
- High power density.
- Low cost.
- Light weight.

Applications of ZVS full bridge bidirectional dc-dc converter:

- Fuel cell vehicles
- Power generators
- Variable dc voltage application
- Bio medical applications



8.1 Hardware Assembly

CONCLUSION

9. CONCLUSION

The design of a new soft-switched isolated bidirectional dc-dc converter is presented in this report. The operation, analysis, features and design consideration are illustrated. Simulation and experimental results for the prototype are shown to verify the operation principle. It is shown that ZVS (Zero Voltage Switching) in either direction of power flow is achieved with no lossy components and no additional active switch. With the dual functions (simultaneous boost conversion and inversion) provided by the low voltage side full bridge, current stresses on the switching devices and transformer are kept minimum. The advantages of the new circuit include ZVS with full load range, decreased device count, high efficiency, and low cost as well as less control and accessory power needs. The power converter is very promising for medium power applications with high power density.

REFERENCES

REFERENCES

[1]. O. García, L.A. Flores1, J.A. Oliver, J.A Cobos, J. de la Peña2, J "Bi-directional dc-dc Converter for Hybrid Vehicles", Power Electronics specialists conference (2006), IEEE 36th volume, Pages 1881-1886.

[2]. Muhammad H. Rashid "Power Electronics Circuits, Devices, and Applications" second edition, (1995), Prentice Hall of India Private Limited, Pages 303-350.

[3]. www.microchip.com (datasheet download for PIC 16F877, MCT2E, MOSFET etc)

[4]. General details about converters, HEV, ZVS etc URL:http://www.wikipedia.org

APPENDIX

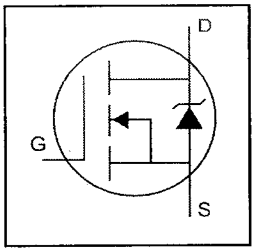
International
IOR Rectifier

PD - 94008

IRFP250N

HEXFET® Power MOSFET

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated
- Ease of Paralleling
- Simple Drive Requirements



V_{DSS} = 200V

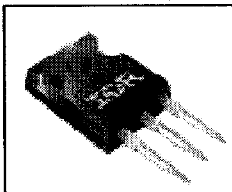
$R_{DS(on)}$ = 0.075Ω

I_D = 30A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-247 package is preferred for commercial-industrial applications where higher power levels preclude the use of TO-220 devices. The TO-247 is similar but superior to the earlier TO-218 package because of its isolated mounting hole.



TO-247AC

Absolute Maximum Ratings

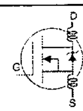
	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	30	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	21	
I_{DM}	Pulsed Drain Current ①	120	
P_D @T_C = 25°C	Power Dissipation	214	W
	Linear Derating Factor	1.4	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②	315	mJ
I_{AR}	Avalanche Current①	30	A
E_{AR}	Repetitive Avalanche Energy①	21	mJ
dv/dt	Peak Diode Recovery dv/dt ③	8.6	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to +175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

Thermal Resistance

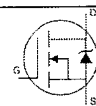
	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	0.7	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	—	
$R_{\theta JA}$	Junction-to-Ambient	—	40	

10/09/00

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	200	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.26	—	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.075	Ω	V_{GS} = 10V, I_D = 18A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	V_{DS} = V_{GS}, I_D = 250μA
g_{fs}	Forward Transconductance	17	—	—	S	V_{DS} = 50V, I_D = 18A ④
I_{DSS}	Drain-to-Source Leakage Current	—	—	25	μA	V_{DS} = 200V, V_{GS} = 0V
		—	—	250		V_{DS} = 160V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
Q_g	Total Gate Charge	—	—	123	nC	I_D = 18A
Q_{gs}	Gate-to-Source Charge	—	—	21		V_{DS} = 160V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	57		V_{GS} = 10V, See Fig. 6 and 13 ④
$t_{d(on)}$	Turn-On Delay Time	—	14	—	ns	V_{DD} = 100V
t_r	Rise Time	—	43	—		I_D = 18A
$t_{d(off)}$	Turn-Off Delay Time	—	41	—		R_G = 3.9Ω
t_f	Fall Time	—	33	—		R_D = 5.5Ω, See Fig. 10 ④
L_D	Internal Drain Inductance	—	4.5	—	nH	Between lead, 6mm (0.25in.) 
L_S	Internal Source Inductance	—	7.5	—		from package and center of die contact
C_{iss}	Input Capacitance	—	2159	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	315	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	83	—		f = 1.0MHz, See Fig. 5

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	30	A	MOSFET symbol showing the 
I_{SM}	Pulsed Source Current (Body Diode)①	—	—	120		integral reverse p-n junction diode.
V_{SD}	Diode Forward Voltage	—	—	1.3	V	T_J = 25°C, I_S = 18A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	186	279	ns	T_J = 25°C, I_F = 18A
Q_{rr}	Reverse Recovery Charge	—	1.3	2.0	μC	di/dt = 100A/μs ④
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See Fig. 11)

② Starting T_J = 25°C, L = 1.9mH R_G = 25Ω, I_{AS} = 18A. (See Figure 12)

③ I_{SD} ≤ 18A, di/dt ≤ 374A/μs, V_{DD} ≤ $V_{(BR)DSS}$, T_J ≤ 175°C

④ Pulse width ≤ 300μs; duty cycle ≤ 2%.

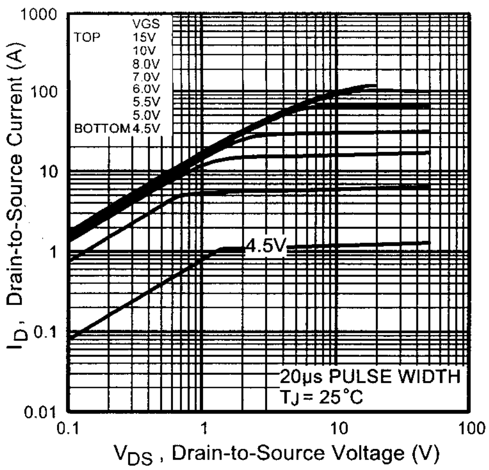


Fig 1. Typical Output Characteristics

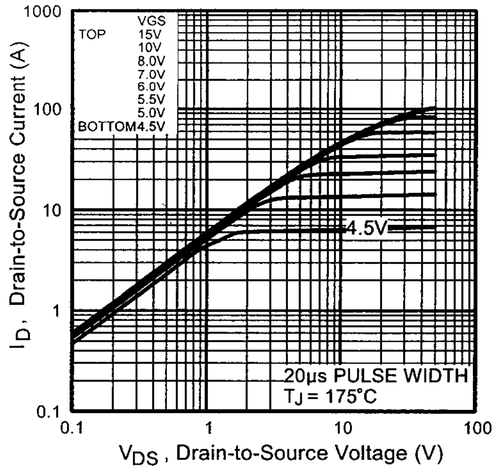


Fig 2. Typical Output Characteristics

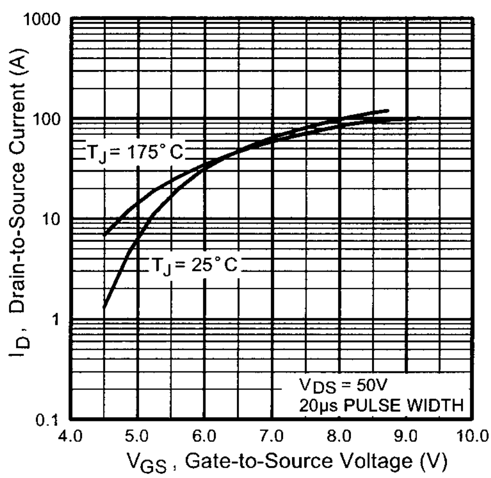


Fig 3. Typical Transfer Characteristics

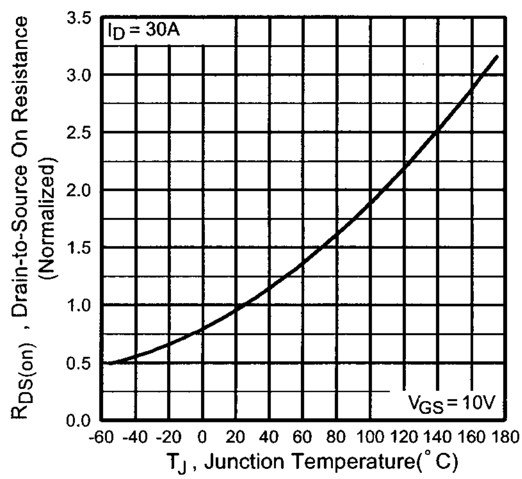


Fig 4. Normalized On-Resistance Vs. Temperature

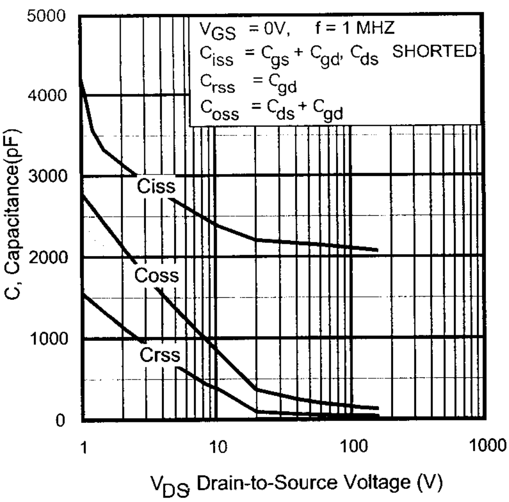


Fig 5. Typical Capacitance Vs. Drain-to-Source Voltage

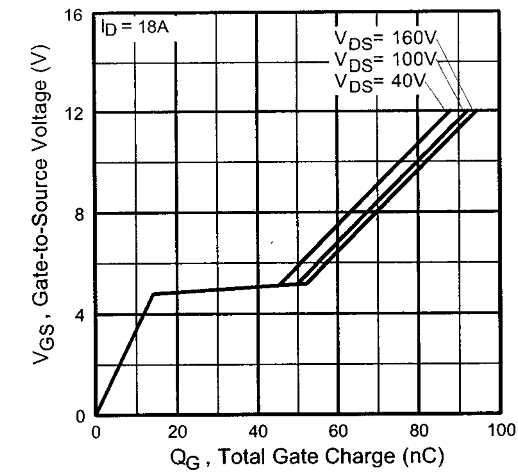


Fig 6. Typical Gate Charge Vs. Gate-to-Source Voltage

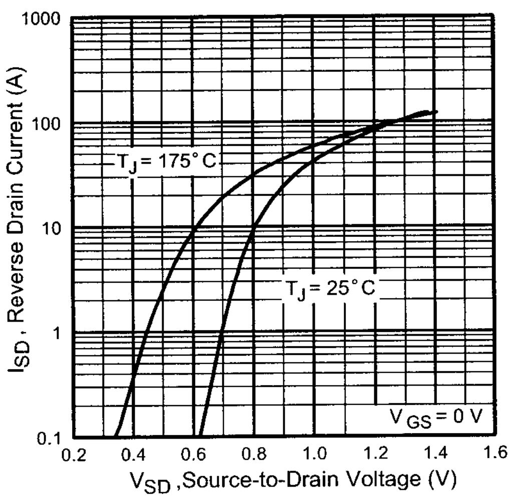


Fig 7. Typical Source-Drain Diode Forward Voltage

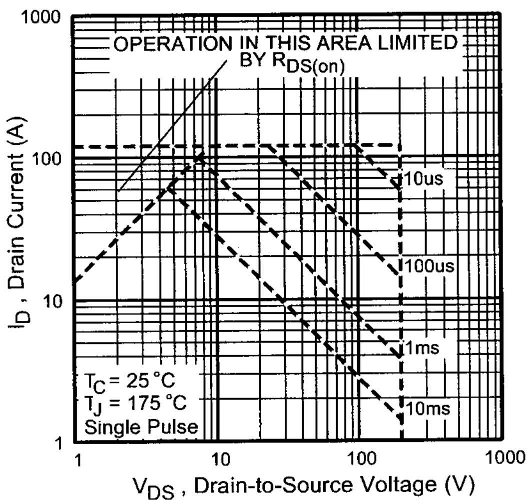


Fig 8. Maximum Safe Operating Area

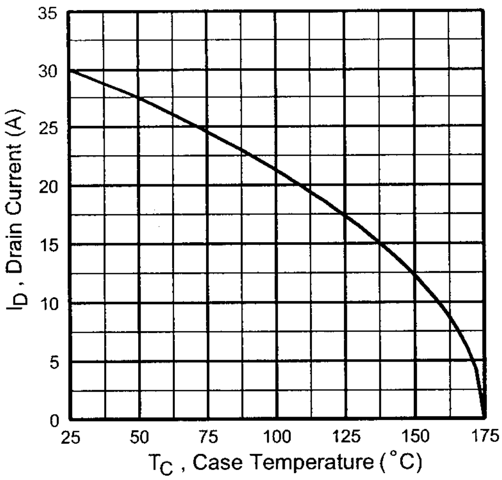


Fig 9. Maximum Drain Current Vs. Case Temperature

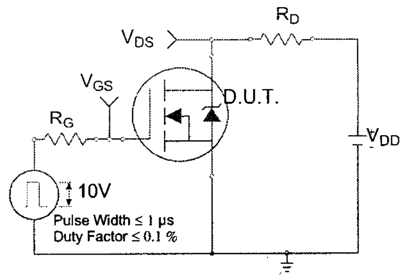


Fig 10a. Switching Time Test Circuit

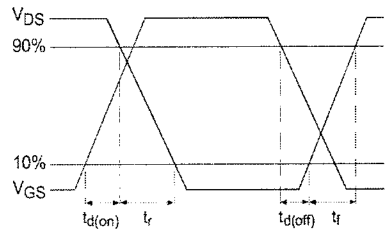


Fig 10b. Switching Time Waveforms

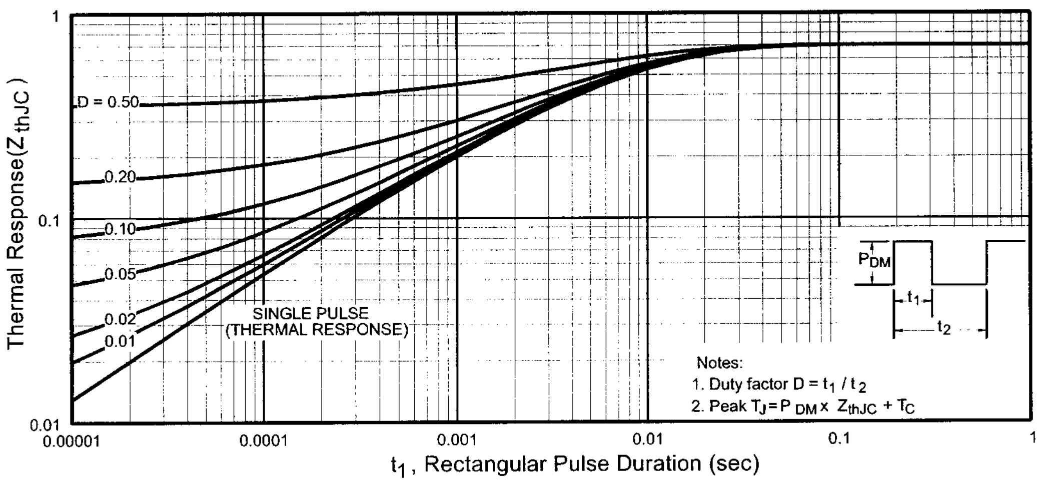


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

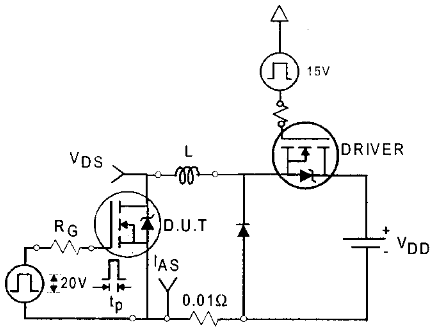


Fig 12a. Unclamped Inductive Test Circuit

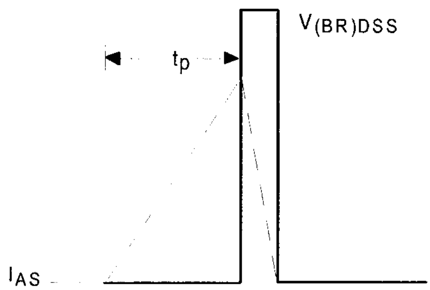


Fig 12b. Unclamped Inductive Waveforms

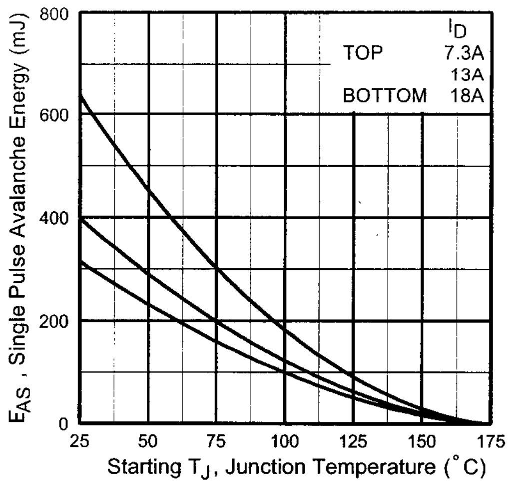


Fig 12c. Maximum Avalanche Energy Vs. Drain Current

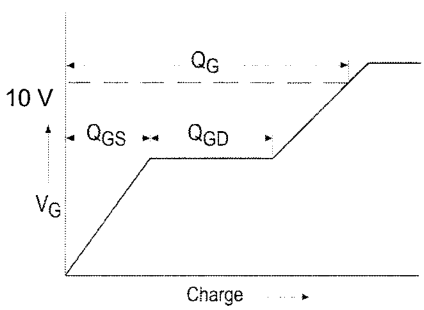


Fig 13a. Basic Gate Charge Waveform

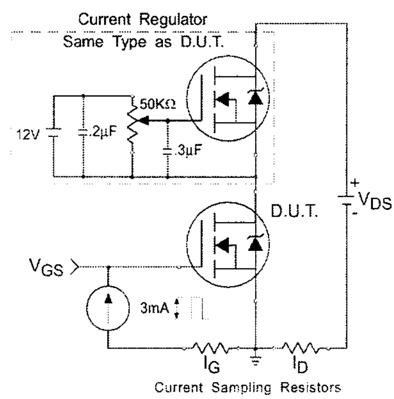
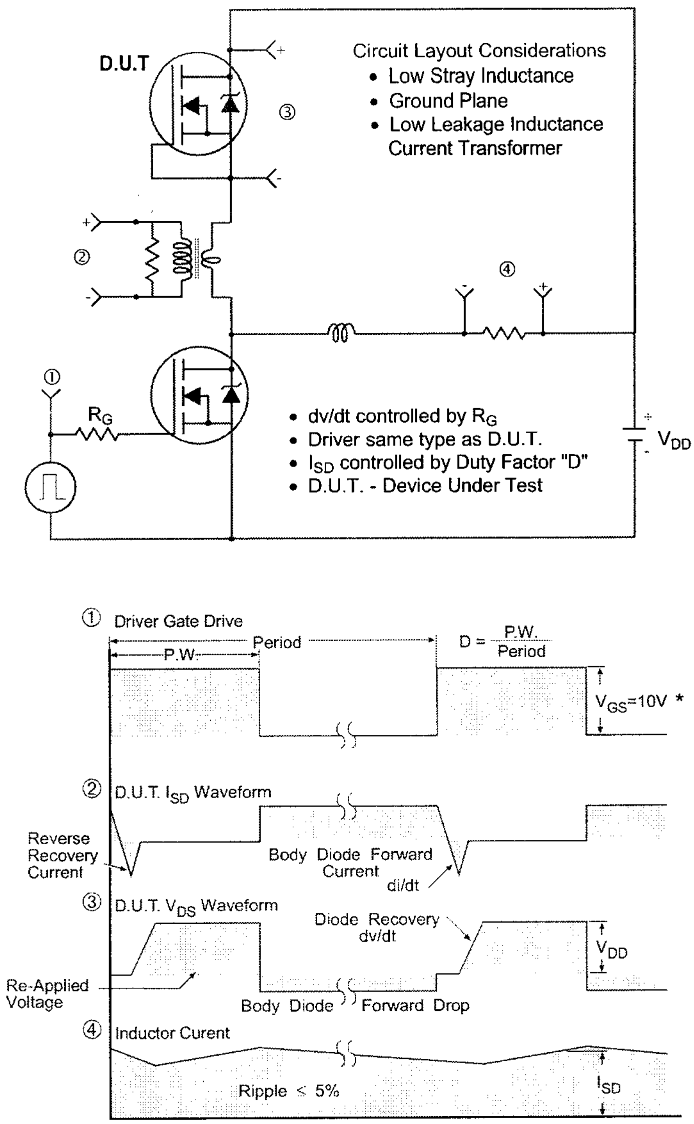


Fig 13b. Gate Charge Test Circuit

Peak Diode Recovery dv/dt Test Circuit



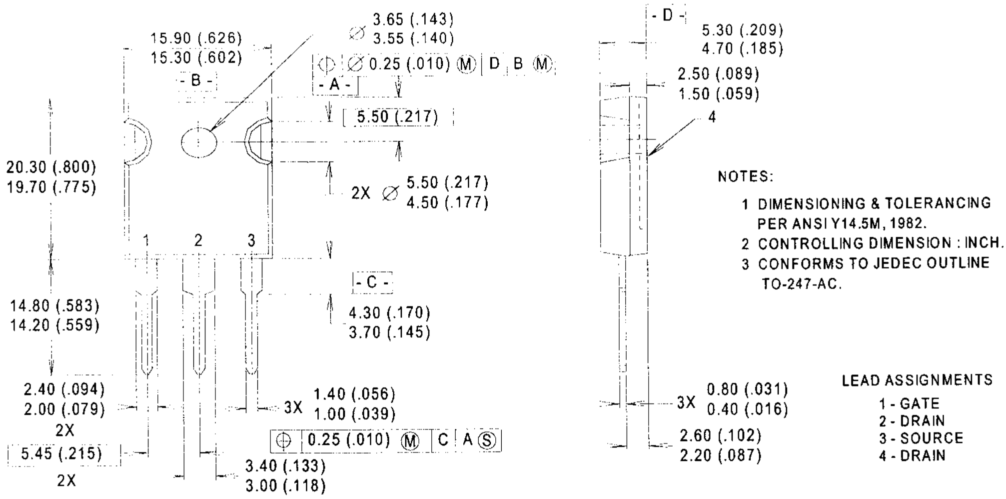
* V_{GS} = 5V for Logic Level Devices

Fig 14. For N-Channel HEXFETS

Package Outline

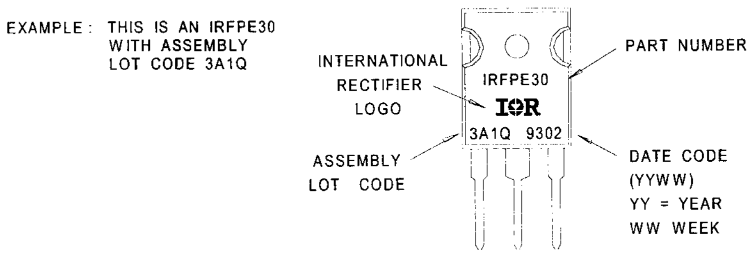
TO-247AC Outline

Dimensions are shown in millimeters (inches)



Part Marking Information

TO-247AC



International
IOR Rectifier

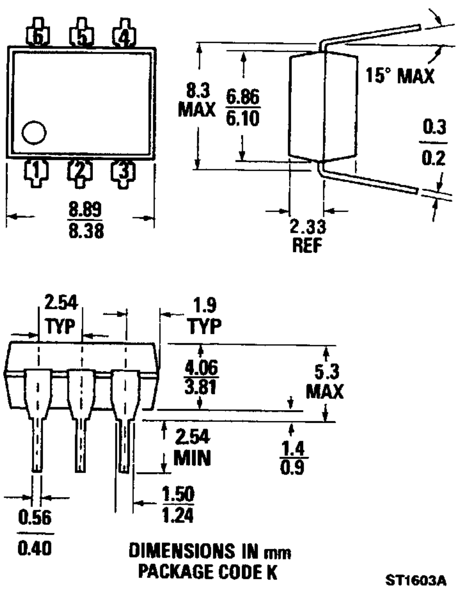
IR WORLD HEADQUARTERS: 233 Kansas St., El Segundo, California 90245, USA Tel: (310) 252-7105
IR EUROPEAN REGIONAL CENTRE: 439/445 Godstone Rd, Whyteleafe, Surrey CR3 OBL, UK Tel: ++ 44 (0)20 8645 8000
IR CANADA: 15 Lincoln Court, Brampton, Ontario L6T3Z2, Tel: (905) 453 2200
IR GERMANY: Saalburgstrasse 157, 61350 Bad Homburg Tel: ++ 49 (0) 6172 96590
IR ITALY: Via Liguria 49, 10071 Borgaro, Torino Tel: ++ 39 011 451 0111
IR JAPAN: K&H Bldg., 2F, 30-4 Nishi-Ikebukuro 3-Chome, Toshima-Ku, Tokyo 171 Tel: 81 (0)3 3983 0086
IR SOUTHEAST ASIA: 1 Kim Seng Promenade, Great World City West Tower, 13-11, Singapore 237994 Tel: ++ 65 (0)838 4630
IR TAIWAN: 16 Fl. Suite D. 207, Sec. 2, Tun Haw South Road, Taipei, 10673 Tel: 886-(0)2 2377 9936

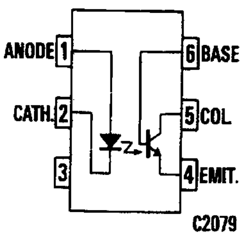
Data and specifications subject to change without notice. 10/00

PHOTOTRANSISTOR OPTOCOUPLER

MCT2E

PACKAGE DIMENSIONS





Equivalent Circuit

DESCRIPTION

The MCT2E is a NPN silicon planar phototransistor optically coupled to a gallium arsenide infrared emitting diode.

FEATURES & APPLICATIONS

- Utility/economy isolator
- AC line/digital logic isolator
- Digital logic/digital logic isolator
- Telephone/telegraph line receiver
- Twisted pair line receiver
- High frequency power supply feedback control
- Relay contact monitor
- Power supply monitor
- UL recognized — File E90700

ABSOLUTE MAXIMUM RATINGS

Storage temperature . . . . −55°C to 150°C
Operating temperature . . . . −55°C to 100°C
Lead soldering temperature (10 sec) . . . . 260°C

INPUT DIODE

Forward current. . . . . 60 mA
Reverse voltage . . . . 3.0 V
Peak forward current
(1 μs pulse, 300 pps) . . . . 3.0 A
Power dissipation at 25°C ambient. . . . . 200 mW
Derate linearly from 25°C. . . . . 2.6 mW/°C

OUTPUT TRANSISTOR

Power dissipation at 25°C ambient. . . . . 200 mW
Derate linearly from 25°C. . . . . 2.6 mW/°C
Total package power dissipation at 25°C ambient
(LED plus detector) . . . . 250 mW
Derate linearly from 25°C. . . . . 3.3 mW/°C
Collector-Emitter Current (I_{CE}) . . . . 50 mA

QT OPTOELECTRONICS

PHOTOTRANSISTOR OPTOCOUPLER

ELECTRO-OPTICAL CHARACTERISTICS
(25°C Free Air Temperature Unless Otherwise Specified)

INDIVIDUAL COMPONENT CHARACTERISTICS

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNITS	TEST CONDITIONS
INPUT DIODE						
Forward voltage	V_F		1.25	1.50	V	I_F=20 mA
Reverse voltage	V_R	3.0	25		V	I_R=10 μA
Junction capacitance	C_J		50		pF	V_F=0 V, F=1 MHz
Reverse leakage current	I_R		.01	10	μA	V_R=3.0V
OUTPUT TRANSISTOR						
DC forward current gain	h_{FE}	100	250			V_{CE}=5 V, I_C=100 μA
Collector to emitter breakdown volt.	BV_{CEO}	30	85		V	I_C=1.0 mA, I_F=0
Collector to base breakdown voltage	BV_{CBO}	70	165		V	I_C=10 μA, I_F=0
Emitter to collector breakdown voltage	BV_{ECO}	7	14		V	I_E=100 μA, I_F=0
Collector to emitter, leakage current	I_{CEO}		5	50	nA	V_{CE}=10 V, I_F=0
Collector to base leakage current	I_{CBO}		0.1	20	nA	V_{CB}=10 V, I_F=0
Capacitance collector to emitter	C_{CEO}		8		pF	V_{CE}=0
Capacitance collector to base	C_{CBO}		20		pF	V_{CB}=10 V
Capacitance emitter to base	C_{EBO}		10		pF	V_{BE}=0

TRANSFER CHARACTERISTICS

DC CHARACTERISTICS	SYMBOL	MIN.	TYP.	MAX.	UNITS	TEST CONDITIONS
DC collector current transfer ratio	CTR_{CE}	20	60		%	V_{CE}=10 V, I_F=10 mA, Note 1
DC base current transfer ratio	CTR_{CB}		.35		%	V_{CB}=10 V, I_F=10 mA
Collector-emitter, saturation voltage	V_{CE} (sat)		0.24	0.4	V	I_C=2.0 mA, I_F=16 mA

TRANSFER CHARACTERISTICS

CHARACTERISTICS		SYMBOL	MIN.	TYP.	MAX.	UNITS	TEST CONDITIONS
SWITCHING TIMES							
Non-saturated collector	Delay time	t_d		0.5		μs	R_L=100 Ω, I_C=2 mA, V_{CC}=10 V
	Rise time	t_r		2.5		μs	Fig. 10
	Storage time	t_s		0.1		μs	
	Fall time	t_f		2.6		μs	
Saturated collector	Delay time	t_d		2.0		μs	R_L=1 KΩ, I_C=2 mA, V_{CC}=10 V
	Rise time	t_r		15		μs	
	Storage time	t_s		0.1		μs	
	Fall time	t_f		15		μs	

ELECTRO-OPTICAL CHARACTERISTICS
(25°C Free Air Temperature Unless Otherwise Specified) (Cont'd)

TRANSFER CHARACTERISTICS (Cont'd)

		SYMBOL	TYP.	UNITS	TEST CONDITIONS
SWITCHING TIMES (Cont'd)					
Saturated t on (from 5 V to 0.8 V)		t_{on} (SAT)	5	μs	R_L=2 KΩ, I_F=15 mA, V_{CC}=5 V
t off (from SAT to 2.0 V)		t_{off} (SAT)	25		R_B=open
Saturated t on (from 5 V to 0.8 V)		t_{on} (SAT)	5	μs	R_L=2 KΩ, I_F=20 mA, V_{CC}=5 V
t off (from SAT to 2.0 V)		t_{off} (SAT)	18		R_B=100 KΩ
Non-saturated Base	Rise time	t_r	175	ns	R_L=1 KΩ, V_{CB}=10 V
	Fall time	t_f	175	ns	
Bandwidth (see note 2)		B_W	150	KHz	I_C=2 mA, V_{CE}=10 V, R_L=100Ω

ISOLATION CHARACTERISTICS

CHARACTERISTICS	SYMBOL	MIN.	TYP.	MAX.	UNITS	TEST CONDITIONS
Steady state isolation voltage	V_{iso}	7500			VAC-PEAK	I_{I-O} ≤ 1 μA, 1 minute
		5300			VAC-rms	I_{I-O} ≤ 1 μA, 1 minute
Isolation resistance		10^{11}	10^{12}		Ω	V_{I-O}=500 V
Isolation capacitance			.5		pF	F=1 MHz

TYPICAL ELECTRO-OPTICAL CHARACTERISTIC CURVES
(25°C Free Air Temperature Unless Otherwise Specified)

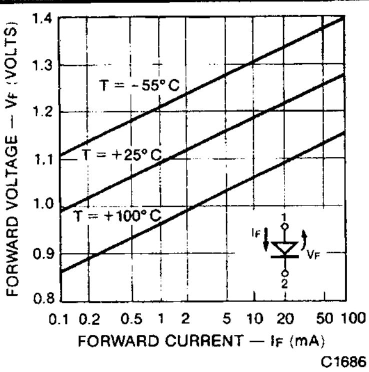


Fig. 1. Forward Voltage vs. Current

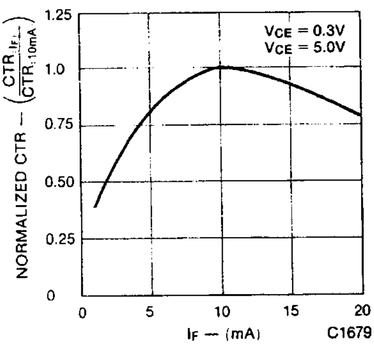


Fig. 2. Normalized CTR vs. Forward Current

TYPICAL ELECTRO-OPTICAL CHARACTERISTIC CURVES
(25°C Free Air Temperature Unless Otherwise Specified) (Cont'd)

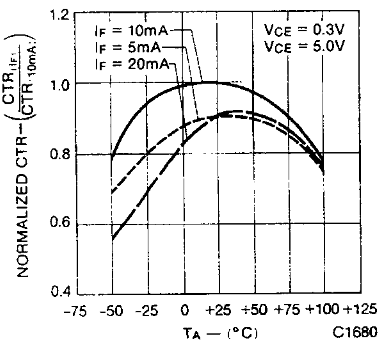


Fig. 3. Normalized CTR vs. Temperature

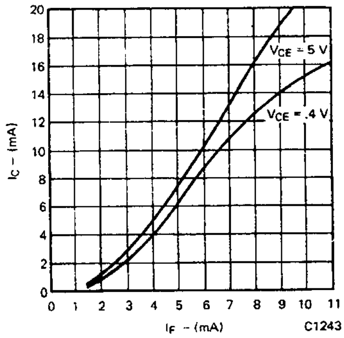


Fig. 4. Collector Current vs. Forward Current

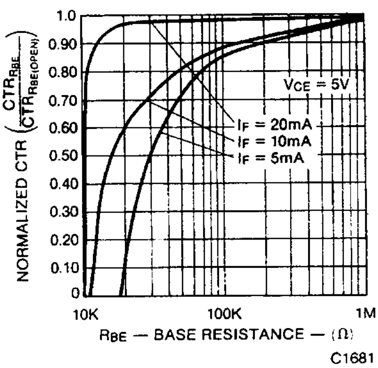


Fig. 5. CTR vs. RBE (Unsaturated)

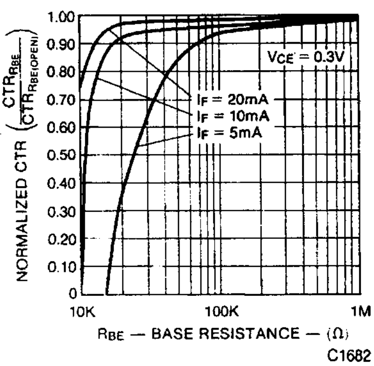


Fig. 6. CTR vs. RBE (Saturated)

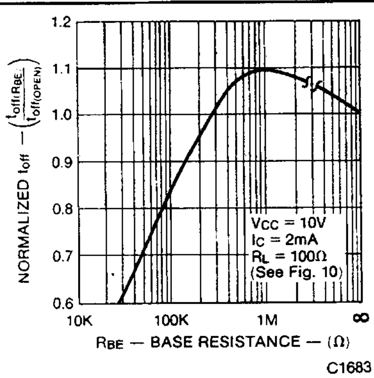


Fig. 7. Normalized T_{OFF} vs. RBE

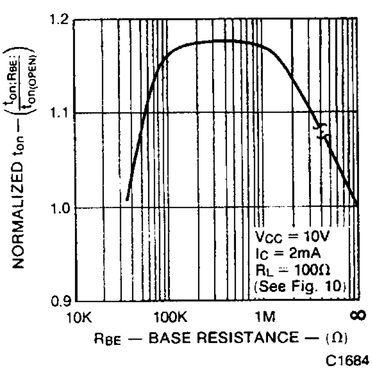


Fig. 8. Normalized T_{ON} vs. RBE

QT OPTOELECTRONICS

PHOTOTRANSISTOR OPTOCOUPLER

TYPICAL ELECTRO-OPTICAL CHARACTERISTIC CURVES
(25°C Free Air Temperature Unless Otherwise Specified) (Cont'd)

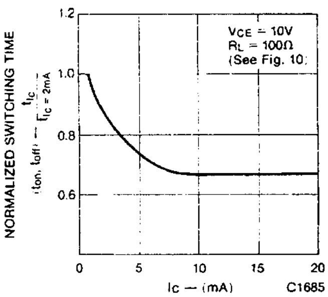


Fig. 9. Switching Time vs. IC

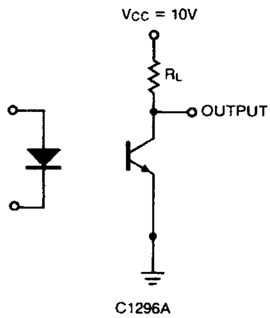


Fig. 10. Switching Time Test Circuit

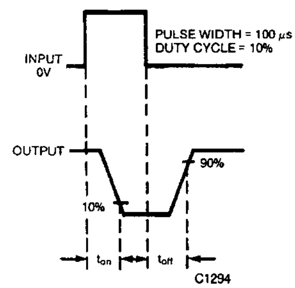
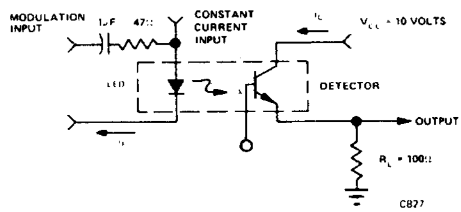


Fig. 11. Switching Time Waveforms

OPERATING SCHEMATICS



Modulation Circuit Used to Obtain Output vs. Frequency Plot

NOTES

1. *The current transfer ratio (I_C/I_F) is the ratio of the detector collector current to the LED input current with V_{CE} at 10 volts.*
2. *The frequency at which i_c is 3 dB down from the 1 kHz value.*
3. *Rise time (t_r) is the time required for the collector current to increase from 10% of its final value, to 90%.*
   Fall time (t_f) is the time required for the collector current to decrease from 90% of its initial value, to 10%.